Treading lightly between the analogue and digital to transform float glass – an alternative glass practice?

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Isabella Kullmann
9th December 2019

ABSTRACT

Treading lightly between the analogue and digital to transform float glass – an alternative glass practice?

This practice-based research project follows two overlapping lines of enquiry. First, it investigates the use of float glass as an alternative to furnace glass for blowing. Second, it explores the creative potential of bringing together digital technologies (waterjet cutting) with conventional hot glass techniques.

The process that I have developed is to stack waterjet-cut float glass into three-dimensional constructions which fuse in the warm-up kiln before being picked up with a blowing iron and worked hot. The precision and predictability of the digital is transformed by the breath of the glassblower, centrifugal force, and gravity as the glass comes alive in the heat of the re-heating chamber.

This exploration of material and process subverts the 'hylomorphic' model, whereby form is imposed onto the material, and instead proposes a collaboration with material where, in the words of Tim Ingold, form emerges through a 'confluence of forces and material'. The writings of Juhani Pallasmaa have also inspired this experimental approach to design and making, which has generated original outcomes in the form of tests, samples, and final pieces.

The elegance of this hybrid process, which embraces 'the seamless integration of digital technologies', lies in its simplicity and material efficiency. Looking to the future, the research proposes an alternative glass practice which is adapted to the realities of contemporary life in the twenty-first century.

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1. INTRODUCTION

Prologue: House NA

In Suginami-Ku, a dense urban district in Tokyo, an ethereal structure of metal and glass rises gracefully between the more conventional houses standing either side. House NA (2007-11) is little more than a series of interconnecting platforms 65 mm thick, supported by narrow steel columns 55 mm wide, and window frames on all sides. [1]

Fig. 1: House NA, Suginami-Ku, Tokyo designed by Sou Fujimoto (2007-11).
Photo: © Iwan Baan.

These staggered floating platforms are multi-functional and serve in turn as furniture, open areas, and horizontal space dividers. Through this spatial arrangement and the use of glass and steel, the architect Sou Fujimoto has re-configured the conventional home as a liminal space connected to the urban environment and the network of the city. ‘I’m not just thinking

[1] Sou Fujimoto and Fernando Márquez Cecilia, 'Sou Fujimoto: 2003 - 2010 ; Teoría e Intuición, Marco y Experiencia - Theory and Intuition, Framework and Experience', *El Croquis*, 151 (2010) p. 112.

about making a home, but about how to create an in-between space and how to produce this resistance point between private and public.'[2]

The starting point for this small family home was to imagine what it would be like to live in a tree growing in a forest. The home, no longer a self-enclosed single unit, becomes part of a living, vibrant organism in a connected network of spaces. What Fujimoto describes as a 'geometrical forest' where the interior and exterior, architecture and nature dissolve seamlessly into a 'synthetical place for living'.[3]

This blurring of inside and outside has been achieved through the medium of glass. The fleeting phenomena of rain, clouds, and sunlight animate the architectural space and engender subtle gradations of transparency through the shifting quality of the light.

Background to the research project

Fig. 2: Serpentine Gallery Pavilion 2013, designed by Sou Fujimoto.
Photo: © Iwan Baan.

[2] Niklas Maak and others, *Sou Fujimoto: Serpentine Gallery Pavilion 2013* (London: Verlag der Buchhandlung Walther König, 2013), p. 31.
[3] Friedrich Meschede and Sou Fujimoto, *Sou Fujimoto: Futurospective Architecture* (Bielefeld; Köln; New York, N.Y.: Walther König, 2013), pp. 37-38; p. 277.

I first encountered Fujimoto's work in 2013 when he was awarded the annual commission to design the Serpentine Gallery Pavilion in Kensington Gardens. This was also the year I started my MA at the Royal College of Art (RCA). Every morning during the first few weeks of the autumn term I made a detour to cycle past the open and irregular grid-like structure of fine white steel bars which seemed to float and merge into the landscape of the park. By November it was gone.

House NA, on the other hand, was not such an ephemeral structure. Fujimoto's proposition, that a home could be a thing of such fragility, lightness, and transparency, I found seductive and troubling in equal measure. House NA seemed to suggest a model for living in our digital and networked age. The notion of the home has become something altogether more fluid, fragile, and immaterial.

But could the messiness of life be contained in a transparent glass box? And, indeed, was it possible to live without the stuff and things which mark the passage of time and define who we have become?

As an MA student spending two years in a School of Material, ostensibly making more 'stuff', these became pressing issues.[4] I attempted to address the problem of 'stuff' in my dissertation, to understand how objects help us to make sense of the world. The psychologist Mihaly Csikszentmihalyi argues that objects serve as props to remind us of our past and our aspirations without them: 'our personal identity fades and goes out of focus'.[5] In a world without things, a virtual world, we could lose our sense of self, our past, and future.

For my degree show I presented a series of vessels which considered the glass object in time and space – the play of light, the fall of shadows, the reflections on the surface, and the refraction of colours through the glass. This series, which subverted the Graal technique pioneered by the designer Simon Gate and the master blower Knut Bergkvist at Orrefors in 1916, was the starting point for the present investigation. [6]

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[4] The School of Material ceased to exist in 2017, when the Ceramics and Glass programme joined the newly formed School of Arts and Humanities.

[5] Mihaly Csikszentmihalyi, 'Why We Need Things', in: Steven D. Lubar and W. D Kingery, *History from Things: Essays on Material Culture* (Washington: Smithsonian Institution Press, 1993), pp. 20-29 (p. 23).

[6] Alistair Duncan, *Orrefors Glass* (Woodbridge: Antique Collectors' Club, 1995), pp 29-31.

Fig. 3: Isabella Kullmann, *Itamaraty # 1,* (2015).
Blown glass, cut and cold-worked, re-heated and blown (10 x 39 x 35 cm).
Photo: © John Bennett.

Instead of cold-working the opaque white blown glass blanks to create patterns on the surface of the glass, as in the traditional Graal technique, I used a circular saw to slice the blanks into elliptical rings. [7] The flat surfaces of the rings revealed a thin line of opaque white encased between the thicker clear glass. I cold-worked the horizontal surfaces of the elliptical rings and then re-assembled them into a staggered structure which was heated up in a warm-up kiln before being picked up on the end of a blowing iron and worked hot. Blown out into different vessel forms, the finished pieces had a gently ridged construction with undulating bands of clear and opaque glass which recorded the arrested movement of the hot glass.

I had originally come to the RCA with the intention of developing my casting practice. However, in my first term my tutor Simon Moore encouraged me to undertake a session in the hot shop. The two processes, casting and blowing, although using the same material, are fundamentally separate disciplines which require different skills and knowledge. I quickly realised that over the course of a two-year MA I would not be able to acquire the necessary

[7] Definitions of technical terms may be found in the glossary on p. 69.

skills – nor the physical strength – to produce the work I had in mind without the help of a proficient glassblower.

My practice, as a result, shifted from that of a solitary maker to working collaboratively with a glassblower. Arguably, the lack of glassblowing skills gave me the freedom to experiment with the material and, as an outsider to the discipline, to question existing practices.

Formulating a research question

The summer I graduated, the Mediated Matter Group at MIT, led by Neri Oxman, published an article which described a 3D printer for the additive manufacturing of optically transparent glass which they had developed working collaboratively with the Mechanical Engineering and Material Science departments.[8]

The printer operates at the high temperatures required to process glass from the molten state to the final annealed product. Molten glass is held in a ceramic crucible in a kiln and extruded through a nozzle in a coiling pattern on to a ceramic plate held in an annealing chamber. The ceramic plate, set on the Z-platform, moves inside the annealing chamber which maintains a temperature above the glass transition temperature. The potential application for such a printer across design, art, and architecture, to produce either one-off artefacts or modular components, is seemingly immense.[9]

Coming within months of my graduation (and before I had set up a studio), this innovation prompted me to consider how I could engage with digital technologies to extend the scope of my work.

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[8] John Klein and others, 'Additive Manufacturing of Optically Transparent Glass', *3D Printing and Additive Manufacturing*, 2.3 (2015), 92-105 <https://doi.org/10.1089/3dp.2015.0021>.
[9] Daniel Lizardo and Michael Stern, who were part of the original research group at MIT, have since founded Lios, a collective to develop and design printed glass artefacts.

Fig. 4: Example of optically transparent printed glass produced by the G3DP printing process developed by the Mediated Matter Group at MIT in 2015.
Photo: courtesy of Neri Oxman and The Mediated Matter Group (2015).

Later that year, I heard the celebrated engineer Cecil Balmond remind the audience, in a talk entitled ‘Material Numbers’, that 3D printers produce exactly what is encoded in the CAD (Computer Aided Design) file. In other words, the form-finding is purely algorithmic, and remains software-dependent. [10] Meanwhile the skilled maker has been replaced, and what David Pye famously described as the ‘workmanship of risk’ has been lost.[11] Yet it is precisely this encounter with the skilled maker, for example working closely with Liam Reeves, the hot glass technician at the RCA, that I enjoy and find stimulating. This is where skills are stretched, ‘what if’ moments occur, and risks are taken.

Could I develop a hybrid glass practice which combines the certainty of the digital with the ‘workmanship of risk’? And could an engagement with digital technologies transform my working methods leading to a ‘lighter’ practice in terms of equipment and studio space? These questions became the starting point for this research project.

[10] Cecil Balmond, ‘Material Numbers’ (unpublished lecture, Peter Dormer Lecture Series, Royal College of Art, London, 2015).
[11] David Pye, *The Nature and Art of Workmanship* (London: Herbert Press, 1995).

Defining the objectives

Researching new technologies in glass, it occurred to me that using a waterjet cutter would allow me to cut far more complex shapes than I had been able to achieve previously by slicing through blown glass blanks with a simple diamond saw.[12]

During the first year of my MA, Dr Vanessa Cutler came to the department to present her pioneering research into the use of a waterjet cutter in combination with kiln-formed glass. Cutler completed her PhD at Sunderland University in 2006, where she instigated the installation of a waterjet cutter in the glass department.[13]

At present, waterjet cutters are only found in large commercial facilities or university departments. However, WAZER, a small start-up company in the United States, has developed a compact desk-top model which was launched commercially in 2018. It is therefore plausible to imagine that in the future this equipment could become a standard tool in a small glass studio.

With this in mind, I arranged a visit to a commercial stone-cutting facility which had both 3-axis and 5-axis waterjet cutters to see if and how I could apply this technology to my current work. In discussion with their technician, it soon became apparent that it would be impractical to use the 5-axis machine, which follows the contours of the shape, as each blown glass blank would first need to be digitally scanned to be able to plot the cutting lines accurately. (By their very nature blown glass blanks are never identical, with slight variations occurring in the thickness of the glass and the finished shape.)

If, on the other hand, I were to use sheet glass and the flat bed 3-axis machine, the process would become much simpler (and relatively affordable). First, I would not require blown glass blanks; second, by using sheet glass I would eliminate the time-consuming stage of having to cold-work the top surfaces of the elliptical glass rings before positioning them in the kiln. If the surfaces are not smooth and flat, minuscule pockets of air become trapped and leave a film of bubbles between the layers of glass when they fuse together.

[12] Vanessa Cutler, *New Technologies in Glass* (London: A&C Black, 2012).
[13] A number of other glass artists based at Sunderland University, including Margareth Troli, Erin Dickson, and Joanne Mitchell, subsequently adopted this technology as a central part of their practice and doctoral research.

When I first considered adapting this technology to my work, my initial intention was to use what is generally referred to as ‘art glass’. This is sheet glass manufactured by hand, either using the blown cylinder method or by rolling out molten glass. The sheets are used principally in stained glass, slumping, and fusing, and very occasionally in the hot shop. I had also considered melting casting billets down to 6mm sheets.

Developed for artisanal production, or ‘studio glass’, this type of glass, and I am thinking in particular of the Bullseye range, offers the glassmaker a vast palette of compatible colours in both transparent and opaque glass with an assortment of stringers and frits. Bullseye continue to develop their product range and regularly introduce new colour tints, surface textures, and effects.

As irresistible as the Bullseye range of sheet glass may be, I concluded that it would be unsuitable for the process I am developing and ruled it out for the following reasons:

First, the standard thickness of Bullseye sheet glass is 3mm (4mm and 6mm are available in clear). Many layers of glass would be required to build a construction with sufficient height to be blown. This in turn would entail more waterjet cutting time which would increase costs. Three-millimetre sheet glass is more fragile than the standard 6mm float glass (industrially manufactured sheet glass) increasing the risk of cracks during transport and cutting. Second, as the glass is made by hand, the cost is significantly higher than float glass. Third, the glass is imported from the Bullseye factory in Oregon, adding transport miles to the final product. Fourth, the irregular surface of the handmade glass could lead to tiny bubbles forming between the layers of glass (see above).

In contrast, float glass has a smooth and parallel polished surface, is easily available, relatively cheap, and comes in thicknesses from 2 mm to 22 mm. Furthermore, if I were to use precision engineering to cut the glass, it seemed more apposite, a kind of ‘truth to materials’, to use float glass – an industrially produced material.

This preliminary groundwork identified three clear practical objectives at the outset:
1. To investigate the feasibility of using sheets of float glass as an alternative to furnace glass for blowing.
2. To test and develop the process of stacking, fusing, and blowing layers of WJC (waterjet cut) glass.
3. To explore the creative potential of this novel hybrid process.

Research methodology

The practical research was carried out through a wide-ranging schedule of tests. I kept a detailed record of each test on a separate test sheet. Together these represent the core of my investigation into material and form and served as a mode to gather data, to evaluate my results, to inform further testing, to drive the research forward, and as a tool of reference for the future. This collection of test sheets, a technical logbook of sorts, exceeds the allowable word count of the appendix and I therefore attach an edited version.

As the test sheets demonstrate, this is primarily an investigation into the use of a material and the development of a process. In his 1993 paper 'Research in Art and Design', Christopher Frayling, later Rector of the Royal College of Art (1996-2009), describes this general approach, based on practical experiments in the studio which are recorded and communicated in a report, as *research through art and design*.

Frayling identifies two further approaches to research: *research into art and design*, which follows established models of academic research, and, in his view, the more problematic *research for art and design*. The outcome of this research, or gathering of material for reference, is not communicated verbally in a written report or journal but instead the thinking, Frayling argues, is '*embodied in the artefact'*. [14]

The final pieces (as opposed to the tests and samples) which I present here attempt to convey my thinking as it has developed over the course of this study. In other words, they are a subjective response to the research, and as such they are the outcomes of *research for art and design* but remain secondary to the primary aim of this investigation.

Aesthetic aims

The aesthetic ambition of the research was to produce an original body of work which would be unique to the process. Ideally the pieces would be not only merely intriguing ('how was this done?'), but also arresting in their own right. At the beginning I had imagined a series of delicate structures but, as my test sheets show, I was unable to achieve such a result: this presented a limitation in terms of the creative potential of the process. Observing how the breath inexorably expanded the glass out into a bubble I focused on designing WJC

[14] Christopher Frayling, 'Research in Art and Design', *Royal College of Art Research Papers*, 1.1 (1993) p5.

structures which would be transformed by the process. In evaluating the test pieces, I considered what adjustments could be made to the line of the cut and the dimensions, proportions, and scale to refine the design. I argue that I responded to an outcome, the glass having found its form through physical principles.

While I did not define explicitly what would represent a successful outcome, on reflection I believe that this should meet at least three of the following aims: the WJC structure (the certainty of the digital) should be transformed by the workmanship of risk at the hot shop stage; the design should be modular and offer scope for multiple variations, and finally it should be repeatable.

To make the test pieces, samples, and final pieces I worked closely with Liam Reeves, the hot glass technician at the RCA. Not only did I rely on his technical skill as a glassblower; I also valued his knowledge and remained receptive to his advice throughout this project. As a student at the RCA I was in the privileged position of being able to draw on the expertise of the technical staff to help fabricate the work, as well as having access to well-equipped and well-maintained studios and workshops.

In future, I will need to rent such facilities on a daily or weekly basis. In the case of a hot shop, which requires considerable financial outlay to set up and run, this is becoming common practice. The glassblower rents out their hot shop and, if required, is available to fabricate the work. A separate fee is agreed for their time. This commercial arrangement arguably makes for a more equitable relationship, offering both parties a choice about whether to enter into such a working relationship.

For such a relationship to be successful the designer should not only understand the affordances of the materials and techniques involved but, as Juhani Pallasmaa argues, they should also be able ‘to communicate their ideas and intentions to the specialist craftsman, whose hands become the designer’s surrogate hands in the execution of the work’. [15]

Thesis structure

An account of the empirical research and the intellectual engagement that drove this project forward are set out in two separate chapters which look at ‘material’ and ‘form’.

[15] Juhani Pallasmaa, *The Thinking Hand: Existential and Embodied Wisdom in Architecture* (AD Primers) (Chichester: Wiley, 2009), p. 63.

In the first chapter, on material, I introduce the notion of the materiality of the city. I take as a starting point the building of Crystal Palace for the Great Exhibition of 1851 to explain how sheet glass became an industrially manufactured building material which would transform our cityscapes. I include a brief summary of the development of the float glass process invented by Alastair Pilkington.

I then consider how sheet glass has been used as a medium for artists by examining the work of Larry Bell, who explores the perceptual qualities of the material. By way of comparison with Bell, and as a contextual review, I introduce and acknowledge the work of Tom Patti and Matthew Szösz, who have both experimented with inflating sheet glass and, as such, have engaged with it as a material to be transformed. I also reference the work of Danny Lane and Ikuta Niyoko. I end this chapter with a brief outline of my own empirical research into the material.

The second and longer chapter focuses on my search for form with the application of this hybrid process and the use of float glass. Referencing in particular the writings of Tim Ingold, Professor of Social Anthropology at the University of Aberdeen, and Juhani Pallasmaa, the distinguished architect, academic, and architectural thinker, I describe how I go from 2D (the sketch, the line, the cut) to 3D (construction, distortion, finished piece). I consider how the breath and the agencies of heat, centrifugal force, and gravity give form, deform, and transform the rigid sheet of flat glass to subvert the predictability of digital design. A form emerges of its own volition.

The broad parameters of the research questions and the main objectives were clearly defined at the start. The historical and conceptual research which I carried out in parallel also informed the practical research as the project unfolded. This research was open-ended and did not subscribe to a particular theory or set out to refute a hypothesis; it did contribute, however, to a more nuanced understanding of material and process.

My research into sheet glass, which focused on its historical development and its application across architecture, design, and art, highlighted its paradoxical nature as both material and immaterial. The parallels which I identified between the perceived immateriality of float glass and that of our digital world guided my choice of low-iron float glass and my decisions not to use colour and to abstain from applying any surface decoration.

By considering the materiality of the city in the context of the development and application of sheet glass I situate the project within an urban environment. This becomes a source of inspiration for some of the designs and a site for speculation as to how an alternative studio glass practice may be embedded into the network of the contemporary city.

A grasp of Aristotle's hylomorphic model clarified two opposing views on design and making, presented by Herbert Read and Tim Ingold respectively. This insight became instrumental in how I approached the design and making process, while Juhani Pallasmaa's observations on embodied thinking encouraged me to embrace the value of uncertainty and to leave a space for the unknown, the uncontrolled, and the serendipitous.

As I disentangle the overlapping lines of enquiry which I pursued over the course of this research project, I wonder if this encounter between digital and analogue, virtual and real, or between bits and atoms, is not simply a response to the challenge of House NA? To create things which through their material (float glass) and their hybrid mode of production may find their place in the fluid modernity which Fujimoto's architecture proposes.

2. MATERIAL

A brief history of sheet glass

The architect and academic Joan Ockman writes that since the mid-nineteenth century, when glass became a modern building material, it has been seen as 'the embodiment of rationalism, in the sense of both philosophical and technical-instrument reason', but at the same time it has always carried with it an 'anti-rationalist' visionary impulse'.[1]

This duality between reason and enchantment, Ockman argues, was most brilliantly exemplified in the Crystal Palace, designed by Joseph Paxton, which was built to house the Great Exhibition of 1851. Paxton, the head gardener at Chatsworth, had been experimenting with prefabricated elements to design and build a series of greenhouses to cultivate exotic plants. His initial design for Crystal Palace, a quick sketch on a sheet of blotting paper, was an expanded version of this model.

The construction, which took under six months to complete, used a flexible model of prefabricated iron girders, joiners, and connectors and nearly 100,00 m^2 of glass. Robert Lucas Chance was awarded the commission to produce the 300,000 panels of blown sheet glass required to glaze the structure. Each panel was made using an improved version of the cylinder method which Chance had introduced to his factory in Smethwick in 1832 to replace the more wasteful spun crown glass.[2]

Crown glass was made by first blowing a sphere, which was then transferred on to a punty iron attached to the crown of the sphere (hence the name), and then spun round with the centrifugal force producing a flat circular sheet of glass with an approximate diameter of 70 cm. The finished sheet was cut into panes of glass. [3]

Cylinder-blown sheet was produced by swinging an elongated bubble of glass in a deep trench to the required length. The cylinder, once annealed, was split along its length. The glass was then re-heated and flattened with wooden blocks. The manufacturing process could therefore

[1] Joan Ockman, 'A Crystal World: Between Reason and Spectacle', in: *Engineered Transparency: The Technical, Visual, and Spatial Effects of Glass*, ed. by Michael Bell and Jeannie Kim, (New York: Princeton Architectural Press, 2009), pp. 45-54 (p.45).
[2] Isobel Armstrong, *Victorian Glassworlds: Glass Culture and the Imagination 1830-1880* (Oxford ; New York: Oxford University Press, 2008), pp. 37–38.
[3] 'History', *London Crown Glass* <http://londoncrownglass.com/History.html> [accessed 11 September 2019].

be done into two discrete stages. This division of labour would guarantee a standardised product: a sheet of glass, known as broad sheet, weighing 16oz (7.26 kg) and measuring 40 x 30 inches (101.6 x 76.2 cm). This improvement in glassmaking contributed to the organised rationalism which underpinned the construction (and dismantling) of Crystal Palace. [4]

The embodiment of Paxton's vision was a glass world which beguiled and dazzled visitors. As we read the description of a German visitor, the writer Lothar Bucher, it is worth remembering that the window tax, imposed by William III in 1697, had only been repealed that year. In 1851, glass was a luxury commodity and not the ubiquitous material that we think of today.

> We cannot tell if this structure towers a hundred or a thousand feet above us, or whether the roof is a flat structure or built from a succession of ridges, for there is no play of shadows to enable our optic nerve to gauge the measurements. If we let our gaze travel downwards it encounters the blue-painted lattice girders. At first these occur only at wide intervals; then they range closer and closer together until they are interrupted by a dazzling band of light – the transept – which dissolves into a distant background where all materiality is blended into the atmosphere. [5]

Held in this vast crystalline structure Bucher loses all sense of perspective and distance. Shadowless, the glass envelops and insulates, contains and scatters light, and then dissolves into the atmosphere.

By the second half of the nineteenth century, sheet glass and the introduction of the vaulting glazed roof were transforming the cityscape. New building types emerged to open up the architectural space: covered glass arcades, railway stations, department stores, factories, winter gardens, glass menageries, and conservatories.[6] The modern city acquired an aura of immateriality as it became a space of fugitive, evanescent reflections: 'memories of light' abstracted into pellucid colours and shapes.[7]

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[4] Armstrong, p. 41.
[5] Lothar Bucher, quoted in Sigfried Giedion, *Space, Time and Architecture: The Growth of a New Tradition*. 5th, rev. enl. ed. (The Charles Eliot Norton Lectures 1938–1939). (Cambridge, Mass. London: Harvard University Press, 2008), pp 253-4.
[6] Anne Friedberg, *The Virtual Window: From Alberti to Microsoft* (Cambridge, Mass: MIT Press, 2006), p. 112.
[7] Armstrong, p. 96.

Over the next fifty years the process of sheet glassmaking became more streamlined and efficient. Pilkington installed gas-fired furnaces imported from Siemens in Germany in the 1870s, which enabled continuous production and accurate temperature control. This innovation was followed in 1907 by the introduction of machine-blown cylinder glass, which used compressed air. Meanwhile, in Belgium Emile Fourcault invented a process for producing large sheets of flat glass by drawing the molten glass up vertically through a system of rollers. [8]

The production of plate glass had also become fully mechanised over this period. Plate glass is made by casting molten glass on to a flat surface and then grinding and polishing both surfaces of the glass sheet to obtain a smooth, parallel, and transparent finish. Pilkington, collaborating with the Ford Motor Company, developed the 'Twin' process for grinding and polishing both surfaces of plate glass simultaneously. This technology was successfully licensed to other plate glass manufacturers around the world.[9]

After the Second World War, recognizing that the technology was outdated and imperfect (almost twenty per cent of the glass was lost in grinding and polishing) and to help maintain the company's position in the global market, Pilkington set out to research a manufacturing process which would offer the quality of plate glass at a comparable price to that of sheet glass. A team of engineers, led by Alastair Pilkington (no relation), investigated the possibility of floating hot glass on molten tin and a first float patent was filed in 1953. The idea was that a ribbon of glass could be floated down the production line on a bath of molten tin. At the same time the glass would acquire a fire-polish, which would eliminate the need to grind and polish the surfaces of the glass after it had annealed. Initially the ribbon of glass was formed by rollers, but in 1955 Alastair Pilkington decided to try pouring the molten glass directly on to the bath of tin to allow gravity and surface tension to spread the glass out evenly. [10]

Three pilot plants were built to test the process, modify the design of the machinery, and resolve many of the technical issues which arose, not least the problems of tin bloom and devitrification; a full-scale plant went into operation in 1957. Throughout this period of research and development, underwritten by considerable financial investment, Alastair Pilkington steadfastly maintained that there was no reason why it should not work and, in

[8] Michael Wigginton, *Glass in Architecture* (London: Phaidon, 2004), p. 271.
[9] David J. Bricknell, *Float: Pilkington's Glass Revolution* (Lancaster: Crucible, 2009), p. 6.
[10] Bricknell, pp. 40–44.

January 1959, the company unveiled the float glass process.[11] Pilkington subsequently licensed the technology which would become the universal process for making flat sheet glass.

The principle of the float process is the following: molten glass at a temperature of 1,100°C degrees is poured continuously from a furnace on to a bath of molten tin. The glass floats on the tin and spreads out to form a level and parallel surface. At 600°C degrees the fire-polished glass becomes a solid ribbon and is transferred to a lehr to be annealed.[12]

Float glass: the material of our cities

In the introduction to his book *Fewer Better Things*, the curator and design historian, Glenn Adamson expresses his disquiet at the erosion of our *material intelligence,* which he defines as a profound understanding of our material environment and the knowledge and skills 'to give it new form'. He attributes this loss to the technological complexities of modern life which have distanced many of us, in every sense, from any meaningful engagement with material.[13]

To begin to recover this material intelligence Adamson suggests that we should be in 'the contact zone', attentive to our surroundings and the objects we own and use. To illustrate this idea Adamson invites us to consider the materiality of our city and, by way of example, he takes the reader for an imaginary walk up Fifth Avenue in New York. He points out the asphalt pavements, the terracotta facades, the steel manhole covers, the brass awnings, and along the way, 'the reflective glass curtain walls of mid-century skyscrapers' which are 'the definition of affectless materiality'.[14] Here, unwittingly perhaps, Adamson draws attention to what I perceive as the problem with float glass when we consider the emotional, functional, and sensorial attributes of the material itself.

The architect Mies van der Rohe first conceived of the glass curtain wall in 1921 when he submitted a proposal for a skeletal structure completely sheathed in glass. As his drawings for the Friedrichstrasse Skyscraper in Berlin show, Mies envisioned a hollow glass crystal

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[11] Bricknell, pp. 56–71.
[12] 'The Float Process', *Pilkington* <http://www.pilkington.com/global/about/education/the-float-process/the-float-process> [accessed 5 September 2018].
[13] Glenn Adamson, *Fewer, Better Things: The Hidden Wisdom of Objects* (New York: Bloomsbury, 2018), pp. 1–10.
[14] Adamson, *Fewer, Better Things*, pp. 82–86.

tower surging forth, 'its mass dematerializing into light and air, reflection and refraction.'[15] While the project itself was not selected, the potential of sheet glass to reveal form and link the building to the landscape would come to dominate architectural thinking over the next fifty years.

Through their use of industrial materials such as plate glass and concrete, the first Modernist architects, Richard Sennett argues, sought to build a 'more coherent and unified society', but the reality was that 'their art created isolation rather than connection'. [16] He writes: 'The peculiar physical sensation aroused by plate is complete visibility without exposure of the other senses.'[17] Behind the glass wall we are isolated and insulated from the smells, sounds, and movement of the city, while out on the streets we are confronted with what Pallasmaa describes as 'repulsively flat sharp-edged, immaterial, and unreal' architectural structures. [18]

Smooth, cold, and inert, float glass possesses none of the tactile qualities associated with natural materials such as stone or wood. Divorced from the realities of matter and craft, the engineered and prefabricated glass curtain wall is, according to Pallasmaa, a product of a 'weakened sense of materiality' which has privileged clarity of vision over a haptic engagement with material. [19]

The architect Jean Nouvel, on the other hand, embraces what he describes as an 'evaporation' of material. [20] In conversation with the philosopher Jean Baudrillard, he asks rhetorically: 'How can we resolve the most material problems with the greatest amount of elegance?' He frames the question in Darwinian terms, and his answer is glass. As Nouvel explains, glass 'has good durability', 'is made of sand' and does not require 'colossal amounts of energy', and he adds: 'glass is also a kind of language, a kind of mutant material'. [21]

[15] Detlef Mertins and Phyllis Lambert, *Mies* (London ; New York, NY: Phaidon Press, 2014), p. 68.
[16] Richard Sennett, *The Conscience of the Eye: The Design and Social Life of Cities* (New York, NY: Norton, 1992), p. 110.
[17] Sennett, *The Conscience of the Eye*, p. 108.
[18] Juhani Pallasmaa, *The Eyes of the Skin: Architecture and the Senses*, 3rd. ed (Chichester: Wiley, 2012), p. 34.
[19] Pallasmaa, *The Eyes of the Skin*, p. 34.
[20] Jean Baudrillard and others, *The Singular Objects of Architecture* (Minneapolis, MN: University of Minnesota Press, 2005), p. 64.
[21] Baudrillard and others, *The Singular Objects of Architecture*, p. 64.

Nouvel, like Sou Fujimoto, uses glass to dissolve the barrier between the inside and the outside and to establish a connection with nature. The landscape is put to use and becomes an active element in the structure of the building. To achieve this seamless interpenetration, as David Leatherbarrow, Professor of Architecture at the University of Pennsylvania School of Design, explains: 'the building must be dematerialized…and light must be treated as if it were matter'.[22] The *affectless materiality* of float glass transcends itself into the atmosphere: 'the old deadening permanence of architecture is abandoned, and the building joins step with the pace of contemporary life'. [23]

The glass sheet as artistic medium

In 1986, on the centenary of the architect Mies van der Rohe's birth, Sennett wrote:

> For the first time in a building by Mies, I felt comfortable leaning back against the glass. I don't want to make too much of this moment, only that it gave me an intimation, through the material, of what the phrase *modern* might truly and positively imply. It was just a sense of the inherent ambiguity of glass; more than a metaphor, it was a field on which the exchange between inner and outer occurs, a field reflecting the violation of space but also enclosing and protecting. And I suppose this is why plate glass is so interesting: now a window on nothing, a mirror of solitude, its possibilities have yet to be explored in the practice of an ambiguous, permeable, violating, warm, and thus truly modern art.[24]

To offer some insight into why 'plate glass [could] be so interesting', I propose to take a closer look at the work of the artist Larry Bell. While many artists from Marcel Duchamp onwards have used sheet glass, in Bell's case it has been absolutely central to his artistic output since the 1960s, although as he likes to point out, 'My medium isn't glass; it's the light that hits the glass'. [25]

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[22] David Leatherbarrow, *Architecture Oriented Otherwise* (Writing Matters) (New York: Princeton Architectural Press, 2009), p. 86.
[23] Leatherbarrow, pp. 88–89.
[24] Richard Sennett, 'Plate Glass', in: Richard Poirier, *Raritan Reading* (New Brunswick, NJ: Rutgers University Press, 1990), p. 363.
[25] Rachel Rivenc, *Made in Los Angeles - Materials, Processes, and the Birth of West Coast Minimalism* (Los Angeles, CA: Getty Publications, 2016), p. 53.

Along with Robert Irwin, Craig Kauffman and John McCracken, Bell was part of a loose group of artists working in Los Angeles in the ’60s who came to define West Coast Minimalism. Their sensuous use of colour, an engagement with making and craft, and an interest in experiential art set them apart from artists associated with the more object-oriented Minimalism to be found on the East Coast.[26]

Their work, often in response to the environment – Los Angeles, the ocean, and above all the quality of the light in Southern California – exudes a cool, shimmering, seductive perfection. Shifting ‘the locus of meaning from the object to the experience’ these artists, along with James Turrell in the following decade, would be at the forefront of the Light and Space movement of the early ’70s. [27]

Originally a painter, Bell inserted panels of glass into his geometric paintings as a visual device to subvert the picture plane and take the painting beyond the two-dimensional surface of the canvas and out into the gallery space. The canvas, the wall, and the space between become one, a volume within a volume. This investigation led Bell to lift the work off the wall altogether and the isometric geometrical paintings became complicated three-dimensional constructions with inserted panels of glass and mirror.

Looking for a more seamless way to introduce a reflective surface into his constructions, Bell started to experiment with vacuum deposition, whereby a small amount of metallic or non-metallic compound is vaporised and deposited as a thin film of material on to the surface of the glass. This allowed Bell to create a reflective surface on both sides of the glass. At the same time, he simplified his constructions, paring them down to an enclosed glass cube set within a frame. Eventually he eliminated the frame altogether. [28]

The simplicity and symmetry of the cube appealed to Bell and he adopted it as the form to carry out his investigations into space and the properties of light. The artist and critic John Coplans described Bell’s glass cube as ‘a physical object, weighty and bound by gravity, in terms of light it is free in space.’[29]

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[26] Rivenc, p. 14.
[27] Melissa E. Feldman, *Another Minimalism: Art after California Light and Space,* [exhibition catalogue] (Edinburgh: Fruitmarket Gallery, 2015).
[28] Rivenc, pp. 53–69.
[29] John Coplans, ‘Larry Bell’, *Artforum* (May 1965), pp. 27-29.

Sheet glass and the process of vacuum deposition have been fundamental to the development of Bell's work over the last fifty years. Glass, as he likes to say, 'has at once three distinctive properties: it reflects light, absorbs light, transmits light all at the same time.'[30] It is the optical qualities of glass that are of relevance here and not the ductile capacities of the material.

With his ongoing series of *Cubes* and *Standing Walls*, Bell explores the ambiguity of glass as both a physical presence and a visual absence—weight and lightness.

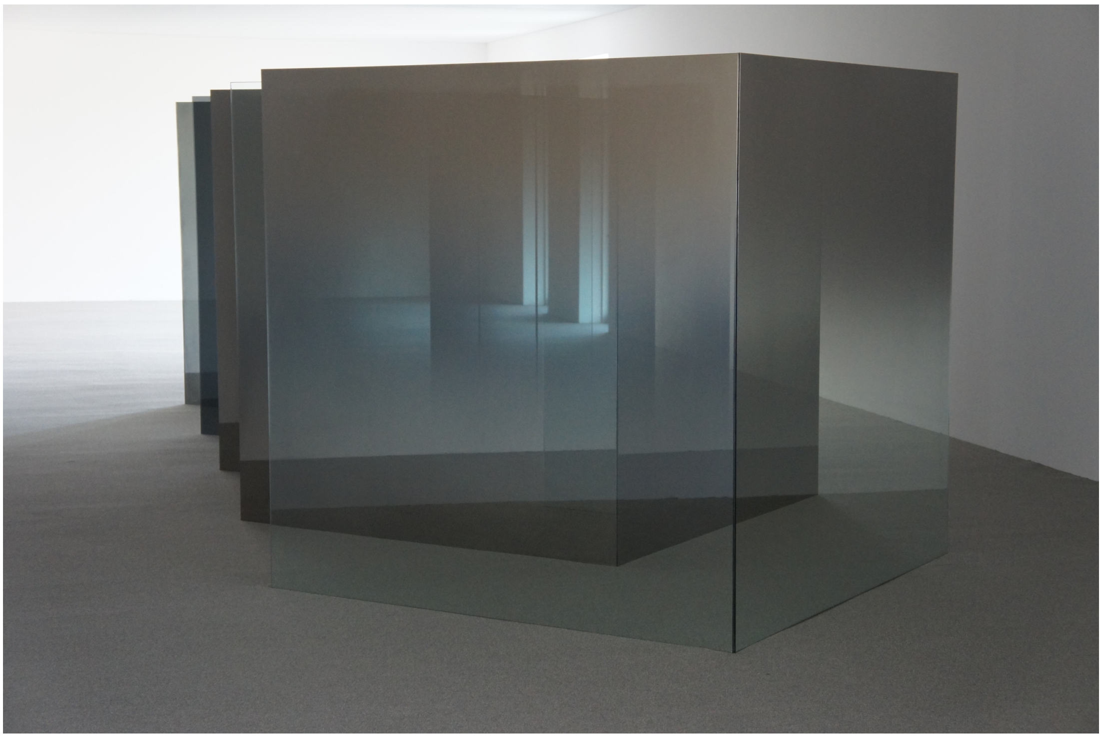

Fig. 5: Larry Bell '6 X 6 An Improvisation' Chinati Foundation, Marfa, Texas (2014).
© Larry Bell, courtesy of the artist and Hauser & Wirth.

I first saw Bell's work at the White Cube gallery in Bermondsey where he had installed *6x6 An Improvisation*, the largest of his *Standing Walls*, which was first shown at the Chinati Foundation in Marfa, Texas in 2014.[31] The 40 panels (72 inches x72 inches) of clear, grey, and Inconel coated glass were placed to form a series of rectilinear spaces within the gallery.

[30] *Interview with Larry Bell. Museum of Contemporary Art, San Diego.*, 2011, Museum of Contemporary Art, San Diego. https://www.mcasd.org/exhibitions/phenomenal-california-light-space-surface [accessed 13 April 2018].
[31] 'Larry Bell: Smoke on The Bottom', White Cube Gallery, Bermondsey, London, 28 April-18 June 2017.

The configuration of the panels is site specific. They are arranged and re-arranged depending on the exhibition space and above all the source and quality of the light: *An Improvisation* re-imagined in each new location.

Fig. 6: Larry Bell, ‘6x6 An Improvisation’, installation view, White Cube, Bermondsey London, (2017).
Photo: Isabella Kullmann.

Visitors to the exhibition circulated around the panels of sheet glass, attentive to the myriad reflections of their fractured figures appearing, disappearing, and re-appearing. The installation was elegant but its physical presence in muted shades of grey against the white walls of the gallery was perhaps just too perfect. Placed in a sterile white cube with controlled overhead lighting, and without the backdrop of a landscape, a striking architectural setting, or the play of light to animate the installation, the inert superficial beauty of the glass soon exhausted itself. And there I would have left things had I not come across an image of *Pacific Bell II*, Bell’s installation for the 2017 Whitney Biennial.

A row of diaphanous glass cubes in shades of translucent red, from pale pink to deep poppy, were strung out like jewels across the roof of the Whitney Museum of American Art to form a gloriously sensuous saturation of colour which, as if in response to Sennett’s exhortation, violated the New York skyline. The sheet glass radiated warmth, and a luminous evanescent beauty; this was no longer the stuff of an 'affectless materiality' but a vibrant material to sculpt and contain light.

Fig. 7: 'Pacific Red', installation view, Whitney Biennial 2017, Whitney Museum, New York, (2017). © Larry Bell courtesy of the artist and Hauser & Wirth.
Photo: Zak Kelley.

The glass sheet as material

Contextual review of the work of Tom Patti, Matthew Szösz, Danny Lane, and Ikuta Niyoko.

The artist and designer Tom Patti shared many of the same aesthetic preoccupations as Bell, but worked on a different scale to produce small jewel-like sculptures which afford the beholder 'an intense perceptual experience' of colour and light. [32] Patti's cubes of layered coloured glass are intimate self-contained works which, in contrast to Bell's installations of glass cubes and walls, do not rely on what Bell himself describes as the 'dynamic of space' for their effect. [33]

[32] Daniel Kuspit, 'Taut Glass' in: William Warmus, Donald B. Kuspit, and Tom Patti, *Tom Patti: Illuminating the Invisible* (Tacoma, Wash: Museum of Glass: International Center of Contemporary Art: Distributed by Univ. of Washington Press, 2004), p. 15.

[33] 'Artists – Larry Bell', *Hauser & Wirth* <https://www.hauserwirth.com/artists/2851-larry-bell?modal=media-player&mediaType=film&mediaId=11757> [accessed 5 September 2019].

Patti, a contemporary of Bell's, began experimenting with blowing sheet glass, either manufactured for the domestic market (window glass) or the car industry in the early '70s. He was arguably the first to do so, and his early work is therefore particularly pertinent to this research.

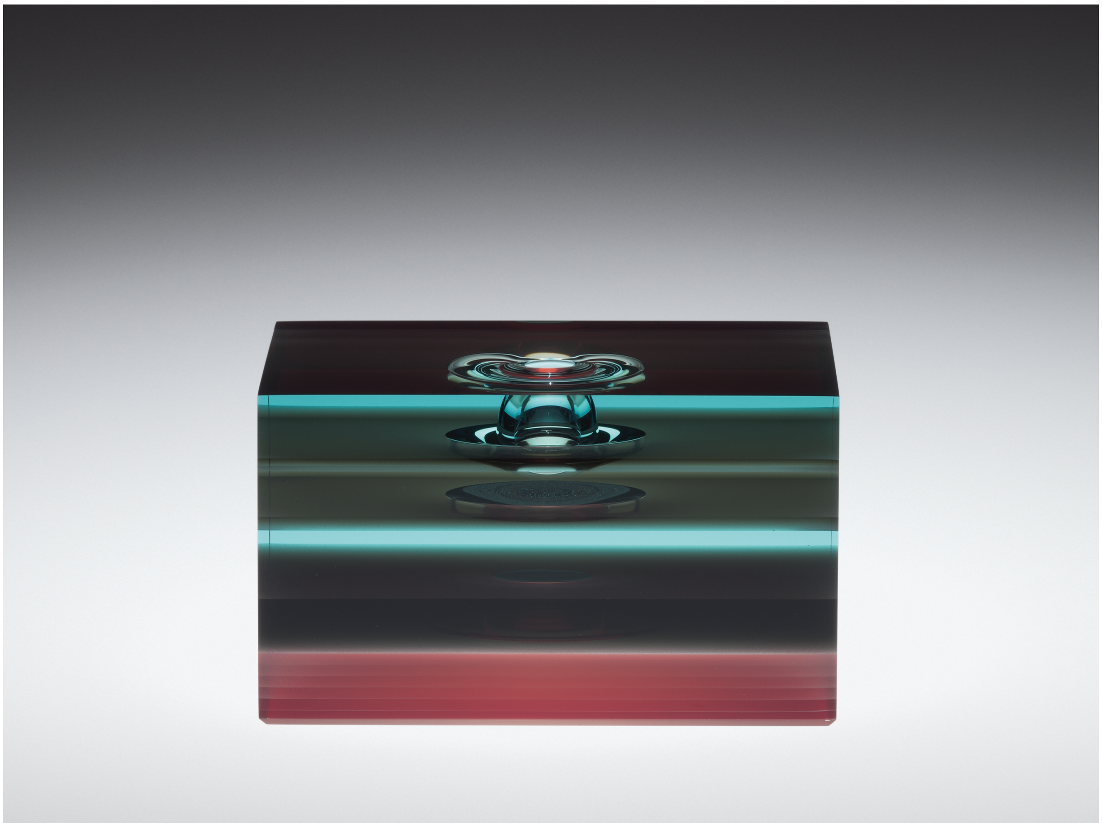

Fig. 8: Tom Patti, *Asahi Lumina with Bronze and Mirrored Disk* (1991-1993), (9.2 x 15.6 x 11.5 cm). Gift of the Ben W. Heineman Sr. Family, Corning Museum of Glass.
© Tom Patti.
Photo: courtesy of the Corning Museum of Glass.

The curator and critic William Warmus remarks in his catalogue essay for Patti's retrospective show at the Museum of Glass, International Center for Contemporary Art in Tacoma (2004) that 'Patti came to flat glass as a raw material that he could use to create a rich language'. [34]

Patti stacked sheets of coloured glass horizontally into small geometric constructions which he then heated up in a kiln. Once the glass had reached its molten state, he would insert air into the body of the glass to form a bubble. Patti describes the outcome as 'blown laminated

[34] Warmus, Kuspit, and Patti, *Tom Patti,* p. 21.

glass'. Over the next two decades, from the mid-'70s onwards, Patti would continue to develop this technique by, for example, assembling the glass vertically, or inserting wire mesh between the sheets of glass, or sealing in air pockets which expanded as the glass was heated up. These small studies in laminated float glass would inform his later work of undertaking large scale architectural glass installations. [35]

With a background in engineering and design (he received a BFA (1967) followed by an MFA (1969) in Industrial Design from the Pratt Institute) and research into inflating plastics at Owens-Corning (1967), Patti's approach to glass making was highly experimental and sits at the intersection of his investigations in art, science, and technology.

Patti stands apart from the expressive and performative aspects of the early Studio Glass movement of the '60s and '70s. As he states in an interview with Warmus, 'Littleton invented the studio furnace; I eliminated it from the studio'. [36] His contemplative sculptures are closer to the crisp industrial design aesthetic and lushness of West Coast Minimalism than to the hand-crafted output of the Studio Glass movement of that era.

Following on from Patti, Matthew Szösz has been developing a highly experimental, diverse, and original body of work including, since the mid-2000s, blowing up stacked sheet glass with compressed air.

Szösz's method is similar to Patti's (and indeed my own) but with the crucial difference that between the layers of glass he inserts a thin sheet of ceramic paper (cut to a slightly smaller size) which acts as a resist to stop the layers from fusing together. Szösz superimposes these 'envelopes' to build a structure which he heats up in the kiln. The outer edges of the glass sheets fuse together to form a seam enclosing the central chamber(s) where the ceramic paper lies. Once the glass reaches a working temperature, Szösz removes the structure and holding the molten glass between thick wads of fibre blanket, he injects compressed air through a brass tube into the sealed edge of the 'envelope'. [37] The structure, as if emerging out of a chrysalis, expands rapidly to find its form. Szösz's interest lies in the physical principles which produce these different forms,

[35] Warmus, Kuspit, and Patti, *Tom Patti*, p. 24.
[36] Paul Hollister, 'Tom Patti; The Code Is in the Glass', *Neues Glass New Glass*, (1983), 74–83.
[37] William Warmus, 'Subversive Process', *Urban Glass Quarterly* (Winter 2017), 21–29. 'Matthew Szosz', *Matthew Szosz* <https://www.matthewszosz.com> [accessed 10 August 2019].

or ‘inflatables’, as he calls them. [38]

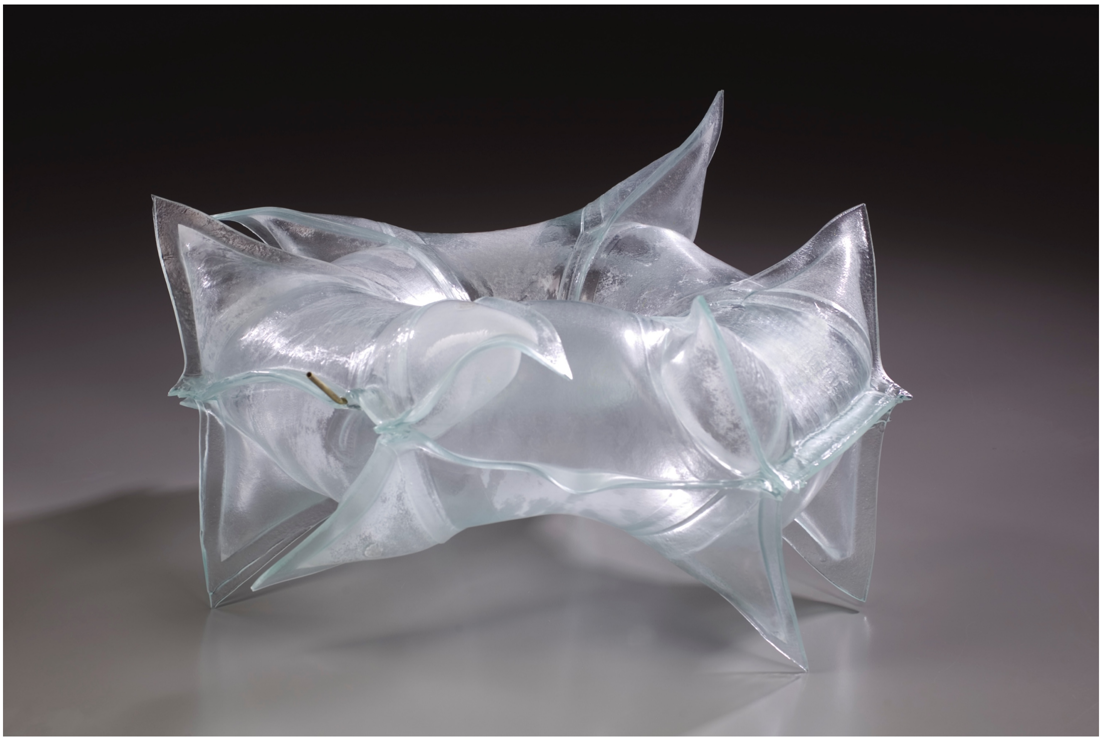

Fig. 9: Matthew Szösz, *untitled (inflatable) no.43*, (2008).
Fused and inflated found glass (48 x 48 x 22 cm).
Photo: courtesy of Matthew Szösz © Mark Johnston.

Patti and Szösz, neither of whom are trained or skilled glassblowers, but who come from design and engineering backgrounds, have developed highly original practices on the margins of the discipline to investigate the creative potential of inflating sheet glass.

Layers of sheet glass have also been used to great effect in the construction of glass sculptures as can be seen in the work of artists such as Danny Lane and Niyoko Ikuta. Lane trained as a stained-glass artist before studying painting at the Central School of Art and Design in London. Since the early ’80s he has been making furniture, large-scale sculptural pieces, and architectural installations using thick sheets of float glass which he cuts, breaks, and assembles, either horizontally or vertically, by laminating, fusing, casting or bracing with steel rods.

[38] Shawn Waggoner, ‘C. Matthew Szösz; How the Way We Make Objects Influences the Objects We Make’, *Glass Art* 31.2 (April 2016).

Ikuta, like Bell, is also inspired by ‘the complexities of light as it reflects, refracts, and passes through broken cross sections of plate glass’.[39] Ikuta uses a layered construction to assemble her graceful sculptures; the cut sheets of float glass are laminated together in a spiral or helical form. The twist adds movement while the edges of the glass sheets, set at graduated angles, pick up and reflect the available light.

Fig. 10: Danny Lane, Chair, (1988).
Layered sheet glass, the back and legs are threaded on to steel rods.
Credit: © Danny Lane courtesy of the artist and the Victoria and Albert Museum, London.

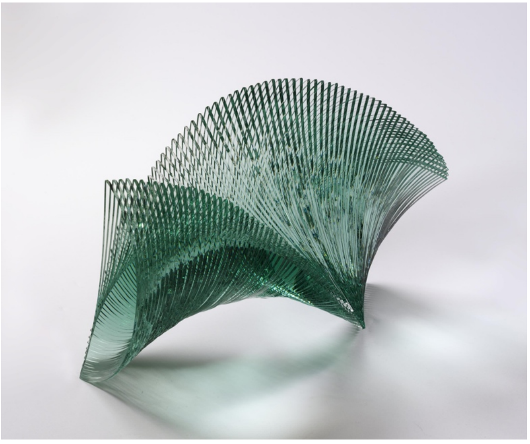

Fig. 11: Niyoko Ikuta, *Free Essence-6 (Ku-6),* (2009).
Laminated float glass sculpture.
Credit: courtesy of the Victoria and Albert Museum, London.

[39] ‘Free-essence 6’, Ikuta Niyoko, *V&A Museum,* http://collections.vam.ac.uk/item/O438336/free-essence-6-ku-6-sculpture-ikuta-niyoko/ [accessed 26 July 2018].

Exploring the material: preliminary investigation into float glass

The first stage of my practical research was to understand the affordances and constraints of using float glass as an alternative to furnace glass for blowing. Pallasmaa suggests that 'the work of the craftsman implies collaboration with the material. Instead of imposing a preconceived idea or shape, he needs to listen to his material'. [40] To become attuned to a material is to perceive and appreciate its inherent properties, qualities, subtleties, and behaviour. This in turn reveals its creative scope leading to more imaginative designs.

By way of an introduction to the material, I made a series of preliminary test pieces which were devised to assess the firing schedule for fusing the layers of float glass in the warm-up kiln, to test different adhesives, to establish an annealing cycle, and finally to observe how float glass responded to and was transformed by heat.

Fig. 12: Preliminary test pieces (2016). The difference in colour between regular float and low-iron float is particularly noticeable in the two larger test pieces.
Photo: Isabella Kullmann.

[40] Juhani Pallasmaa, *The Thinking Hand,* p. 55.

The flat sheet of float glass is essentially a finished product manufactured primarily for buildings and vehicles. For the purpose of this research I am using it here as an alternative to furnace glass. The layered float glass construction is heated in a warm-up kiln and a re-heating chamber; once the glass is hot enough it can be blown on the end of a blowing iron. This unconventional use of float glass obviates the need for a furnace. However, compared to glass batch which has been formulated specifically for glassblowing, it presents certain challenges. Float glass has a much shorter working range: it melts at a higher temperature and cools faster. The glass is stiff, and not as malleable as studio furnace glass. Furthermore, tin ions are absorbed onto the surface of the glass, which was in direct contact with the molten tin. These factors – the short working range and the oxidation of tin ions on the surface – lead to devitrification, and what is known as 'tin bloom'. It should also be noted that the studio and the hot shop are not pristine environments: whatever is floating around in the atmosphere will be deposited as particles on to the surface of the glass. In the words of Dr Jane Cook, Chief Scientist at the Corning Museum of Glass, 'devit happens'. Cook suggests that rather than trying to counter the effects of devitrification, a more pragmatic approach would be to accept it as an inherent quality of the glass. [41]

These preliminary tests demonstrated that when designing a construction it was important to consider how layers of glass of different shapes, sizes, and thicknesses would warm up and retain their heat. To limit devitrification and to avoid stressing the glass, the temperature should be kept as uniform as possible throughout the piece. With traditional blown glass the gather is hot at the centre and radiates heat outwards while in this case it is the opposite: the construction, having been heated up in a kiln, is hotter on the outside.

This initial phase of testing was wide ranging: I explored the use of Optul colour frits, powder pigments, and inclusions. I also experimented with low-iron float glass from different manufacturers (AGC Clearvision and Pilkington Optiwhite), as well as coloured float glass (grey, bronze, and blue). At the same time, I began to acquire a sensibility to the material and came to appreciate the clarity, smooth surface, dense purity, and flawless perfection of this glass.

[41] Conversation with Dr Jane Cook at the Corning Museum of Glass, 22 August 2018.

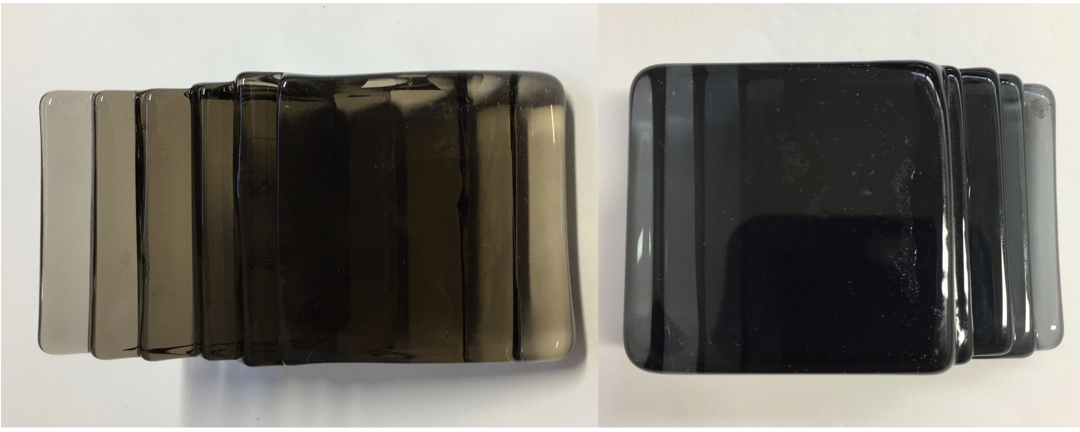

Fig. 13: Testing colour depth with bronze and grey Pilkington Optifloat (2017).
Photo: Isabella Kullmann.

In the next stage of testing, where I would be using WJC (waterjet cut) glass, I decided that the use of clear glass would impose a rigour and simplicity to my search for form. At this point at least, I preferred not to be led astray by the seductive qualities of coloured glass.

To reduce the variables, I settled on Pilkington Optiwhite, a low iron float with a thickness of 6mm, as a suitable material for this research. [42] This is also, incidentally, the glass that the architect Renzo Piano chose to glaze 'The Shard' in London (2012). [43]

In the introduction I outlined the pragmatic reasons for choosing to use float glass, even though, as I would discover, this would present certain technical challenges – in particular with regard to devitrification. I am also sensitive to the perceptual qualities of the material, which I have discussed in reference to Bell and Patti's work. However, by using float glass I would also like to offer small moments of material attention. I aim to transform the flat sheet of glass – to give it form, texture, and weight: in other words, a material presence.

The transparency and thinness of industrially produced glass, this dematerialisation of material, I would like to suggest find its parallel in our digital world. Christopher Bardt, Professor of Architecture at the Rhode Island School of Design, observes that digital tools such as a waterjet cutter require 'an idealized materiality, absolutely consistent and flawless', and thus he argues that 'the ideal digital material is, in fact, *immaterial*'.[44]

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[42] AGC Clear Vision offers great clarity and, judging by test samples I made, is slightly whiter than Pilkington Optiwhite; however, I couldn't find a supplier in or near Sunderland where the glass was to be waterjet cut.
[43] 'A Vision of the Future – The Shard' *Pilkington* <http://www.pilkington.com/uk/news-insights/blog/a-vision-of-the-future-the-shard> [accessed 6 September 2018].
[44] Christopher Bardt, *Material and Mind* (Cambridge, MA: MIT Press, 2019), p. 292.

I remain ambivalent about this sublimation of matter, and with this hybrid practice I would like to question the prevailing tropes of lightness and transparency by turning digital information which is 'intangible, dynamic, and transient' into (small) things which are 'tangible, static, and mainly persistent'.[45]

[45] Campenhout, van, L. D. E., Frens, J. W., Overbeeke, C. J., Standaert, A., & Peremans, H., 'Physical Interaction in a Dematerialized World', *International Journal of Design*, 7.1 (2013), 1-17 (p 2).

3. FORM

Introduction

In *The Origins of Form in Art,* Herbert Read (1965), states laconically: '*Form* in art is the shape imparted to an artefact by human intention and action'. [1] He qualifies his definition by adding that shape may be a better term to describe the 'creative implications' of making forms. Two decades later, Philip Rawson, ceramics curator and educationalist, writes:

> Forms are ways of arranging and articulating material in space. They exist first of all in the mind, classifying experience of the world. The moment you manufacture a thing according to a formal idea, what you make is no longer a true form but an embodiment or expression of it.[2]

These two definitions imply that form arises through intention, from an idea conceived in the mind, which is then imposed onto the material to become an artefact. This understanding of form finds its origins in Greek philosophy and its later Medieval and Renaissance interpretations. In Plato, the Forms are 'objects of pure thinking', separate from our experience of the world. [3] Ordinary things may only participate in or be copies, approximate versions, of the abstract ideal of the Form.

Aristotle introduces the doctrine of hylomorphism from the Greek words for matter (*hulê)* and (*morphê*) form. This states that every physical object is made of matter and form, and addresses the following four *causes* or explanations:
Material: what is it made of?
Formal: what is it?
Efficient: who created it?
Final: what is its purpose?

[1] Herbert Read, *The Origins of Form in Art* (Thames and Hudson Ltd, 1965)., p.66
[2] Philip S. Rawson, *Creative Design: A New Look at Design Principles* (London: Macdonald Orbis, 1987), p.72.
[3] John Boardman et al., *The Oxford History of the Classical World* (Oxford; New York: Oxford University Press, 1995), p. 242.

A thing's form is its essence, and should not be confused with it shape. For example, a statue of Socrates is the shape of Socrates but not the form of Socrates. [4]

A further level of complexity is added when Aristotle considers potentiality and actuality to explain change from one state to another. For example, a plank of wood is *potentially* a table but it is only an *actual* table when it acquires the form of a table. The plank of wood itself was a tree before it was felled and planed. Material therefore is not the same as matter. As Glenn Adamson explains: '"Matter" only becomes a specific "material" when someone sees its potential and puts it into action – thereby finding a way to put an intention into the world'. [5]

Ann-Sophie Lehmann, Professor of History of Art and Material Culture at the University of Groningen, contends that Aristotle's hylomorphism originally held form (ideas) and matter (materials) in equilibrium. She argues that Western thinking, over the centuries, 'tilted' this balance in favour of the idea.[6] This notion of the primacy of the idea over matter came to dominate art history, and as a result the discipline distanced itself from its core practice and understanding of materials. [7]

The anthropologist Tim Ingold, writing some fifty years after Read, suggests: 'Form came to be seen as imposed, by an agent with a particular end goal in mind, while matter – thus rendered passive and inert – was that which was imposed upon.'[8] Ingold invites us to abandon the hylomorphic model altogether and instead to think of making as 'a process of growth'. He suggests that we should 'join forces' with active materials 'in anticipation of what might emerge'.[9]

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[4] Thomas Ainsworth, 'Form vs. Matter', in *The Stanford Encyclopedia of Philosophy*, ed. by Edward N. Zalta, Spring 2016 (Metaphysics Research Lab, Stanford University, 2016) <https://plato.stanford.edu/archives/spr2016/entries/form-matter/> [accessed 3 November 2018].

[5] Adamson, *Fewer, Better Things*, p. 155.

[6] Ann-Sophie Lehmann, 'The Hierarchy of Materials' (The Royal Academy, London, 2019).

[7] Ann-Sophie Lehmann, *Cube of Wood. Material Literacy for Art History* (Groningen: Rijksuniversiteit, 2016) <https://www.academia.edu/24457536/Cube_of_Wood._Material_Literacy_for_Art_History_Groningen_2016> [accessed 9 July 2019].

[8] Tim Ingold, 'Bringing Things to Life: Creative Entanglements in a World of Materials', *ESRC National Centre for Research Methods NCRM Realities Working Paper Series*, 15 (2010).

[9] Tim Ingold, *Making: Anthropology, Archaeology, Art and Architecture* (London; New York: Routledge, 2013), p. 21.

Following Ingold's entreaty, the artistic aspiration of this research is to explore what new forms may emerge from the unconventional use of material and process which I am proposing. The intention is not to reproduce objects which can be made through established studio glass techniques, such as blowing, fusing or casting, but instead to achieve a set of outcomes which would be unique to the process itself. What these glass artefacts could be in terms of form or function (if any) was unknown at the outset – I had no preconceived idea.

This chapter focuses on the 'practice' element of this research project. In the first part, I describe the process which I have developed and highlight its creative potential; in the second part, I look at specific examples to reveal how through re-iterative testing, refinement of the design, and 'what if' moments, I eventually find form.

This search for form has been guided on the one hand by a study of design principles as set out by Philip Rawson and on the other by a close reading of the writings of Tim Ingold and Juhani Pallasmaa. Juxtaposing these two contrasting approaches to design, material and making, I consider the implications of a hybrid practice which brings together the accuracy and predictability of CAD and the precision of waterjet cutting technology allied with traditional hot glass skills to transform sheet glass. Rawson advocates a formal approach to design thinking, while Ingold and Pallasmaa encourage a 'confluence of forces and materials' as opposed to a 'transposition from image to object'. [10]

To set this analysis in context, I weave through this account the work of Larry Bell, Tom Patti, Matthew Szösz, Danny Lane, and Ikuta Niyoko (see previous chapter). Working at different scales and with very different outcomes, all of these artists share as their primary medium sheets of float glass which they cut and assemble into three-dimensional sculptures.

In search of form

The making process, or form finding, is done in four discrete stages over time and in different sites. The first three stages, design, cutting, and construction, could be described as 'hylomorphic': I impose my idea onto the material. In the fourth and final stage, the material finds form with the vagaries of hot blowing – a form emerges almost through its own volition.

[10] Ingold, *Making*, p. 22.

Stage one: design

The rigid sheet of float glass is essentially a plane, the equivalent of a blank canvas or a sheet of paper. The cut across the smooth surface of the glass becomes analogous to a line drawn or traced on a sheet of paper. As Rawson observes:

> Drawings are done with a point that moves. ...The essential feature remains that something generically classed as a point, a tool acting as some kind of surrogate for the hand with its fingers, has made a mark that records a two-dimensional movement in space.[11]

The 'point' used to create the mark on the sheet of glass could be either a standard diamond cutter or the head of a waterjet cutter (WJC). The cutting tool is the equivalent of a pen, not a pencil, as the lines cannot be erased. I use the analogy of the pencil/pen/glass cutter, which produces a line, an outline, a cut, as a method for designing the modular components of the float glass constructions.

The cut begins as a sketch, the merest outline of a thought. I prefer to use a pencil to think through designs: these are rapid and reiterative sketches to test out ideas. The immediacy and fluency of the pencil, the most basic and universal tool, keeps a trace of fleeting thoughts. The line remains supple. I sketch out the outlines of the separate modules on sheets of superimposed tracing paper to visualise how they will translate into layers of glass. As the drawn lines become more assured and lose their hesitancy, I reproduce them on the computer screen using Adobe or Rhinoceros (Rhino) 3 software. The line becomes precise, while at the same time the software allows me to develop the design further by, for example, scaling up or down, flipping, rotating, or repeating. If I then add the Z dimension to the design, the line takes off in space. Complex curves may be achieved by rotating the profile of a line. I can extrude, loft or revolve these lines into a 3D virtual model, which I am free to deform through stretching, bending, slicing, extracting, or enfolding surfaces to create gravity-free non-Euclidean geometry.

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[11] Philip S. Rawson, *Drawing* (The Appreciation of the Arts, 3) (London, New York: Oxford University Press, 1969).p.15

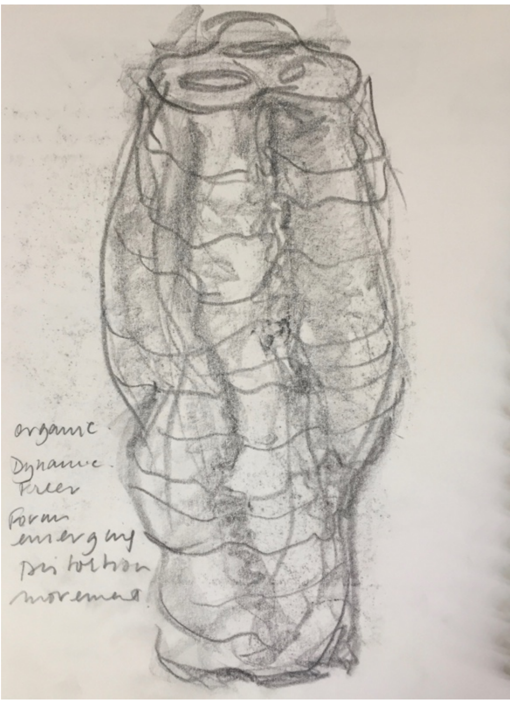

Fig. 14: Isabella Kullmann, pencil sketch (2018).
Fig. 15: Isabella Kullmann, pen and watercolour sketch over Adobe drawing (2018).

When working in 3D, I calibrate the grid in Rhino settings to the exact thickness of the glass I will be using. This allows me to deconstruct the virtual model into slices, which I then project onto the 2D surface, set to the dimensions of the sheet of glass to be cut. The line, once fixed and saved in digital code, is transferred via a DXF (drawing eXchange format) file to the WJC. [12]

This method of designing, shifting back and forth between the pencil sketch, the computer, and tracing paper maquettes, has evolved over the timespan of this project to become a personal, effective, and highly enjoyable practice.

[12] The CNC (computer numerical control) file is written via waterjet-specific IGEMS software which is compatible with dxf and dwg files (imported from CAD or vector-based software such as Adobe Illustrator, Rhinoceros (Rhino) 3D and AutoCAD).

Fig. 16: Isabella Kullmann, maquette for sample 042.02.18 (2018).
Fig. 17: Isabella Kullmann, tracing paper collage (2019). Superimposed sheets of tracing paper are used to work out the internal structure for sample 083.07.19.

Stage two: the cut

Using a diamond glass cutter, I score a straight line from edge to edge across the surface of the sheet of glass to elicit a fracture. A gentle tap and the crack runs the length of the score line. I snap the glass to divide the sheet in two.

The rigorous economy of the straight line – the shortest line between two points – is imposed by the tool. The tool dictates the geometry of the line.[13] In other words, the tool and the material determine the structure, as can be seen in Bell's and Patti's glass sculptures, which are based on a modular system of squares and rectangles.

Lane, on the other hand, eschews the considered cut and instead, in an altogether more physical approach, underlining the Punk aesthetic of his early work, cracks and breaks the glass into irregular chunks, 'transforming delicacy into danger'.[14]

Either purposefully cut or brutally fractured, these cuts become outlines, which separate and divide out the sheet into new shapes.[15] Ingold describes lines 'as separators, dividing the

[13] Curved lines may also be made with practice and skill.
[14] Thomas Connors, 'Breaking Glass: Danny Lane', *Glass* (New York Experimental Glass Workshop), 41 (Fall 1990), pp. 22-29.
[15] Rawson, *Drawing*.p.94.

surface on which they are drawn between what is on one side of the line and what is on the other: in this sense they are analogous to cuts'. [16]

As Rawson observes, there are two basic lines: the straight and the curved. The curved line, however, can be inflected. 'Since a curved line is capable of infinite inflection, it can make any shape to which it is applied unique', Rawson points out.[17]

With a diamond cutter, as we have seen, the cuts are restricted to straight or gently curved lines. If I change the tool, in this case from a diamond cutter to the head of a WJC, I am able to inflect the line. The head of the WJC, like a pen, is able to trace infinite curves in a line. The outlines of the modular elements break away from the geometric rigour of the rectangle to become flowing organic lines separating out unique shapes. The application of precision engineering, accessed through digital code, has freed the line.

Fig.18: Waterjet cutter in the Ceramics and Glass Department at Sunderland University cutting the modules for sample 025.03.17 (2017). Photo: Isabella Kullmann.

[16] Ingold, *Making*. p. 134
[17] Rawson, *Creative Design*.p.85

The WJC, operating at between 30,000 and 60,000 psi combines a high-pressure water jet with 120 grade garnet abrasive. It glides a few millimetres above the surface of the glass, tracking the x and y co-ordinates of the vector image encoded in the computer numeric code (CNC) file. The garnet suspension blasts through the nozzle head and, through a process of abrasion, releases the shapes from the glass sheet, which is weighed down on the bed of the WJC to immobilise it.

The head of the WJC has become a tool, a kind of 'surrogate' for my hand to draw a line. While Rawson states that the line is: 'a two-dimensional trace on a plane, it has *in itself* no three-dimensional value' in this case, however, the line, now a cut, through and across the sheet of glass, acquires a three-dimensional value.[18]

The cut produces an edge. When made by a break it leaves a clean, clear edge, but when made by waterjet cutting it has an abraded finish. The character of the two cuts are quite different: one is sharp and transparent, showing the colour of glass, and the other is opaque, white, and rough to the touch.

Lane remarks that the jagged sharpness of broken glass 'gives information about the material'. [19] It also leaves a trace of the making process. Vanessa Cutler, for example, does not cold-work the abraded edges of her WJC pieces. [20] Ikuta, meanwhile, seeks to 'draw a line in space'. The layered edges of the glass sheets give her sculptures a 'linear existence' – a visible line in a transparent medium. [21]

Working with this manufactured transparent and uniform material, which possesses neither texture nor irregularities, we become sensitive to the almost imperceptible subtleties that it affords the maker. This sensitivity to material, acquired over time, informs the design process. The curator and glass historian William Warmus, describing Patti's sculptures, writes about 'the hidden aesthetic quality of the edge in each pane of glass'. [22] In Bell's

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[18] Rawson, *Drawing*, p. 95.
[19] William Ganis, 'On Edge', *Glass: The Urban Glass Art Quaterly* 107 (Summer 2007), 50-55.
[20] Cutler.p.36
[21] Takeda Atsushi, 'Niyoko Ikuta The Glass of a Flickering Heart', *Neues Glas/ New Glass*, 4 (1992), 18–27.
[22] Warmus, Kuspit, and Patti, *Tom Patti,* p.21

cubes, for example, the darker line of colour where two glass panes meet to form a 45-degree angle, remains for the artist ‘the most interesting thing about the cubes’. [23]

The edge of the sheet of glass therefore becomes a defining element in the float glass object. It delineates a contour, suggests volume, and adds colour and depth. The edge holds the transparent invisible material within a discernible form while leaving a trace of its manufacture.

Stage three: construction

The shape cut out of the sheet of float glass could be described as a module. A modular construction method ‘offers a large variety of possible structures’, according to Hann. [24] Looking at outline, colour, volume, and surface I propose to examine in more detail the creative potential of stacking sheets of cut glass.

As I have shown, by using a WJC instead of a diamond glass cutter, I am able to obtain curved lines to make unique shapes or modules. I stack the modules, one way, and then another, or turn them over. Even with simple modules, stacked at slightly different angles in a helix, I can change the direction of a curve to create a more dynamic outline.

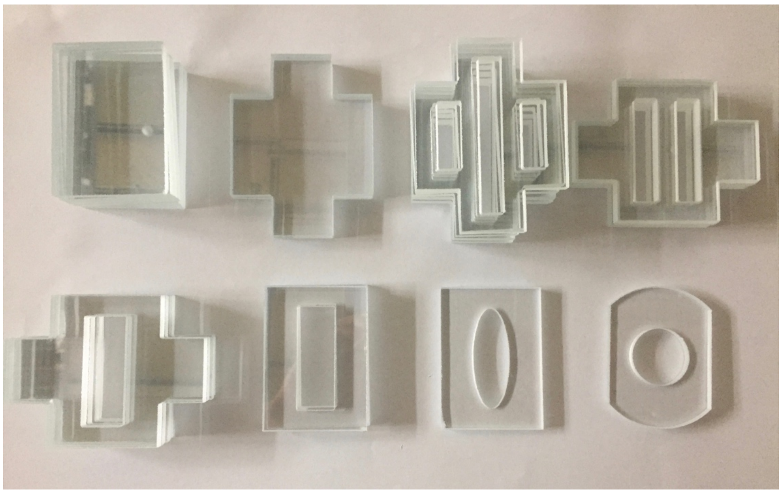


Fig. 19: Waterjet-cut modules for sample 070.05.19, (2019). Photo: Isabella Kullmann.

[23] Marie de Brugerolle, ed., *Larry Bell: Carre d’Art Musée Contemporain de Nimes*, *25 February 25 May 2011* (Dijon: Les Presses du Reel, 2011).
[24] Michael Hann, *Structure and Form in Design: Critical Ideas for Creative Practice* (London; New York: Berg, 2012) p. 144.

When I come to hold the module, the perfectly cut shape, I establish a haptic connection with the physical model. The model no longer inhabits ‘the mathematicised and abstracted immaterial world’ of computer imagery: it has become real. [25]

Although I may have had a specific construction in mind, I often re-configure the design, either through necessity (pieces are lost in the WJC process) or on impulse. There is a space here, a pause in the process, for spontaneity, improvisation, and revision. I playfully assemble and re-assemble the glass modules into a variety of different configurations to explore alternatives either for the present design or to revisit in the future. The design is not set until I bond the layers of float glass together. The bonded sheets of glass, a stratification of material, recall the principles of additive manufacturing, whereby forms are built up through layers.

Fig. 20: Assembling the construction for sample 080.05.19, (2019). Photo: Isabella Kullmann.

I stack the glass modules in layers to build a structure. As Hann notes, structure is ‘the (invariably) hidden framework or skeleton underpinning form’, while form is ‘the external appearance of a design defined by the outline’. [26]

This distinction between structure (hidden) and outside form or shape needs to be qualified when working with a transparent material. The abraded edges of the modules of WJC glass

[25] Pallasmaa, *The Thinking Hand*, pp. 96–97.
[26] Hann, *Structure and Form in Design*, p. 14.

delineate the contours of the layered glass which make up the structure. There is no form at this point – it is all structure.

The layering process offers scope for exploring colour and creating tonal variations within the body of the piece. Float glass is available in grey, bronze, shades of blue (aqua and turquoise), and green. These are body colours where oxides are added directly to the melt. In a small hot glass studio, the furnace glass is usually clear – only exceptionally will a colour melt be charged. Colour is most commonly obtained by using frits, powders, or colour rods together with the clear glass, either by applying the colour to the hot clear glass or by making colour cups. The colour sits between layers of clear glass.

With sheets of body-coloured float glass it is possible to build up colour density, shifts in tone, or create colour variations within a single piece (054.11.18). Patti explored the perceptual colour shifts in his work to great effect while the distinctive green cast of clear float, a result of iron naturally found in silica, becomes 'another value of blue-green'. [27]

Unlike Patti, I find this residue of colour a distracting presence. I prefer the optical clarity and whiteness of low-iron float which heighten the illusion of nothingness. I am seeking to give form – volume and mass – to a material which is celebrated for its transparency and immateriality.

For the purpose of this project, as I have explained, I decided to work with 6mm sheets of low-iron float. In the future I intend to experiment more widely with coloured float glass. I will also use different thicknesses of glass, for example 8mm or 12mm, within a single piece to build up a changing rhythm of horizontal lines (the trace of the edge) across the surface of the glass.

Stage four: transformation

Commenting on design theorist David Pye's celebrated book the *Nature and Art of Workmanship* (1968), Glenn Adamson invites us to consider where, within the continuum of a process, the *workmanship of certainty* and the *workmanship of risk* lie.[28]

I situate the *workmanship of risk* in this fourth and final stage, which takes place in the hot shop. It is here that all the work which hitherto had a predictable outcome (in other words a product of the *workmanship of certainty*) may come precipitously and irremediably undone.

[27] Hollister, 'Tom Patti'
[28] Adamson, *Fewer, Better Things*, pp. 19–26.

The glass structures are heated overnight in a warm-up kiln set to 30°C per hour, to 500°C; the temperature is then ramped up to 680°C when ready for pick-up. A punty bit and a collar are fashioned out of short stacks of float glass which were placed alongside the constructions in the warm-up kiln. These can be re-used throughout the session if the blowing irons are kept warm. The constructions are held at 680°C, the highest temperature, for about 10 to 15 minutes, depending on their size and configuration, to allow the layers of glass to fuse but not slump.

Fig. 21: Constructions in warm-up kiln (2019). The extra stacks of glass are used to fashion collars to pick up the constructions with the blowing iron and bits for the punty iron.
Photo: Isabella Kullmann.

The construction is picked up with a blowing iron and swiftly transferred to the re-heating chamber. Conventional glassblowing begins with hot glass straight from the furnace, the heat emanating from the core of the gather. Here, the outside of the structure is warmer than the inside and the glass requires a good flash in the re-heating chamber (colloquially known as a glory hole) to equalize and distribute the heat as evenly as possible.

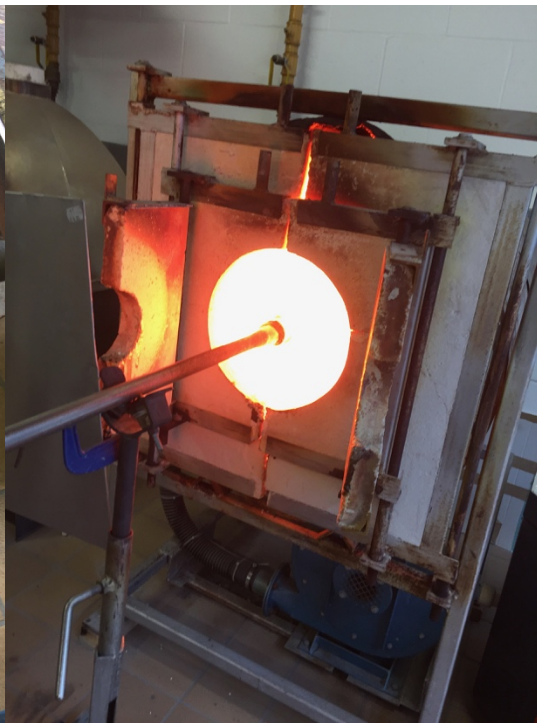



Fig. 22: Sample 051.05.18 on the end of the blowing iron. The layers of glass are clearly delineated and the structure still retains its abraded surface from the waterjet cutting.
Fig. 23: The glass is flashed regularly in the re-heating chamber to keep it hot throughout the process.


Fig. 24: The glass structure is transformed by heat and the glassblower's breath.
Fig. 25: The glass is transferred to a punty iron and the neck of the piece is opened up slightly with a pair of jacks. The neck will be cut off with a pair of shears to leave a clean hot finish (2018).
Photos: Isabella Kullmann.

The inert material comes alive in the 1,200°C temperature of the re-heating chamber. The glass takes on a radiant dark golden glow. The angular edges of the stacked layers of float glass soften into a gentle bead. The heat rubs away the abraded edges left by the WJC and surface scratches disappear. The glass object loses its opacity to reveal its internal transparent structure. The glass has been revived and rejuvenated by the heat – the result of an effortless fire-polish.

As the glassblower's breath travels down into the structure, the internal volume expands to form a bubble. The breath, immaterial and evanescent, stretches and pushes out the stepped construction of the layered glass. The layers of glass sink into each other to leave a faint trace of their material presence in the horizontal ridges across the external and internal surfaces of the glass – a memory of their transformation from a flat sheet of glass to a curved unified surface. The structure has become whole transformed into a 'shell' with an internal volume. [29] A blown vessel has been created, as demonstrated with a proof-of-concept test piece (049.04.18).

This transformation of material, unlike, for example, in firing ceramics or casting glass, is visible to the designer and the glassblower, who are 'in the moment' throughout. The process now becomes a question of timing and judgment: when to arrest the life-giving processes of the breath, the heat, the movement, and let the glass solidify into a form before cracking it off the blowing iron. Too late and the internal structure etiolates before collapsing into the walls of the glass shell. Too early and the outcome lacks energy, remaining static while the surface of the glass fails to acquire the smoothness and transparency of a fire polish. Here lies the *workmanship of risk.*

This search for form, an exploration of material and process, was carried out through extensive testing: producing small samples to assess and compare the different outcomes. I set out the parameters of the design but the form finds itself through the agency of heat, the breath, centrifugal force, and gravity. I look to disrupt the ordered predictability of the digital to find a space for risk and the uncontrolled.

At the beginning of this research project, freed from the pressure to produce a finished piece, this experimental approach to design was almost random. I had no idea what form would eventually emerge from the WJC curves and outlines I designed and the constructions I assembled.

[29] Rawson, *Creative Design*, p. 87.

Pallasmaa emphasizes that design is *work*: a laborious search 'in the darkness of uncertainty' and not a sudden 'effortless flash of insight'. He celebrates the value of uncertainty and vagueness to stimulate and maintain our curiosity pushing the creative process into 'an alien territory'.[30]

While I had shown that it was technically possible to create blown glass vessels using sheets of float glass, finding my own sensibility with this process and material proved far more elusive. At times, I recognized a certain quality, a small detail, a curve, or a line within a piece which gave me a hint of what could be. Too often, the quiet elegance of the WJC structures, their opaque surfaces softly registering the shifts in the light within their complex internal geometry, was blasted away at the hot shop stage. This effacement and distortion of digital precision, which I intentionally sought out, also led to a disappointing loss of delicacy and refinement. Achieving a satisfying outcome became a challenge.

Fig. 26: Samples ready for a session in the hot shop (2019).
Photo: Isabella Kullmann.

[30]Pallasmaa, *The Eyes of the Skin*, pp. 108–12.

Finding form

Looking at specific examples, I would now like to examine how, through further experimentation, reiterations, and serendipity, I refined the designs to produce a set of considered final pieces, which to some degree illustrate the ideas that underpin this research.

One of the stated aims of this research was to produce glass artefacts which would be impossible, if not very difficult, to make using conventional glassblowing techniques. The outcomes would thus be unique to the process. Reflecting on how this could be achieved, I considered what a WJC would allow me to do that would be so radically different. As I have explained, by using a WJC I can cut curves safely, quickly, and accurately to create outlines, but I can also create internal cuts within the same outline. By stacking up the modules I would be able to arrange multiple internal channels for the breath within a single glass object.

The intention was that the final form should emerge, as if organically, from the breath inflating and deforming the internal structure – a form that would be impossible to design or predict through computer modelling. The breath, as Warmus poetically suggests in writing about Patti's work, becomes 'the transparent mark' which transforms and fixes the medium of glass. [31]

Stacked bubbles

The first sample (025.03.17) I made to explore this idea was based on a simple cylinder assembled with circular layers of glass each with between one, two, three, four, or five circular holes distributed randomly across the surface of the module. The sample blew out unevenly. The breath followed the path of least resistance (or more precisely, greater compliance) towards the thinner and therefore hotter areas of glass. The channels expanded into alveolae of different shapes and sizes. The morphogenetic nature of the process was unexpected and exciting

A later test (034.05.17), with a more vessel-like profile, and with the cuts distributed evenly was, in my opinion, less successful. The regular pattern of the internal structure, once blown,

[31] Warmus, Kuspit and Patti,'Tom Patti', p.50.

lent an almost industrial feel to the object, while the ridged contour recalled the look of pressed glass. The result appeared deliberate rather than organic.

Fig. 27: Isabella Kullmann, sample 025.03.17 (2017). The piece was cracked off the blowing iron; the rim cold-worked and the outside surface sand-blasted (9.14 x 13 cm).
Photo: Isabella Kullmann.

I developed the design further by adjusting the profile, varying the shapes and sizes of the blow holes, working out more complex channels for the air, and scaling up (042.02.18; 046.03.2018; 051.05.18). The internal structures expanded out into a mass of superimposed bubbles of various shapes and sizes.

A blown glass vessel will naturally become spherical as the surface tension pulling silicon dioxide molecules together equalizes.[32] Bubbles in effect minimize the surface area that surrounds a prescribed volume of air. The optimal geometric form for enclosing the largest volume is therefore a sphere, not a cube. The air will smooth out the angles of a rectangle.[33] In mathematical terms, this is known as variational geometry and it has engendered a field of

[32] Maurice Raymond Flavell, 'The Development and Application of the Use of Encased Voids within the Body of Glass Artefacts as Mans of Drawing and Expression' (unpublished PhD thesis, Edinburgh College of Art/ Heriot-Watt University School of Design and Applied Arts, 2001).
[33] Siobhan Roberts, 'In Bubbles, She Sees a Mathematical Universe', *The New York Times,* April 8, 2019 <https://www.nytimes.com/2019/04/08/science/uhlenbeck-bubbles-math-physics.html> [accessed 18 April 2019].

mathematical research from the nano to macro. Andrea Prosperetti, Professor of Mechanical Engineering at University of Houston, writes that 'bubbles are emptiness, non-liquid, a tiny cloud shielding a mathematical singularity'.[34]

The final form was not achieved through design, imposing my concept on to the material alone; instead, the material found its form through physical principles – a 'mathematical singularity'.

Once the blown bubble is cracked off the blowing iron or transferred to a punty iron, it is no longer a closed bubble: it becomes a vessel – in this case a vessel with many internal bubbles, cavities, or holes. Viewed from above, the internal structure resembles a bronchial tree with separate superimposed chambers emanating from its central core or spine. Seen sideways on these chambers may be read as closed bubbles, while the solid areas of the object appear hollow. This visual ambiguity, which plays on our perceptions of the material as immaterial, expresses one of the underlying themes of this research as outlined in the previous section on float glass.

Fig. 28: Isabella Kullmann, group of samples exploring multiple bubbles within a single piece (2018).
From left to right: 051.05.18; 042.02.18; 046.03.18.
Photo: © Ester Segarra.

[34] Andrea Prosperetti, 'Bubbles', *Physics of Fluids*, 16.6 (2004), 1852-1863 (p.1852).

The simplicity of a single cut

The conduit for the breath, which creates and inflates a bubble, is essentially an opening in the mass of glass, but it does not necessarily follow that this should be a circular or oval hole. Could it just be a single cut? A Fontana-esque gash in the glass? The simplicity of the single curve had a reductive elegance which appealed – a spontaneous gestural line across the surface of the glass. In an attempt to move away from the inevitability of a blown sphere, I thought that a line along the length of an oval might produce a more surprising outcome than when centred within a disc.

I made a series of sketches within the template of an oval, loose and smooth lines drawn in a single stroke. Translating the spontaneity of this line into Rhino was arduously slow. Using a mouse had none of the expressive joy of the freehand drawing with a pencil, something that Pallasmaa recognizes when he writes about the 'mediated construction' of a computer line:

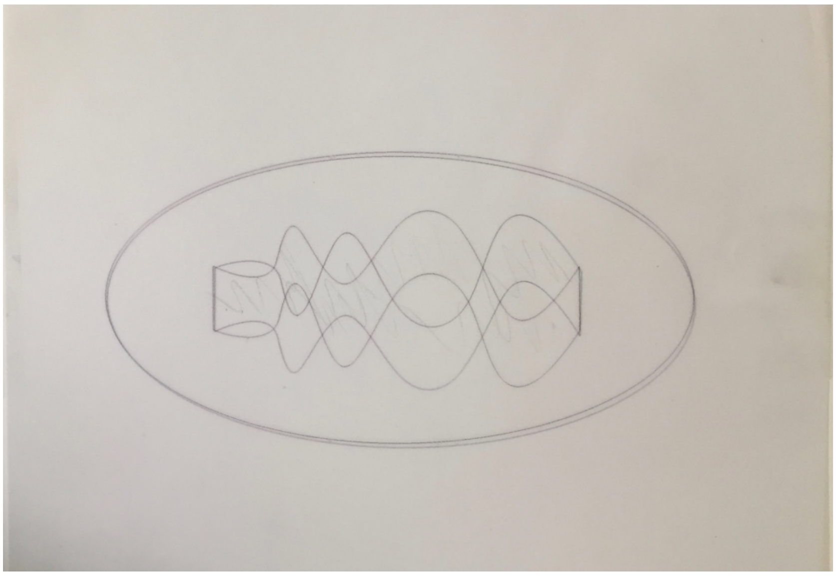
> In comparison to the expressive richness and emotive life of the hand-drawn line, the computer line is a laconic and uniform connection of two points (computer lines can, of course, be articulated to simulate lines drawn by hand, but their essence is the emotionless factuality of mathematicised space). [35]

Once I had the line represented in Rhino, this opened up infinite possibilities to play with the final design. Not only was I able to stretch the line, scaling it up or down (as detailed above), but from one single repeatable line (or cut) I would be able to develop a versatile modular system. By flipping over the identical WJC modules or rotating them 180 degrees, I was able to build up a complex internal structure. This internal structure could be re-arranged with each new iteration. The height, determined by the thickness of the sheet of glass and the number of modules used in the construction, could also be altered every time.

When blown out, the elliptical form kept its oval shape at the top and at the base where it curved up gently to leave a shadow gap. Meanwhile the sides expanded outwards; the internal structure stretched out into a meshwork of glass filaments or trabeculae, which

[35] Pallasmaa, *The Thinking Hand*, p. 100.

produced a honeycomb-like pattern when the piece was viewed sideways on (062.01.19; 065.02.19; 067.03.19).



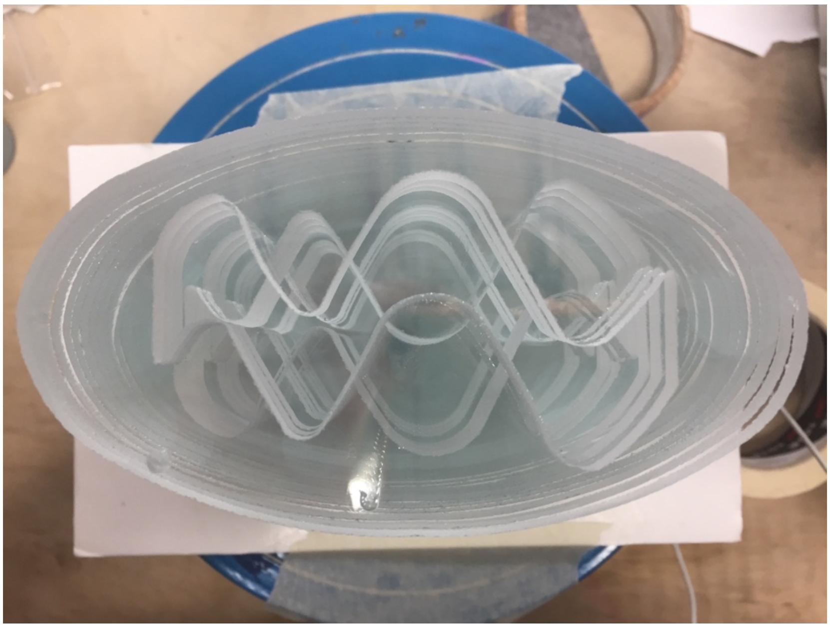


Fig. 29: Isabella Kullmann, tracing paper sketch (2019).
Fig. 30: Construction process (2019). Building a complex internal meshwork by flipping the WJC modules over for sample 067.03.19.
Photos: Isabella Kullmann.

As I acknowledge in the accompanying test sheets, the design requires further adjustments, but I have included these samples for two reasons. First, to demonstrate how a simple modular system can produce a complex outcome, and second, to show how the internal entanglement of glass filaments are a concrete illustration of the ‘interwoven lines of growth and movement', which Ingold describes when he writes about the fluxes and flows of materials. [36]

Fig. 31: Isabella Kullmann, *Untitled # 067.03.19* (2019). Blown waterjet-cut float glass (15 x 14 cm). The superimposed cuts have been transformed into a meshwork of filaments which viewed sideways on have the aspect of a honeycomb pattern.
Photo: © Alick Cotterill.

My approach to form-finding did not necessarily follow a linear trajectory. I would describe it as branching out simultaneously in different directions from a stem of assimilated knowledge which I acquired over the timespan of this research project.

This was certainly the case when I considered how to develop the idea of the single line or cut. Instead of a loosely drawn curve, could the cut not have the dynamic quality of a spiral? And how would this cut affect the outside form?

A first test (055.11.18) produced an unexpected and encouraging result. The stepped, or angled, spiral gave the glass an almost moiré effect, but on this relatively small scale it did not seem to affect the outward form of the piece. When scaling up, however, the construction blew out into a clumsy and irregular baggy shape (061.01.19). The areas where

[36] Ingold, 'Bringing Things to Life'.

the glass wall was thinner, as determined by the spiral void, inflated more rapidly than the areas of thicker glass. The internal spiral dominated the piece. The graceless lumpiness of the outcome was so far from my sensibility that I temporarily abandoned the design.

Encouraged by the results yielded by an elliptical shape based on an oval (see above), I revised and simplified the design. I stretched out the spiral to fit comfortably within an oval, and instead of giving the construction a contoured profile I made all the modules the same size (075.05.19). The WJC construction itself had a pleasing delicacy and simplicity.

The WJC construction was picked up out of the warm-up kiln with a blowing iron, given a long flash, and blown. The piece inflated unevenly into yet another baggy shape, the delicacy of the design seemingly lost. We considered discarding the piece and moving on to the next one (hot shop time is precious) but instead, in a 'what-if' moment we decided to spin it out. Quite unexpectedly and almost miraculously a graceful shell-like form appeared at the end of the punty iron – a perfect illustration of the complete process: the precision of the digital transformed by heat, breath and centrifugal force, allied with *the craftsmanship of risk.*

Fig. 32: Isabella Kullmann, sample 075.05.19 (2019). Blown waterjet-cut float glass (4.3 x 19 x 15 cm).
Photo: © Alick Cotterill.

Fig. 33: Isabella Kullmann *Untitled # 081.07.19* (2019). Blown waterjet-cut float glass (14.5 x 30 cm).
Photo: © Alick Cotterill.

A further example (081.07.19) confirmed that the result was repeatable and the design could be scaled up. An unexpected twist was revealed when I compared the pieces and noticed that they had spun out in opposite directions. I had unwittingly flipped the WJC modules when building the constructions.

Variational geometry: smoothing out the angles

Hot glass will naturally blow out into a sphere as it seeks to minimize the surface area (see above). In other words, geometrical shapes based on angles are not germane to the language of blown glass (unless blown into a mould). To explore the 'variational geometry' which smooths out the angles into curves I made a series of samples based on rectangles and on hexagons, taking my cue from Rawson's analogy of the crystal and the fruit. 'The set of angular relations are the **crystal** aspect of the form; the curving continuity of the surface its **fruit** aspect.' [37] This was a useful way to think about volumes, and blown volumes in particular. Rawson observes that without a crystal aspect forms may become 'saggy and

[37] Rawson, *Creative Design*, p. 246.

unformed', something I had found when the constructions were overblown, while without a fruit aspect they may be 'rigid, dry, stereotyped' – see (071.05.19; 080.05.19).

Fig. 34: Isabella Kullmann, *Untitled # 080.05.19* (2019). Blown waterjet-cut float glass (15 x 16.8 cm).
The top and bottom section have retained their crystal aspect while the middle section has blown out too much and smoothed out the angles.
Photo: © Alick Cotterill.

Inspired by the architecture of House NA, I designed a cantilevered construction of rectangular volumes. As anticipated, the vertical walls swelled out while the right-angled corners framed the blown glass within a gently curved structure. The breath had softened the sharpness of the angles. Meanwhile, the strict internal structure of rectangles had been transformed into an architecture of parabolic and catenary arches. The outcomes were intriguing but, if anything, too complicated (069.03.19; 070.05.19).

Fig. 35: Isabella Kullmann, sample 070.05.19 (2019). Blown waterjet-cut float glass (14.8 x 12.4 cm). Photo: © Alick Cotterill.

Paring down the design and scaling up, I made a further piece based on a rectangular grid (079.05.19). Aiming to produce a final piece of work and not another test sample, I considered the proportions, how the piece would stand at its base, and the design of the modules in the top section to enable a clean hot-finish.

The construction blew out into a controlled form and the internal structure of rectangles produced a grid which intentionally recalled the electric cables and phones lines criss-crossing the streets from one building to the next in the photographs I had seen of House NA. The attention to detail, the knowledge of the material, and the understanding of the process all contributed to a reasonably successful outcome.

In the opening chapter of *Making: Anthropology, Archaeology, Art, and Architecture*, Ingold describes what he terms 'the art of inquiry' to explain the relation between thinking and making. The theorist, he argues, 'makes through thinking', while the craftsman 'thinks through making'. With the art of inquiry,

> …every work is an experiment: not in the natural scientific sense of testing a preconceived hypothesis, or of engineering a confrontation between ideas 'in the head' and facts 'on the ground', but in the sense of prising an opening and following where it leads. You try things out and see what happens.[38]

As I trust I have demonstrated in this account, it is in the spirit of the *art of inquiry* that I undertook this search for form.

Fig. 36: Isabella Kullmann, *Untitled # 079. 05. 19* (2019). Blown waterjet-cut float glass (21.2 x 15.4 cm).
Photo: © Alick Cotterill.

[38] Ingold, *Making*, pp. 6–7.

4. CONCLUSION

I conclude this thesis by considering the merits and limitations of the alternative studio practice which I envisage.

In broad terms the practical aim of this research project was to develop a hybrid glass practice which brings together digital and analogue techniques to transform sheets of float glass into three-dimensional artefacts. I have demonstrated the possibility of using float glass as an alternative to furnace glass and established the parameters of the process, as the tests and samples clearly demonstrate. I suggest that these outcomes also give an indication of the creative scope of such a process. In other words, I believe that this is the beginning of an innovative glass practice rather than the conclusion of my research into material and form. I also argue that the process itself has the potential to be developed further and taken in new directions by other makers and designers.

The aesthetic aim was to produce a sample of work which would be unique to the process. The most exciting results were obtained when the intervention in the hot shop, in the fourth and final stage, completely transformed the waterjet cut structure to produce a form which could not have been achieved in either traditional glassblowing or anticipated by CAD, seen, for example, in samples (025.03.18; 042.02.18; 046.03.18; 070.05.19; and 075.05.19).

Having obtained a successful outcome, a prototype of sorts, the process offers scope to refine or modify the design further, scale or up or down, or simply repeat. Different coloured float glass may be used to introduce layers of colour within a single piece or to create a tonal shift. Alternatively, the thickness of the glass could be varied to produce a horizontal pattern along the surface of the glass object. The height of the WJC construction may be adjusted by varying the number of modules or the thickness of the glass. The creative challenge lies in designing WJC modules which will yield exciting results.

By using a WJC I am able to cut any curve, so the potential to explore form is seemingly infinite. However, as I have shown, variational geometry will lead a blown structure to tend towards sphericity. I have exploited this physical principle in a number of ways, such as exploring the geometry of the right angle, the permutations of a single curve, the spiral cut, or by creating multiple channels for the breath. A complex internal structure of catenary arches, a meshwork of filaments, or layers of superimposed bubbles emerge as the glass form inflates, stretches and swells. The outer form, however, distended by the breath, may sometimes become baggy. Further experimentation, building on the knowledge I have acquired, would undoubtedly lead to more finely resolved designs. Exciting results may also be achieved if one does not inflate the construction but simply uses heat, movement, and centrifugal force as tools, as I discovered with sample 078.05.19.

Fig. 37: Isabella Kullmann, sample 078.05.19 (2019). Waterjet cut glass, re-heated and spun. (5.9 x 14 cm).
Photo: © Alick Cotterill.

Scale is determined by what the glassblower (or a team of glassblowers) can handle comfortably. A WJC construction of two 6mm thick sheets of float glass (50 x 50cm) was about the maximum weight that Liam Reeves could lift out of the warm-up kiln single-handedly (051.05.18; 061.01.19). One should also bear in mind that for optimal results it is best to keep the distribution of heat across the surface of the glass as even as possible. This is harder to achieve with tall, thin pieces, as the area closer to the blowing iron will not be as hot as the crown of the piece deep inside the re-heating chamber. However, tests showed that grey, bronze, or aqua float retained the heat better and softened at a lower temperature than low-iron float, which would suggest that by using coloured float one could overcome some of the problems arising from the heat differential (054.11.18; 057.11.18).

The transformation of material from 2D to 3D is recorded in the samples and final pieces. The layering of the sheet glass adds a discernible ridged texture to the surface of the object, while the iridescent sheen that occurs as a result of tin bloom attests to the reality of the push and pull of materials. When compared to the smooth unified surface of blown glass these attributes could be considered flaws, but I have come to think of them as intrinsic to the quality of the pieces, and because of this I have not attempted to erase or conceal these 'imperfections' through cold-working.

For the sake of expediency, and to keep within the parameters I had set myself (see Material chapter), I used new sheets of low-iron float glass throughout this project. However, as the glass is given a fire-polish in the re-heating chamber, which rubs outs the scratches on the surface and softens any chips around the edges, this process lends itself to recycling or up-cycling float glass. There is scope for further research in this area, both technically and artistically – for example, re-using the glass from a building before it is demolished or re-modelled to make site-specific work. An environmental impact assessment report could also be considered to determine whether such a practice is more sustainable than more conventional studio glass practices with similar outputs.

And what of the objects themselves? A series of vessels (as any blown form is)? Functional or non-functional? Their scale places them within a domestic setting where they may be animated by the shifting quality of the light, the reflections and refractions on their ridged surface, and the abstracted colours around them. They play with the ambiguity of float glass as both material and immaterial to highlight the complexities of our virtual world. They are the outcome of a particular attention which finds its inspiration in the contemporary city.

Treading lightly

Running as a constant throughout this research has been the notion of *treading lightly,* which I introduce in the title. By embracing what Daniel Miller describes as 'the seamless integration of digital technologies' and applying these technologies to a tradition of glassblowing that stretches back over millennia I have outlined a speculative model adapted to the way we live now. [1]

I describe this as a 'diffuse' practice: a practice which is not grounded in a workshop or studio, but instead remains flexible, moving on and off site. The reality of living in a major city such as London is that studio or workshop space is scarce and expensive. To equip and maintain a functioning hot shop or a cold shop, with the attendant health and safety

[1] Daniel Miller, 'Technology and human attainment', in: Jonathan Openshaw, *Postdigital Artisans: Craftsmanship with a New Aesthetic in Fashion, Art, Design and Architecture* (Amsterdam: Frame, 2015), p. 199.

requirements, is often beyond the means of a single craftsperson or even a small group of makers. Instead, I advocate a light and fluid approach to making where facilities are rented as and when required, precision engineering is accessed via digital networks, and the monolithic structure of the workshop, once fixed and immutable, is adapted to the realities of life in the twenty-first century.

As this innovatory research demonstrates, digital technologies are expanding the creative possibilities for studio glass while at the same time encouraging makers and designers to subvert established practices in order to imagine new models which are more relevant to contemporary ways of living and working.

GLOSSARY

Annealer or lehr

A temperature-controlled kiln where the glass is cooled slowly to avoid any internal stress.

The following programme was used in this study:

Set at 500 °C

10°C p/h to 400°C

15°C p/h to 200°C

Switch off.

Blowing iron

A steel hollow tube on which glass is gathered and blown.

Cold-working

The collective term to describe the many techniques used to alter or decorate glass when it is cold, principally grinding and polishing.

Coloured frit

Fritted glass which is commonly used in fusing glass and *pâte de verre.* Optul Spezialglas GmbH manufactures a float-compatible range in an assortment of grain sizes and colours.

Devitrification

Crystals may form on the surface of the glass when it is cooled or heated too slowly or quickly within a temperature range of 600 – 700°C for float glass.

Fire-polish

When briefly exposed to heat the surface of the glass melts and the surface tension smooths the surface of the glass to give a polished finish.

Float glass

To manufacture float glass, molten glass at a temperature of 1,100°C degrees is poured continuously from a furnace onto a bath of molten tin. The glass floats on the tin and spreads out to form a level and parallel surface. Over the last fifty years this has become the universal process for manufacturing sheet glass.

Glass batch

The mix of raw materials which are required to make glass. Studio glass artists commonly use pre-mixed glass batch which has been pelletized by manufacturers, such as Glasma and Spruce Pine Batch, for safer storage and use. The glass batch is melted in a furnace.

Glastac gel

A fusing glue manufactured by Bullseye Glass.

Graal technique

The colour overlay of a glass blank is cut or sandblasted to reveal the glass beneath. The glass blank is re-heated again and given a fire-polish and blown further.

Hot-finish

A hot-finish is obtained by shearing off the collar of the glass bubble. This can be done if the glass is transferred to a punty iron; otherwise the glass will be cracked off the blowing iron. The cracked-off glass bubble, once annealed, will need to be cold worked to obtain a neat rim.

Hot shop

Workshop for glassblowing which along with a furnace for melting glass and an annealer, will include typically basic equipment such as a work-bench, a marver, a re-heating chamber (glory hole), a pipe warmer, a small kiln, an assortment of blowing pipes …

Kiln

A small heating facility found in all hot shops. It is used to re-heat glass at a lower temperature than a furnace. The WJC constructions were re-heated in a kiln prior to the hot shop session.

The following programme was used in this study:

30°C p/h to 510°C – hold.

Full (top temperature) to 680°C when ready for pick-up with the blowing iron.

Marver

A metal surface on which the hot glass is rolled into shape.

Re-heating chamber or glory hole

A gas-fired chamber used for re-heating the glass during the hot shop session. The glass needs to be kept hot throughout to avoid internal stress.

Pierce points

As the waterjet cutter pierces the sheet of glass it creates a circular entry point; these 'pierce points' are slightly offset so as not to interrupt the line of the cut.

Punty bit

A small gather of glass at the end of the punty iron.

Punty iron

A solid steel tube. A blown vessel may be transferred from the blowing iron on to the punty iron to heat further and hot finish.

Punty mark

The scar that is left on the bottom of the piece when it is cracked off the punty iron.

Sofietta

A tool used to inflate the glass further after it has been transferred to the punty iron.

Tin bloom

Tin ions absorbed onto the surface of the glass during the float process oxidize and leave an iridescent sheen.

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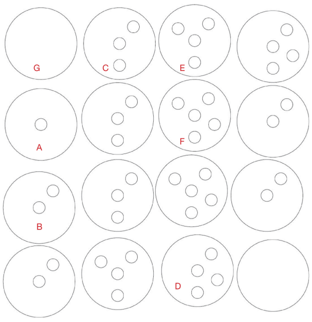
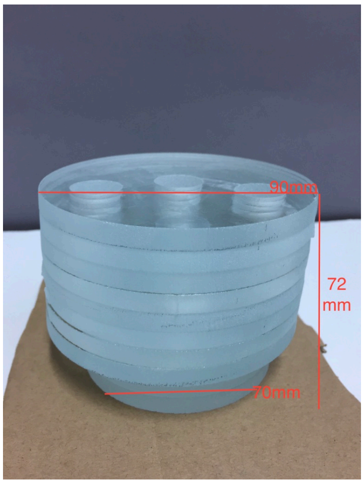
APPENDIX

The core of this study is based on empirical research which was carried out through a wide-ranging set of tests. The outcome of each test was recorded on a separate numbered test sheet. To keep to the allowable word-count I have only included the test sheets to which I refer in the text.

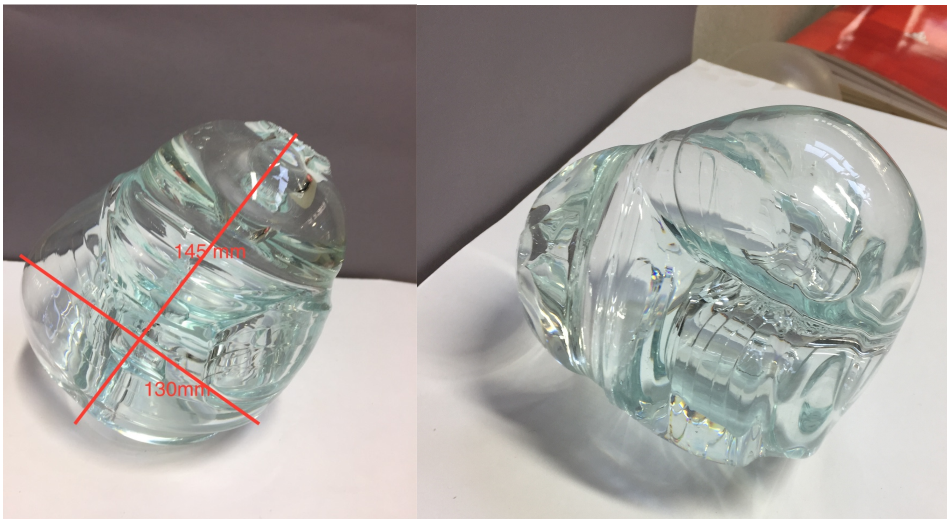
Date
22 March 2017
Sample
025.03.17
Glass
Low iron 6 mm. WJ cut pieces Pilkington Optiwhite.
Construction
Diameter of cut blow holes 15mm.





Notes for hot shop
Pick up with blowing iron to enclose the three holes on the top layer of glass.
See how construction inflates.

Outcome



025.03.17

Four holes inflated. The heat following the path of least resistance made one bulge out and stretch to the point of coming apart at the seams –a thin line from the layering process is visible.

Unlike the other two pieces no cracking.

A few areas of pooling and trapped air which has stretched.
The lines created by the layering are visible within the body of the glass.

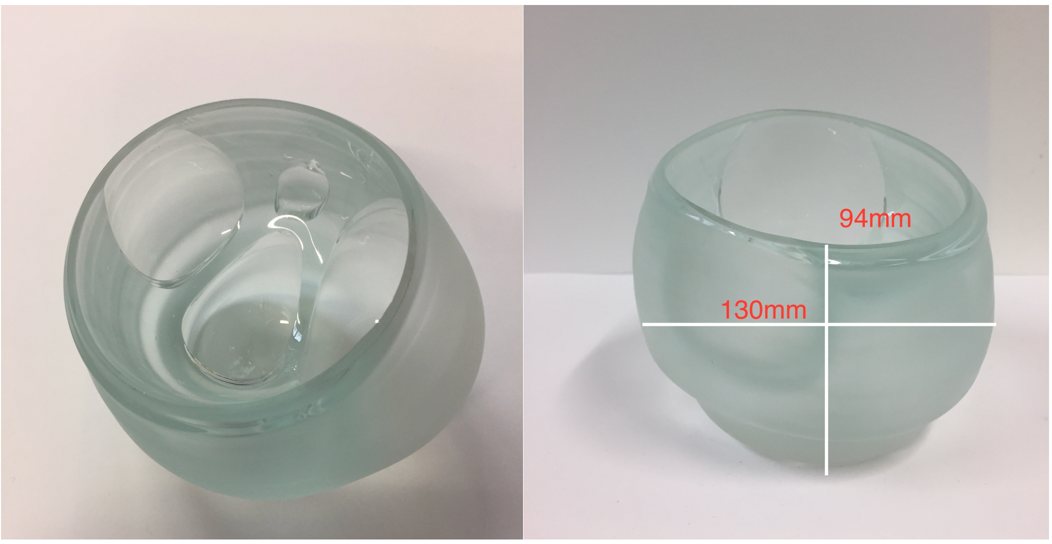
To do cut and cold work top.

Evaluation/personal response

This is more exciting than I had anticipated. Potential to develop further but here again more consideration needs to be given in placing holes. Consider dimension. Build up solid base.

Cold work

Sandblasted using 220 grit. Applied Osmo clear wood wax finish.



Date

7 June 2017

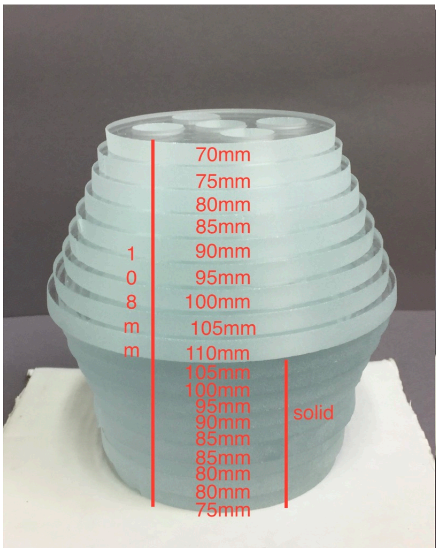
Sample

034.10.17 (blown October 2017)

Glass

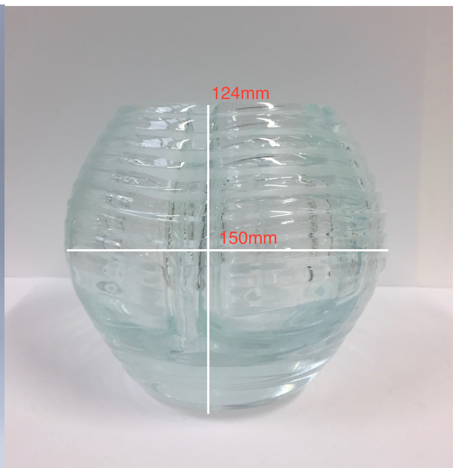
6 mm Pilkington Optiwhite (supplied by Team Valley).
Waterjet cut at Sunderland University 17th May 2017.

Construction



Hot shop

Pick-up, heat up, blow. No punty.



Outcome
Cavities inflated regularly with an interesting internal structure. The whole piece required more heat to rub out pierce points completely and smooth out some puckering and bubble strips along the joins. The ridges are more evident, sharper than in 033, and this lends a more industrial look and feel to the glass.

Evaluation/personal response
Here again as in 033 the overall look is too heavy and industrial. Not exciting enough.

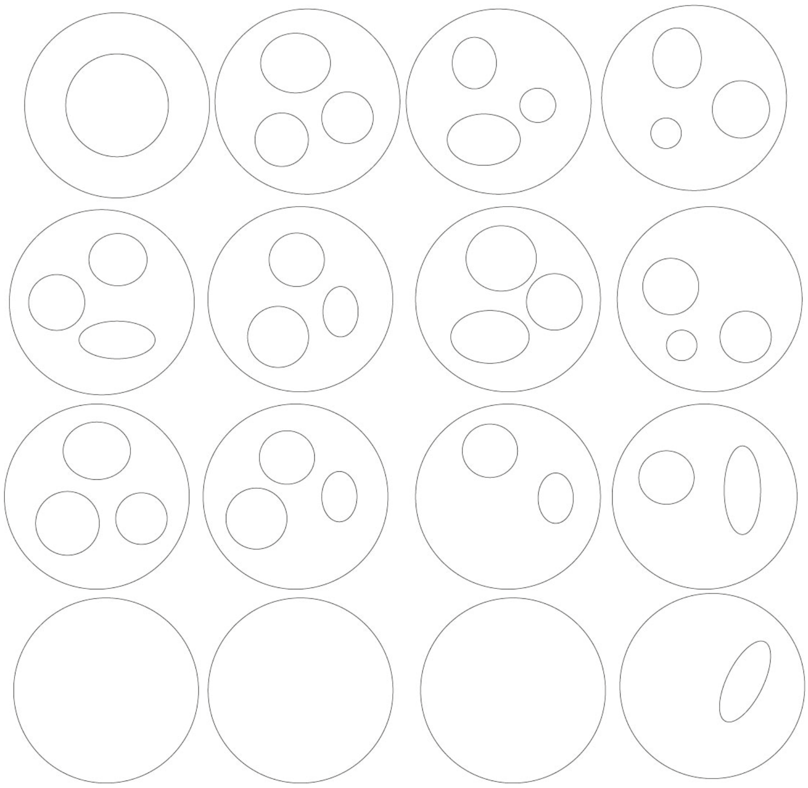
Future Testing
More imaginative designs are required at the waterjet cutting stage to be able to produce more exciting objects in the future.

Date
February 2018

Sample
042.02.18

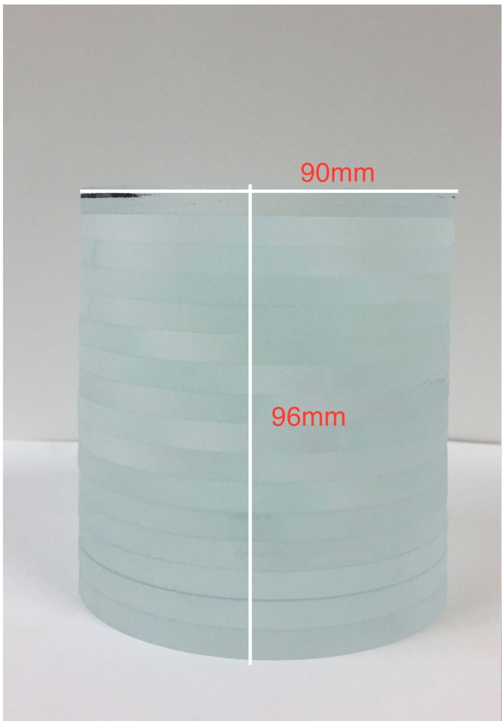
Aim
Investigating the cylinder. Random cellular, cluster configurations within a cylinder.

WJC File



Glass
6 mm Pilkington Optiwhite (low iron float).
Water jet cut at Sunderland University. All discs look clean with no chipping. Very good cuts.

Construction
Swapped disc 7 with 10. Positioned disc 10 further down the at the bottom of the construction to avoid it inflating out too much (narrow space between two holes) and collapsing.
16 layers (including disc for pick up).



Notes for hot shop

Heat well. Paper marver to smooth out ridges. Blow very gently. Keep hot. Don't punty as I would like inside cellular structure to stay sharp. Heat top with torch to achieve even distribution of heat. Or punty without opening up for several quick flashes??

Hot shop

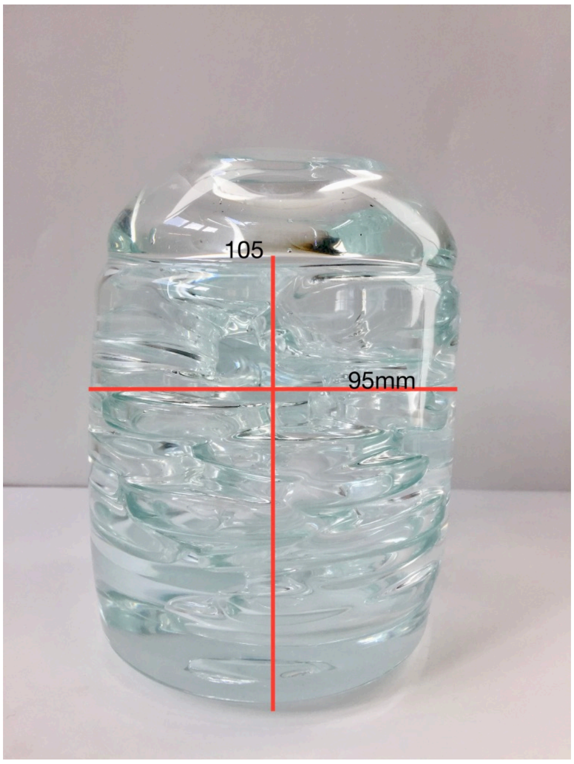
Picked up, paper marvered and on the table, heated for a long time, torched top half of the piece to try to obtain an even distribution of heat. The bottom of the piece inflated gently but when flattening the base the glass in that area immediately showed signs of devitrification. Re-heating rubbed out devitrification. Piece was then puntied and Liam used the sofietta to blow again gently into the piece. Devitrification reappeared at the base of the piece (now punty end) not possible to re-heat.
Conclusion: Devitrification appears suddenly when there is a disparity in the heat in the glass: outside hotter than the inside when attempting to change the shape of the piece.

Make sure piece is as hot as possible, limit manipulation, let the glass move through gravity and centrifugal force.

Outcome

As noted while working the piece, there are areas of devitrification and pooling at the bottom of the piece (see above). The sides of the cylinder are not straight, bulging out in the large middle section. Working with a cylinder construction the layers of glass are barely visible having melted in and been hand marvered to smooth out and straighten the sides of the vessel.

The cavities have buckled more in the bottom section. The edges here softened into a more rounded profile.



Evaluation/personal response

The piece is intriguing. The proportion is off, too wide, not tall enough, which gives it a squat heavy feel. The oval cut outs have pleasingly kept their shape and not blown out into circles. The bubbles have blown out into a random and unpredictable structure. Viewed from the side, it is difficult in some areas to discern what is solid from what is hollow which adds to the intrigue. The light catches the surface of the bubbles giving them an almost silvery aspect which makes the piece come alive. To develop further.

This sample was much improved after cold-working (see below).

Cold work

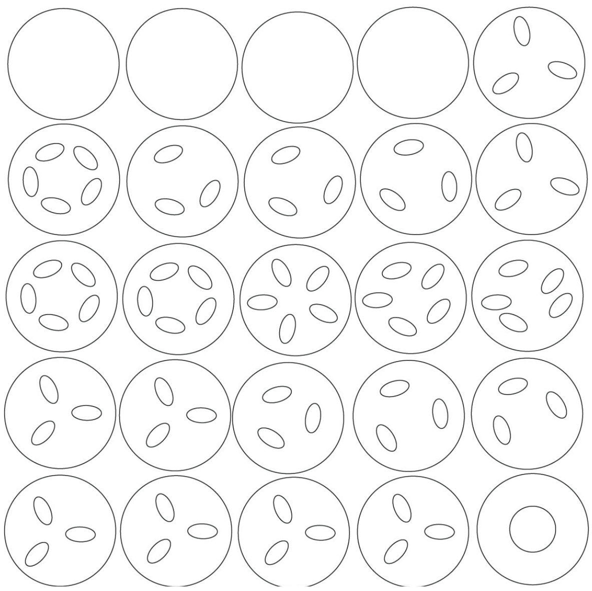
Take off top, cold work rim. Remove punty mark, cold work.
Consider sand blast and brush polish to give softer finish to the outside and make the inside the focus.

Final cold working

Base: cold-worked on flat bed 80 grit.
Reciprolap 600 grit (residue of staining of 600 grit). Next time I must make sure that I have water and some detergent in the piece to stop it drying out and marking the glass.
Reciprolab cerium
Outcome: high polish.
Top
Flat bed 80 grit
Great care required to keep all the internal edges bevelled to stop chipping.
And then hand lapped to 600.
Reciprolap cerium finish.

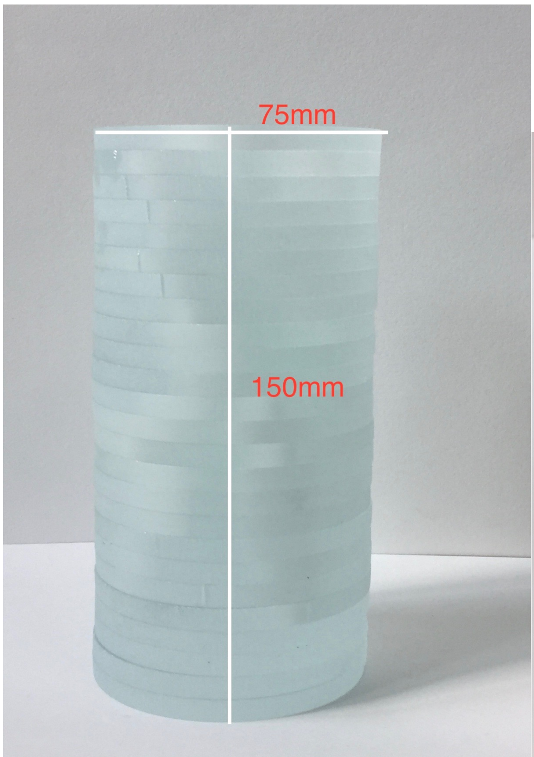
Future Testing
Develop design. Try to limit devitrification when working hot.

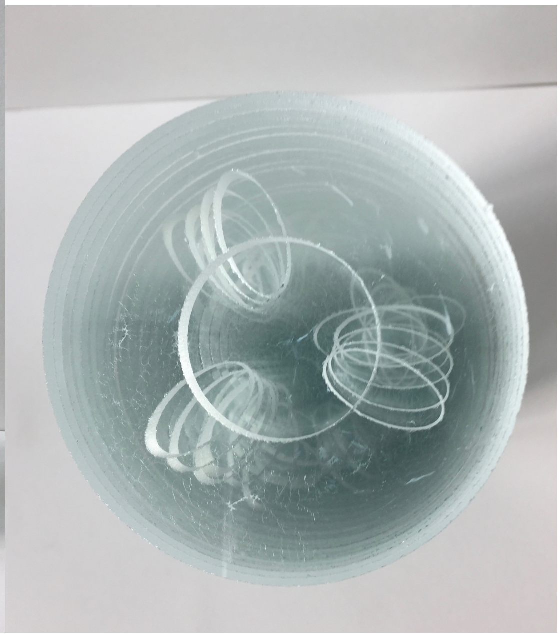
Date
23 March 2018
Sample
046.03.18
Aim
Following up on sample 042 aim to refine design and proportions.
-Increase scale (height)
How does this affect working with the material?
Heat distribution
Punty & torch
To see how identical elliptical cuts (10mmx20mm) inflate and expand within the body of the glass.
How the breath travels down through the channels
How the internal shape, created by the cuts, emerges
Control hazing and devitrification through heating and minimal handling.
Rub out the edges of the layered glass through heat and hand marvering
Keep a straight smooth outside line.
WJC File
Transform cylinder 02



Glass
6 mm Pilkington Optiwhite supplied by Team Valley. WJC at Sunderland University. 7 March 2018

Construction
Set up in a spiral.





Notes for hot shop
Pick up. Heat marver to smooth out sides.
Very gentle blow
Punty & torch for even distribution
Make sides straight after blowing
Take care about pushing glass to limit devit and hazing

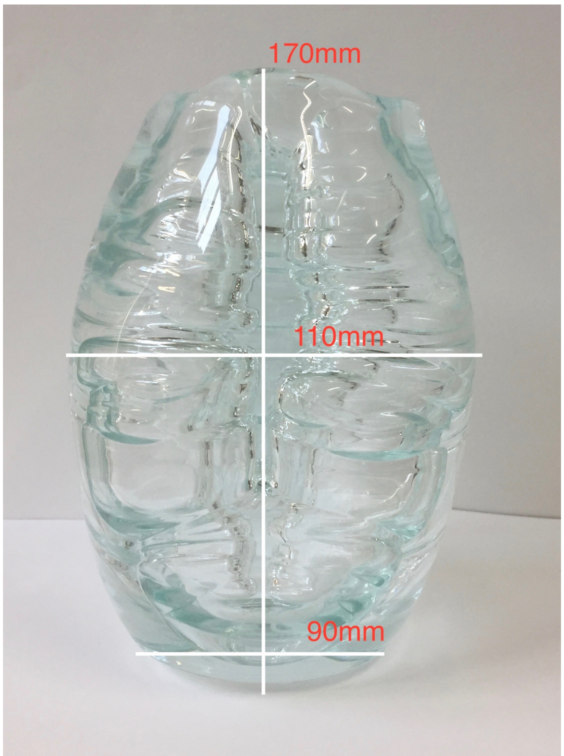
Hot shop
Picked up, marvered, a long flash in the glory hole, blew and blew some more to inflate as much as possible before the glass became too thin at the bottom. Transferred to a punty iron to apply enough heat to the top of the piece to smooth out ridges. Given a hot finish and pushed the top section in by hand to follow the shape of a triangle that the glass seemed to be taking with its three cavities at the top.

Outcome
The glass has increased in size from a height of 150mm to 170 mm and to a width of 110mm at its widest point. The quality of the glass is good, no evidence of devitrification and only a few small bubbles trapped in the layers of glass.

The inside has blown out into a series of chambers: three at the top, then sub-dividing into five in the middle section where 6 layers of glass had 5 elliptical cuts and then back to 3 chambers at the bottom of the piece where 9 of the layers had 3 elliptical cuts. The size of the bubbles, although emerging from identical sized cuts, varies depending on their position in the construction. The middle section inflating more has produced wider bubbles.

The layers of glass, although softened, are nonetheless visible and the gentle ridges can be felt by running my fingers down the bottom section of the piece.

The piece was designed with a central spine with the layers of glass rotating around it. This spine is visible form the top but is barely discernible looking at the piece sideways on.



Evaluation/personal response

An encouraging development. Although the outside form is mundane, an elongated bubble, the inside and the visual effects of the layered glass and the chambers within the object are intriguing. The optical transparency of the glass has created a perceptual illusion whereby it becomes difficult to distinguish between solid and hollow. Looking sideways canyons appear between the bubbles which read as immaterial (empty) but are in fact material (solid).

The rounded angles of the internal bubbles catch the light beautifully adding an almost silvery sheen to some areas.

The structure has taken on a cellular/ molecular form. Growth, distortion, dissolve.

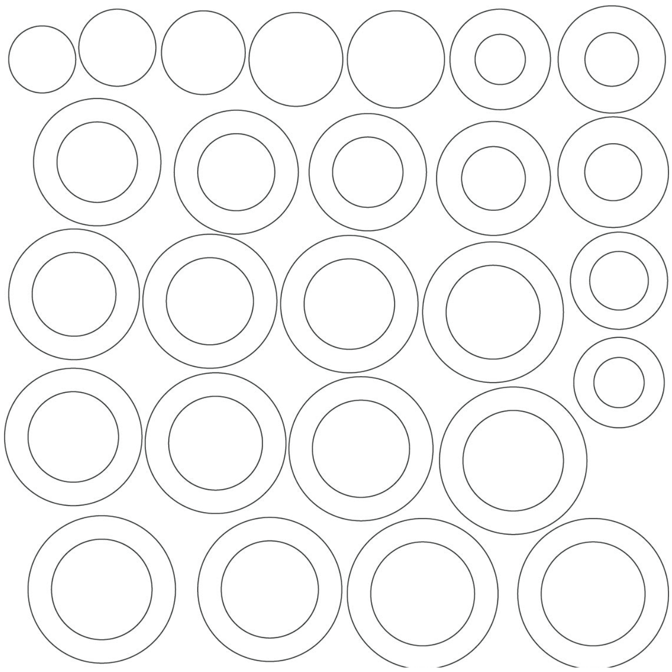
Interesting to observe the water line at different levels in the separate chambers.

Future Testing

To develop the visual illusion of solid and hollow material/immaterial.

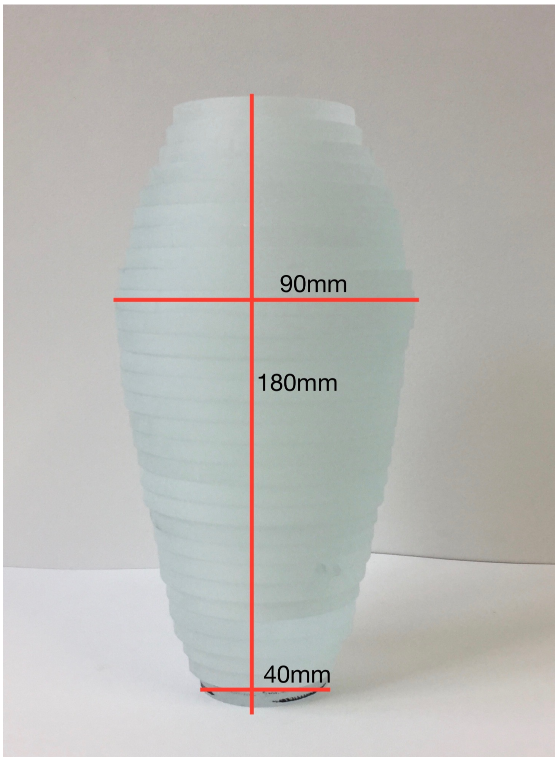
To see if the outside shape can be controlled more by the size of the cuts and their position within the construction. In other words, is it possible to keep a cylinder shape and not have the construction blow out into a bubble shape? Can this be done by leaving thicker walls in the mid-section of the piece, the hot air travelling down instead of following the path of least resistance ie: to the thinner wall of glass.

Date
19 April 2018
Sample
049.04.18
Aim
Starting with a shape that is close in dimension and form to a finished blown vessel to see how the shape is transformed by the breath and heat.
Proof of concept.
WJC File



Glass
6 mm Pilkington Optiwhite, supplied by Team Valley. WJC at Sunderland University 4 April 2018.

Construction
Total 30 layers (extra 4 rings on separate files).



Notes for hot shop
Blow and observe.

Hot shop
Inflated. Puntied.

Outcome

Achieved a traditional blown form.

The ridges are visible throughout the piece. In the bottom section they have a more prominent rounded profile while in the middle and widest section they have smoothed out to leave a line of devit.
The glass again is murky. The quality of the float glass become an issue when blowing out thin.

Evaluation/personal response

Interesting to see outside shape. This is a proof of concept to show that you can produce traditional forms using this process. By starting with a cut shape, the making time in the hot shop to produce this piece is far quicker than using traditional glass blowing methods (gathering, blowing, etc).
However, the quality of the glass is simply not good enough to make this a viable production method.
Without the internal structures (see tests ….) the piece, as a simple of vessel, is of little interest.

Future Testing

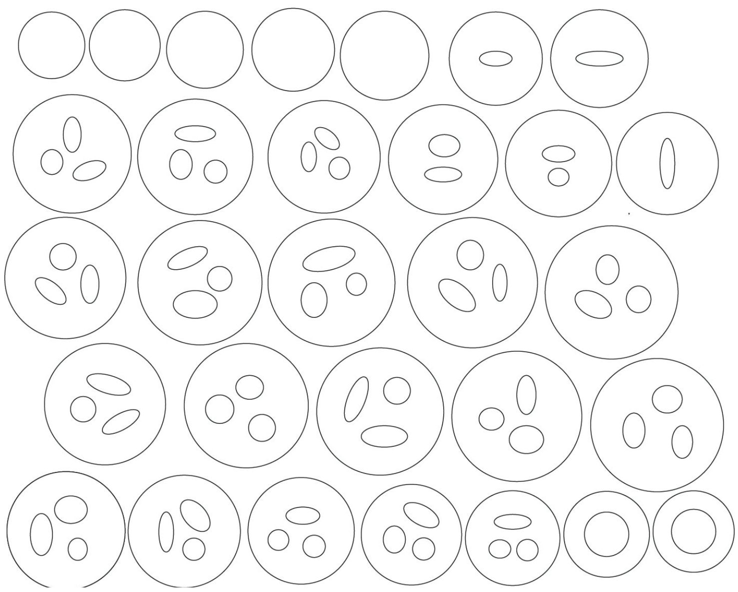
To consider retaining the outside shape but with an internal structure.

Date 22 May 2018

Sample 051.05.18

Aim
Increase size
Check with Liam maximum weight he can pick up comfortably
Blow out as much as possible to see how the form inflates and deforms
How the air travels down the structure

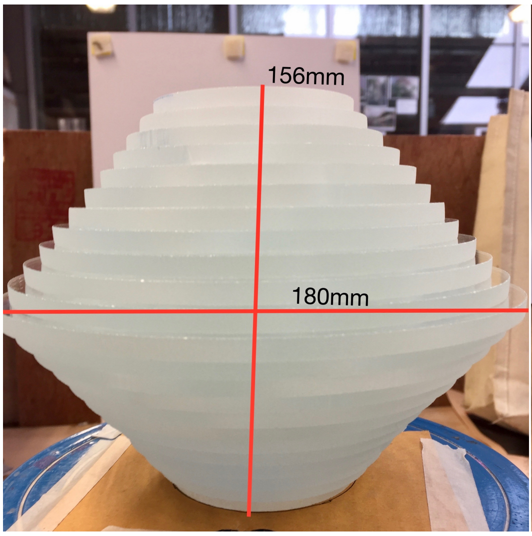
WJC File



Glass
2 sheets (450x500) 6 mm Optiwhite supplied by Team Valley. WJC Sunderland University 11.5.18.

Construction

051.05.18

Notes for hot shop
Pick up, flash, heat up. Inflate as much as possible.

Hot shop
Heating up schedule: 30p/h to 500 and then full to 680.
On opening the warm-up kiln, I noticed that the largest ring positioned in the middle of the piece had a crack running right across it.
This would have been caused by an uneven distribution of heat in that section. The temperature difference may have created a stress which caused the glass to crack. The outside, a single 6mm sheet which extended further than any of the other rings, becoming much hotter while the inside in the middle section taking longer to heat up.
The warm up schedule was conservative at 30 degrees an hour to 500. This could be adjusted to 20 or 25 degrees an hour. Or a longer soak at 680 would be another possibility. To discuss with Heike.
Alternatively, this could be solved through the construction and design by ensuring that large thin surface areas of glass do not extend beyond the central body of the piece.

The air (breath) was escaping through the cracks but by marvering the piece Liam was able to seal up the cracks and blow out the construction. The piece was transferred to a punty iron to allow the top section to heat up in the glory hole. The top was blown out using a sofietta. Two simple rings at the top of the construction made this possible. An improvement in the design.

Liam noted that this was about as heavy as he could work comfortably.

Outcome
Not quite a sphere, the shape here again is inelegant.
Increase in height: 156 mm to 200 mm.
Increase in width: 180mm to 198 mm.
4 lines of puckering at the base and 3 at the top where the rings have blown out. The tiered edges and the rings having been stretched out.
Areas of devit are visible on the outside in particular at the base. Looking down into the piece, I note that the glass which stretched out into thin strands has devitrified.
Some small areas of pooling.

Evaluation/personal response
I had expected the outside form to blow out into a more organic shape, the contours bulging in and out where the cuts were closer to the edge of the shape. Instead it is not quite a sphere. The internal structure is complex and exciting with thin and thicker stands of glass radiating out from a central core.
Because of all the layers (23) of 6mm glass it is in fact difficult to read the internal structure looking at the piece sideways on. Light bouncing off the edges of the layered glass creates multiple reflections which animate the object but also make it difficult to see though to the inside. Looking down into the piece through the small, hot-finished opening one can begin to discern sections of the structure but it is impossible to see the whole without adjusting one's gaze.
Interestingly, it reads better from afar.

Cold working

To try to rub out the puckering through cold working would be difficult, long, and tedious and ultimately may not achieve the desired effect as it will flatten out the rounded profile of the layered glass.

To flatten out the top will leave an irregular opening which might sit uncomfortably with the shape of the object. I must attempt to design pieces that require very little cold-working once finished. Extensive cold-working would require access to a cold-shop (my own or rental) or alternatively I could outsource the work which all adds to the cost of the final piece.
To do: lens the base and polish out the puckering at the very top of the piece to give a clear transparent finish which should provide a better view into the internal structure.

Future Testing

. Consider how to reduce puckering along the edges when blowing out the vessel. Reduce the incremental step in the size of the circumference between each layer of glass. Increase width at base and top.
. Be attentive to surface area and thickness of glass to eliminate stress when heating up.
. Consider using 12mm glass when building larger construction to reduce the number of layers to make the piece more legible and less ambiguous. I would like to be able to see through the layers into the internal construction.
. Make the internal cuts larger to reduce weight and devit when stretching out the glass.
. Consider using both 12mm and 6mm glass in the same construction.
. Provide a thicker base to allow the piece to blow out more at the base more than 36mm. 60mm?

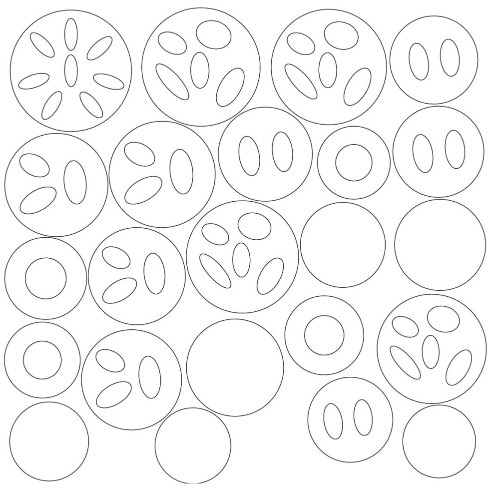
Date
November 2018

Sample
054.11.18

Aim
Variation on hyberboloid. See how geometric structure is transformed/deformed.

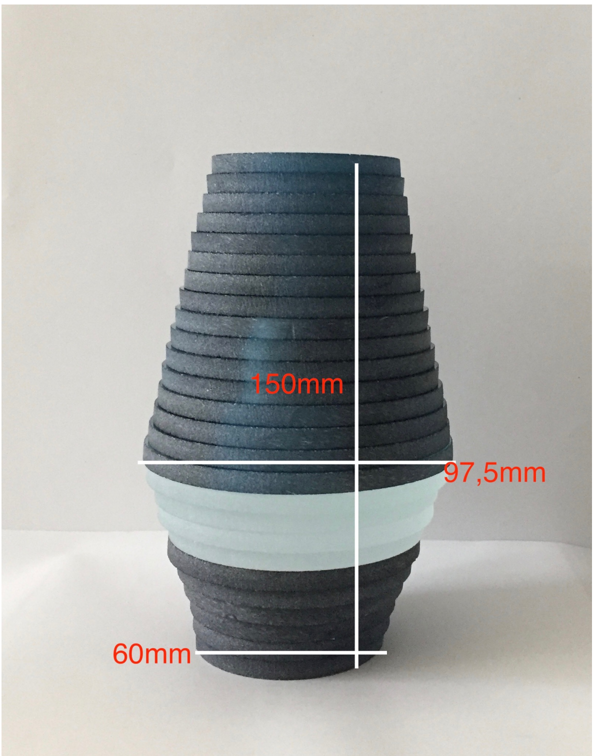
- Colour test aqua
- Variation in tone
- How colour or bubbles travels down into solid
- How internal shapes emerge in Fibonacci sequence 1; 2;3;5;

WJC File



Glass
6 mm Pilkington Optiwhite & 6 mm Optifloat aqua supplied by Team Valley. WJC Sunderland University 29/10/18.

Construction
Aqua – solid x 6
Clear – solid x 4
Aqua – cut x 16

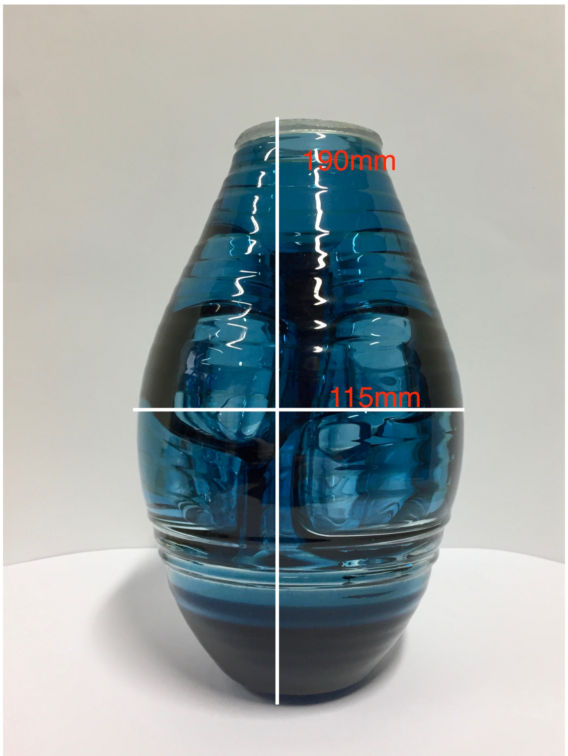


Hot shop 15/11/18
Some slippage in the upper section which may have been caused by 053 toppling over in the warm-up kiln. See test sheet 053.11.18 for other possible causes.

As the coloured glass (aqua) is softer that the clear glass, the cut chambers in the aqua section inflated more quickly than the solid clear which was stiffer. Rather that moving down into the solid section of clear glass, following the path of least resistance, the hot air was going back up and pushing out the sides of the aqua section.

Outcome
The shape blew out well. As anticipated, there were no compatibility issues between the aqua and low-iron float. Areas of pooling are visible in the layers of clear glass, however, none are visible in the aqua section. The blue glass has blown out slightly into the clear but this effect would be more pronounced and visible if I had inserted one or two more layers of uncut aqua glass. The stepped ridges in the clear base are more pronounced; the incremental difference between the sizes of the rings were larger in the solid section.

Making the cut cavities three layers thick has given the internal structure more presence and is more effective than in previous models where the cuts were only one layer thick. When the cuts were one layer the final internal structure often looked confusing.



Evaluation/personal response

The colour fade in the aqua layers of glass is successful. In particular the darker sections, where there was more glass, are a rich deep blue.
The pronounced outline of the WJC structure has softened and blown out into an oblong standard vessel shape.
When filled with water the internal chambers become more visible and look quite beautiful.

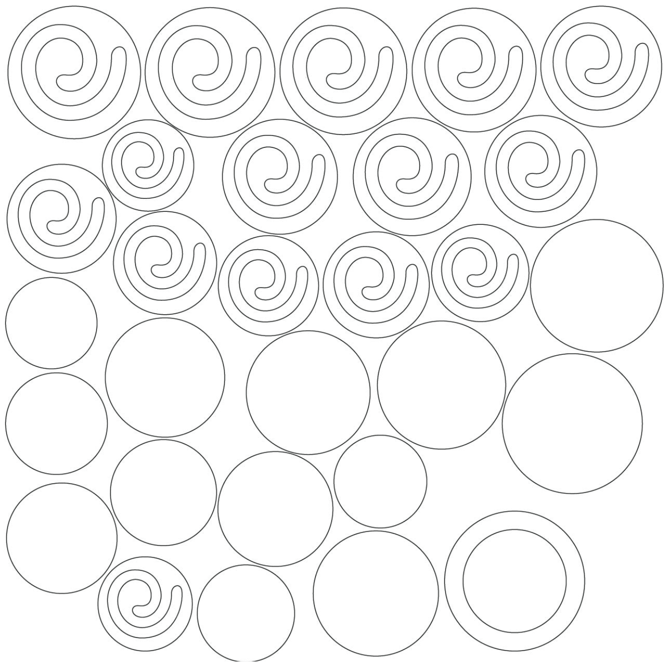
Future Testing

Consider how softer glass will be transformed by heat and breath compared to clear glass. This needs to be factored into the design. Reduce the size of the internal cavities to allow for thicker walls in the sections of coloured glass (?).
See how the external outline can be made more surprising and/or arresting. How to move away from the standard blown shape? How does the internal structure affect external outline?

To do: improve design of outline of shape
Test with grey and bronze float glass.

Date
November 2018
Sample
055.11.18
Aim
To see if possible to subvert tyranny of the bubble by creating different types of internal cuts. In this test a spiral -- what internal shape does this create? How does the breath deform the spiral.
Does this affect outside shape?
How does it travel down into solid?
Thinner walls. Uneven wall thickness may impact external shape.

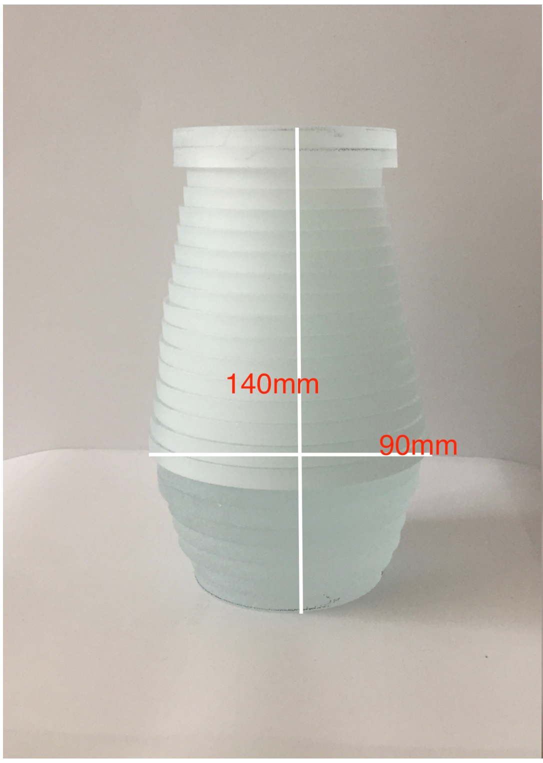
WJC File

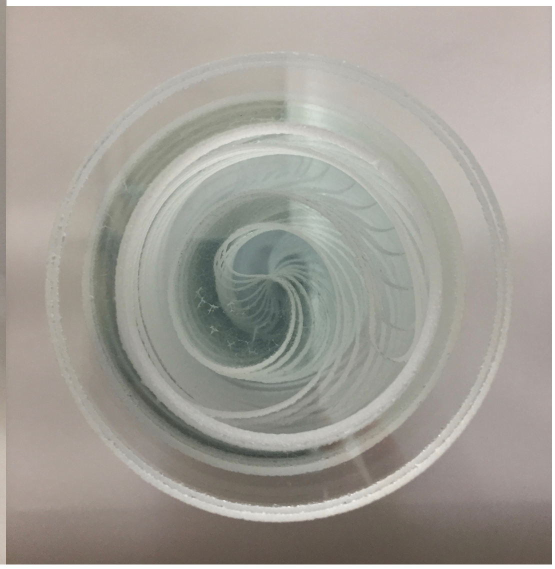


Glass
6 mm Pilkington Optiwhite supplied by Team Valley. WJC Sunderland University 29/10/18.

Construction
Rotated each piece slightly as I built up the structure to create a vertical spiral as well as horizontal.
Solid x 7
Cut x 15

Extra 2 at top to create suitable base for collar.

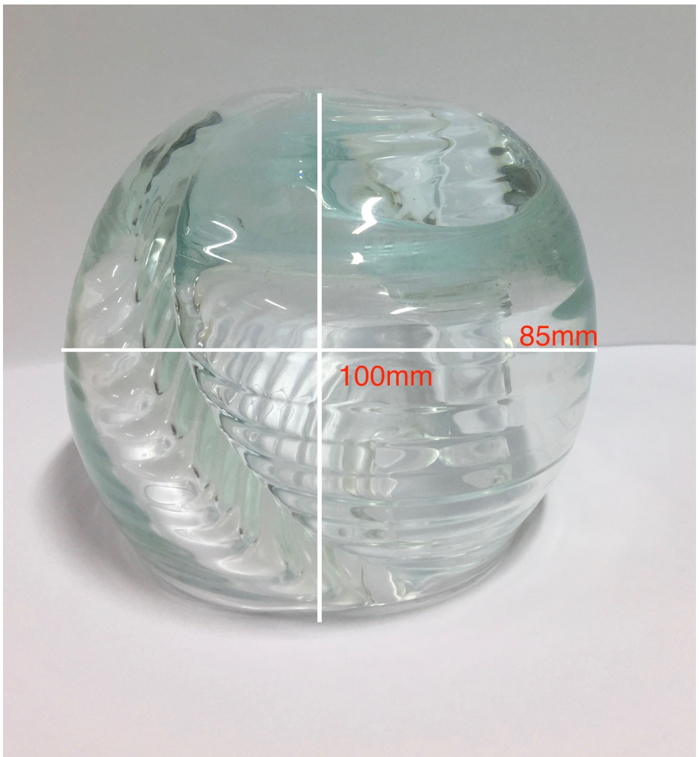




Hot shop 15/11/18
Some slippage of the layers in the top section meant that that air was escaping through a gap in the construction and it was not possible to inflate the piece (see test 053). The slippage may have happened when test piece 053 toppled over and accidently nudged the piece or caused a vibration in the kiln. Or it could be any one of the reasons outlined in test 053.

Outcome
Put the piece in the lehr to anneal.
Will saw off the top section which was out of alignment and attempt to inflate the piece during the next session in the hot shop.

Another go in the hot-shop
Picked up the truncated construction and blew it out as planned. Puntied and hot-finished.



Outcome
The top of the piece is baggy. It looks as if the top ring slumped inwards which may be a result of sawing off the top and leaving a ledge between the internal spiral and the external ring.
A lot of devit is present at the base. Graduated angle too steep at the base?

Evaluation/personal response
The spiral would be more effective if it were centered all the way up and not leaning to the side to join the edge of the ring. The stepped spiral gives a moire effect when seen upside down. This effect was completely unexpected but is exciting and certainly has potential. The internal structure is more interesting, particularly if viewed upside down, as it creates intriguing optical illusions including an ambiguity between solid and hollow.

The spiral has had no effect on the external shape.

There is certainly scope to develop this further but it requires more refinement and consideration in the design. The quality of the glass becomes an issue if I am looking to create optical illusions.

Future Testing
Develop and refine the design to see if it is possible to make the spiral more centered. How could this work? Does the spiral always move to the edge when blown out? No internal support structure. Consider how to position the spiral cut within the body of the glass.

For next test:

. use grey glass (softer)
. figure out how to keep spiral central
. keep the spiral the same size to see how this changes the outcome
. set within cylinder shape not graduated to see what this does
. set the layers of glass one on top of each other and not in a stepped construction (?) (maybe???)

Date
November 2018

Sample
057.11.18

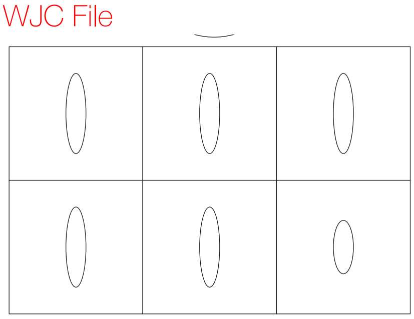
Aim

- Demonstrate difference between the stiffer low-iron float and the softer coloured float.
- How is the cube transformed by breath. How do the faces distort? Geometric transformations. Softening the straight lines of the cube.
- Set at an angle see how the horizontal and vertical planes are transformed.
- How does the breath travel down into the solid section.
- A single simple elliptical cut was made through the layers in the top two sections. To present a simple visual record of the process.
- How easy to shear off the neck and hot finish the top.

Technical: following up on the last series of tests applied Glastac Gel in 4 small beads at each corner. Will this allow air to escape?

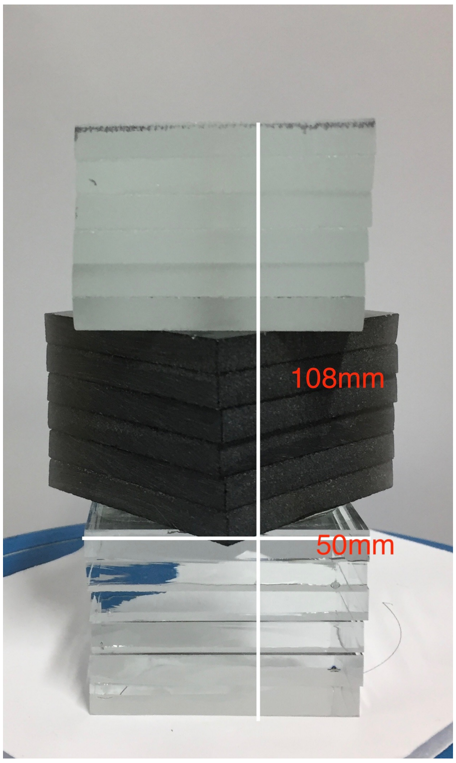
Cleaned all surfaces of the glass with methylated spirit.

WJC File



Glass
6 mm Pilkington Optiwhite & 6 mm Optifloat bronze supplied by Team Valley. WJC Sunderland University 29/10/18.

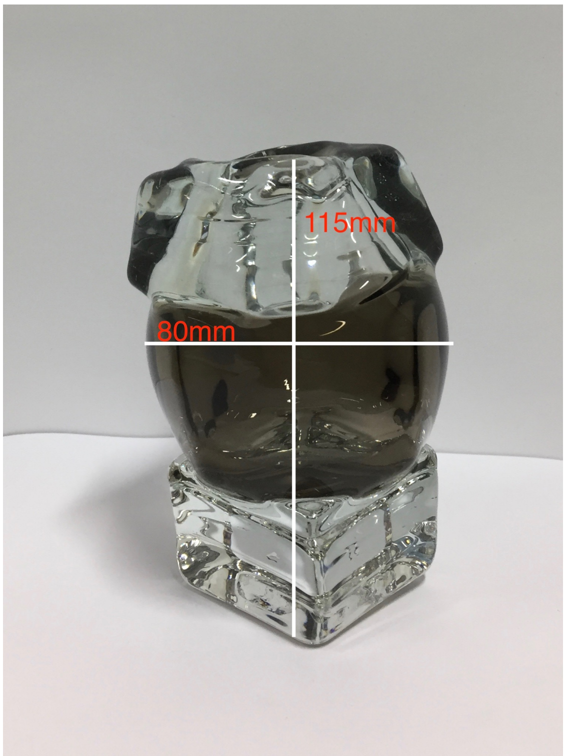
Construction
6 low-iron float in solid; 6 bronze cut; 6 low-iron float cut.



Notes for hot shop
Pick up blow . Observe how structures inflate. Hang?
Transfer to puntee to distribute evenly and for hot finish at the top.

Hot shop
As above but did not hang.

Outcome



Very useful to demonstrate:
. how a bubble blows out (top section).
. how much softer the bronze glass is compared to clear. This needs to be taken into account when designing pieces with sections in different colours.
. how the angles are softened.

Evaluation/personal response
. I like the softness of the bronze and the feint trace of the edges left after blowing.

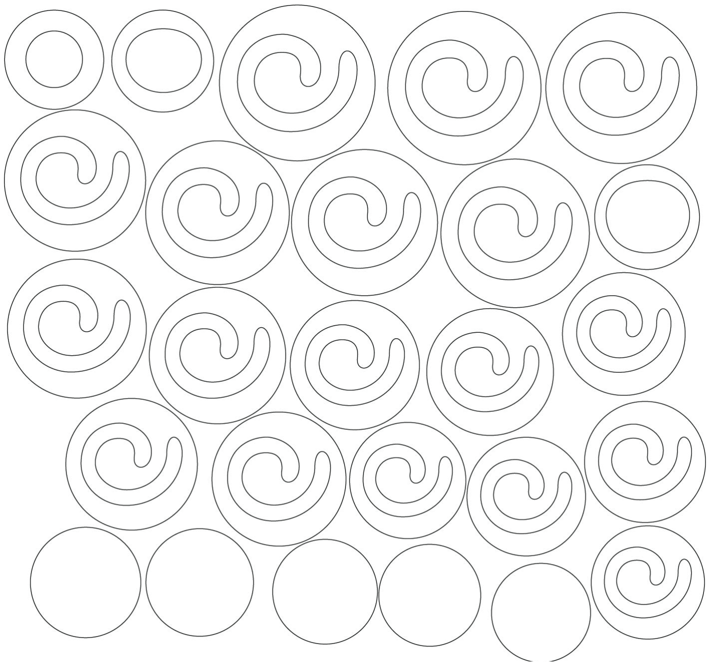
Future Testing
To consider making more crystal-like structures where the edges dissolve and are barely suggested. Re: Rawson's analogy of the crystal and the fruit.

Use bronze glass.

Date
23 January 2018
Sample
061.01.19

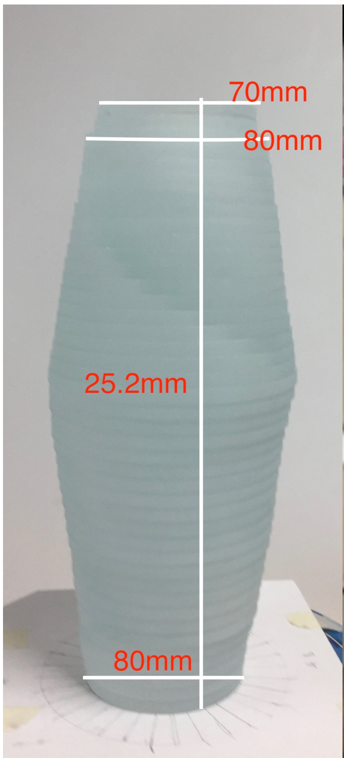
Aim
To observe how the internal spiral affects the external form.
How does the form evolve?
Make the ridges of the layers smoother and less prominent through marvering.
Scaling up. Is the size and weight manageable?

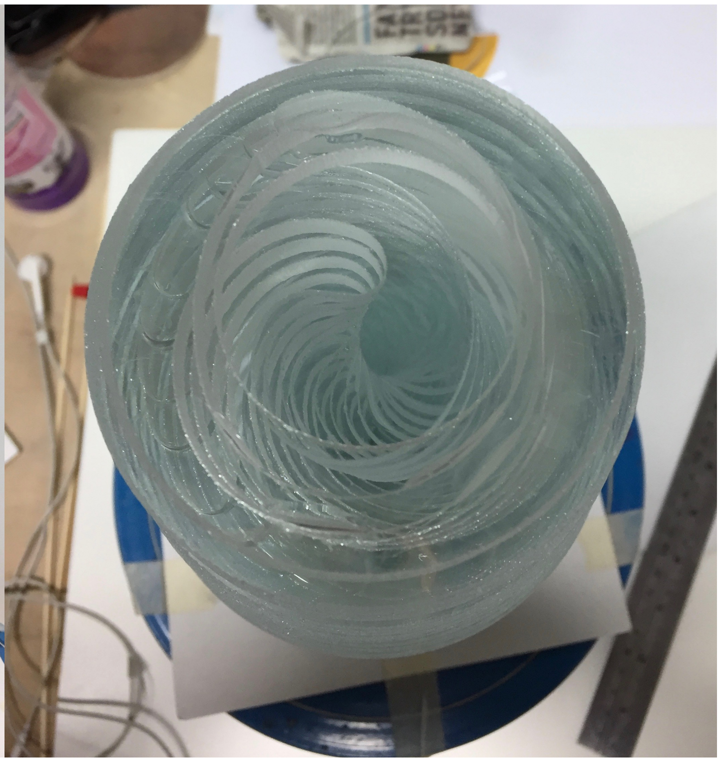
WJC File



Glass
6 mm Pilkington Optiwhite supplied by Team Valley. WJC Sunderland University 14/01/18.

Construction





Notes for hot shop

Pick-up; heat well, marver to soften the edges of the layers of glass and blend them in to the form.
Punty to distribute heat.
Shear off collar to allow heat inside and to soften the edges of the internal spiral.

Hot shop

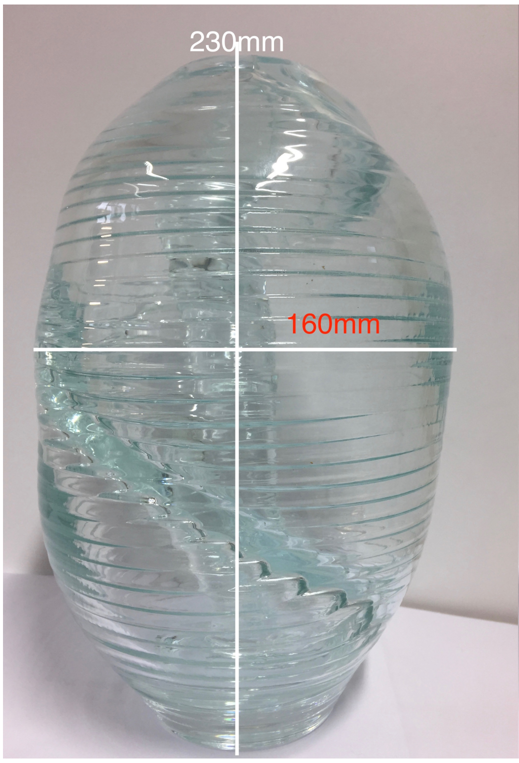
Done in 25 mins as Liam was short on time.
Picked-up, paper-marvered, heated, inflated. Maybe a tad too far (?). The bottom half of the piece closer to the heat source blew up faster ballooning out while the top section didn't move. This created a slightly awkward discrepancy in the shape. The top section (cooler) retained a more conical shape while the bottom section (hotter) ballooned out. When the piece was puntied and the neck sheared the movement of the spiral and the heat continued to transform the shape. A shoulder developed and the piece lost its form.

More heat!!!More time.

The piece (2 sheets of 6mm 500x500) was about as much as Liam could work with comfortably.

TIP: Make 4 or 5 simple rings at the top to leave a circular opening to easily insert a sofietta.

Minimum circumference of the ring 40mm (internal) 70mm (external). Better to make larger.



Outcome

A crack appeared at the top of the piece where the glass is very thick. I found the door of the annealer ajar when I came into the hot shop. Maybe a cool draft pinged the piece. Make sure to put the pieces at the back of the annealer in future.

The shape has blown out too much in the middle section. Uneven heat distribution. The ridges have softened well at the top but more heat was required at the bottom.

Areas of devit along the stepped edges of the internal spiral.

Evaluation/personal response

Although this looked exciting when it was turning on the end of the blowing iron; the internal spiral moving up and down, the final result is disappointing. The outside form is baggy. The piece was blown out too much, losing its shape in the process. The thinner edges blowing out more depending on the angle of the spiral.

The internal spiral gives a sense of movement but nonetheless is sausage-like. Too strong it dominates the piece and lacks subtlety. Here again there is ambiguity between solid and hollow: material/ immaterial.

Even without the crack at the top I would need to do something to the top of the piece as there is an uncomfortable shoulder. The piece narrowing towards the top has blown out unevenly. Although I wanted the internal structure to affect the outward form this has not been successful.

The scale is good and the increase in size makes it easier to see the design which doesn't look as complicated or as fussy as in the smaller test pieces.

The base is not right. Maybe not have a stepped base(?).

The overall effect is lumpy and graceless and is far from my personal sensibility.

At this point, I need to develop work which is closer to my sensibility rather than pieces that may be interesting technically. I absolutely need to find my own language with this process and material.

To do: saw off the top to take out the crack. This should improve the line and open up the piece to be able to see inside. Cold-work and polish.

Future Testing

Alter the design to give the outside form more of a V-shape wider at the top than at the base this should give the outside a more regular form. Wider but not so tall should also help with heat distribution(?). How wide, how tall, irregular outside shape? Or a cylinder(?)

Or leave aside for the time being?

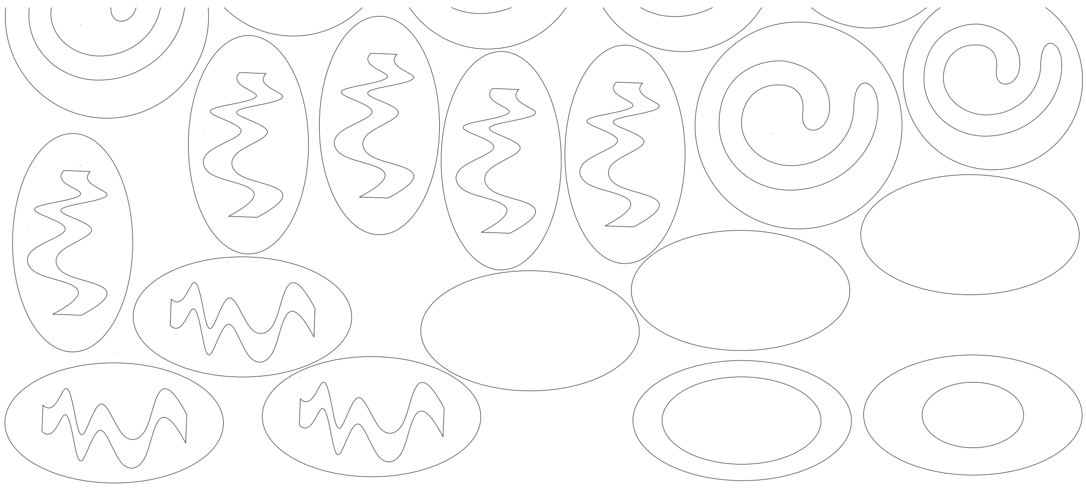
Date
23 January 2019

Sample
062.01.2019

Aim
Test piece to see how the cut informs the shape. How does the shape inflate areas of thick and thin glass. The cut analogous to a sketched, flowing, line. Line = cut. Complex patterning produced by flipping over the glass module. How does the air find its way down?

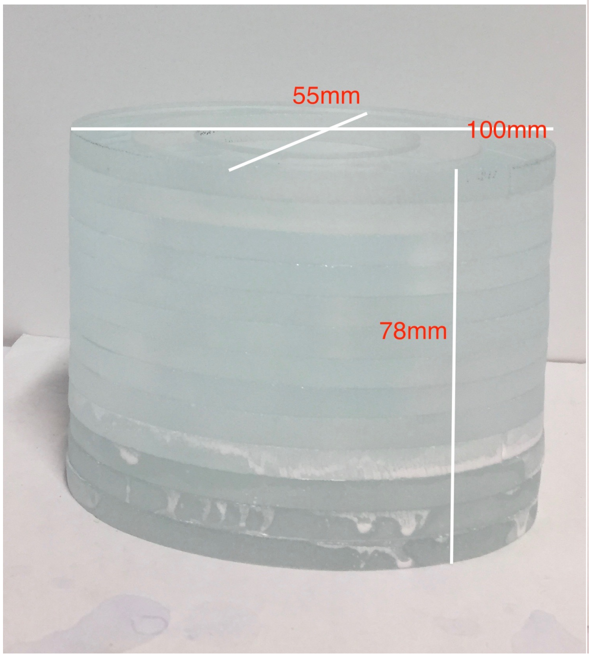
Sprayed super spray Overglaze (a kind of flux) on tin side of the 4 modules at the base.

WJC File



Glass
6 mm Pilkington Optiwhite supplied by Team Valley. WJC Sunderland University 10/12/18.

Construction



Notes for hot shop

Pick-up & blow. Observe what happens?
Will the sides push out irregularly?
Will the oval keep its shape? Or become cylindrical?

Hot shop

Unfortunately session on 24/1 was cut short (40 mins) so we didn't have time to work on this piece. Annealed overnight. Will be tested at next session.

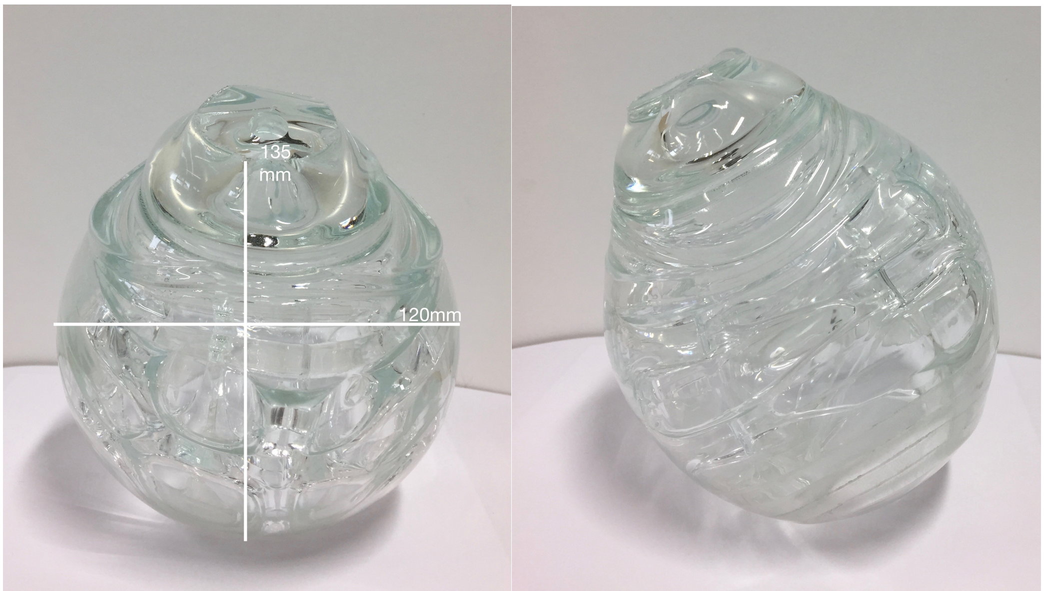
7/2/19

Picked-up, heated up, and blew. The sides inflated evenly. I had expected the sides to push out into a contoured form depending on thickness of the glass. The thinner areas blowing out more while the thicker areas moving less. In fact, the construction blew out into a bubble once again demonstrating that the form inevitably blows out into a sphere of sorts as the gases (breath) seek a state of equilibrium.

The internal structure did look intriguing.

The base was too thin to punty.

Outcome



The shape is not quite spherical.
The elliptical rings at the top have melted down at the sides to form a ridge at the top just below the neck. At the base, which was blown out, the slight ridge of the elliptical rings provides a fulcrum for the piece to sit and balance on at an angle.

The internal cuts have blown out into a complex network of etiolated glass strands and cavities.

The overglaze (flux) was not at all successful and has left a dirty film on the glass. Furthermore in one area it has stopped the layers from fusing together and instead has left a sharp edge and a slightly gapping slit. Not to be repeated.

Evaluation/personal response

At last a promising result. Although there are a few glitches for example the murky residue left by the flux and stretch marks at the top, this sample holds something of my sensibility within it and is not merely intriguing. The internal structure is fragile, the form although simple is nonetheless pleasing; the overall effect, to my eyes at least, looks fresh and contemporary.

As this sample demonstrates, not using a stepped construction, simplifies the overall look of the piece. The edges of the layers of glass, which read as horizontal lines, are not so prominent and have melted into the body of the glass making for a smoother surface and a more harmonious form. There is more clarity here.

To do: Saw off the top and cold work & polish the rim.

Sand blast the curved elliptical base and then hand-lap with 600 to achieve a smooth matt finish which will disguise the areas of pooling at the base.

Future Testing

Develop this design further with the end of year show in mind.
Increase scale
Work with variations of the ellipse (see 064).

062.03.19

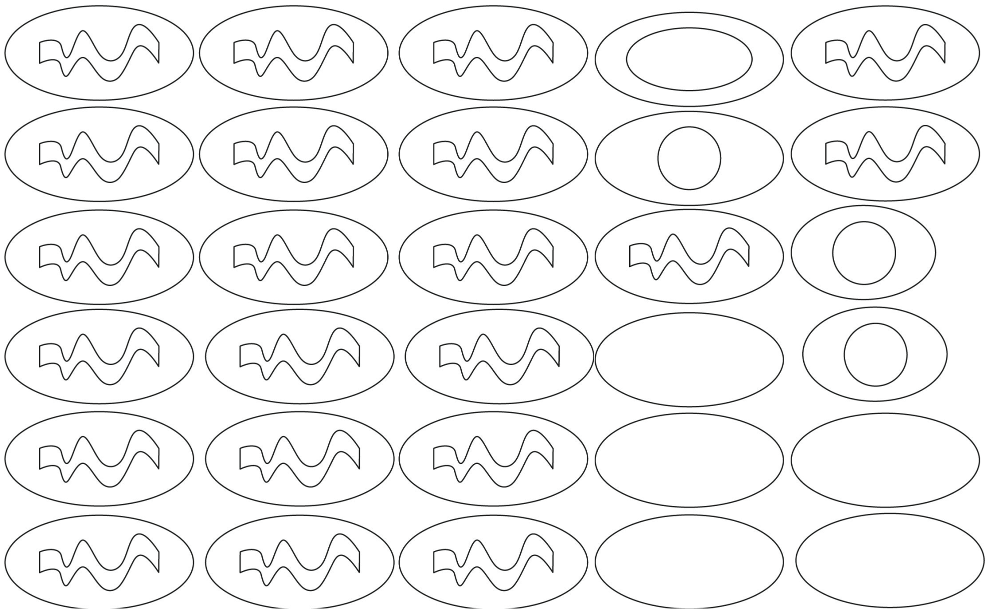
Refine the design in particular the top of the piece.
I like the rounded base. If the piece is not so high I may not need to punty to distribute the heat.
Make wider shorter constructions.
Create more cuts and patterns.

Date
28 February 2019

Sample
065.02.19

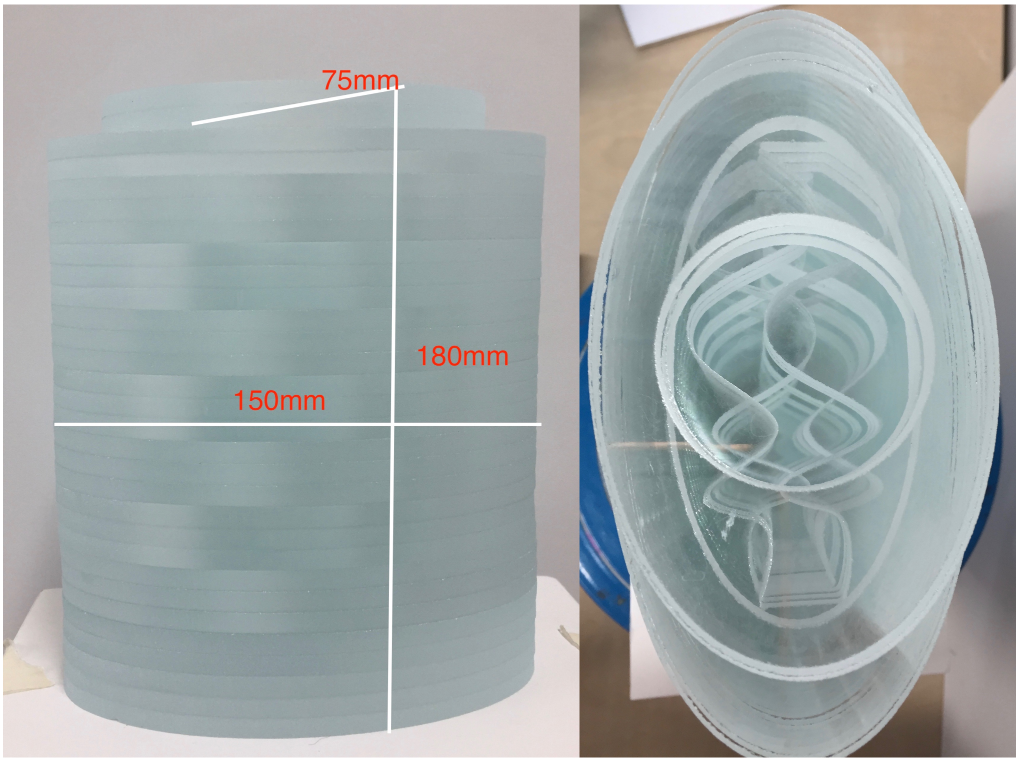
Aim
Scaling up sample 062.
Simplified the design of the cut.
Added two extra layers at the top to provide a neck which can be sawn off.
Consider how to finish off the top when cold working.

WJC File



Glass
6 mm Pilkington Optiwhite supplied by Team Valley. WJC Sunderland University 20/2/19.

Construction



Identical external and internal (cut) modules. Built the construction up in series of threes, flipping the glass over every three modules to create a complex patterning.

I particularly like the subtle effect that the difference in areas of thick and thin glass has on the abraded surface of the glass (see above). Repeating pattern.

Notes for hot shop
Pick up and inflate to push out the sides and the base.

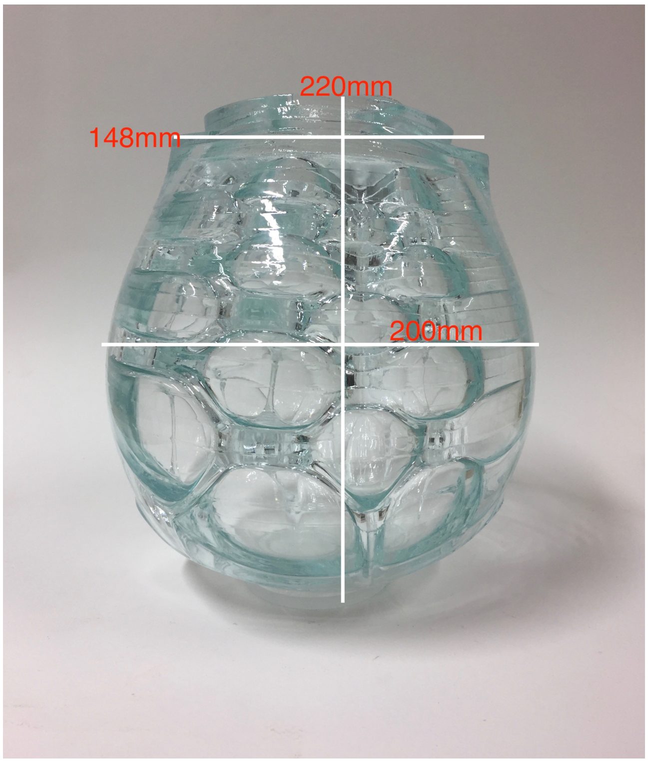
Hot shop
This is about the maximum weight Liam can pick up comfortably.

Inflated until the sides and the base bulged out and the oval corners rounded out slightly. I had decided not to punty the piece as I wanted a rounded base so that the piece could sit at an angle as in sample 062. However, this meant that the top of the piece was not as warm as the bottom which has had an impact on the shape, more pear-shaped than 062, and the hard edges of the sheet glass have not softened and blended into the surface.

Outcome
As anticipated, the edges of the layers of sheet glass in the top third have not softened and blended in as much as in the lower section. This has left a rippled effect on the surface of the glass in the very top section. There is some devit at the top in the collar, however, this is evenly distributed and not unattractive. Need to consider if I leave it as if or cold work out.

The piece has inflated into a soft overripe pear shape (ref: Philip Rawson). From the outside the repeating pattern of the internal cut reads like a honeycomb structure while

looking down into the vessel a series of wavy lines of thicker glass, almost tooth-like in their formation, appear on the inside of the two faces. Etiolated threads of glass connect these two faces to form a network.
The colour in this thicker heavier sample is far more grey/blue than in sample 062.



Evaluation/personal response

The inside structure viewed both looking down and from the outside, where it appears as a surface design of stacked bubbles on the inside face of the glass, is successful. The shape of the object itself sadly is baggy (again).

The scale is wrong occupying an uneasy middle-ground between large and authoritative and small and delicate. Furthermore, I am drawn to the small, light, transportable, and notionally functional as opposed to heavy and immobile 'statement glass'.

Future Testing

To consider max height of the construction before it needs to be puntied to distribute heat across the entire piece. Working at a smaller scale and only scaling up, if at all, when I have absolutely nailed the design.

Try new cuts for the internal shape.

Consider how to finish off the piece in the cold shop.

Cold working

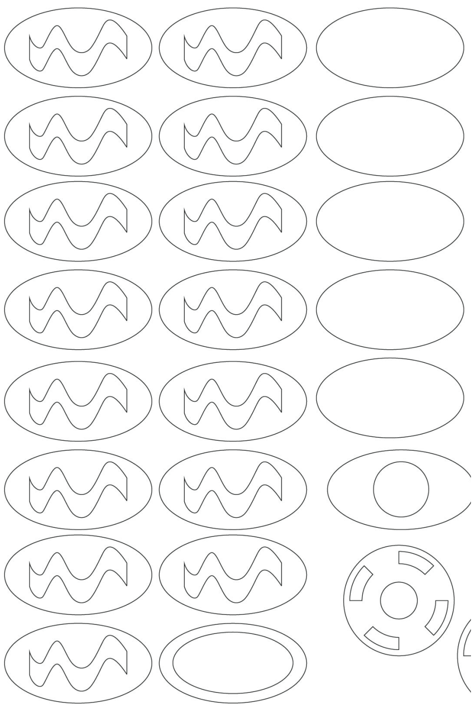
I had just finished taking down the top of the piece on the diamond flat bed, I set it up to check that I was done, turned back to switch off the flat bed and as I did I heard a loud clear bang. Chunks and shards of glass scattered across the cold-shop floor. A moment's distraction…and the piece rolled off the work bench.

Date
27 March 2019

Sample
067.03.19

Aim
Revisit tests 065 & 062 to find a scale somewhere between the two. More delicate and lighter than (065) and slightly larger than (062) to have more impact.

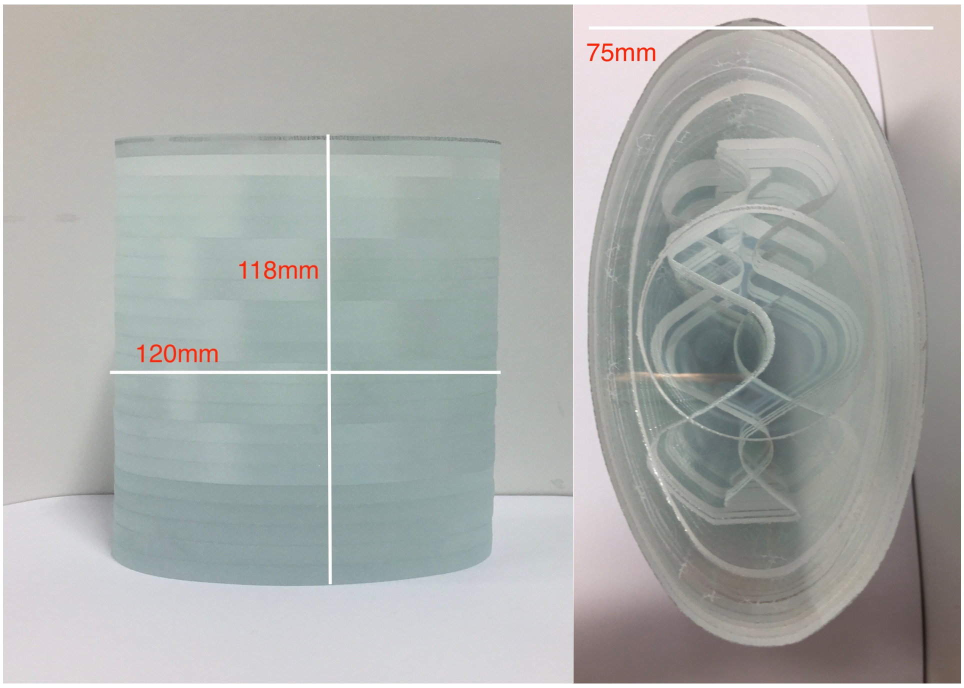
WJC File



Glass
6 mm Pilkington Optiwhite supplied by Team Valley. WJC Sunderland University 20/3/19.

The lines of the WJC ellipse and the internal cut were not quite as smooth or perfect as they are normally. I have checked the adobe file and the Jpeg which look fine. The problems may have arisen from saving the file in different formats: Rhino, Adobe, DXF. Something to monitor in future.

Construction



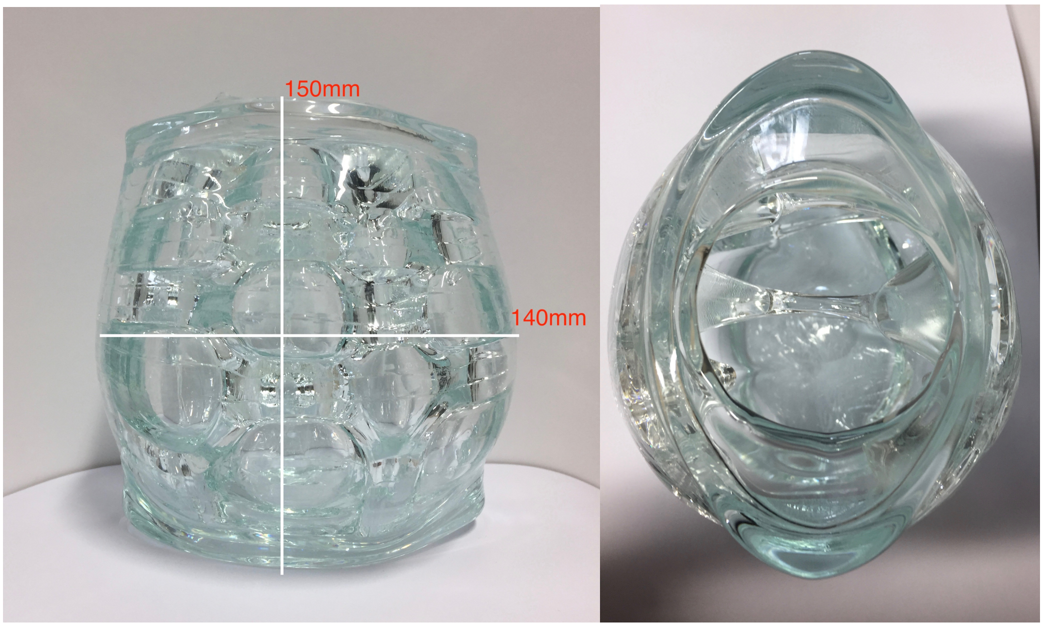
Notes for hot shop

Pick-up blow, inflate until the shape softens out into a more rounded form.

Hot shop

As above. Unable to inflate the top half as the internal structure obstructed the insertion of the sofietta.

Outcome



The form is lumpy (with dips and mounds) and has not blown out into a smooth shape. The piece required more heat and air to inflate into a more rounded shape and to smooth out the layers of glass. One of the glass strands of the internal structure has melted away completely, leaving only two, which creates a gap in the pattern and the internal symmetry is lost.

The internal structure could be described as a trabeculae ref Wikipedia: a trabeculae, latin for small beam, is a small, often microscopic, tissue element in the form of a small beam, strut or rod that supports or anchors a framework of parts within a body or organ.

Works better with a hot-finish although in this case it is a bit scrappy and will need to be cold-worked.

Evaluation/personal response

While the scale is good, the proportions are not quite right. A tad shorter perhaps? More heat and air.

Future Testing

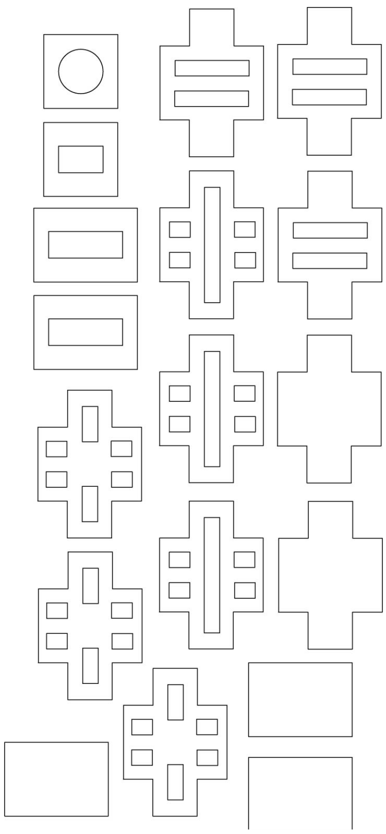
Re-work the internal cut to avoid the glass network from melting away. Possibly? Later? Another time?

Date
27 March 2019

Sample
069.03.19

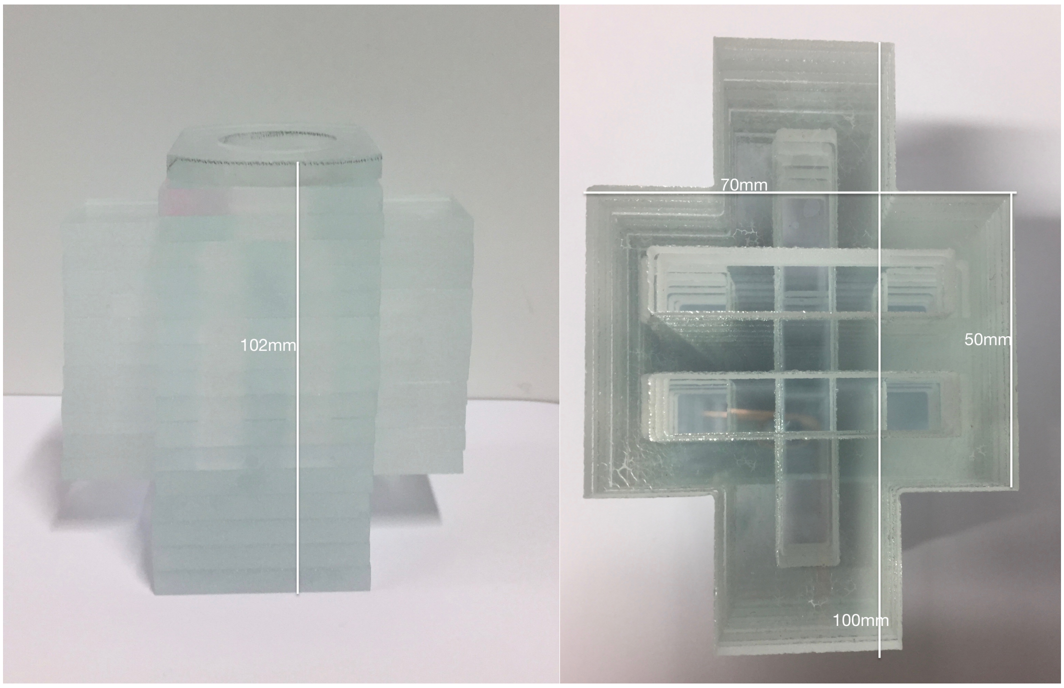
Aim
Small sample to see how a geometric shape based on a cube with rectangular cuts and straight faces will be transformed through this process with reference to Philip Rawson's analogy of the crystal and the fruit when finding form. It is also inspired by the geometric construction of House NA.

WJC File



Glass
6 mm Pilkington Optiwhite supplied by Team Valley. WJC Sunderland University 04/3/19.

Construction



Used both fusing gel (Glastac Gel) and a tiny drop of Bohle Verifix LV740, which held the construction together. This has made such a difference and allows me to carry the constructions down to the hot shop on the ground floor and place them in the warm-up kiln without the layers of glass sliding around.

Notes for hot shop
Pick-up and blow – not necessary to punty to achieve good overall fire polish and softness.

Hot shop
The last layer of glass is on one side of the cantilever was beginning to peel off and had to be gently be pushed back up with a pair of jacks. Cause: the glass began to slump (?) or as Liam suggested not enough fusing glue around the perimeter.

Punty and hot-finish

Outcome
The quality of the glass is good. There is no staining from the glue which I had noticed in sample 066. I used less Bohle; the re-heating chamber was heating correctly; and the smaller size of the piece allowed for a more even distribution of heat.

There is some devit, which has stretched out into a mottled pattern.

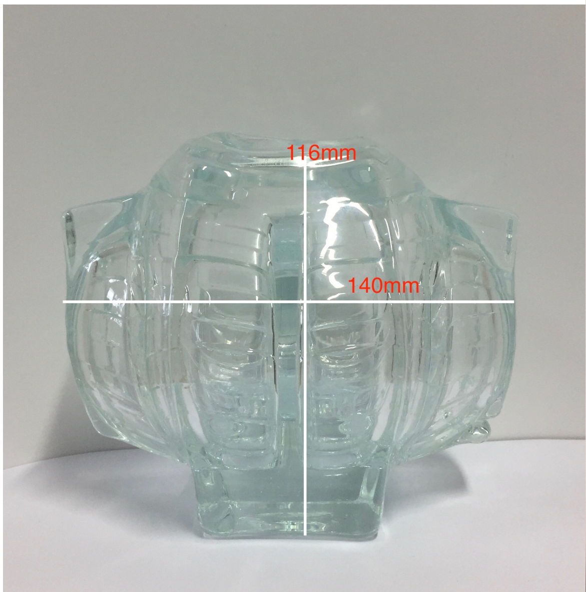
The internal rectangular cuts (blow holes) have created an internal structure of beams, arches, and separate cavities. The geometry of the external construction has blown out into vertical ridges, edges, and corners. On the two widest faces the internal square cuts have pushed the glass out of form two gentle and regular curves on both sides.

The construction was well-balanced and the cantilevered sides have blown out evenly into a balanced structure.

The base has retained its rectangular shape.

A clean hot-finished top.

This may be accidental; not having a module of the correct dimensions to allow a collar to fuse on to the construction, I cold-worked two sides of a pre-cut circle to the dimensions of the top rectangular final module.



Evaluation/personal response

This is an exciting development partly because achieving straight edges and corners in hot glass without using a mould is impossible this alone opens up a range of future possibilities.

It is also visibly a construction which has been deformed by heat and breath and as such tells the story of this research project explicitly. Having said that, it is fussy and much more needs to be done to the design to pare it down and produce something altogether more elegant, balanced, and refined.

Of note:

- the rectangular base which has kept its shape.
- The edges and corners which have softened but still retain the geometry of their straight lines.
- The successful hot-finish. No cold-working required to finish off the top of the piece.
- The geometric internal structure.
- Subverting the bubble (nearly).
-

Future Testing

Take a lead from successful hot-finish to refine design of the top and collar (as above).

Develop more designs with straight edges around rectangle, square, pentagon, hexagon…or derivations thereof both internal and external.

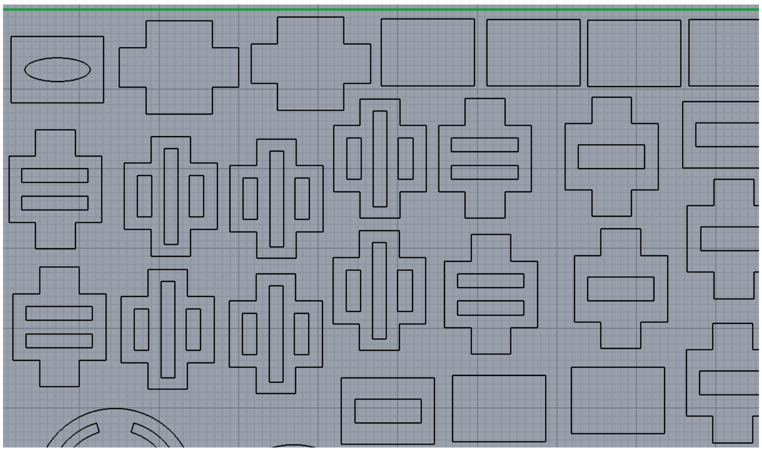
Keep to a relatively small scale.

Date
2 May 2019

Sample
070.05.19

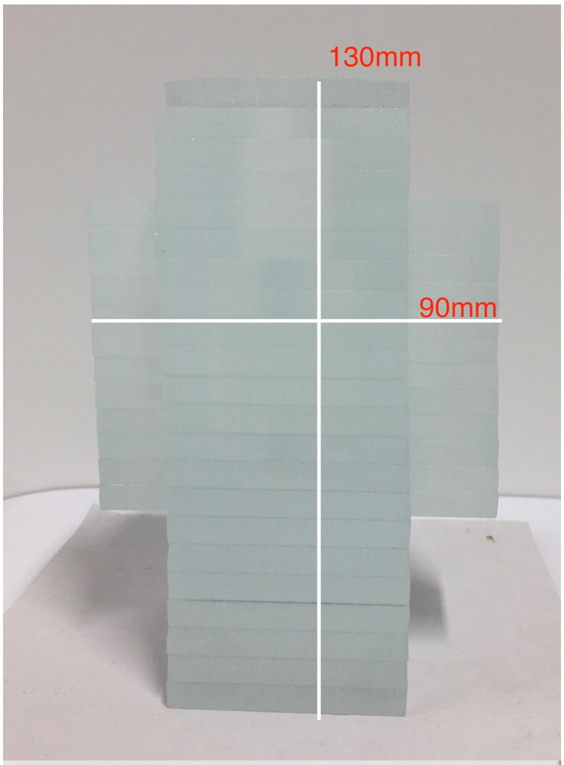
Aim
Following up on test 069.03.19.
Simpler internal construction
Taller
Improved proportions and balance.
Geometrical cuts and construction purposefully recall architecture of House NA.
Reproduced the cut of the top component from 069.03.19 as the design achieved a successful hot-finish.

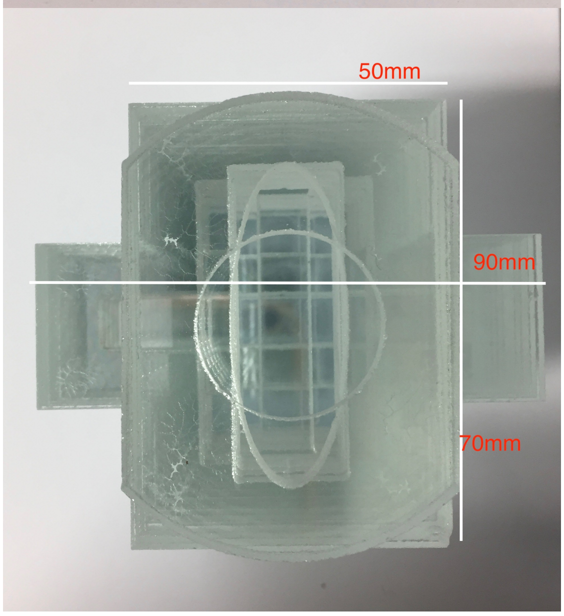
WJC File



Glass
6 mm Pilkington Optiwhite supplied by Team Valley. WJC Sunderland University April 2019.

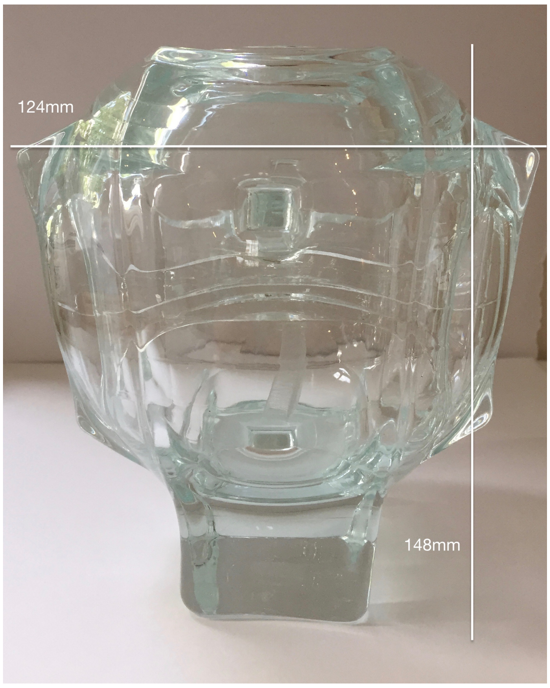
Construction
Did not use all the elements as the proportions did not look quite right.





Notes for hot shop
Pick-up and blow. Observe how the right-angle geometry of the construction is transformed both on the inside and the outside. Punty to ensure even distribution of heat. Clean hot-finish.

Hot shop
As above.



Outcome

The solid base has softened and curves slightly upwards but has kept its rectangular shape. There is a small oval area of tiny bubbles which revealed itself after cold working the punty mark out. This may have been left by a discrepancy between the punty iron which was hotter than the base (?).

The overall quality of the glass is good. The internal struts have devit but this is not distracting.

There is a narrow horizontal gap where the foot meets the bubble which suggests that the prop which supported the cantilevered section in the warm-up kiln should have been placed closer to the foot.

The piece has blown out, the sharp corners have become vertical curves but have retained a visible line while the corners, although softened by heat, have kept their angles. The internal rectangular cuts have created an internal structure of parabolic and catenary arches. On the narrower face were the structure touches the internal edge of the form this gives the illusion of a hollow rectangular rod crossing the form. On the wider face, the cantilevered section, has created an internal ring and arches which in turn create a complex optical illusion.
The hot finish is successful with the adapted design of the final component which finishes the piece off neatly.

Evaluation/personal response

While the final form is neither right proportionally nor harmonious (the cantilevered section sitting awkwardly on the rectangular base) this is nonetheless a successful piece because it is so very different and new compared to conventional blown glass. This seems full of exciting potential to develop further.

Future Testing

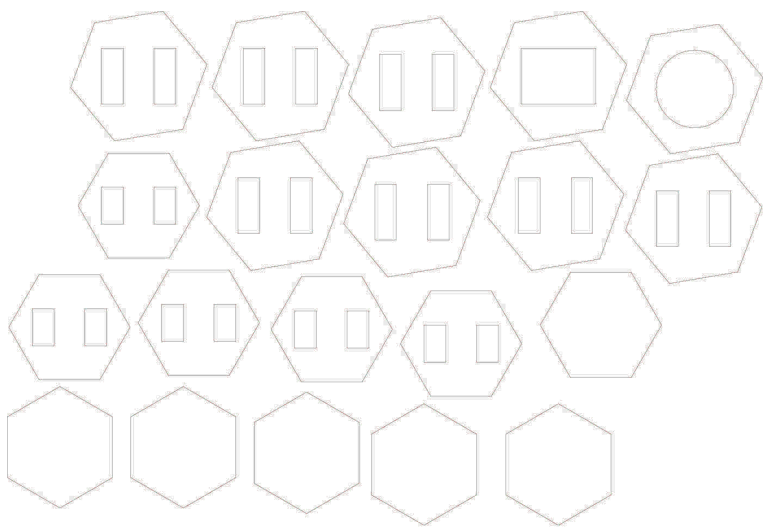
Further refinement required through scale, proportion, and geometry.
To do: make a larger, taller, simpler rectangular structure with a simple internal grid based on the rectangle. A cross shaped-structure from the base upwards to play on the internal optical effect of the internal ring.

Date
2 May 2019

Sample
071.05.19

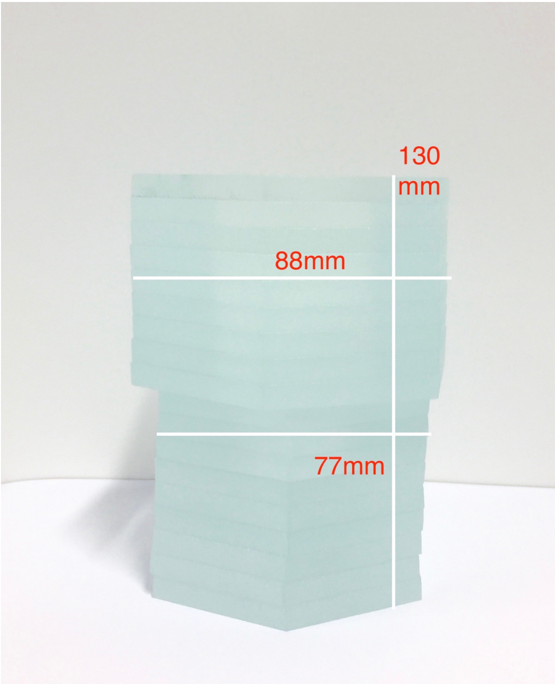
Aim
Following up on sample 69.03.19. A geometric design based on two hexagons sitting at a slight angle to each other; the taller one on the top.
References Philip Rawson's analogy of the crystal and the fruit. Will the sharp angles of the construction be transformed in the hot-shop into a mellow, soft fruit.
The vertical lines are straight to minimise the stepped-angled layered construction of earlier samples.
How will the step shift in size between the two hexagonal blocs be transformed in the hot shop.
How are the rectangular cuts in the internal structure transformed? Shape of internal cavity. Subverting the bubble?

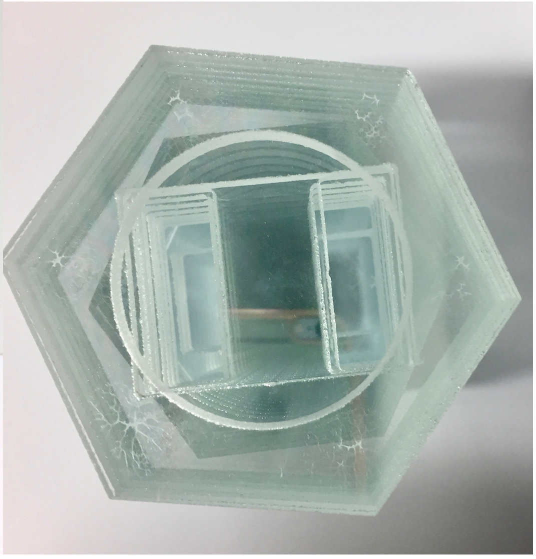
WJC File



Glass
6 mm Pilkington Opti-white supplied by Team Valley. WJC Sunderland University April 2019.

Construction

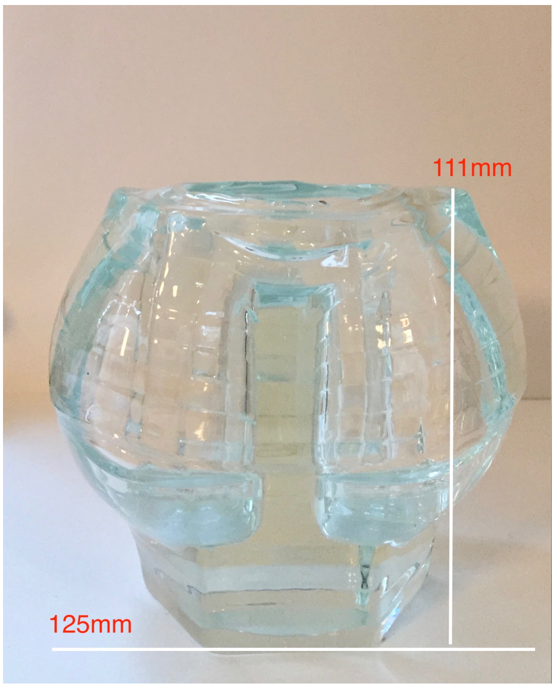




Notes for hot shop
Pick-up, blow, punty. Consider how to finish off.
Observe what happens to internal rectangular channels.

Hot shop
As above + shear, hot-finish.

Outcome



The straight edges have survived.
Some devit and pooling, particularly visible in the base.
The layers of glass remain visible.
The two internal rectangular cavities have ballooned out leaving a thick wedge of glass in the centre.
The stepped change between the hexagonal blocs has left a clear dividing line.

Evaluation/personal response

A successful sample with scope to develop further.
Keeping the vertical contours straight rather than stepped following a curved contour is certainly an improvement; the rounded contours instead coming from the internal bubble as it expands.
The angular structure is effective.
I like the detail of the transition from the smaller hexagon to the larger one on top.
I think the internal bar is heavy and clumsy.

p.s in sample 080.05.19 I only made one internal rectangular opening to eliminate the internal structural bar (an RSJ of sorts) but in doing so I now realise that I lost the flat face of the piece which I find an attractive feature.

Cold work: Ground lens + polished base.

Future Testing

See test 080.05.19

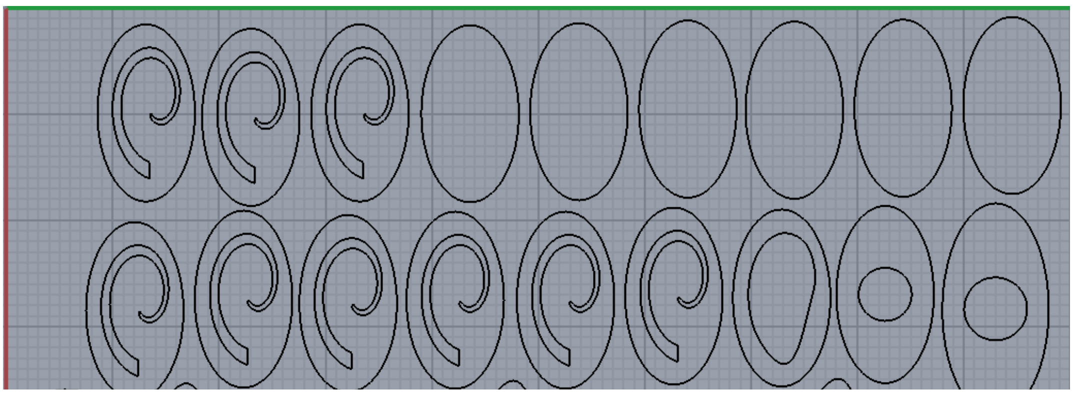
Date
2 May 2019

Sample
075.05.19

Aim
To revisit the spiral design (055.11.18; 058.12.18; 061.01.19).
But in this case:
- containing the spiral within an ellipse
- simplifying the spiral and stretching it out into an ellipse (Rhino)
- Making the profile straight and not contoured
- Not setting the modules themselves at graduated angles which made the spiral move up.

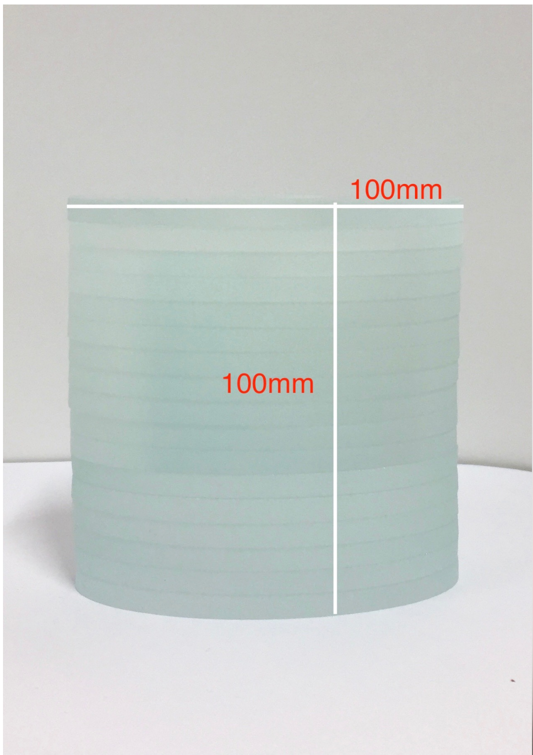
I love the proportions of this construction and the delicacy of the cut. An argument for making the constructions smaller rather than larger. The advantage of the digital software is to be able to scale up or down. There is always the impulse to go big when small can be just as effective, if not more.

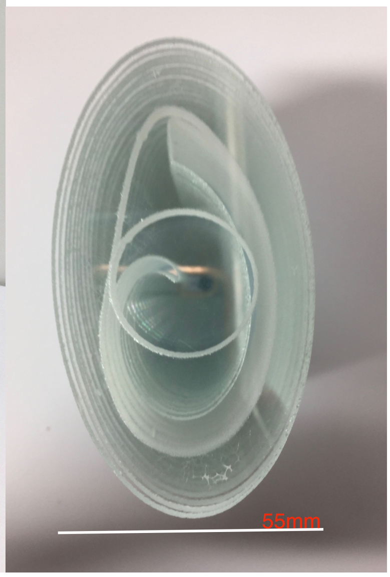
WJC File



Glass
6 mm Pilkington Optiwhite supplied by Team Valley. WJC Sunderland University April 2019.

Construction





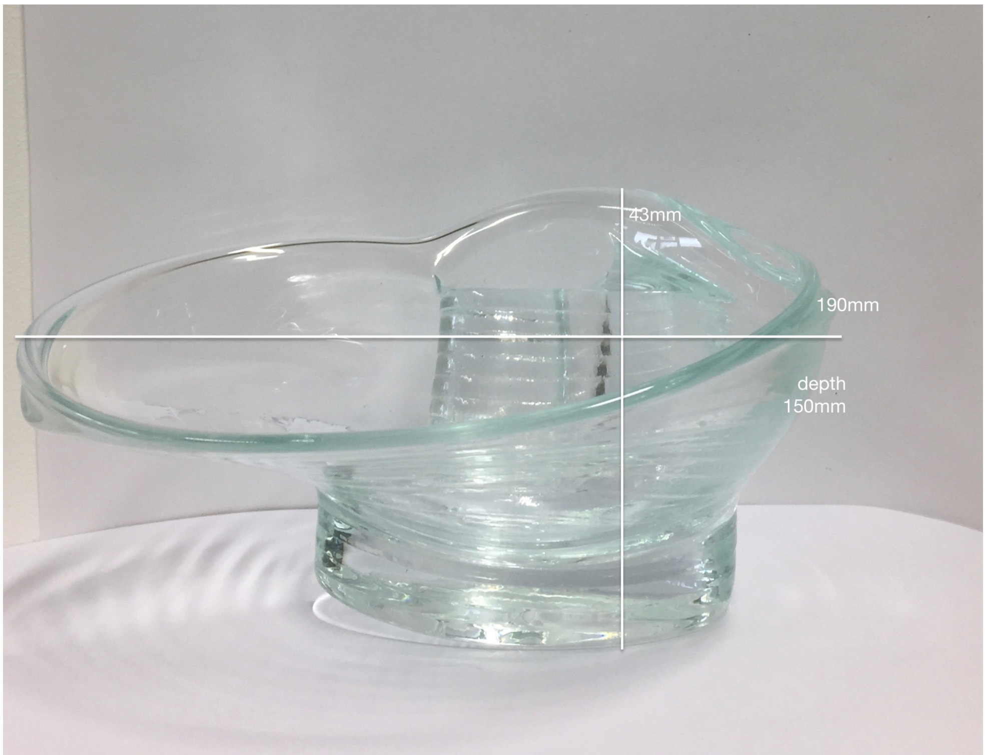
Notes for hot shop

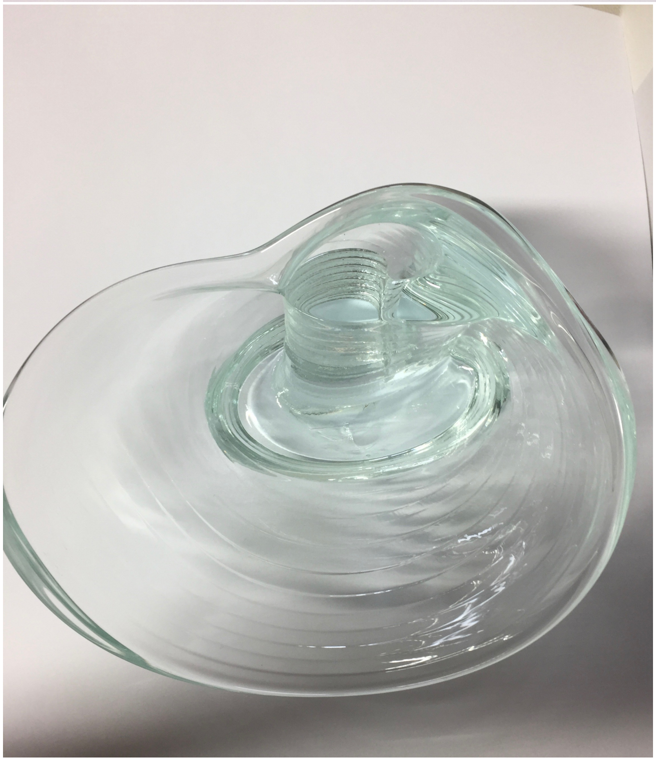
Pick-up, blow, paper marver to keep sides smooth (?).
Punty. Finish?

Hot shop

As the piece blew out, the top section (closer to the heat) ballooned out more while the foot stayed reasonably elliptical. Continued to blow. The spiral cut gave the walls an uneven thickness: one side bulging out more than the other and the spiral bending and leaning in towards one wall. At this stage, it was a formless failure, having lost the delicacy and perfect proportions of the WJC construction… we decided to push it further. We puntied the piece and gave it a quick spin. The piece was off kilter, the punty was (accidently) off centre but then almost miraculously and quite unexpectedly a graceful shell-like form appeared at the end of the iron. The perfect illustration of the process: the precision of the digital transformed by heat, gravity, and centrifugal force allied with the craftsmanship of risk.
But let's see what it looks like when it comes out of the lehr…

Outcome





Evaluation/personal response

The delicacy of the WJC has been translated into an unexpected, and rather lovely shell-like form. The elliptical base remains to anchor the piece. The hot-finish has produced a smooth undulating line which records the movement of the hot glass. The layers of glass leave a faint trace of their presence on the surface of the glass, a *facture*, which is made more visible by the shadows the piece casts (see above).

The precision of the waterjet can be seen in the spiral column which now leans to one side and the cut, no longer central, has been pushed to the edge where it leaves a clean, delicate swoosh of a cavity.

This is a result which is much closer to my sensibility not only the outcome itself but also the way it was made: the complete transformation of form through process. A search for the unexpected.

The simplicity of the form and the cut.

Would it be possible to reproduce? Possibly not – but is this necessary in the context of this research project? It is precisely the (un)knowingness of this process allied with the material that drives this research forward and which I find so seductive and beguiling.

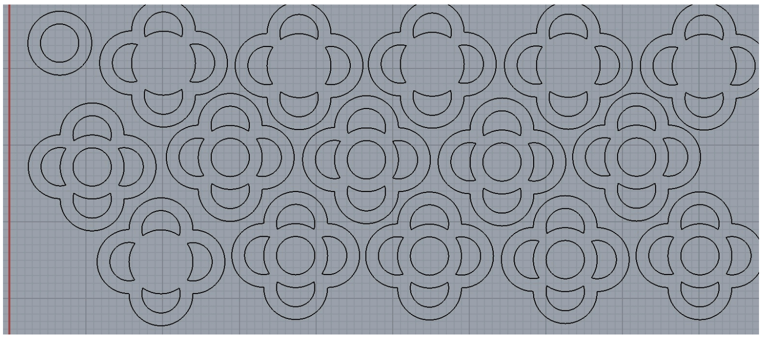
Future Testing

Working with the ellipse, which opens up into a shell or a bubble, but varying the cut. Just one cut, a gash.

Date
15 May 2019
Sample
078.05.19

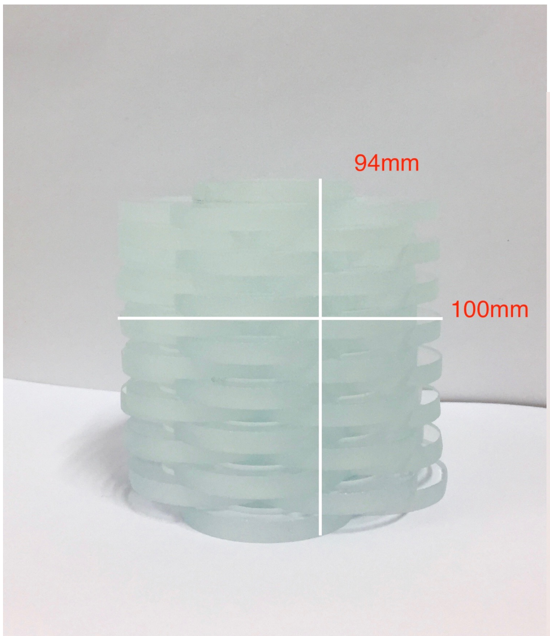
Aim
Exploring the modular construction. Using the same modules as 076.05.19 but with a different construction. I'm hoping with this sample that the edges will soften to create an intricate pattern on the outside with the central core expanding slightly. Who knows? Will the central core expand out into the cuts.
I like the textile like surface of the looping contours. Will this be retained?

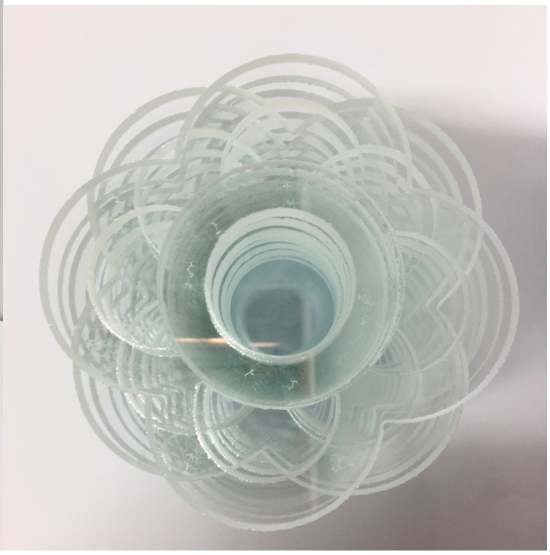
WJC File



Glass
6 mm Pilkington Optiwhite supplied by Team Valley. WJC Sunderland University 8 May 2019.

Construction



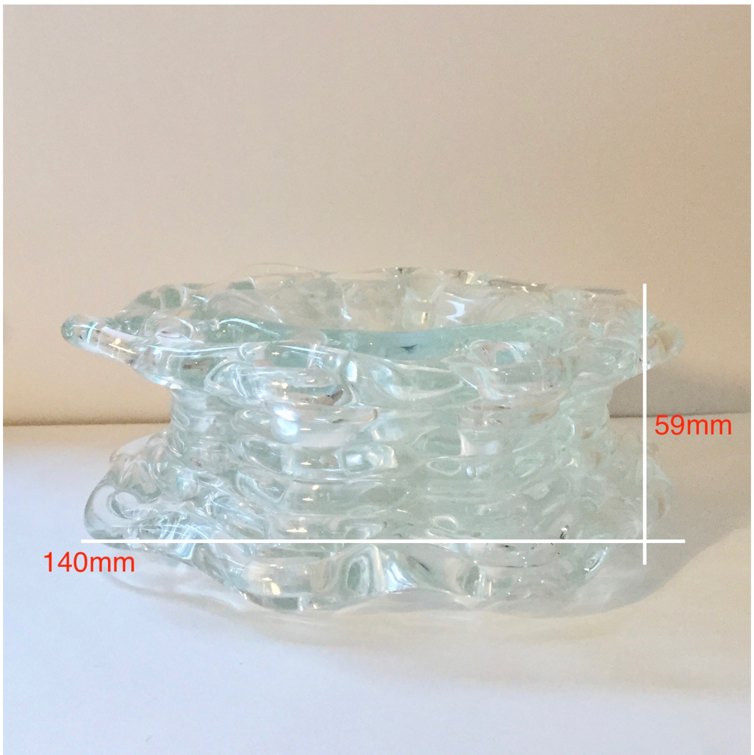


Hot shop

Didn't blow. As the expanding central core/ bubble will have become trapped within the cage. Picked up spun, transferred to punty iron.
The loops beaded out, the section closed to the heat source flared out, leaving a middle section relatively cylindrical and then it opens up at both ends.

Looked ridiculously frilly at the end of the punty iron.

Outcome



Well it does look like a doily but it is intriguing and very different.

The loops in the top and bottom section, closer to the heat source, have begun to stretch out beyond the core to create thinner, sinuous strands of glass.
In the middle section the overlapping pattern has created a weave-like textured finish. There is some devit here but it adds a pleasing sheen to the overall look of the piece.

Evaluation/personal response

This is certainly an intriguing piece and I suppose more successful than I had anticipated when I first saw it on the end of the punty iron.

There are elements which I particularly like such as:

- The weave texture.
- The central core of the piece with its internal pattern (middle photo above).
- Structure looks very different when you turn the piece over (see above).

There is something decidedly feminine about this which I also like.

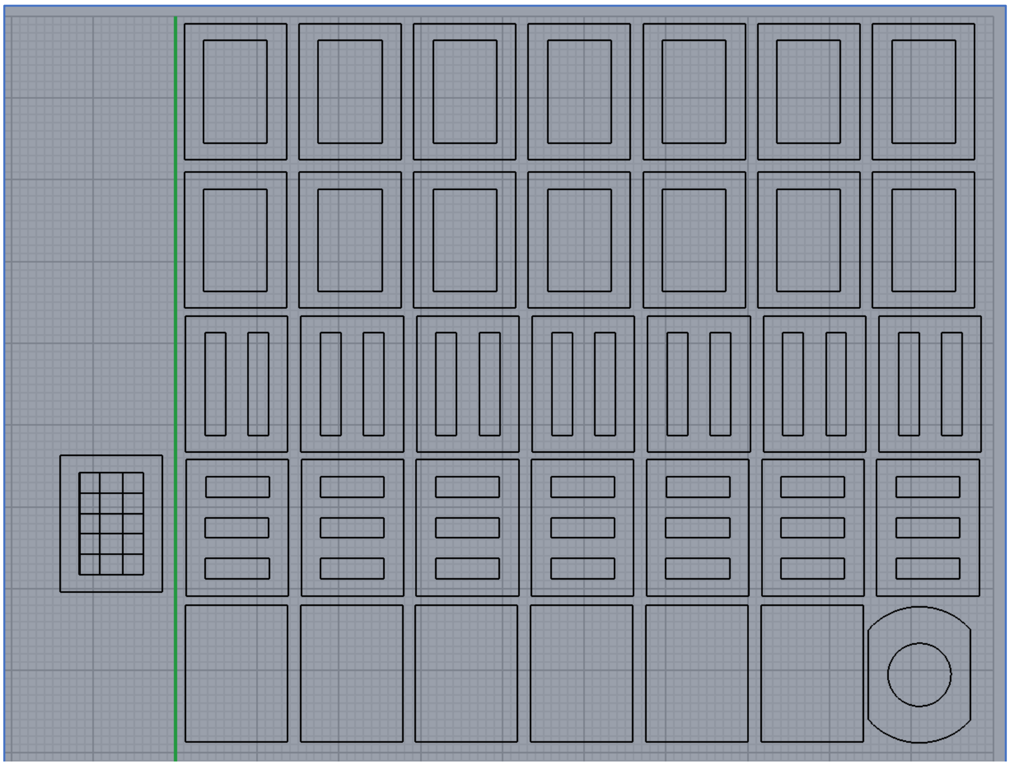
Future Testing

I am certain that it offers scope for future development but I can't quite think how this could be achieved. I will put it aside for the time being, just leaving it at the back of mind to mull over, and will come back to it later.

Date
30 May 2019
Sample
079.05.19

Aim
To produce a resolved final piece following on from sample 070.05.19. Taller & larger with a simplified design which explores the variations of the rectangle to produce an internal grid-like structure. Aiming for elegance, lightness, balance, and simplicity.

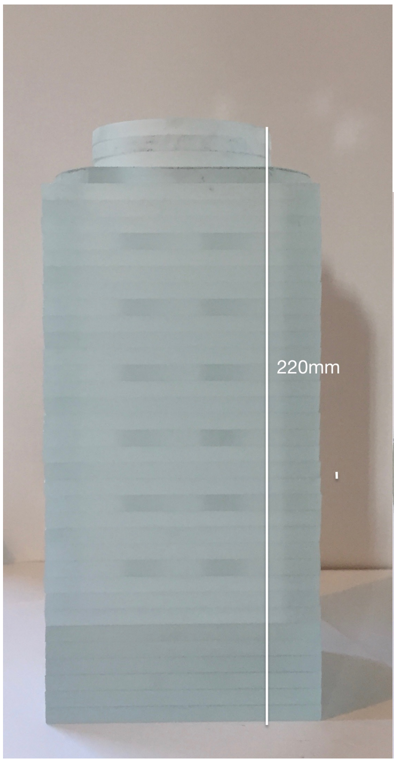
WJC File

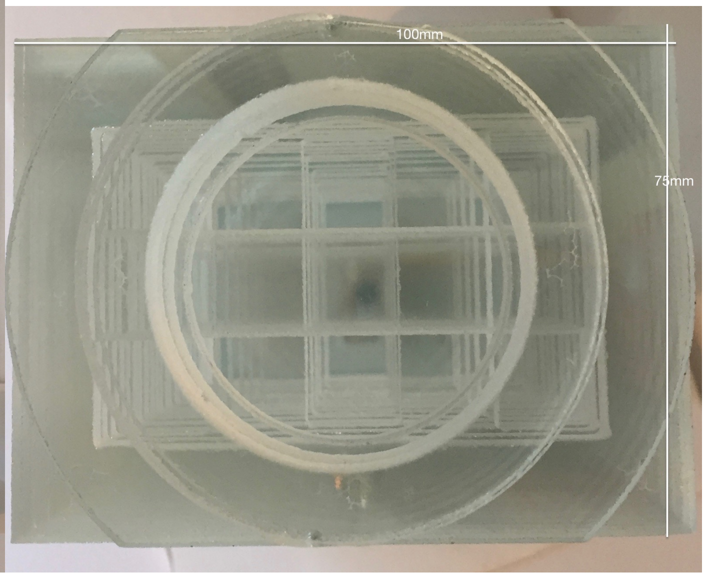


Glass
6 mm Pilkington Optiwhite supplied by Team Valley. WJC Sunderland University 20 May 2019.

Construction
1 – simple rectangle cut
2 – 2 vertical cuts
3 – 3 horizontal cuts.

1; 2; 1; 3; 1; 2; 1;3;1; etc…until the top module designed for a hot-finish. I then realised that the construction would make it impossible to insert a sofietta. Added 3 extra-rings to increase the depth of the internal void to allow enough room to insert a sofietta.





Notes for hot shop

Pick-up, controlled blowing. Be careful not to blow out the shape. The walls are thinner 14.15mm so should inflate quickly. Take care to preserve the memory of the straight lines.

Hot shop

As above. Did not use the sofietta as the overall shape was already good and it would almost certainly have blown out into a baggy form.

Puntied to even out the heat across the entire piece; hot-finish.

Outcome

The quality of the glass is good. There is some devit in the central grid-like structure but this has translated into a delicate striated pattern which adds to the overall effect of the piece rather than detracting.
The glass has received less heat than in previous samples. The surface of the glass has not received an overall fire polish which would have rubbed out the trace of the layers, here instead, the lines are clearly visible and furthermore the glass has a slightly mottled appearance and texture to it.

The piece was blown out just enough to provide:

- A slightly curved base which adds a shadow gap at the bottom and makes the piece seem less stolid.
- The vertical corners of the base have a slight curve to them.
- The top section of the piece, which is narrower as it wasn't blown out using a sofietta, has four corners of solid glass which taper down into the piece. These four corners delineate the structure well.
- The top and bottom provide a rectangular structure from which the piece blows out gently.
- Neat hot-finish.

Evaluation/personal response

While I was not certain how the piece would blow out, this is certainly the most considered and 'designed' piece so far. The design was pared down and refined, thought was given to the overall proportions, the base, and how to finish off the top. Working on a bigger scale seems successful although this does present issues with ensuring an even distribution of heat. In this case, however, the slight ripple effect and texture scatter and diffuse the light adding a certain softness to the glass object.

A very satisfying result, genuinely original – a final piece for my exam and show next year.

Cold work:
Ground a lens and ground down the centre of the base flat to provide extra stability and to keep the piece straight. 600 grit, pumice, cerium.

Hand-finish the lens with 3MM paper.

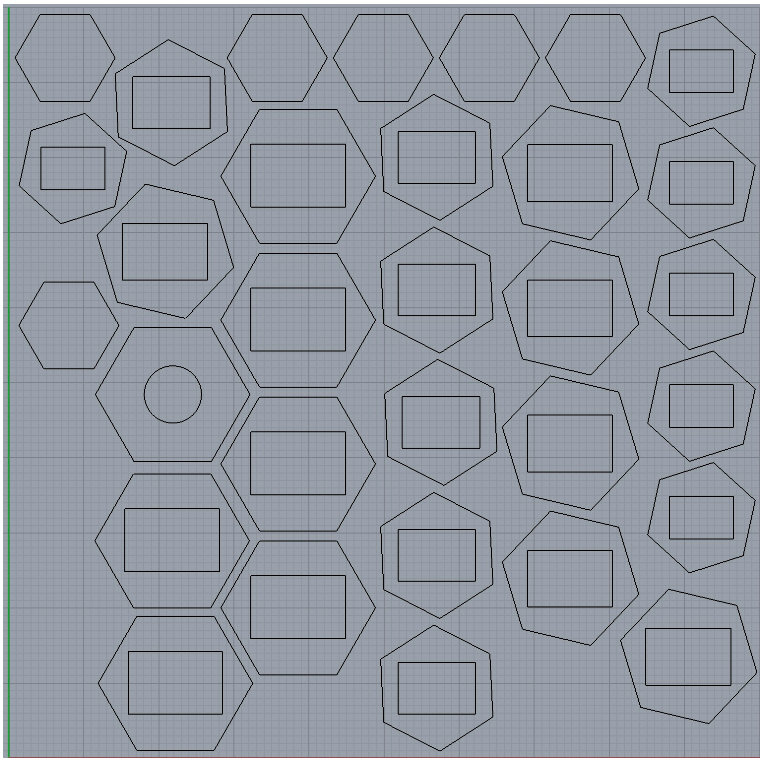
Future Testing

Keeping the same proportions, a framework as such, produce a different internal structure based on diagonal lines: the grid gone amok.

Date
30 May 2019
Sample
080.05.19
Aim
To produce a resolved final piece following on from sample 071.05.19. Increase scale. Transformation of crystal, as described by Philip Rawson, hard angular crystalline hexagonal transformed by heat and the breath to give softer, curvy contours.

How does the internal rectangle affect the contours: variations in the thickness of the glass.

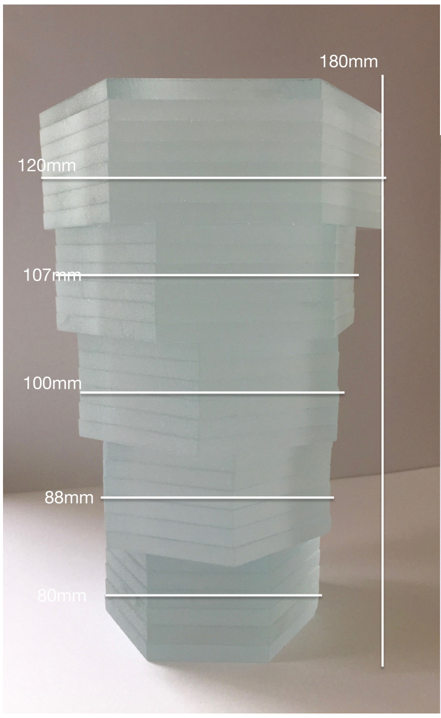
WJC File

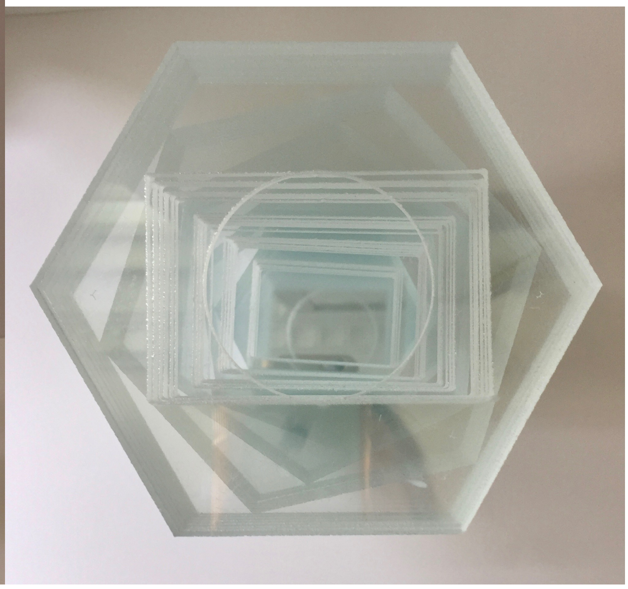


Glass
1 complete sheet (600 x 600 mm) of 6 mm Pilkington Optiwhite supplied by Team Valley. WJC Sunderland University 20 May 2019.

Construction
Built in sections of 6 layers of glass, then glued the 5 modules together. An extra module at the top for the collar and a hot-finish. The construction was put together at home using Glastac Gel and Bohle adhesive.

080.05.19





Notes for hot shop

Pickup, blow out to transform the shell while still keeping memory of corners. Punty. Open-up the top? Shear off collar, clean & neat hot-finish.

Hot shop

The piece began to soften in the warm-up kiln and lean slightly. Straightened out later but nonetheless base (first hexagonal bloc) should probably be slightly wider in the future. Picked-up blow, puntied, heat, shear off collar, hot-finish.

Outcome

Quality of the glass is good.
Some devit visible on the underside of the corners of the hexagons.
Here again the comparative lack of heat has left a slightly mottled and textured surface which diffuses and softens the light.
The angles are more prominent in the top half of the piece while in the bottom section they have blown out more.

Evaluation/personal response

The angular top section of the piece is successful, strong and structural. I particularly like how the corners of the top hexagon have curved upwards.
Here again the areas of transition between the hexagons of different sizes are subtle and effective.
The base needed to be taller to make the overall effect less squat.
The chief problem is that the lower section has blown out too much.

Future Testing

While it is perfectly acceptable as a final piece, there are some improvements that could be made to refine the design further:

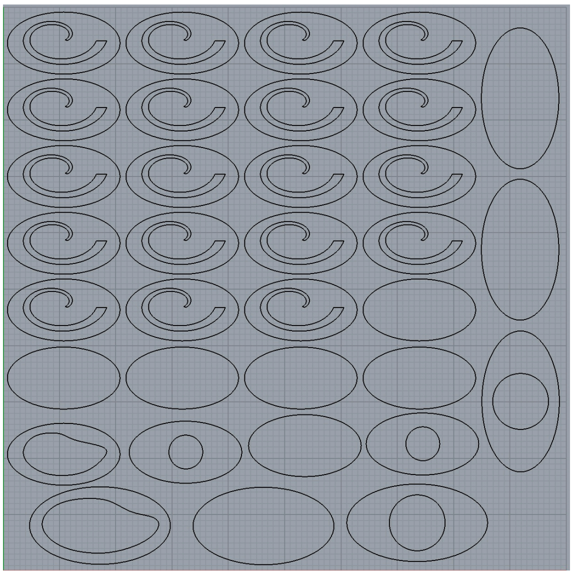
- Taller base
- Make the opening in the second hexagon smaller to provide thicker walls which won't blow out to the same extent.
- Provide an internal structure to give a flat face as in sample 071.05.19.
- Consider internal structure.

Date
3 July 2019

Sample
081.07.19

Aim
Following up on 075.05.19 see if it is possible to repeat and scale up slightly. Final piece?

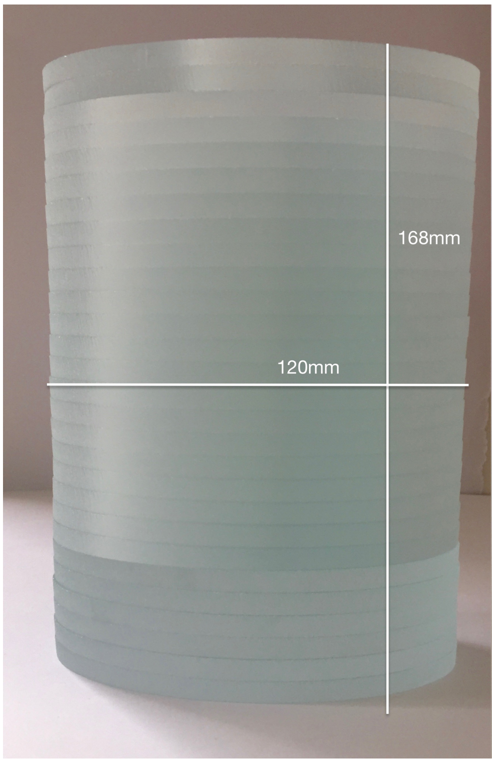
WJC File



Glass
6 mm Pilkington Optiwhite supplied by Team Valley. WJC Sunderland University June 2019.

Construction
Constructed at home using Glastac gel and Bohle adhesive.

081.07.19



Notes for hot shop

Pick-up, blow, punty, spin.

Hot shop

As above.

Note re: kiln settings – after pick up reset the kiln from 680 down full to 600 to avoid slumping and back up again to 680 when ready for pick-up.

Outcome

Quality of the glass is good. Some devit, translating as a slight haze, to be found on the base but this appears to be on the surface and can probably be removed by cold working.
The glass has stretched out softly; the ridges are more prominent in the centre and towards the base as you would expect.
The core has a strong, upright structure which fans out without collapsing into the wall of the glass. The internal curve of the spiral is not as delicate as in sample 075.05.19. Interestingly, and I only noticed this because I compared the two pieces, they flare out in opposite directions. Comparing photographs of the original constructions I realised that the spirals were positioned in opposite directions (ie: the glass modules were flipped).
Design for hot-finish good to adopt with all future pieces of the same or similar design.

Evaluation/personal response

Yes -- a final piece.
I was concerned that we wouldn't be able to reproduce the movement and form of the earlier sample 075.05.19 but we have and it is lovely.
The flowing organic form brings to mind Tapio Wirkkala's Kantarelli vase while the wheel cut vertical lines find their equivalent in the horizontal lines of the layered glass.

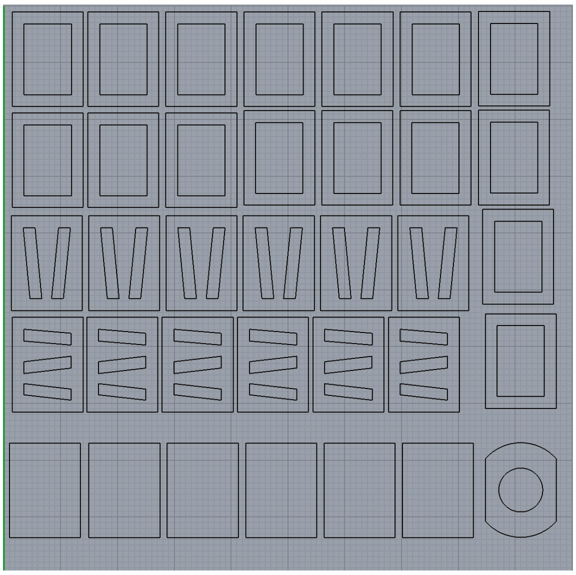
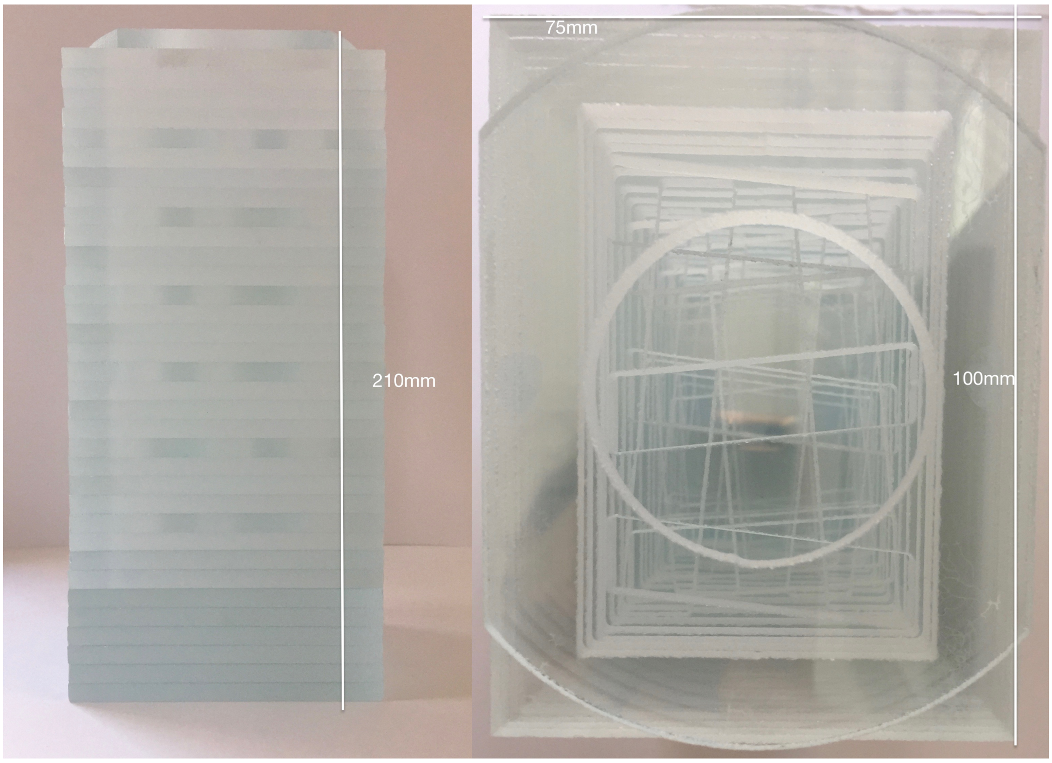
Cold work

Cold work base flat. Careful to ensure that piece is upright. Cerium finish to achieve a transparent polish so spiral can be seen when piece is turned over.

Future Testing

- Scale up slightly using the same proportions to achieve a little more height and span.
- Make two constructions using identical modules but flip the glass sheets so that they flare out in different directions. Does Liam always turn clockwise when spinning ?
- Work with colour: grey and aqua to produce some exciting tonal fades within the same piece. The central core should remain much darker than the shell where the glass is stretched out.

Date
3 July 2019
Sample
083.07.19

Aim
Following up on sample 079.05.19 with the aim of making a pair: a rectilinear grid and a complex network. Keeping the same proportions and working within the same rectangle put in this instance the lines are not parallel but intersect beyond the frame. A final piece?
WJC File

Glass
6 mm Pilkington Opti-white supplied by Team Valley. WJC Sunderland University June 2019. 1 complete 600 x 600 mm sheet.
Construction


083.07.19

Slightly adapted the construction, alternating the cuts, to disrupt the regular pattern created by the difference between uncut (solid) and cut (clear) areas of glass on the outside of the piece. Unsure if this was a good idea??

Notes for hot shop

Pick-up and blow as in sample 079.05.19. Punty for even distribution. Aim for a little more heat throughout the piece. Keep slightly curved base.

Hot shop

As above but could have done with a bit more heat. Blew out a tad too much.
Not enough glass at the top to shear; simply left.

Outcome

Pear-shaped, the profile is not as tight or controlled as 079.05.19.
There is some devit and, as with 079.05.19, the layers haven't melted into each other as in some other examples. The layers of glass remain clearly visible. Ripple effect which diffuses the light and when the sunlight hits the piece it shimmers with light.
The cut outs have melted into the sides leaving a narrow ledge which in turns creates an interesting horizontal pattern on the outside.
The base is good; curving upwards to leave a shadow gap.
The hot-finish is fine…just. It would have been better had there been more glass to shear off and fashion a neater, hot-finished, rim.

Evaluation/personal response

I prefer the neater more controlled shape of 079.05.19 but this is nonetheless acceptable and can certainly be considered a final piece.
The internal structure was not transformed into the complex and random network I had anticipated. Instead the structure melted into the sides and in fact has become simpler as a result. The cuts have left sections of glass which bridge the sides, the shapes of these are not altogether pleasing as they resemble shards but in the context of float glass, the city, architecture etc this to some extent is apposite. The patterning on the outside is effective and indeed this would be an area to develop further: working with the cuts to create a visual effect on the inside surface of the glass. The piece is more striking when seen sideways on rather than looking down into it. Effective when seen from afar with light or sunshine radiating through and across the layers.

Future Testing

- Scope to develop the internal structure to affect the pattern on the surface of the glass.
- Design and proportions of the outside form: A square, a hexagon?