
*Fig 1: Silica 3D printed glass tile*

# Obscurity and Translucency – *a circular material paradigm*

Mette Ramsgaard Thomsen, Martin Tamke, Maria Sparre-Petersen, Emil Fabritius Buchwald, Simona Hnídková

## 1. Introduction

Silica examines the making of 3D printed tiles from recycled container glass. We explore how robot-controlled extrusion can offer new material practices by which to fabricate glass elements of an architectural scale. We pursue working with recycled container glass powder – a waste product derived from the reprocessing of recycled container glass – to contribute to circular development within an interdisciplinary artistic development context in the meeting between architecture and glass design.

Silica is a collaboration between architects Mette Ramsgaard Thomsen, Martin Tamke and glass artist Maria Sparre-Petersen with research assistant Emil Fabritius Buchwald and architecture student Simona Hnídková.

## 2. Conceptual framework: glass as an architectural material

Glass is one of the heroic modernist materials. Along with concrete and steel, glass has defined the emergence of a new spatial identity and in turn a new perception of its inhabiting subject. In his text "Glass: The Fundamental Material of Modern Architecture" written in 1935, Le Corbusier calls for a second machine age in which technologies of manufacture would restore mankind's harmonious relationship with nature. Here, he saw the controlled industrial mass fabrication of transparent and translucent plate glass, along with glass bricks and prismatic or diamanté glass, as an exceptional modern material for a new architecture sensibility (1). In this architecture, the subject is bathed in light and contained in bright interiors allowing a new exposure of life, brilliance and flow. But, if Le Corbusier and his contemporaries opened up architecture to nature through either the horizontal slit or the curtain wall, Maison de Verre did something very different. Conceived and built by Pierre Chareau in the years 1929 – 31, Maison de Verre is a cornerstone in modernist history. While celebrated for its use of prefabricated glass block walling, it presents the curtain wall not as an open surface, but instead as an opaque depth concealing its interior. As critical theorist Emma Cheatle reflects "… the façade obscures more than it reveals: blank, translucent cast lenses, an endless pattern … There is no visible door, no visible interior." (2). Famously, Maison de Verre is the clinic and home of a gynaecologist (3). The inherent conflict between the intimacy of programme and the overriding material narrative, creates a tension that contradicts the artlessness of the modernist schema. Here, glass is used to conceal and control, its translucency is used to suggest candour while at the same time veil its interior life.

Silica takes point of departure in this conflicted parallel narrative of glass as an opaque veil. The central reason for this is the material resource of recycled soda lime glass powder. Silica develops new composites by which to reform the powder as a thick paste that can be extruded through a 3D printing process and then sintered through firing. By building on a paté de verre process, the property of the new sintered glass is a translucent opacity. The extrusion process allows low scale control of deposition and therefore a highly detailed forming. In Silica, this process is used to form the tiles with varying density, thereby grading the translucency of the tiles.

*Fig 2: 3D printing process followed by firing*

## 3. Recycling - glass in a new context of production

Silica is understood as a first probe into rethinking how we address recycling in architecture. The vision and ambition of the large framing project is to develop the conceptual, design-based and fabrication-based methods for printing architectural structures locally with recycled materials from demolished buildings. As such, the project ties into wider efforts to redress contemporary industrialised processes and invent the sustainable practices that can rethink how materials are sourced, how they are used and how they are recycled. Concepts of Circular Economy, Cradle to Cradle Design or Integrated Design, as reflected in the UN Sustainable Development Goals, aim at defining design paradigms that challenge the "take, make and dispose" approach of the conventional linear economy, and instead increase awareness of resource circularity, sustainable production and the reconciliation of economic, environmental and social goals (4).

Glass recycling in artistic applications has previously been explored by Oseng (5) and Siikamakki (6), both through traditional fabrication processes, while the new technological developments afford a wider range of aesthetic opportunity. This idea of reconciliation echoes Le Corbusier's call for restoration of a harmonious relationship between mankind and nature. As we stand before the fourth machine age - industry 4.0 – we find ourselves repeating an appeal for using technology to re-find an environmental alignment, but with a new agenda and a new sense of urgency.

*Fig 3: Soda lime glass is a highly recycled material. In Europe 74 % is recycled. Sweden, Belgium and Slovenia recycle more than 95 %. On the global scale recycling amounts to 35%. For every six tons of recycled glass used as an alternative to virgin materials in production processes, carbon dioxide emissions are reduced by one ton. Over a ton of raw materials are saved for every ton of glass recycled. Besides reducing emissions and consumption of raw materials, recycling extends the life of plant equipment, such as furnaces and saves energy as energy consumption drop about 2-3% for every 10% cullet used in the manufacturing process (7). The team has received 1 ton of soda lime powder from Reiling A/S as a donation for the project. Reilling is the sole processor of recycled glass in Denmark, supplying cullet for the container glass production company Ardagh Holmegaard A/S.*

## 4. MATERIAL

Glass is 100% and infinitely recyclable without loss of material qualities. As such it presents an interesting case for circular resource thinking. Globally, the call for new sustainable material practices for glass production is urgent. Glass is made of sand and sand is a is a finite resource. Due to the exponential increase in the use of concrete and glass in the building industry we are running out of buildable sand resources (8). Currently, glass from demolition is not recycled. Requirements for recycled flat glass is high and therefore flat glass is not being recycled to a significant degree (9). In Silica, we have therefore chosen to work with recycled container glass. This glass has the same molecular structure as flat glass, it is already being recycled at an exemplary rate in a functional circular system in most European countries, it is abundant, cheap and readily available in most parts of the world, hence the project is potentially applicable on a global scale, which is important with regard to impact.

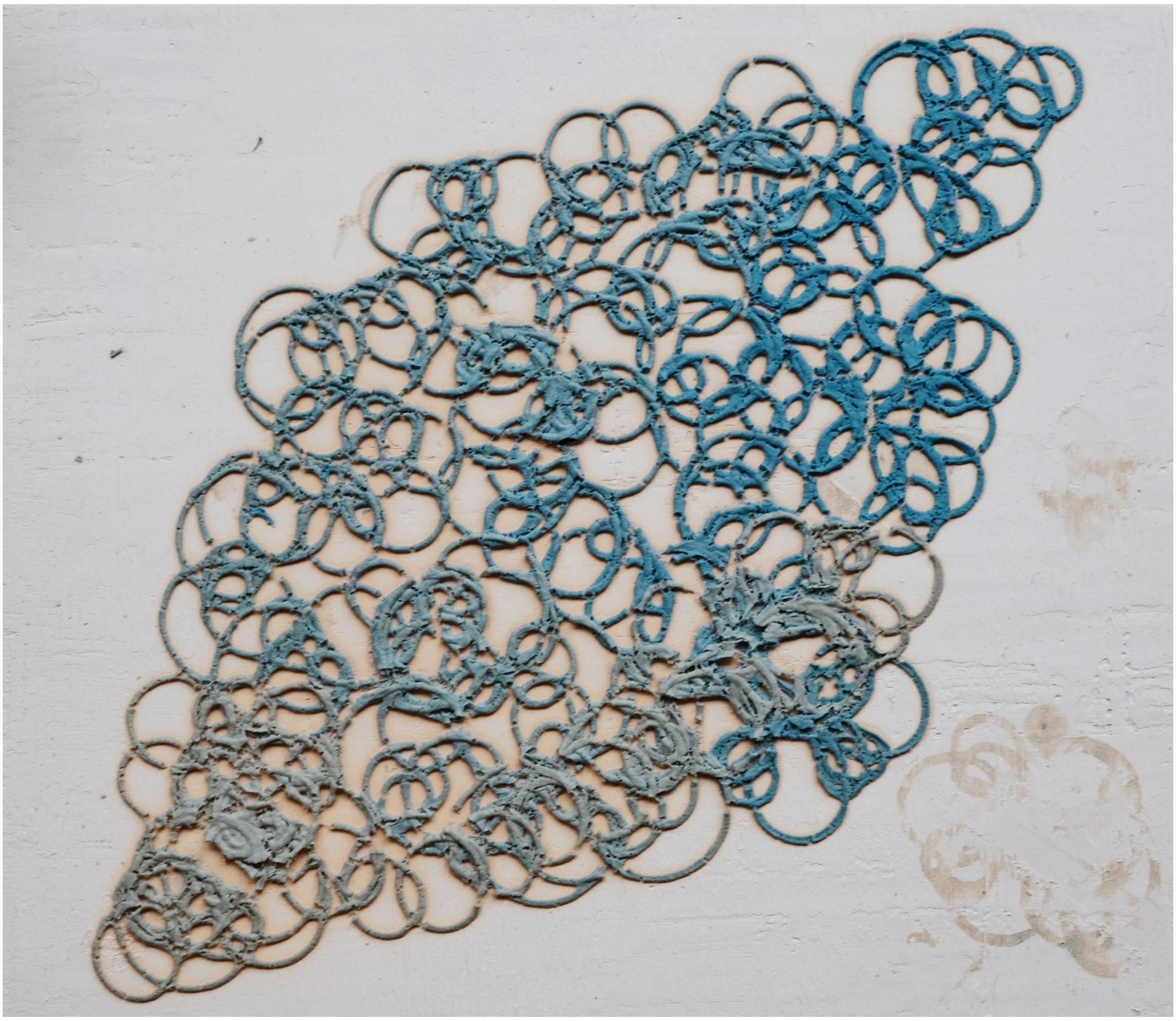

*Fig 4: Adding graded colour to the glass paste*

This material choice also makes the project very different to other efforts in 3D printing glass. In recent years, attempts at printing glass has been successfully completed by Markus Kaiser (10),in his artistic project Solar, where he built a 3D printing rig, powered by the sun, that sintered glass directly on site in the desert. MIT media lab has developed a melting kiln that extrudes clear glass similar to a regular 3D printing process (11). RISD has created a system with a platform that moves underneath a vessel with a hole, filled with hot glass that runs through the hole and forms a somewhat chaotic geometry (12) and KIT is printing the glass through a complex process combining nano technology, polymer support structures, light- and heat sintering (13). However, these efforts use high quality crystal glass that can only be recycled with glass from the exact same batch. In difference to these processes Silica develops a two-part process in which the 3D extrusion of the glass paste takes place before the firing.

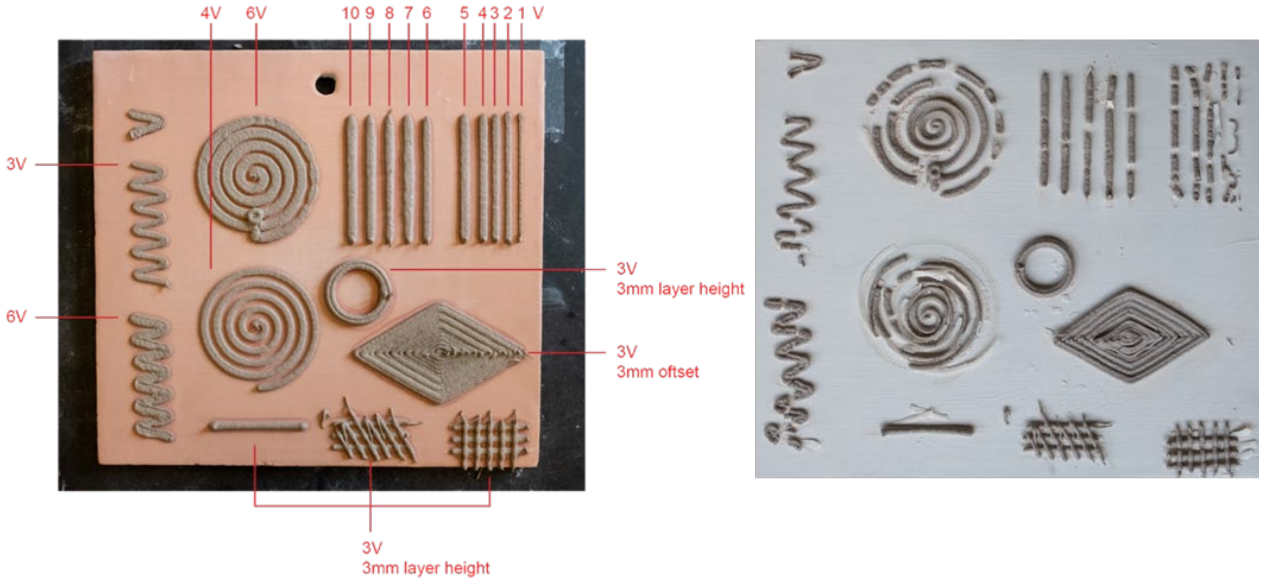

*Fig 5: Topology tests of print and firing parameters*

## 5. Technique

The innovation in Silica is therefore both its circular material composition as well as its forming process. Through experimentation we have developed and understood how these parameters change as the material composition varies and how the robotic fabrication process can be steered through design algorithms.

In our process we mix the glass powder with wheat flour and water in order to bind the material for 3D printing. This natural binder is burnt during firing creating an inherent porosity that can be controlled by varying the recipe of the paste as well as the firing temperature. An opportunity in this process of making is the adding of colours. For this purpose, we have used ceramic stains that fires up to 1300 degrees Celsius. By varying the amount of stains added to the material mixture, which regulates the saturation of the colours. Furthermore, we have investigated ways of creating continuous colour gradients by filling varying colours in the same printer cartridge.

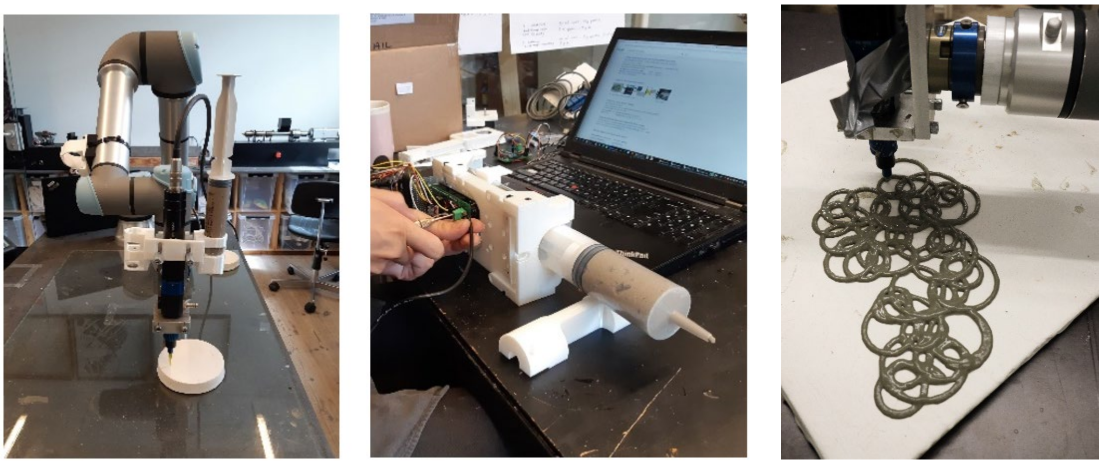

*Fig 6: Developing the print process*

The paste is 3D printed through an extrusion process. For this process, we have developed bespoke tools for extrusion that allow us control over the flow rate. The set-up consists of a robotic arm with an attached tube that feeds the glass paste from the printer cartridge. A linear actuator ram feeds the paste to a ViscoTec dispensing pen attached to the end of the robotic arm that allow us to stop and start the printing procedure according to the design and gives us control of fine printing.  Glass has an inherent capacity to become 6 mm thick upon fusion, which coincides with the fact that the mixture needs a high concentration of flour in order to flow properly through the dispensing device and avoid pulling apart in the firing. The print paths are therefore scaled to these inherent material properties.

Once the print is completed, the material is fired in a ceramic kiln. Through experimentation we have found that best temperature for sintering is 950 ° C. Where higher degrees improve sintering, the material sticks to the separator and the layout of the pattern is blurred. Due to devitrification, a termo-chemical process that transforms the glass from an amorphous to a crystalline molecular structure, the fired material has a porous structure and is no longer classified as glass. Nevertheless, if the material is recycled it will still be compatible with soda lime glass and be able to turn back into the amorphous glass state if fired at higher temperatures. During the cooling process, the glass contracts which may cause points of cracking if the material cannot contract uniformly. To prevent this breakage, we have developed methods of using the design of the patterns to strategically deposit the material for controlling the contraction.

*Fig 7: Contraction in the firing process*

## 6. Designing the Silica patterns

In order to control the material behaviour, we have chosen to work with long continuous line patterns to generate the toolpaths for the tiles. The needed consistency of the paste for the kiln firing procedure lowers the general precision during the printing process. Working with continuous lines requires less stopping and starting of the extrusion process, which a higher degree of precision. Through experimentation, we have learned that working with directionality, continuity, density and overlapping allows us better control of the deformation during kiln firing process. Inspired by spirograph drawing in which seemingly complex continuous lines are controlled through simple mechanisms, we have developed a system for creating continuous patterns, which can be steered by adjusting the amount of self-intersection points in defined areas to vary the density and thickness of the tiles. The entanglement of the lines create adhesion between the layers, which are bond through pressure of gravity in the kiln. Working with longer continuous lines also gives the opportunity to load varying colours into the printer cartridge to produce seamless colour gradients throughout the tiles.

To test the material in an architectural scenario we have developed a shingle system by which the tiles are assembled into an architectural skin. The tiles are graded in their pattern, controlling the porosity in respect to light penetration. The prototype system consists of 12 individual tiles, varying from dense to sparse patterning, creating an overall screen. Bespoke brackets attached to an underlying scaffold are carrying the tiles in custom angles to avoid joining of fragile tile boundaries and to alter the experience of the screen from different viewpoints.

## 7. Conclusion

Silica examines the 3D printing of glass materials through a two fold process. On the one hand, it builds an in depth understanding of the parameters of fabrication and devising means by which to control these through digital design methods and their interfacing with robotic fabrication processes. On the other hand, it critically questions the architectural, aesthetic and performative properties of these material practices and their embedded methods. By using the architectural typology of the tile as a place of investigation, we ask how these new material practices can suggest new ways of understanding architectural boundaries through conditions of porosity, translucency, frosting and patterns. Combining two conditions, one creative, circular and technological, the other analytic, conceptual and designerly, we are interested in understanding how these new circular material practices extend existing architectural vocabularies in aesthetic, conceptual and practical ways.

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