THESIS REFLECTION

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01| PERSONAL REFLECTION

The past eight months, which I am involved with my graduation thesis, have been a unique and exciting learning experience with ups and downs in the whole study and research process. This timeframe and needed tasks wouldn't be possible without the assistance and encouragement of many people. People that come from my familiar environment providing me support, and my professors, who shared their knowledge, expertise, enthusiasm and wondering about the evolution of my research topic on C&D glass waste up-cycling. They always standed by my side to inspire me, providing another perspective on every aspect, and finally keeping my feet on the ground when I lacked motivation and obstacles rested on my experimental research.

In general, working on a thesis like this is an experience like no other before. The exciting world of glass is not something that I was accustomed to, since my background is based on architectural design and expression. However, due to the fact that the more I read about glass as a material, the more fascinated I become about it, acting as an encouragement to get one more step at a time. However, the road to this wasn't easy.

My topic choices posed various challenges that I had to go through, and solve within a relatively limited amount of time, since investigating and developing the up- and recycling feasibility of float glass, in order to create a glazed facade panel made by recycled glass coming from Construction & Demolition cullet, considering at the same moment the embodied energy that it possesses, isn't a simple task. This effort is combined by many different but linked together topics, commencing glass technology, glass families and composition, production techniques, glass waste classification and their recyclability, problems and limitations in the current existing or not recycling systems and simultaneously, the selection of C&D glass waste, which constitutes a significant waste stream, its mass quantities of flat glass that is either landfilled or diverted to a next-use market, for instance aggregate. Nevertheless, even if this type of glass is of great number around us, small efforts have been made by the float industry such as the glass waste to be used as high-quality cullet into the glass sheets production. The aforementioned fact implies that there is a lack of data and figures on the market, making my efforts to further unveil the possibilities of recycled glass more challenging. This also entails that the mapping of an ideal recycling collection system for cullets coming from the built environment and the life cycle assessment of the embodied energy, which is included in the life cycle of the new product and it is needed to complete my thesis approach, to be a little more difficult and time consuming, but not unattainable research.

As far as the preliminary results of my research are concerned, there is a constant evolution and experimentation in the opportunities that recycled glass cullets are given with every firing exploration. The comprehend and extent literature review on every aspect of glass technology and recycling with the right programming, enthusiasm, additional knowledge and the instructive assistance, helped me to adapt to each new normal, in order to support my work and my ideas, to point out better directions for the optimal result of the recycled C&D glass panel. All these also helped my whole approach to the research and the experimental process to be more recreational and enjoyable, in combination with the inspiring feedback from my mentors, and the out-of-the-box conversations and thoughts.

Apart from the whole experience and if the final result is successful or not, the process seemed to be a steep learning curve. Here, I taught myself to look into the things that are possible to be done in a way, instead of letting myself be led by the difficulties and challenging situations I falled into. The whole process made me more optimistic for the next steps on the recycling float glass within the sustainable closed-loop approach.

02| GRADUATION PROCESS

02.1 The relationship between the graduation topic and the master programme.

The ‘’Building Technology’’ master track covers a wide spectrum of knowledge and design skills linked to both architecture and engineering. The dominant focus of the program is sustainable strategy into the scope of the built environment. Moreover, it emphasizes on the development of innovative design thinking, and the generation and implementation of smart building elements and systems within the limits of efficiency and sustainable approach.

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 and engineering sector, creating the perfect link between indoor and outdoor environment. Glass is a readily recyclable material, that can be remelted and reformed again and again, indefinitely, 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.

The current graduation thesis is mainly related to sustainable material science and glass recycling held by the ongoing research of ‘’Glass & Transparency Group’’ of TU Delft. Moreover, it aims to further contribute to this quest for novel glass solutions for the built environment, with investigations into the innovative and sustainable glass recycling strategy.

02.2 Elaboration on research method & approach upon the scientific relevance, related to the graduation studio.

Built environment makes up one of the industrial sections with the highest utilization of energy demand, exploitation of natural resources and waste generation, causing environmental pressure generated by the construction and demolition sector. This consideration places it, as a substantial field, where sustainable approaches such reuse and recycling have to take ambitious and pioneering actions. Sizable quantities of various materials and products in C&D sector, and extended construction areas represent the ideal and inviting circumstances, where recycled materials could be exploited in a circular economy. Over and above that, the EU already sets rules and targets in order to make certain this waste is handled in a way that preserves the natural world and circularity is promoted.

Specifically, in the Netherlands a major campaign has been launched in 2016, driven to a fully circular Dutch economy by 2050. For Dutch, the building sector constitutes a significant part of their financial system. In response to that, specified Agendas set goals for this strategy to be also implemented in the Construction & Demolition industry, which will tackle the environmental, economic and societal challenges.

Looking at the world of construction, glass panes are all the time used material for façade applications in transparent surfaces of the building envelopes. However, the continuously increasing trend in the architectural and engineering field, towards wider applications of glass surfaces and demand for transparency in the building facades, has spread the need for float glass extended generation. Consequently, the impact to the environment surges, due to the illogical energy consumption, the increased greenhouse emissions and the depletion of the limited natural resources. This stresses the need for a well-organized closed-loop recycling system for C&D glass waste.

Generally, the sustainable design graduation studio focuses on innovative design technologies and methods into the scope of the built environment. The current thesis aims to further contribute to this quest for innovation in sustainable glass recycling by focusing on finding circular ways to redefine the production of flat glass with the aim of casting methods and assessing the embodied energy which is included in the life cycle of the new product. So, determined efforts are made, in order to deal with this unsolved problem of flat glass waste, with the assistance of circular principles. The prevention of waste generation, the shift to reuse, remanufacturing and recycling, along with the ecological design approach, give the right perspectives to use resources efficiently and conclude on positive environmental impacts.

02.3 The relationship between research & design.

Main part of the current thesis is the concept ''Design through Research''. The review of an extensive literature into various sectors from glass technology, glass recyclability and architectural glass waste to the mapping of the current recycling process of flat glass, in order to recommend suitable solutions to overcome any barriers rest on the path to sustainability. The time being, it is obvious that a linear flat glass waste chain incurs, so the need to switch towards a circular life-cycle of such waste is rising. The growing interest, in this transition to a closed-loop recycling, can be also seen and encouraged by float glass industries and different actors of the whole construction sector.

After gathering an extensive amount of information and data, which were cross-referenced between numerous studies and authors, the primary foundation was set. That served as the starting point for the experiments, indicative variables, design considerations and criteria.

Nevertheless, purpose of this research is to develop and experimentally verify with the aid of casting, not only new design concepts and engineering their fabrication in accordance with the design criteria, but also an ideal recycling collection system for cullets coming from the C&D sector. These recycled panels are introduced by means of closed-loop alternatives that extend the service life of these products, establishing at the same time the foundation for a circular life-cycle of architectural glass. This is achieved by experimentally testing the recyclability of different flat glass waste used instead of raw material, as monolithic thick-walled components are created for built environment applications, produced through the casting method. According to the literature, higher thickness compared to the conventional thin-walled glass is able to tolerate higher contamination rate, something that is also verified through the experiments exploration and experimental studies prior to mine, held by the TUDelft Researchers.

The final results of the material exploration indicated some promising and interesting outputs, even if it is based only on a specified number casting samples. Recycling C&D cullet is an ambitious path to meet the market's needs, while it contributes to the circular economy performance based on natural resources reuse. Design and specifications, for new facade components with the use 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 the construction sector. Moreover, the current thesis provides the guideline for further performing laboratory scientific study to the recycling of flat glass waste.

02.4 The way that research approach worked out and led to the aimed results.

The well-organized and prioritized literature review according to new findings, most important authors, cross-referenced information, and understanding of the current obstacles and limitations of C&D glass waste, assisted me to make the whole study effort to work out properly. Accordingly, the findings of the bibliographic search were classified into the three main parts of the literature body of my thesis, which was no other than the glass technology, glass recyclability and deep exploration of the C&D glass waste stream. These laid the foundation to draw conclusions on how to proceed with my experiments and which parts of them to determine carefully.

However, owing to the labor intensive and time-consuming experimental process in the laboratory, limited the amount of specimens to be tested. Moreover, further exploration could be held on the compatibility tests in the final composite glass panel, along with the design of a unique connection system for its implementation in the built environment. Additionally, a coherent indication in the safety evaluation of such components would also be essential.

03| SOCIAL IMPACT

03.1 The relationship between the graduation project and the wider social , professional and scientific framework.

Nowadays, the contemporary world is moving towards more robust and sustainably efficient environments on account of the present 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. 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, only a small part gets recycled mainly by the packaging industry. 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, as set by the current rigid float glass generation process, aftereffects from coatings, lamination, adhesives or incompatibility to the recipe, closing their life-cycle in the landfill.

With the growing demand for glass, and the waste that comes of the Construction & Demolition sector, it is deemed as 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 be applied for new concepts for 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 experimental approach may be really challenging but it would give great potential while probing new data through a case study, and start filling the scientific gap that exists at the present time. The mapping of this upcycling method, in combination with the research-based exploration through material casting tests provide the next step for a deeper understanding in the float glass upcycling process. Any development within this field could act as a guideline and inspiration for future reference and investigation for architects, engineers, scientists and the glass industry.

Moreover, the development of responsible manufacture and consumption is capable of attaining results with remarkable social, financial, and last but not least benefits related to ecosystems's value chain. Consequently, glass recycling in the C&D field qualifies the mitigation of human demand in nature and its footprint by putting away energy and natural resources, while it introduces locally new job offers.

03.2 Ethical issues or dilemmas encountered doing the research.

Primary scope of the research is to explore the most possible and at the same time efficient scenarios of C&D glass recycling on the fabrication of the panel. Every step and part indicated moments in which choices had to be made. Through the research, various challenges were explored until reaching the desired result. Considering the findings, outlining the available options with arguments, led me in every decision that I had to make until the end. Even if often, this was mainly a chain of fortune events and afterwards just the decisions made based on the results, due to the lack of background knowledge on this topic and the fact that I was working almost blindly.

The ethical issue that I faced wasn't about how this new knowledge would be handled, provided that wouldn't hurt human life, built environment and ecosystem –they will only benefit from such a study–, but it mainly had to do not to be showed inadequate in the research that I committed myself in, and with responsibility and proper research to give reliable results to promote them within the spectrum of truth and error avoidance, while providing at the same time expanding knowledge of the topic of flat glass closed-loop recycling. However, driven by sustainability and circular strategy, every result is accompanied with experimental validation and shows the potentials and limits of recycled cast glass products.

03.3 The extent that research results are applicable in practice.

At first sight, the current research prioritizes the upcycling of glass coming from the float line. With the growing demand for this material, and the waste that comes of the Construction & Demolition sector, it is deemed as 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 be applied for new concepts in the built environment. Glass recycling is qualified to convert the manufacturing industry to its supreme productiveness with the smallest damage to the ecosystem through waste generation and concludes in significant environmental benefits. It is really important to mention that this upcycling system in examination is a new approach based on data, coming from the industry, glass experts, and small but ambitious efforts that have been done in this field to overcome any barriers rest on the path to sustainability.

Recycling this cullet is an ambitious path to meet the market's needs, while it contributes to the circular economy performance, based on natural resources reuse. Design and specifications, for these new facade components with the use of glass-recycling, takes us a step closer to the national programme «Circular Netherlands in 2050» that aids to reach pioneering material savings and become zero waste in the construction sector.

With the aim of the cast glass method, the manufacture of the glazed panel is achieved through a more flexible process with small-scale production and bigger thickness of the object, which actually is able to tolerate more contamination and impurity rates than thin-walled glass. Moreover, it minimizes logistical and environmental costs of waste collection and transportation. The final product applicability can be met not only on a facade envelope but also in other architectural elements such as glazed floors and inner partition walls.