

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	Isidora Matskidou
Student number	5166187

Studio		
Name / Theme	Building Technology Sustainable Design Graduation Studio	
Main mentor	Faidra Oikonomopoulou	Structural Design & Mechanics
Second mentor	Alessandra Luna Navarro	Design of Construction
Argumentation of choice of the studio	N/A	

Graduation project	
Title of the graduation project	RE-Façade Glass Panes: made by C&D recycled glass
Goal	
Location:	Delft, The Netherlands
The posed problem,	<p>Hardly any other material, that is present not only in our everyday environment but also in the built one, could sufficiently meet the current extensive usage of glass. An existence so ordinary that we infrequently notice, glass is a material that has always fascinated architects and engineers. It witnessed an immense progression in the architectural sector creating the perfect link between indoor and outdoor environment.</p> <p>However, the intense industrial manufacture of glass derives a high volume of embodied energy, and together with glass waste discarded at their end-of-life, resulting in a significant impact on the ecological footprint. Glass is a readily recyclable material, that it can be remelted and reformed again and again into articles with the same quality and properties as the original one, nominating it as a perfect candidate in the transition efforts for a low-carbon environment. Although, it is rarely recycled into new glass products. With apparent benefits in the recycling loop, aiming in the reduction of raw material use and non-renewable energy, the CO₂ emissions shrinkage and finally conclude in products' whole life-cycle, at the moment, a neat closed-loop system carries out just for the post-consumer</p>

	<p>containers. Unfortunately, the vast majority of all the other remaining waste products of the glass industry are either down-cycled to low-value applications or they are sent into the landfill, aggravating the existing inextricable problem of glass up-cycling.</p> <p>Among the down-recycled or landfilled glass, there is a great proportion of high-value float glass used for architectural purposes, coming from the Construction & Demolition sector. This great quantity of building glass category, which is rarely recycled into new glass products in its end-of-life, points out the large potential in upgrading the glass recycling process. More recycled glass cullets in the production line could come through 1.23 million tons of raw materials and minimize by 230 thousand tons the gas emissions per year in Europe (Deloitte, 2016).</p> <p>Generally speaking, there are four principal barriers in the upcycling of C&D glass, related to the collection and manufacture of flat glass, and the glass status.</p> <ul style="list-style-type: none"> • Starting with, flat glass waste currently has a low market value, seeing that a properly organized recycling collection and treatment system is absent. Due to the lack of local treatment & recycling facilities to handle the source waste, following as a consequence in demanding logistics that environmental and financial profits of glass recycling are diminished. • Secondly, the float line industry is a rigid, fully automated and continuous process which is not flexible to switch its flow stream, since it operated only under a concrete recipe; a change in the raw material batch would result in the reduce and loss of production for competently modifying the material composition in the continuous ribbon. • What is more, cullets coming from disparate glass compositions cannot be easily homogenized in a mixture, owing to different rates of melting points, thermal expansion coefficients, annealing times and recipe compatibility. • Finally, the inability of thin-walled glass elements to accommodate contamination with unwanted foreign materials remains the main technical barrier in glass recycling. Contamination from C&D waste glass is impractical or technically strenuous to be removed (e.g. lamination, adhesives, coatings), which acts as stress concentrators congesting failure by stress loss or product foaming on the filling line. Besides, it can jeopardize the
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	<p>optical properties of the material, a rigorous prerequisite in float production line since it owns a characteristic color tint, concluding in a nonacceptance of external cullet into the close-loop even if it is completely pure.</p> <p>Cast glass technology could be a promising strategy for transcending the main barrier of C&D cullet refusal, owing to impurities or different glass synthesis. An interesting method that enables the fabrication of monolithic glass components with higher thickness than conventional flat glass. Owing to this monolithic nature, panels out of cast glass are allowed to carry more contamination and flaws than a sheet of thin-walled glass, barren of jeopardizing the strength or optical quality. Further, glass casting is a non-automated small-scale technique which affords opportunities for experimentation in the firing schedule and glass formulas (Oikonomopoulou, 2019).</p>
research questions and	<p>In accordance to the problem statement, the main research question can be formed as follows:</p> <p>“In what ways can we develop glazed facade panels made by recycled glass, coming from the Construction & Demolition cullets through an upcycling approach?”</p> <p>The main research question can be further analyzed into the following sub-questions:</p> <ol style="list-style-type: none"> 1. What are the main practical implications and limitations of recycling C&D glass elements? 2. How can the linear model of C&D glass recycling be modified to better besem the circular economy? 3. In what ways can we decompose and redesign an efficient and viable supply chain that can scale up the recommended upcycling of C&D glass waste? 4. What are the financial and environmental advantages of implementing product-life-extension strategies in C&D glass? 5. What are the current end-of-life scenarios and which could be the circular life options with the aim of the life-cycle assessment? 6. In what ways can different glass products coming through various treatment processes affect a new manufacturing procedure and thus the feasibility and marketability of the resulting product? 7. How casting methods can be employed for the glass panels manufacture for built environment applications and what are the advantages and limitations of this method? 8. What are the main engineering criteria and challenges involved in the development of a glazed facade panel made by C&D cullets?

<p>design assignment in which these result.</p>	<p>Scope of this research is to develop and experimentally verify with the aim of casting, not only new design concepts and engineering its fabrication in accordance with the design criteria, but also an ideal recycling collection system for cullets coming from the C&D sector.</p> <p>These new building components can be introduced by means of closed-loop alternatives that extend the service life of these products, establishing at the same time the foundation of the circular life-cycle of architectural glass. However, to totally comprehend how this upcycling method could be performed, first and foremost it is crucial to come up with all the obstacles that rest on the conventional life-cycle of C&D glass and must be overcome. With the aim of such glass waste as raw material, monolithic components will be created for built environment applications, produced through casting method, with higher thickness compared to the conventional thin-walled glass, in order to be able to tolerate higher contamination rate. This more flexible process with small-scale production, can play a major role in minimizing logistical and environmental costs of waste collection and transportation, whilst confining the necessity for further treatment and purification. Finally, the whole embodied energy of this new concept will be assessed for further analysis and understanding the whole effectiveness of the proposed supply chain of this novel recycling method, providing at the end a complete overview of the closed-loop alternatives highlighting its environmental savings in contrast to the linear waste chain.</p> <p>Recycling C&D cullet is an ambitious path to meet the market's needs, contributing in the circular concept, rested on resources reuse. Design and specifications, for new facade components with the aim of glass-recycling, will take us a step closer to the national programme «Circular Netherlands in 2050» that aids to reach pioneering material savings and become zero waste in construction sector. Responsible manufacture and consumption will achieve results with significant social and economic, but most important environmental advantages for the value chain. Considering glass recycling in C&D sector enables the reduction of ecological footprint and products' embedded energy, while it creates locally new job positions and opportunities.</p>
<p>Process</p>	
<p>Method description</p>	
<p>The research consists of four main phases, which are categorized according to the whole process development of the novel upcycling system and the new concept design. Its phase</p>	

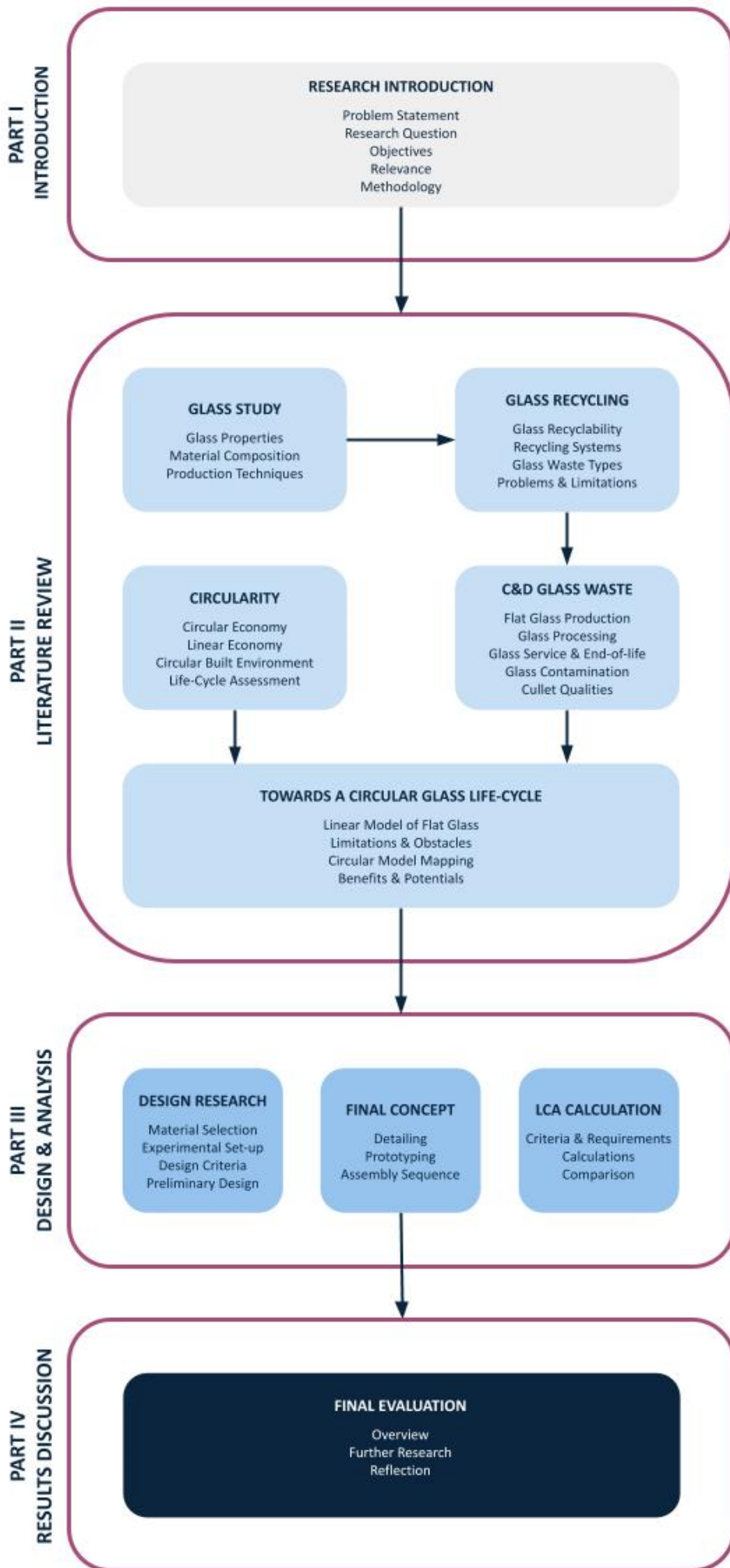
has a specific focus, as shown in the figure below: the introduction, the literature review, the design & analysis and the results discussion.

Part I concentrates its scope in the research's introduction, illustrating an initial overview of the report, from the problem statement and the scientific gap to the concept objectives and the relevance to the society.

Part II provides all the theoretical framework of the research coming from the requisite literature review and data collection, which accrued by exploring various reports, papers, books, and sites on the web, relevant to the chosen topic. It actually prepares all the background of glass technology to assist in the new concept evaluation and design, earning meaningful insights for the survey's subject, whilst it helps in thorough comprehending of the problem in question. This part is also divided into smaller chapters. Chapter 1 includes the study of glass as material, providing an overview about its origin, composition, properties, the families coming according to the specific characteristics and the production-formation techniques of glass. The following chapter acts as a link between the research, concerning the circular economy as an imperative need while our world is moving towards more sustainable environments, highlighting the need of an upcycling method for glass recycling. Chapter 3 focuses on glass recycling and its aspect from the current linear systems collection and its limitations to a more technical path about the contamination on glass which affects the quality standards on recycling cullet. Based on the aforementioned chapters, next in the line is a focus on the Construction & Demolition glass waste that helps to understand the current situation and how this can be tackled. Chapter 5 concentrates on life cycle assessment on glass recycling as it is at the present and causes a significant environmental impact. Finally, the next chapter illustrates a new circular model of C&D glass recycling representing all the obstacles of the current status and suggesting improvements towards a sustainable concept of glazed waste management.

Part III develops the design and analysis procedure holding for the experimental validation of the proposed recycling system and the glazed facade panel deployed within the frame of the current study. More specifically, it indicates all the necessary preparation for the upcoming design through decision making such as the material selection, the experimental set-up, as well as the evaluated design criteria. Then, the design is developed through exploring methods concerning the casting process and the shape formation. At the end of this phase, a design evaluation is held to identify a final concept scenario. The next chapter indicates the application of the glazed panel made by C&D glass cullet. It includes the prototyping process, the detailing and finally the assembly order, integral stages for the realization of the concept, while the engineering part of the panel takes into account the data recovered from the literature study. Finally, a life-cycle assessment is investigated to highlight the benefits compared to the existing linear life model of the glass products.

Part IV concludes with the overall evaluation of the research and experimentations. The presented conclusions, the reflection on production and design of the installation of the recycled glass panel made by C&D cullet through the casting method reveal all the contingents for further exploring and development for other applications and recommendations for future studies.



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Reflection

Generally, the sustainable design graduation studio focuses on innovative design technologies and methods into the scope of the built environment. The thesis topic is mainly related to sustainable materials and glass recycling held by the ongoing research at TU Delft.

Nowadays, the contemporary world is moving towards more robust and sustainably efficient environments on account of the violent climate emergency, the abatement of nonrenewable energy and the shortage of natural resources. The whole ideology, infrastructure and legal system are crucial to alter all the more!

Glass is one of the oldest synthetic materials, which carved its own path into human activity, not only in everyday life but also in the scientific and technological aspects (Dyer, 2014). A widely used material, likewise in the building industry, its production continues ascending, causing a significant environmental impact. Even if glass is a material totally recyclable in theory, and the recycling of it has been conducted since its discovery (Dyer, 2014), only a small part gets recycled mainly by the packaging industry (Bristogianni et al., 2018). Essentially, glass waste remains a significant unresolved problem and a considerable part refers to float glass, mainly used for architectural purposes, coming from the construction and demolition sector. This results from the fact that there isn't a proper recycling system of such waste and also most of the discarded cullet fail to pass the quality standards due to contamination -aftereffected from coatings, lamination, adhesives or incompatibility to the recipe-, closing their life-cycle in the landfill.

Consequently, with the growing demand for glass, and the waste that comes of the Construction & Demolition sector, it deemed necessary to explore the possibilities and potentials of investigating and mapping a closed-loop recycling system that will provide us the needful sustainable material to create new concepts to be used in the built environment. It is really important to mention that this upcycling system in examination is a new approach based on data coming from the industries and glass experts, and not many experiments have been done in this field. As it is in the aftermath, this new experiment may be really challenging but it would give great potential while probing new data through a case study. The mapping of this upcycling method, in combination to the final product and detailing will provide a deeper understanding and any development within this field could act as a guideline for the applicability for future reference and investigation from architects, engineers and scientists. Therefore, this research indicates a scientific relevance as it illustrates possibilities of C&D glass recycling and it is also socially relevant, as it will attribute many advantages related to the environment and the financial upgrade.

