Towards Making the Unmakeable: How 3D Printing Can Inform Kiln Formed Glass Practice in the 21st Century

A thesis submitted in partial fulfilment of the requirements of the University of Sunderland for the degree of Doctor of Philosophy

November 2018

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University of Sunderland 2018

Abstract

This research considers the junction of hand and digital making in relationship to studio glass at a point where the role of making by hand is being questioned and re-evaluated in an expanded field of art and design.

Although working with glass requires both technical skill and knowledge, the primary drivers for innovation across history are aesthetic. This study is no different and motivation for it came out of artistic aims that were frustrated by the limitations of traditional methods and materials. Rather than reject existing practices, this research seeks to connect to and expand on the artistic legacy of Czech glass, which contributes to its roots. Through the reconsidering the importance of the history and influence of Czech cast glass this project addresses strategies for the future through exploration, experimentation and documentation of the development of new combinations of approaches, processes and materials. The aim is to extend the sculptural language of kiln formed glass through innovation and new content without losing the legacy of heritage.

The recent addition of digital technologies to a practitioner's tool-kit has facilitated the creation of artwork in glass, which would be impossible to produce by hand making methods alone. Developments in software and desk top 3D printing are now providing easier access to digital design and making methods for artists and makers opening up new territories of form and content. Taking a practice based approach to combining analogue and digital methods for making artworks in cast glass this research explores forms and structures which would be impossible or nearly impossible to make by hand methods alone. It is this potential for the embodiment of what is termed 'the unmakeable' within this research that will drive forward kiln formed glass practices into the 21st Century and beyond.

This research contributes to the advancement of technological and aesthetic possibilities in kiln formed glass through the development of two main making approaches described as 'orthodox' and 'improvisational' which combine CAD, 3D printing and glass casting methods. The results of this research include

bodies of original artworks as well as visual and written information and evaluation in the form of this thesis. Together these offer new knowledge to the field of Studio Glass where there is limited critical evaluation of the relationship between digital and analogue technologies applied to kiln formed glass.

Author Declaration

According to the regulations, I declare that during my registration I was not registered for any other degree. I have not used material in this thesis for any other academic award.

Statement of Copyright

Acknowledgements

With thanks to the Arts and Humanities Research Council for funding this PhD, without which it would not have been possible. Very special thanks to my supervision team Dr Jeffrey Sarmiento and Colin Rennie for their continuous support, encouragement and focus. As director of studies, Dr Sarmiento has shown tremendous belief and understanding of the path I have followed and my aspirations for the research and this thesis.

I am very grateful to Julia Stephenson and National Glass Centre for inviting me to take part in the *Wearable Glass* project, which was such a positive experience, and to the two inspiring jewellers, Maud Traon and Emmeline Hastings, with whom I worked. Thanks to Dr Erin Dickson for supporting my early forays into 3D printing in the Fablab and to Dr Beryl Graham whose words of calm wisdom helped me during long hours of writing up. Thanks too, to staff and students at the University of Sunderland in Ceramics and Glass who have helped, shared and been there as friends along the way.

I would also like to offer thanks to the Ordered Universe project for supporting me in taking part in *Light Embodied* exhibition and *Science Imagination and Wonder* Conference at Pembroke College, Oxford, 2018. Thank you too, to Contemporary Applied Arts, Contemporary Glass Society, *Slovo* magazine and European Glass Context for including me in their exhibitions, publications and conferences 2015-2018. Many thanks are due to the Pilchuck Glass School, USA, for giving me the opportunity to be an instructor and test out approaches and practices 2016 and 2018.

Heartfelt thanks to Steve, my partner, family and friends who have listened, supported, believed in me and waited while I have carried out this project.

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Chapter 1 Introduction

This research considers the combination of hand and digital making in relationship to studio glass at a point where the role of making by hand has undergone a paradigm shift across art, craft and design (Make-shift, 2016, Making Futures, 2017).

A key aim in this research was to evolve new practices of designing and making using digital technology to extend analogue practices which had not changed significantly over thousands of years. ‘The more digital our lives become, the more we crave the physical’ (Crawford, 2015, p.29) raises the question of how to navigate the digital/physical balance which is addressed in this research through the development of two main making approaches.

The recent addition of digital technologies to a practitioner’s tool-kit has facilitated the creation of artwork in glass, which would be impossible to produce by hand making methods alone. I refer to this as the ‘unmakeable’ throughout this thesis. It is not the flawless regularity that the digital process appears to promise that motivates this research, rather its potential to combine with the material presence of the handmade, translated through the casting process into glass sculpture to produce previously ‘unmakeable’ forms and structures.

1.2 Brief background to study

The context for this research is studio kiln formed glass practice. This could be summed up as specialised skill and knowledge of kiln formed glass materials and techniques applied to the making of objects and artworks in a studio setting. This includes situations engaged in making one-offs, series or very limited editions of artworks in the form of objects, sculptures and installations. The field of research in kiln formed glass include techniques, materials, methods and approaches, subject matter, sources of inspiration and reasons for making, exhibiting, history, and contextualising of the artworks.These have

been considered and discussed in the Contextual Review chapters 2 and 3 in this thesis.

This research seeks to explore the potential for desk top 3D printing to impact on studio glass practice. 3D printers are relatively new to individual users ‘personal fabrication only became a possibility around 2007 with the development of the first ‘‘open source’ 3D printers that private individuals could actually afford to own’ (Barnatt, 2014, p.12). Since then there has been rapid development in the design and production of desk top 3D printers, 3D printable materials and improved accessibility to information regarding 3D printing processes.

This research has been carried out through a practice based methodology which is centred in the researcher’s own practice of kiln formed glass. The background and experience of the researcher is an important factor concerning the context, motivation, practical investigation and practice basis of the methodology of this research. This led to the decision to write the thesis in the first person to give the reader a direct connection to the individual carrying out the research towards clearer understanding of the process and context of the research. This and other aspects of the thesis are unconventional as is the timing of the undertaking of this PhD, which follows many years of professional practice, teaching and a previous post as researcher funded by the Arts and Humanities Research Board (now Arts and Humanities Research Council).

Although I have been in the centre of studio based kiln formed glass in UK for decades, my identity as an artist, educator and researcher and accompanying philosophy developed through formative experiences in 1980’s Czechoslovakia.

Glass is my primary sculptural medium, chosen because of its particular material and metaphorical qualities in relation to the human condition: qualities of strength, fragility, translucency and transparency.I see glass as an unparalleled sculptural medium in its ability to carry meaning and convey ideas which can be expressed through form using mass and void, colour and light. These qualities are explored and reinterpreted in new ways in this research.

1. Libenský/Brychtová, 2000, *Stooping*, Libenský/Brychtová Museum Železny Brod,

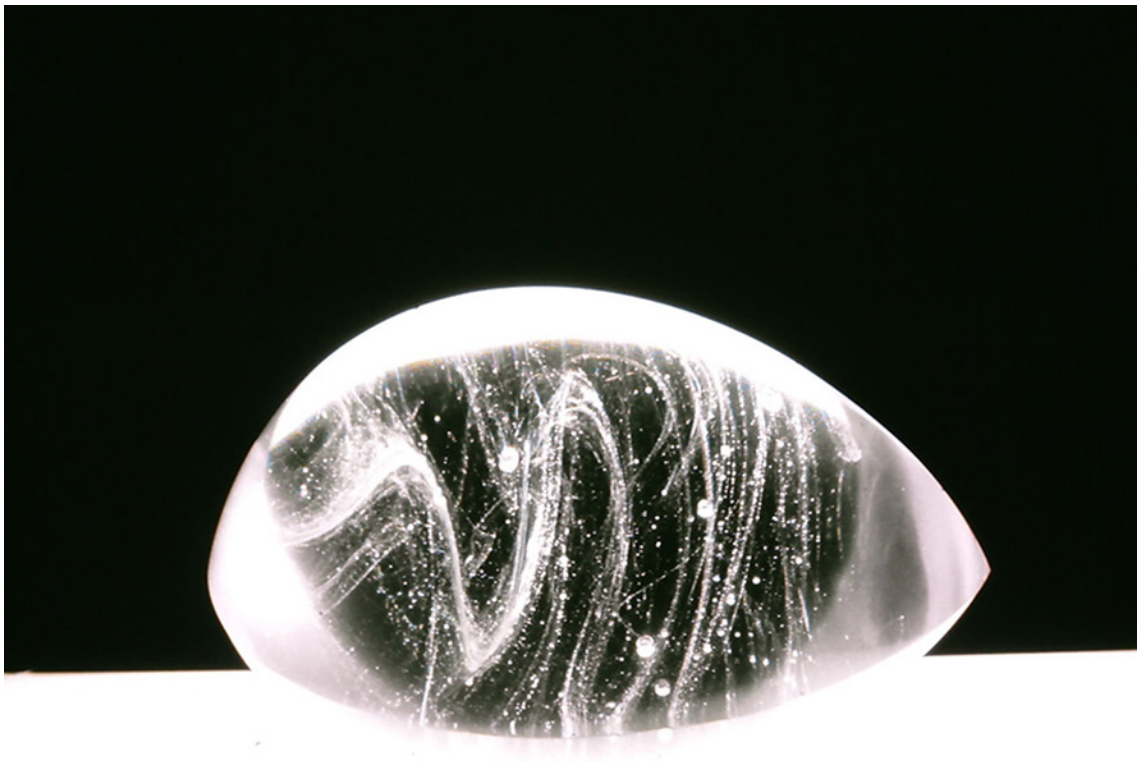
This research focuses specifically on kiln casting, which involves the making of a mould into which glass is melted in a kiln to accurately reproduce its shape, detail and surface. Essentially casting enables the creation of a defined shape from a liquid material through the redistribution of its mass. From the 1980's to 2002 the main focus and expertise in large scale glass casting was in Czechos lovakia, now Czech Republic, centred around artists Stanislav Libenský and Jaroslava Brychtová and the students educated and influenced by their approach, myself included. Originally Libenský was a painter and Brychtová a sculptor. The combining of their methodologies and skills based on principles from sculpture and architecture across cubism, constructivism, and expressionism have been strong influences on kiln formed glass practice in an

International field of glass research. Jiři Šetlík (2002, p.6), describes the work of Libenský and Brychtová as ‘The exploration of space as the setting of life’ reflecting their persistent interest in the exploration of the human condition and nature, developed through monumental scale spatial sculpture in glass.

The influence of Czech glass within research includes University of Sunderland where historian, curator and renowned author on the subject of Czech glass, Dr Sylva Petrová, was professor of glass (1998-2012) and chair of the Institute for International Research in Glass. The University also had long term connections with Czech and Slovak artists involved in research notably Zora Palová who taught glass at the University from 1996-2003 and Alena Matějka, who was a visiting artist in 2003.

The basis of my own practice is connected to Libenský and Brychtová where glass is used as a sculptural medium for its material qualities and as a metaphor for the human condition. Drawing inspiration from everyday environments I generate and express ideas and use metaphors and similes as a way of compressing complex concepts into smaller elements and spaces. These concepts are interpreted into three dimensional, hollow forms with different shapes inside and out to explore connections with and questions around what it is to be human through making artwork in glass.

> *With glass as with people, the inside is as important as the outside – both have body, skin and inner landscape. Sometimes you can clearly see in, sometimes what you see is distorted, as through a lens, and sometimes translucency veils your view. Ideas around vision and perception and aspects of the human body, all have a part to play in the translation of feelings into tangible, tactile forms. (Thwaites, 2000)*



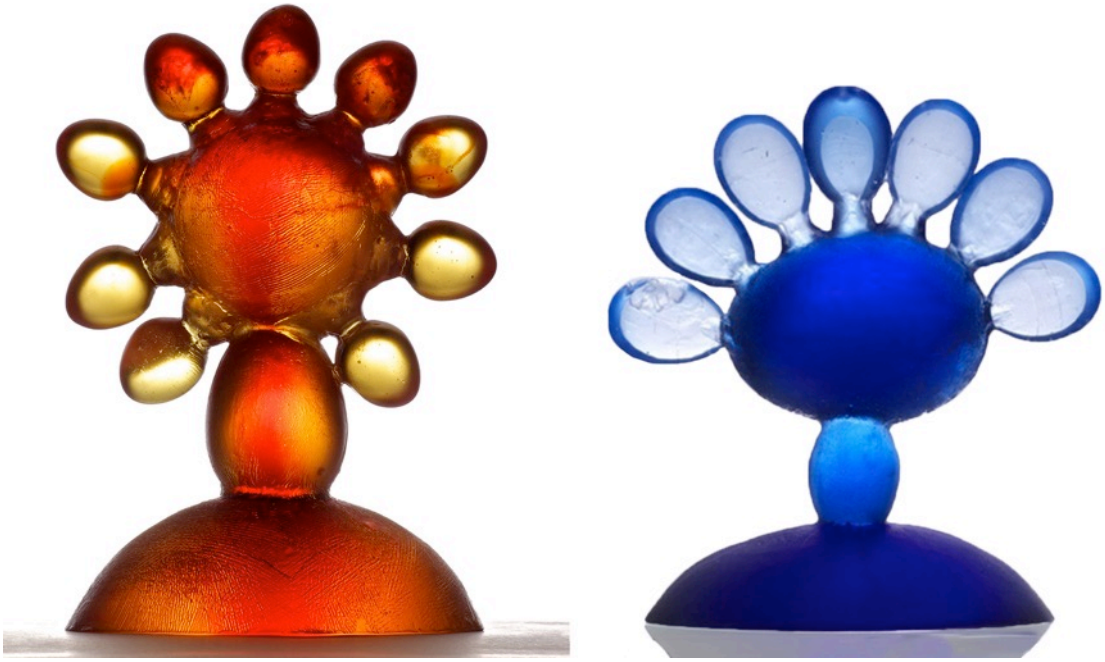
2. Angela Thwaites 1999, *Tearseed*

This research aims to extend this concept through the creation of multiple layers of shape within shape to create complex three-dimensional forms which it would not be possible to make by hand alone, but can be designed and produced in glass using new combinations of digital and analogue processes. These combinations of practices are ‘increasingly understood as a distinctive set of knowledge, skills and aptitudes, centred around a process of reflective engagement with the material and digital worlds’ (Schwarz and Yair 2010, p.9).

As indicated by the statement above, meaningful engagement and understanding of making and digital environments can only be built on specialist knowledge and skill applied to material and process. This PhD thesis is therefore predicated on my experience as a glass practitioner developed over more than thirty years. Depth and breadth of knowledge has been gained through studio practice, teaching across universities masterclasses and adult education and individual and funded research.From 1999-2002 the AHRB (now

AHRC) funded a project on which I was a researcher based at the Royal College of Art, London, investigating contemporary materials, methods and practices in mould making for kiln forming glass. This resulted in my collating information from the research as a CD-ROM, *Mixing With the Best* (Thwaites, 2002) and later being commissioned to write a book 'Mould making for Glass' (Thwaites, 2011). This combination of art practice, scholarship and research serves to underpin the research methodology of this PhD. The unconventional nature of this thesis could be considered a hybrid of reflection on previous publications combined with new practice based research which engages with the innate relationship between materials, process and form using glass as the primary medium of expression.

By expanding current themes in my artwork as well as developing new approaches, my research aims to extend the expressive potential of kiln formed glass practice from where it is now into the future through combined analogue and digital approaches. The relationship between traditional and digital technologies and how they impact on kiln formed glass practice is central to this research. The creation and development of formerly impossible shapes, manipulation of form and reproduction across a range of scales, and the possibility for repeats with or without mass individualisation or customisation are all areas to be investigated through this relationship.



3. Angela Thwaites, 2011, Flora Borealis II and I. Photos Robert Taylor

1.3 Rationale

Lost wax has lost its way – once a method of reproducing copies or editions of a design or form, it is now usually used to create one off pieces in glass and there is a clear need to modernise practices. It is high time to reconsider Walter Benjamin's idea of 'The work of Art in the Age of Mechanical Reproduction' (2009, pp.228-259) and look at copying, authorship and authenticity in a digital age. This research reconsiders these ideas through a practice based viewpoint by combining analogue knowledge and methodology with select aspects of digital technologies.

The merging of analogue and digital is current practice in art and design. However, within the field of craft this practice is in its early stages with glass lagging behind at this point in time. Shillito states that 'Digital technologies enable us to push boundaries' and 'produce new work that was previously impossible, extremely difficult or physically and financially unviable' (2013, p.14) it is therefore vital to use digital means to move glass practices forward.

Kiln casting glass particularly, has relied heavily on traditional analogue techniques and practices notably the lost wax process. Knowledge and materials have been developed and refined but little has changed in basic production methods over 4,000 years of casting glass. With the advent of digital technologies, for example rapid prototyping and 3D printing, a much broader spectrum of starting points for form and production become possible. Models may be drawn or initiated in several ways and 3D printed in a range of materials using various methods. In some cases it has become possible to dispense with the material model altogether by 3D printing a mould around a virtual model (Matthias and Jorgensen, 2010).

3D printing is seen as an ideal means by which to reproduce multiple identical objects or objects each with individual qualities. Building on existing research and practice, I focused on the hybridising of analogue and digital technologies to explore the making of cast glass forms which would be either extremely time consuming or virtually impossible to make by analogue methods alone. Through ‘disturbing tradition as one might disturb water – to see whats there and whether to fish something out’ (Foster 2006, p.) to create unique three dimensional forms to be translated into permanent glass objects ‘mixing art and play in a way that is in danger of making people think’ (Craig, 2014).

The significance of past and present working together to challenge perception is echoed in the artwork of Beauvais Lyons, who makes composite creatures, ‘artistically fabricated fakes’ providing ‘solid evidence of worlds that never existed’ (Craig, 2014) objects which capture a sense of things already existing in history or things re-imagined in the present questioning the future – works of speculative fiction and speculative archaeology.

4. Gayle Matthias, 2014, Sinew II

Digital technology in art, craft and design, has been the subject of a number of research projects and PhD studies including Cutler (2006), Dean (2003), Jorgensen (2015) and Dickson (2015). However change in this area is rapid which presents ongoing opportunities for further research and investigation. At the point of starting this research the exploration of 3D printing for glass was relatively new and under-documented.

This PhD research considers the unity of digital and traditional practices in kiln casting glass. The recent addition of digital technologies to a practitioner's tool-kit has facilitated the creation of work which would be virtually impossible to produce by hand making methods alone. This was summed up succinctly by Dries Verbruggen (Making Futures, 2015), who described digital technology as giving 'complexity for free' and Jonathan keep who states that digital technology 'takes you to places you would otherwise not go' (Keep, 2016).

5. And 5a. 3D printed vessel forms at *The Good The Bad and The Beautiful*, 2017, NCCD, Sleaford

Frayling, in his manifesto for the New Bauhaus, (2011), focused strongly on the transformative role of digital technology in design and making. He emphasised the need for material knowledge and experience in relation to digital technology and identified that the tacit knowledge of the maker was beginning to *precede* conceptualisation (Frayling, 2011, p136). There have already been significant

developments in digital art and design using various approaches and forms of 3D printing, from early adopters working on large scale sculpture and public art such as Gormley,(1998) and Anish Kapoor,(2008-9); through to more recent investigations. The most relevant of these is the investigation of Jorgensen and Matthias, (2010-15), into virtual models and directly 3D printed investment moulds. However, their research was curtailed by the dissolution of the Autonomatic research group and at the start of this research, no existing definitive text or documentation of the relationship and use of 3D printing for kiln forming glass had been identified. Throughout this study, desktop 3D printing has become increasingly available to a broader range of practitioners, makers, situations and studios so the need for practice based information is growing.

Digital technology is changing the ways in which we do things, prompting fundamental discussion around the values of traditional material-based skills and knowledge, of which glass making is a particularly interesting example.

The unique qualities of glass have continued to engage artistic thinking and practice across millennia and are still relevant now. Due to its particular material properties including its density, transparency/translucency glass allows for sculpting with light, colour and volume like no other substance available to a maker. With glass it is possible to play with visual perception in unique ways. It has a timeless quality, maintaining its potential as an expressive medium for contemporary artwork. Glass also allows for simultaneous views of the inner and outer forms of a sculpture, creating visual illusions, fragmentation of planes, dematerialising the material:

> *The physical properties of glass naturally lend themselves to a cubist aesthetic. In one glance we can see all of a work's surfaces as well as its interior. Sculpted glass planes can reveal the way they intersect. Glass can swallow space and light, dematerialize it, and rematerialize it. Glass can capture motion in its environment and alter it with changing light, bringing time – the cubist fourth dimension – into the act of perceiving it. The material holds light within itself, encouraging association with the spiritual. (Kehlmann, 2002, p.11)*

6. Libenský/Brychtová, c.2000, *T Space* from *Impression of an Angel* series, Libenský/Brychtová Museum, Železný Brod, Czech Republic

The technique of cast glass exemplifies these unique sculptural possibilities and is fundamental to the methodology and approaches used in this research. This project aims to bridge the space between hand and digital processes for glassmakers and disseminate new knowledge and approaches in an accessible way. Through documentation and collation of information, and through the artworks themselves, I aim to increase the appeal of digital technologies to studio practitioners and students who are not digital experts at the start.

Before starting this PhD my sculptural desire was to create three dimensional forms with multiple layers and complex structures inside, to express a sense of worlds within worlds. Struggling to reproduce these forms using conventional lost wax casting processes I saw a presentation by Jonathan Keep (2013)

showing innovative ceramic sculpture produced using a 3D printer he had ‘hacked’ himself and open source coding he was developing to create new ceramic forms. This process started to raise questions of what benefits digital technology could offer to a maker with significant material knowledge and skill who needed to extend ‘the possible’ in terms of form, structure, content and potentially scale of studio glass practice.Accuracy and efficiency of reproduction along with possibilities of ‘mass individualisation’ (Dean 2003) all represent benefits that studio glass could access through combining analogue and digital technologies to create previously impossible forms and structures and radically develop content and approach. Seeing these potential benefits demonstrated through process and material aided the formulation of research questions and initial practical experimentation of this project.

Dean’s design model described above, led to questions of what production and reproduction are in a digital context and pointed further towards issues of authorship and authenticity, copies and copying and Intellectual property rights (IPR). This was, therefore, identified as area for research and consideration as part of this study which ‘raises rhetorical (for the moment) questions about the terms of authorship and aesthetic control in the future’ (Warnier et al 2014, p.92).

1.4 Research questions

The following research questions and aims were formulated from the application process for the PhD and refined and expanded through the contextual review process. The initial question of ‘How can 3D printing inform studio based kiln formed glass practice in 21st century?’ evolved from identification of the limitations of existing analogue practice which I described as ‘ lost wax having lost its way’ (Thwaites, 2014). From this starting point and with the addition of results from initial practical experimentation, research questions have been framed and refined through contextual review and interrogated via a series of

case study experiments produced through the research process upon which a dialogue of reflection and action has been carried out.

1.4.1 How can analogue and digital processes be combined to produce previously 'unmakeable' artworks in cast glass and create new ways of thinking and approaches to making?

1.4.2 How can Czech glass heritage inform contemporary kiln formed glass making?

1.4.3 How is kilnformed glass practice being affected by a culture of open source and shared information?

1.5 Research Aims

This study had the following aims:

1.5.1 To consider the language and significance of form, colour and scale in kiln formed glass against the background of Czech glass heritage

1.5.2 To consider a democratic context for contemporary practice in kiln formed glass encompassing social, critical and technological change

1.5.3To use CAD and 3D printing in combination with analogue glass casting processes to make the 'unmakeable'

1.6 Methodology

This section of the thesis describes the particular approach I took to methodology, which was practice based. Research was carried out through practical investigation in a studio setting involving creative and technological processes, combined with contextual review and case studies in the form of bodies of artworks made, and with reference to precedents and models within associated research projects and writing.

‘Mixing with the Best’ (Thwaites, 2002) surveyed over one hundred contemporary kiln formed glass practitioners which informed empirical testing of dozens of different approaches and material combinations in relation to mould making for casting glass. Building on this previous practice based research experience and method and informed by the contextual review, I carried out studio based experimentation using CAD and 3D printing to create models for casting in glass. Translation of 3D printed forms into glass was predicated on my knowledge and experience developed through this previous research and in my practice. This included recipes and methods for mould making, knowledge of casting and kiln firing processes and types of glass, cold working and finishing techniques.

The main methodology for this PhD is practice based. My working methodology is rooted in traditional, analogue approaches and processes. These include the use of clay, plaster and wax for making models, methods for master and refractory mould making, casting glass and cold working and polishing techniques for refining and finishing forms and surfaces in glass. Practice drives research and determines the progress and the nature of the research through engagement with materials. The forms and textures of artworks created in glass develop their own tactile and visual languages which are derived from everyday experiences and impressions, bearing witness to life. This methodology is re-evaluated and differently applied in this research through the addition of digital technology, which adds significantly to the palette of tools and strategies previously available to studio glass practitioners.

Practice based research in art and design is a well-trodden path which has been discussed and documented extensively since the mid 1990’s. I aim to add to this discussion through the methods and approaches I have taken and in the relationship these have to others in the field.

1.6.1 Researcher/practitioner position

Starting with a definition of my research position where ‘the practitioner is the researcher; [and] from this informed perspective, the practitioner identifies researchable problems raised in practice, and responds through aspects of

practice' (Gray and Malins 2004, p.20).This is a multi-faceted role where the researcher is:

- a generator of the research material –art/design works, and participant in the creative process
- a self-observer through reflection on action and in action, and through discussion with others (ibid, 2004, p.21)

Having established that practice is at the heart of the rationale, aims and questions raised in this study and that it provides both the location for experimentation and the methodological basis of the research. I can proceed to describing my methodologies in more detail with reference to other academic research in proximity to my own and to citing relevant texts on the subject of methodologies in creative practice.

1.6.2 Creative and reflective practice in research

Through adopting a practice based methodology I have allowed insight and knowledge to be developed through research, observation and analysis of practical experimentation and results, rather than predetermined theory directing the investigation. In her book, Barrett (2010) describes how theory and methodologies 'emerge' from the specifics of studio enquiry, which 'constitute the generative strength that distinguishes practice as research from more traditional approaches' (ibid, p.135).Barrett also cites Haraway's notion of 'situated knowledge' where she critiques the scientific method for effacing 'the particularities of lived experience from which knowledge emerges' (ibid, p.135). The role of real experience in research methodology is further reinforced by the statement that

> *Methodology is responsive, driven by the requirements of practice and its creative dynamic. It is essentially qualitative and naturalistic. It acknowledges complexity and real experience – it is 'real world research' (Gray and Malins, 2004, p.21).*

As a practitioner who has accrued a significant amount of 'situated knowledge' and 'lived experience' through my practice, I have the potential to offer informed insight to feed into the research process combining and building on these

existing methodologies. The importance of insight and reflection based on professional experience and knowledge is also highlighted by the writing of Schön (1983), frequently cited in art and design research (Brachlow, 2012; Dickson, 2015; Gray and Malins, 2004; Tvede Hansen, 2009; Jorgensen, 2015). Schön established two distinct reflective processes 'reflection *in* action' and 'reflection *on* action'. Carried out by professionals in practice, 'reflection *in* action' indicates the capacity for experienced professionals to react intuitively and responsively to new situations and problem solving. The second, 'reflection *on* action' is a retrospective process of critical evaluation. Both of these reflective practices have been engaged in the practical experimentation aspects of this research and critical analysis of results.

Useful comparison with my position as experienced practitioner/researcher can also be made with Tvede Hansen (2009), who describes his methodology as being 'occupied with how design research, which includes own experimental design practice, can utilize the researcher's background as a practitioner and make the practice be central for the research'. Tvede Hansen engages Schön's model in combination with 'research through design' (Frayling, 1993, p.5) where practice and research are totally integrated and design is used as a method of inquiry. Resulting 'epistemic artefacts' are viewed as tools to develop theory 'in interplay with a verbal reflection and discussion in the context of practice based design research' (Tvede Hansen, 2009). Schön and Frayling are also cited by Dickson, (2015, p.17) where she refers to Frayling's idea of the thinking being 'embodied in the artefact' (Frayling 1993, p.5). Dickson goes on to explain that 'the knowledge gained through theoretical research is exemplified in the body of artwork' (Dickson, 2015, p.17). The artworks I have produced for this study embody the research carried out and exemplify the key aim of making the 'unmakeable' using combinations of digital and analogue approaches.

7. Dr Erin Dickson, 2016, working on *Mould* at National Glass Centre, Sunderland

Other useful comparative's are Jorgensen (2015) where he describes his approach as 'reflective conversation' also based on Schön (1983), and Brachlow (2012) focused on extending practices for studio based kiln cast glass practitioners through a reflective research process. In both cases the existing experience and knowledge of the practitioner/researcher is cited as a basis for the methodology of the research.

Throughout the research, constant process of reflection led to insights on the practical progress and results, on the methodologies in use and on the contextual review. These insights influenced and shaped the research in terms of the direction of further practical experimentation and the development of combined approaches to creating form and structure, led to further contextual review and guided the overall development of methodologies.

1.6.3 Practical methodologies: Orthodox and Improvisational approaches

My approach can also be viewed in relation to that of the 'bricoleur' where multi methods of research, taking place in the real world, are overlapping, complex and sometimes ' ''messy", open to change, interaction and development' suggesting 'that methodology is derived from, and responds to, practice and context' (Gray and Malins, 2004, p.74). PhD studies in art and design at the University of Sunderland employing this approach include Dickson (2015) and

Collier (2011) both of whom employ a bricoleur approach first described by Lévi-Strauss (1962).

Although there is a sense of bricolage in some of the approaches I have taken, the way I have related to it differs from that of Dickson and Collier.My approach is closer to that described by Nachmanovitch (1990) where improvisation is discussed in the context of music and life. Nachmanovitch emphasises the need for mastery of practice before improvisation can be developed and sustained. He describes improvisation as ‘intuition in action’ (ibid, 1990, p.4) but that it must have a structure to support it. He states that ‘limits yield intensity’ and ‘improvisation is not breaking with forms and limitations just to be ‘free’ but using them as the very means of transcending ourselves’ (ibid 1990, p.84).

The potential for unexpected and creative new outcomes arising from improvisation is also described by Lorca in his lecture ‘Play and Theory of the Duende’ given in Buenos Aires, 1933 and subsequently compiled into an essay. Lorca describes Duende as ‘a power and not a behavior, it is a struggle and not a concept’ (Gili, 1960, p127). It is the soul or spirit of Flamenco where improvisation from musicians, singers and dancers can give rise to extraordinary moments of performance and produce entirely original and ‘of the moment’ outcomes. In any case, mastery of technique supports and makes possible improvisation and this can then result in positive unexpected qualities and outcomes. I have used improvisational methodology, based on my own mastery of techniques and understanding of form, to develop and explore making strategies and approaches within the practical investigation of this research.

8. Angela Thwaites, 2014, flamenco drawing as print on glass. Photo D. Lawson

The principle described above, of transcending rather than breaking with form, is important to me on two levels. In practical terms, I have applied improvisational methods to explore and create new three dimensional models to be cast in glass. In a theoretical way that a musician takes a song or a melody as form upon which to improvise, I have taken the philosophical approach of

Libenský and Brychtová as a ‘form’ upon which to improvise but at a micro scale, not the monumental scale at which they excelled. How I have worked with this is to take a real world/everyday starting point, distill an essential idea into a three dimensional form and cast it in glass to create sculpture with a sense of meaning and a relationship to what it means to be human. I have revisited this idea in several parts of this thesis so it requires further discussion. In Chapter 3, I quote key early influence during my education, Barbara Hepworth. Hepworth makes no differentiation between herself and the landscape that inspired her, describing her making of sculpture as springing from a deep response to life itself (3.3.1., p.96). See also Chapter 1.,1.2, p.18 where I refer to the use of metaphor and simile as artistic devices and the idea of life and art being inseparable, carried forward through the Libenksýs teaching into my own art practice.

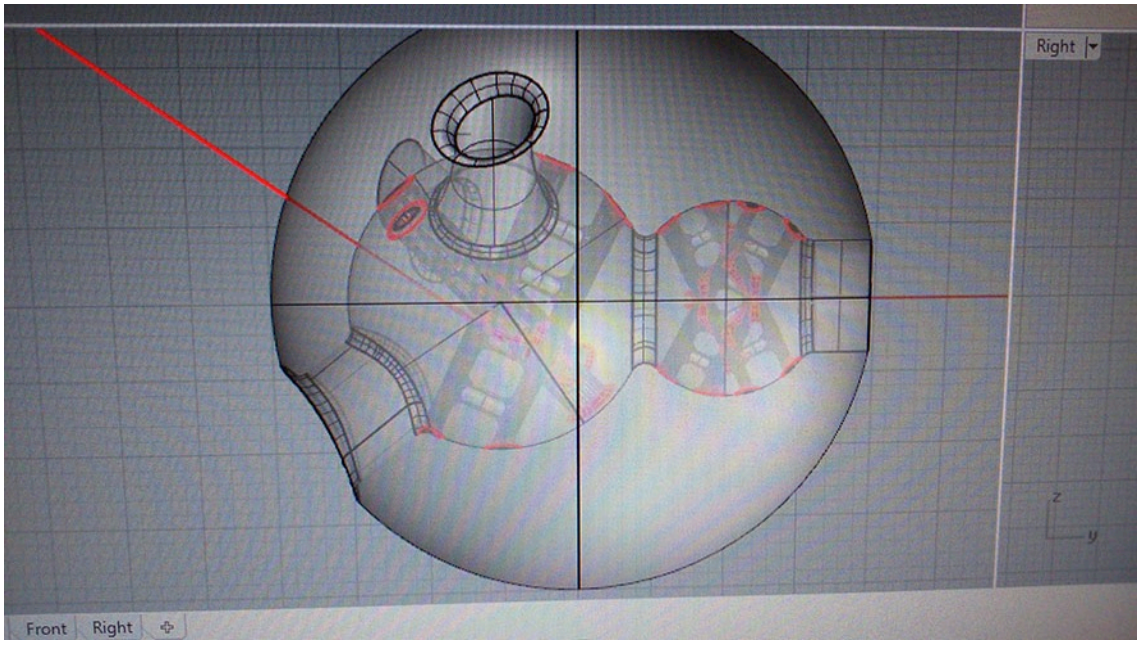
Not only is the act of making a significant part of what it is to be human connecting deeply and indivisibly with nature and life itself, but the subject matter from which my artwork is drawn is real, everyday life experiences. My aim is to connect the viewer through references, however subtle or implied, to the everyday sources and starting points I use to develop ideas and place the viewer at a new angle from which to consideration of their own humanity and existence in the world. This is actioned via form, colour, surface and texture, scale and titles of the artworks which are all rooted in real everyday things and situations.

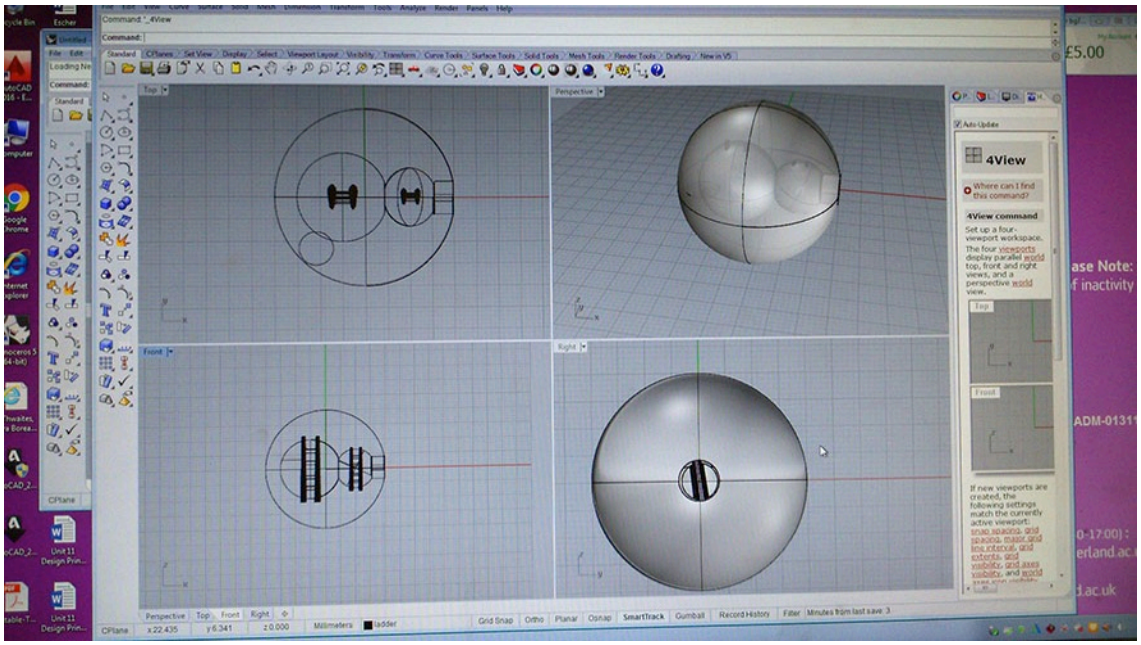
‘Repeat with difference’, described in Chapter 4, also engaged an approach that can be likened to that of a musician improvising on the form or a song. Starting with an idea for a form which would work at different scales and proportions, I created a CAD model, which was repeatable with ‘of the moment’ changes at the point of print so the form and character of the object was explored and developed through various iterations across a range of scales and proportions. This can be equated to the analogue practice of having a master model from which to create repeats, but without needing to make a master mould, which would have fixed dimension and proportion. This has wide reaching implications freeing up creative outcomes significantly as well as saving time and materials.

9. *Globeys*, 2016, 3D prints, repeat with difference

The period of practical experimentation from October 2015-June 2016 resulted in a number of unexpected outcomes which were observed, recorded and considered for further action. As the processes were tested and investigated, a number of unforeseen occurrences from the glass casting process were observed and considered. These were the reproduction in glass of fine strands of PLA (Polylactic acid, or polylactide filament) which had been applied to the 3D print to create air vents, and the reproduction of the shape and detail of the plasticine used to create the reservoir reflecting the intensity of colour of the glass into the form itself. These unexpected reproductions in glass could be termed ‘felt difficulties’ as described by Stephen Scrivener in ‘Evolution of Methodologies conference’, University of Sunderland 2016. Scrivener described a practice based research process of encountering unforeseen outcomes, reflection on these and arriving at change in understanding. This relates closely to Schön’s ‘reflection *on* action’ described above. This change in understanding through reflection on ‘felt difficulties’, in this case unexpected results in cast glass, led me to identifying opportunities which I had not anticipated. The first was for the casting of even smaller, finer and more complex forms and structures as I one strand filament thickness of PLA (1.75mm diametre) had reproduced accurately in the cast glass. The second unforeseen outcome led to designing the shape of the reservoir on CAD so that it could be 3D printed and become part of the overall form of the piece once it was cast in glass, as well as

containing the molten glass during the casting process. Considering and embracing these unforeseen results therefore led to positive change of understanding and creative new outcomes being adopted into the practical research process.





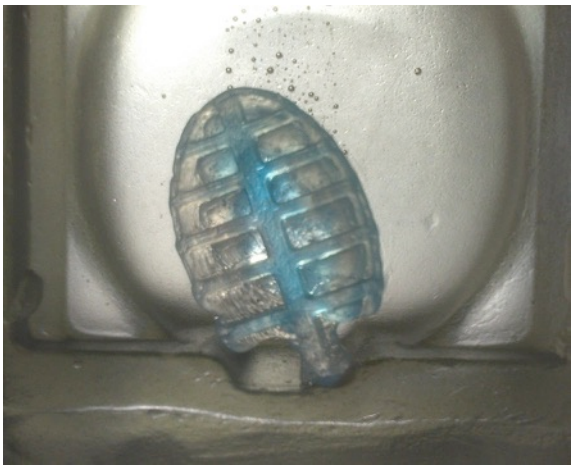
10. and 10. a. Images of CAD models *Globey* in progress

In the practical investigation carried out for this study, I experimented with two main, contrasting approaches to model making with some variations and combinations between the two. These were developed simultaneously and used

concurrently to inform and reflect on each other. I am calling these approaches the ‘orthodox’ and the ‘improvisational’. The ‘improvisational’ approach was developed as a practical method of construction which relates to bricolage discussed above and also to Schwitters’ ‘Merzbau’ (1927 - 1943) which were interior architectural installations created through a three dimensional collage technique.

The ‘improvisational’ approach was used to construct models for casting through combinations of 3D printed elements, some of which were fragments, and inclusions of other combustible materials, collaged together in three dimensions. These composite models were then invested and cast in glass. By contrast, the ‘orthodox’ approach was used to create what have been termed ‘essential’ forms by Libenský and Brychtová which were modelled in CAD, 3D printed and then cast as one piece in glass and finished using cold working techniques.

Reflection *in* and *on* the results of the ‘orthodox’ and ‘improvisational’ approaches led to more experimentation and improvisation which further expanded possibilities for forms and compositions. This included a further development of the ‘improvisational’ approach which was the casting of 3D print elements in glass which were then embedded into a larger wax form, shown in image 11. below. This wax and glass combination was then invested, the wax steamed out, new glass loaded into the mould which was put through a casting firing. The new glass filled the form where the wax had been, merging with the pre cast elements to create one overall, new, homogenous form. (See image 11a. below). Variations on this ‘improvisation’ involved cold working, composing and then re-casting, fusing or cold bonding glass elements together and then carrying out further finishing as necessary to create finished artworks. Further description of practical experimentation, details of the development of ‘orthodox’ and ‘improvisational’ approaches, can be found in Chapter 4 of this thesis.



11. Images of pre cast elements being set in wax, and 11.a *Seascape*

1.6.4 Interviewing myself – an experimental approach

As part of the unconventional approach I have taken to aspects of the research and in the writing of this thesis, I experimented with interviewing myself with Libenský and Brychtová with the aim of illustrating the impact of their philosophy and methodology on my own. The experimental approach I took was informed by two methodologies encountered as part of the contextual review process and the Universities of Sunderland/Northumbria CDT sessions. Inspiration for the creative aspect of the interview was drawn from the speculative artworks of Beauvais Lyons which combine factual and imagined content resulting in new

insights and understanding of history, memory and human relationships with objects/artefacts.

12. Beauvais Lyons, 1993, *History of Ceramics*, Lithograph, Hokes archives.

The idea of interviewing myself came out of the connections between artistic practice and Biographical Narrative Analysis highlighted in Given's workshop sessions (2017) where he described Biographical Analysis as having been derived and developed through different disciplines as an 'excellent way of making theoretical sense of social phenomena' (Aptizsch, 2007, p3). Putting these approaches together, I created an interview scenario between myself and Libenský and Brychtová, based on a real conversation they had had (Kehlmann, 2002, pp.24-33). Weaving together their interview responses with my own questions and observations, my aim was to connect the ideas, methods and philosophy of Libenský and Brychtová with approaches to research and methodologies which I have taken in this study.

As a reflection on this speculative approach to interviewing, I observe that Libenský and Brychtová's life-long commitment to research through

experimentation, reflection and further development based on gained knowledge in the field of monumental glass casting, exemplifies the ideas of ‘situated knowledge’, ‘emergent methodologies’ and ‘reflection *in* and *on* action’ described above. Their methodological approaches continue to be relevant and I aimed to build on these in my own research methods for this study.

The creation and development of formerly impossible shapes, manipulation of form and reproduction across a range of scales, and the possibility for repeats with or without mass individualisation or customisation are all areas which were investigated through this relationship. Detailed recording and documentation have enabled the development of an understanding of the implications of changes in balance between digital and analogue. This has resulted in the establishment of a method of charting and navigating this balance.

The creating of hollow objects, where one form can be seen inside another, is described as ‘core casting’ by glass makers. Core casting is seen, like metaphor, as being a suitable way of distilling a complex idea into a simpler form of mass and space. Made in glass, shapes within shapes are visible through the transparent or translucent body of the material giving a layered sense of visual complexity to a simple form.

The researcher’s ongoing interest has been in the human condition and everyday starting points. These were developed through drawing and modelling, using metaphors and similes as strategies to characterise and abstract forms and structures. Abstraction acts as a way of compressing complex concepts into smaller elements or spaces, a means of layering up ideas and forms to create a whole. These forms and structures are then further developed and through model, mould making and kiln forming processes, realised in glass.

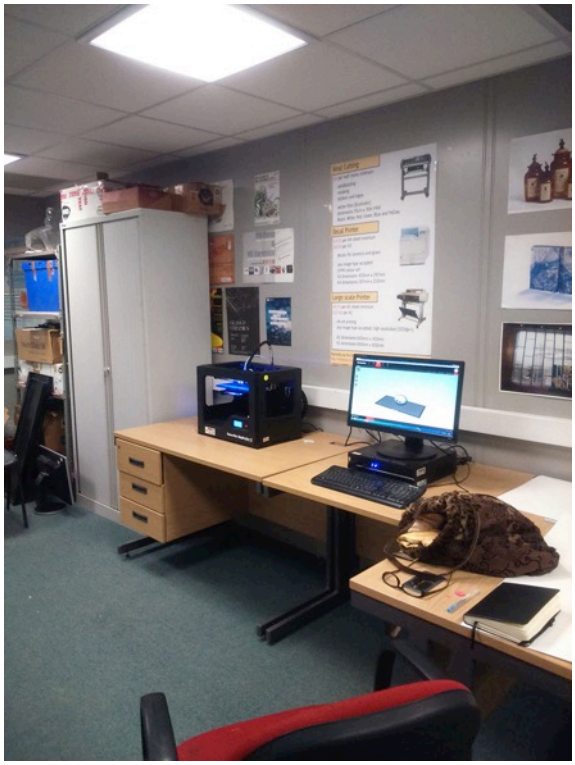
During the PhD, strategies and situations for gathering visual material included regular journeys between London and Sunderland, where I made rapid sketches and photos on my phone through the train window. The importance of

everyday moments to practice is captured by writer Hisham Matar in ‘The case for ordinary’, Guardian Newspaper (2017):

> *The myth is you do the ordinary and the extraordinary will happen…Not all myths are untrue, of course, yet some of my best writing happens on the bus or while walking, and I must stand to one side, writing quickly, trying to catch the line of words that had just passed through my head like a butterfly (Matar, 2017).*

The Contextual reviewing process was woven into and throughout the PhD. This served to focus research questions, to inform and refine the direction of the studio practice by providing a perspective from which to reflect and analyse ongoing results. As well as interrogating texts, observing and analysing actual objects both historic and contemporary was part of this ongoing review process. Access to museums, exhibitions, collections, 3D print and maker fairs and fablabs was integral to both the contextual review and practical process aspects of the research. Continuing the contextual review was a necessity for keeping up to date with the rapidly changing environment of digital art practice and technology.

The studio facilities and environment were a key aspect of the study without which it would not have been possible to carry out the practical aspects of the research. These comprised access to University facilities and staff expertise and my own individual studio, knowledge and experience. This allowed for testing in two related but differing studio set ups which supported continuity to test replication of methods and approaches across a range of scales and facilities. The university facility provided access to a range of digital facilities, soft and hardware, including 3D printers, scanning equipment, water jet cutter and Fablab. My own studio is equipped with specialist kiln formed glass equipment set up for working on a small scale. Both of these situations are seen as the setting where ultimately the findings from this project will be used and further developed in the future.



13. University of Sunderland Bot room

1.7 Definitions

New technologies are often accompanied by acronyms, brand names and processes which may or may not move into common usage. As part of this study, terms and vocabulary relating to the area of research have been considered across digital technologies particularly 3D printing. Contextual review identified glossaries of specialist technical terms for digital technologies/ 3D printing notably Cutler (2013), Shillitoe (2013) and Barnatt (2014). Also as a result of contextual review, gaps in definition and in some cases a need for new vocabulary have arisen. The following have been used frequently in this thesis so I offer readers my own interpretations and meanings:

Computer Aided Design (CAD) ‘engineering based software for designing in two and three dimensions’ (Shillito, 2013, p.153). This research project has focused on the use of Rhino and TinkerCad used to create 3D models for 3D printing. Rhino is a commercial 3D computer graphics and CAD software developed in the USA. Rhino’s geometry is based on a mathematical model (NURBS non-uniform rational basis spline) which produces precise representation of curves

and surfaces which facilitates the modelling of organic free form shapes in 3D. TinkerCad is a browser based digital design software which has a simple interface for modelling in 3D. It has a menu of existing shapes which can be selected and manipulated on one workplane to create ‘stl’ or ‘obj’ file formats that can be directly exported for 3D printing. Other 3D modelling softwares include Solidworks and ZBrush and browser based options include Sculptris and Onshape.

‘Digical’ - this has been created from digital and physical cut and put together to refer to new combinations of the two working together inseparably. The first use of this I saw was the title of a seminar hosted by the 3D print company Imakr in London, 2016.

‘Digital footprint’- this describes the traces left by the digital means of manufacture on a surface – for example fine linear texture left by a FDM (Fused Deposition Modelling) 3D printing process showing the path of the extrusion of the filament. This texture can be translated into glass, or other materials, through careful mould making and casting.

‘Open source’ – refers to soft and hardware in a non-commercial 3D printing context where designs for ‘everything’ from making your own 3D printer, files to print objects, pieces of code, are available as free downloads. The beginning of open source, self-build 3D printers included the RepRap (replicating rapid prototyper, 2005).

‘Repeat with difference’- I have used this to describe the process of making changes to a form or model, pre-print, using software or printer settings to alter scale/proportion/orientation and lay out. Changes which impact the 3D print in terms of texture and support structure and therefore also impact glass cast from the 3D prints. Repeat with difference relates to ‘individual customisation’, ‘mass customisation’ or ‘mass individualisation’ though the implication of these descriptors is that changes are made by customers not by the designer/maker.

‘3D printing’, is a computer-controlled process of building up a three dimensional form or object by material being added in layers. The use of this

term as distinct from ‘additive manufacturing’ or ‘rapid prototyping’ has been selected to position this research in studio based practice and scale, rather than an industrial context.

‘Unmakeable’- I coined this term to describe forms and structures which had proven impossible to make as models and cast in glass at the start of this research study. It refers particularly to hollow forms with complex interior spaces and structures which in this PhD have been explored on a miniature scale.

‘Unobject’- this term emerged to move emphasis from finished object making towards open ended exploration of combinations of ‘digical’ process, method and systems. It was used as the title of the masterclass I co-taught with Dr Erin Dickson at Pilchuck, 2016.

The range of glass techniques and processes in this study is ‘kiln forming’. Despite researching this term during the contextual review, finding a comprehensive and accurate definition has proved elusive, adding to the need for documentation and shared knowledge in the field. To address this need I am using my own definition:

Kiln forming includes a range of effects of the action of heat on glass placed in a kiln or chamber; resulting in fusing, bending, stretching or flowing of the material. Most often a mould, dam or template is used to restrict, guide or define the final shape.

PLA is polylactic acid or polyactide. It is biodegradeable and bioactive, derived from renenable resources such as corn starch, cassava or sugar cane. It is produced as a filament which softens at relatively low temperatures but maintains its thread like quality so it is printable or extrudable through the nozzle of a 3D printer.

1.8 Overview of thesis

The overall approach to writing this thesis is unconventional. Although the focus is on the new research carried out for this study, it also takes an approach which could be read from the perspective of PhD by previous publication. This is particularly apparent in Chapter 3, ‘Creating a Context, Engaging Czech Heritage in New Kiln formed Glass’, and the two papers on which it draws (see Appendices). These cover historical accounts of Czech glass context relevant to this PhD and to my personal background, education and practice which has supported development of the research, its direction, outcomes and methodologies.

Appendices include details of kiln firings carried out, 3D print experiments, papers presented at conferences and masterclasses, exhibition participation, commissioned magazine articles and images of artworks and process.

Illustrations in the thesis and in the appendices include professional photographs of particular artworks and documentary images of methods of making, equipment and facilities and exhibitions and installations.

Chapter one outlines the background, motivations, methodologies and rationale for the research and sets out the aims, objectives, and research questions to be addressed by the research.

Chapters two and three give the historical and contemporary perspectives which set out the context for the research. Chapter two covers the extensive Contextual Review including the History of Kiln formed Glass, Digital art and design, research perspectives and relevant PhD research and conference papers.

The third Chapter focuses on creating a context through engaging Czech Heritage in new kiln formed glass. It gives an overview of the history and legacy of Czech Glass and its importance to this study, my personal connections to it and its significance in a wider context. This chapter also maps my own history, previous research and practice and concludes with discussion on the

importance and power of making. Some aspects of the way I have chosen to write bear relationship to PhD by previous publication though this is balanced by a full practical investigation using new methodologies and technologies.

Chapter four describes the new practical investigations in detail including methods and approaches engaged for developing a strategy for making the ‘unmakeable’. It includes case studies of experiments and artworks made for the research, and details intentions, approaches, issues, methods and outcomes. At the end of chapter four I have trialled a method of interviewing myself as if in conversation with Libenský and Brychtová to draw out connections with their teaching and philosophy, reflect on my own aesthetic aims and lead into the concluding chapter.

Chapter five concludes the thesis and provides reflections on the research, its aims and questions and what has been achieved including outcomes, originality and contribution to knowledge, and potential areas for further research.

14. Angela Thwaites 2017, mini *Ballcyl* vessels. Photo D.Lawson.

Chapter 2 Contextual Review

2.1 Introduction

The contextual review discusses practice and associated theory in the area indicated by the title of this thesis. It was carried out to inform the practice aspect of this research, identifying and underpinning the direction of practical exploration, and as an aid to reflection upon its potential, outcomes and contribution to knowledge.

The review has covered a broad range of both historical and contemporaneous contexts. Sources include books, the internet, exhibitions and accompanying catalogues, journals, conference papers, related research and PhD theses. The subjects of the review include studio glass, kiln formed glass, selected relevant art/design, digital art/design, 3D printing and associated technologies.

In relation to research question 1.4.1: How can analogue and digital processes be combined to produce previously ‘unmakeable’ artworks in cast glass and create new ways of thinking and approaches to making? And question 1.4.3: How is kiln formed glass practice being affected by a culture of open source and shared information? Sources were identified in terms of newly published books, PhD theses and research papers, transcripts from conference papers and on-line journal articles and websites which provided up to date information relating directly to digital/physical combinations of process, open source and issues of authorship, access and use of software, images and information on digital and digital /analogue artworks produced using 3D printing across a range of materials and contexts.

Regarding research question 1.4.2 How can Czech glass heritage inform contemporary kiln formed glass making? Sources included my own extensive library of books and exhibition catalogues on glass, including many specifically on Czech glass from 1980s to the present. The University of Sunderland library gave access to books, catalogues, journals and previous theses on glass and digital technology for glass.

The British library was also a great resource where books, papers, exhibition catalogues, including texts on Czech glass and Czech Cubism and relevant theses which were downloaded from the Ethos database of published theses. Many of these included bibliographies and indicative further reading. Online journals, conference transcripts and publications were also consulted at the British Library which led directly to further reading and research. Research in the field was carried out on two visits to the Czech Republic to Lhotský s.r.o and the Museum of Glass and Jewellery, Jablonec, and in Prague, the Czech Cubist Museum in the House of the Black Madonna, Dox Centre for Contemporary Art, Galerie Kuzebauch and Artěl. Numerous research visits to exhibitions and collections in the U.K included Manchester City Art Gallery, The Hepworth Wakefield, the National Centre for Contemporary Craft and Design, Sleaford, Victoria and Albert Museum and The Design Museum, London.

The aim of the review was to consider and analyse 3D printing in the current context of art, design, and making, particularly in relation to studio based glass making. This provided information towards defining the current relationship between 3D printing and studio kiln formed glass practice. In order to understand and define the current and then consider the future it is necessary to establish terms used and also to reconsider the past.

2.2 Research Context

The research context within which this PhD is situated is a fast changing one due to constant innovation in digital technologies. University of Sunderland contributes significantly to the field of research in ceramics and glass. Particularly relevant to this study are University of Sunderland PhDs exploring digital technologies for creative application to glass by Cutler (2006), Sarmiento (2011), Dickson (2015), and Mitchell (2015), and the expertise and ongoing research in the area of members of the academic and technical staff Mitchell, Rennie and Sarmiento. This expertise and significant track record of research along with associated facilities, a history of connection with Czech Glass and my ongoing relationship with the Glass and Ceramics at the University were all key factors in my applying to the University of Sunderland.

Other research which is particularly relevant in terms of 3D printing includes the studies of Jorgensen and Matthias (Autonomatic, 2010) and Tvede Hansen (2009). Using a Z corps 3D printer Jorgensen and Matthias dispensed with the material model altogether by using a virtual model and 'Binder jetting' process. Here the build process involves layers of powder laid on a build platform and a binder solution is jetted onto it in the shape of each object layer (Barnatt, 2015, p.63). This process enabled 3D printing of moulds directly around the space the model would have occupied. The progression of this research was curtailed partly by the dispersion of the Autonomatic research group and also Z corps being taken over by 3D Systems so the original 'Zprinters' are no longer supported by the company (ibid p.63). However while visiting Jorgensen at University of West England (2017) I saw the early stages of forming a robotic control for the Zprinter in the Fine Print Research Centre.

Jorgensen's own PhD (2015), a useful contrast to my own study, contains two strands of practice based enquiry one of which is studio based kiln formed glass. Jorgensen describes his research as containing 'two practice elements serv[ing] to investigate tools, factors, and approaches that are involved when independent practitioners engage in innovation in the context of digital fabrication' (Falmouth University, 2015).

Hansen at the Royal Danish Academy of Fine Arts, explored the 'Experimental use of digital media within the field of ceramics' (2009) which explores the making of 'epistemic artefacts' through design based practice using 3D digital graphics and rapid prototyping to create artefacts for developing discussion and theory. Both of these PhD's explore and expand the use of digital technologies including 3D printing of different kinds and sit alongside the research I have carried out.

Regarding research into studio glass, Brachlow's PhD 'Shaping Colour: Density, Light and Form in Solid Glass Sculpture', (Royal College of Art, 2012) relates closely to this study through Czech glass heritage particularly the application of colour volume in glass casting.

15. and 15.a Heike Brachlow, 2011, *Themes and Variations*, showing colour volume principle under differing light conditions

The ‘All makers Now?’ Conference (Falmouth University, 2015), considered the present and future of making in the light of rapidly changing digital developments. Barney Townsend stated that by 2014, 3D printing had ‘reached the peak of inflated expectations’ on the Gartner Hype Cycle (Gartner 2014). This was largely as a result of expiring patents on the FDM 3D printing process in 2009 (Townsend, 2015, p. 159). So by 2014 the global market for 3D printing had reached $2.5 billion with growth forecast as $16.2 Billion by 2018 (ibid p.159).

Dean, an early adopter of digital technology within his jewellery practice, describes his studio, ‘futurefactories’, as virtual, and states that ‘a wide variety of systems and technologies are employed in the work. Where it is physically produced is not the issue. It could already be done in your own home’ (ibid,

2003). This aligns with ideas of 3D printing as a revolution where the norm was foreseen as custom objects, parts and products 3D printed to order on a very local basis and/or within the home (Barnatt, 2014, pp.147-150). Although this revolution is not evident in the way that Barnatt and Townsend had predicted, there have been significant changes and developments in the accessibility of 3D printing and associated technologies during the time frame of this research.

2.2.1 Brief Historical perspective on the kiln forming of glass

> *Virtually every age of civilization has endowed us with magnificent works of art. Among these the most fragile and therefore the rarest and most moving, are objects made of glass (Bloch-Dermant 1980, p.7).*

As part of this brief overview of kiln formed glass history and as background for this study, innovation and documentation are key points to consider. Both these areas have been limited and limiting to knowledge and practice historically.

Kiln forming glass is by nature technical, but this cannot be considered without the simultaneous understanding that the techniques have been and continue to be, driven forward by artistic concepts and necessities of expression. However, In terms of techniques and materials, little has changed in millennia. Withheld information, in the form of historic practices of secrecy concerning techniques, has not only restricted creative vision and aesthetic aims but also stultified technical innovation.

Janine Bloch-Dermant in her book ‘The Art of French Glass 1860-1914’, states, ‘From the beginning the pâte de verre process seemed to invite secrecy and mystery. According to Petronius, the Emperor Tiberius was so concerned that the process not become generally known that he had a *pâte de verre* worker be-headed’ (Bloch-Dermant 1980 p .168). Little surprise then, that documentation is sparse, even now, and mostly written by non-practitioners so restricts understanding of working contexts, motivations for and methods of production.

Kiln formed glass has fallen in and out of fashion over its long history. Some of the oldest pieces of glass are Assyrian, Egyptian, Roman and Turkish dating from approximately 4,000 years ago. These include very sophisticated kiln formed glass artefacts from vessel forms to tiny intricate beads and pâte de verre jewellery pieces (Underwater Archaeology Museum, Bodrum, Turkey), but almost nothing is known about who made these pieces or how.

16. Pâte de verre beads, Museum of Underwater Archaeology Bodrum

Although these and other ancient glass objects survive in museums and collections around the world, there is a dearth of documentation, particularly regarding kiln forming which was superseded by glass blowing around 50 AD. Casting glass is an ancient technique and pre dates blown glass by many centuries. Historically, casting was often carried out using lost wax techniques

developed out of skill and knowledge used for metal casting, adapted for glass. Lost wax is used for creating batches or series of pieces, often generated from a master mould which allows for repeats of the same form. In metal production, lost wax methods work efficiently as metal heats up quickly, flows like water and can be cooled rapidly without stress forming in the material. Regarding glass this has never been the case. The facility to control and sustain accurate temperatures plus much more time is needed for heating, annealing and cooling glass. This meant that it and other kiln forming processes became economically inefficient approaches for volume production.

A resurgence of interest in kiln formed glass took place in early nineteenth century Europe based on creating unique pieces or limited editions. In France in the late 1880s, Henri Cros, working with wax, clay and glass to create sculpture, was motivated to explore pâte de verre techniques by the philosophical quest for ‘an original solution to the problem of making polychrome sculpture without recourse to subsequent colouring or the use of heterogeneous material’ (Olivié,1983). This quest resulted in some innovation based on employing ancient techniques and connecting them to contemporary ceramic practice from factories such as Sèvres, in France. A number of artists took up the practice of pâte de verre including Albert Dammouse (1848-1926), Ringel D’Illzach (1849-1916), Georges Despret (1862-1952), François Décorchemont (1880-1971), Amalric Walter (1870-1959) and René Lalique (1860-1945). Although there is some documentation on the artworks of these artists, information on their techniques does not exist in any detail, and the Daum factory near Nancy in France still guards information about its pâte de verre production closely. The importance of these artists and understanding of their aesthetic aims has been and still is influential including aspects of this research, including mould making techniques, scale and use of colour.

The idea of cross disciplinarity towards innovation is not new. Developments in glass through the Industrial revolution described by Comte de Laborde at the Great Exhibition in London,1851,‘the future of the arts, sciences and industry lies in their co-operation with one another’ (Bloch-Dermant,1980, p.7). The roots of glass as an artistic medium are born out of the 19th Century where influence

from the industrial revolution and the art and crafts movement combined in particular and sometimes contradictory ways.

2.3 Times of change, glass as an expressive medium in late 19th and early 20th Centuries

In restless, fast changing times it is pertinent to draw comparison with turbulence experienced in previous eras and find echoes relevant to artistic practice and visual language now. The tectonic shifts of the late nineteenth and early twentieth centuries including Civil and World War engendered passionate artistic response seen in Cubism, Dada and Surrealism. These events and responses have much in common with those of present times; considering the developments of glass as an expressive artistic medium will help to connect the historical with the contemporaneous.

After the industrial revolution in Europe and the USA, glass making existed only in an industrialised setting so artistic expression was not on the agenda. Late 19th / early 20th century artists – Daum (1853-1909), Tiffany (1848-1933), Lalique (1860-1945) and others - 'were not individual artists concerned solely with artistic expression… they were designers, responsible for developing new products' (Vanderstukken, 2016, p.14). These products were made to guarantee the survival of the glass industry, not for building the reputation of the individual designer/artist.

Slowly this started to change, partly as a result of the Arts and Crafts movement 'and during the Art Nouveau, Art Deco and Bauhaus periods, the medium [glass] gained popularity' (ibid p.13). The glass industry began to realise that unique objects and artistic experimentation could have value and positive influence on mass production. As well as being popular in decorative arts, glass was beginning to play a key role in architecture in modernisation and modernity of the early 20th century.

Glass as an expressive medium has had a bifurcated development. On one side artists working within the Modernist period started to explore industrially produced sheet glass and mirror, for example Duchamp (1887-1968), Pešanek (1896-1965), Wilmarth (1943-1987) and Bell (1939-). On the other side, skill and knowledge of glass within the hands of makers was developing in Europe and the USA from the late 1940s and 50s. The division between these two approaches is rooted in the Renaissance where so-called liberal and mechanical arts were separated, particularly in Europe. This separation has continued over hundreds of years and prevented connections between and development of art, craft and design up until the Bauhaus ideal aim for unity. Arguably this utopian idea of unity has not yet been reached as hierarchies and separations are still at work in contemporary trans/post disciplinary contexts.

'Glass is a unique material for sculpture, and it is a contemporary material' … 'because only recently, since World War II, have artists truly learned how to use it sculpturally' (Oldknow, 2008, p.7). This could be true if the definition of sculpture is predicated on scale being large, which is contestable and there were reasons why scaling up was problematic. A number of artists were working with glass as a sculptural, expressive medium from the 1940s onwards, among them Edris Eckhardt (1905-1998) and Sidney Waugh (1904-1963) in North America, and Erwin Eisch (1927-), the Roubíčeks (René, 1922-2018 and Miluše, 1922-2015) and Libenský/Brychtová (Stanislav, 1921-2002 and Jaroslavá, 1924) in Europe. It was not until a stable energy supply and later computerised temperature controllers came into being that large scale really became possible.

2.4 The beginnings of the studio glass movement

In his seminal book Techniques of Kiln formed Glass (1997), author, educator and practitioner Keith Cummings states, 'The catalyst which caused the 19th and 20th Century renaissance of kiln formed glass was the industrial Revolution' where 'techniques freed from their mundane roles, became acceptable vehicles

for individual, personal exploration and expression' (ibid p.35). Objects made by hand became 'exclusive, unique and ceased to be anonymous' (ibid p.35). This led on, in the mid 20thCentury, to the rise of 'studio movements' in the 1950s and 1960s where practitioners across a range of material fields notably ceramics and glass established individual or small scale studios and workshops in which to carry out autonomous practice. The names of these makers became well known and individual makers gained status 'adopting the Fine Art practice of signing each piece like a canvas' (ibid p.35). At this point in time where intellectual property issues have fast changing boundaries, this sense of an absolute authorship is being reconsidered. This is considered in more detail later in this Chapter.

As it became established, the focus of the Studio Glass Movement in the USA involved mainly hot and blown glass techniques whereas in Europe, interest covered a broader range of approaches including kiln forming, cold working and engraving. This difference is highlighted by Sylva Petrová (2001,p.14) who sees 'the term 'studio glass' [a]s not a correct term' in relation to glass developments in Czech and many other countries including France, Russia, Finland, Latvia and Estonia. This perspective is echoed by Anna Vesele who comments that it is quite difficult to pin point the beginnings of the modern glass movement across European countries because of the variety of techniques and approaches being developed in each country and by individuals (Vesele 2010, p.31).

2.5 Multiple views, reproduction and authorship

Technology dominates human life across the planet. The development of tools, technologies and knowledge of material have been gathered together and passed down over millennia. Digital tooling is just the next step taken in this evolution as it constantly changes and updates itself within a rapidly shifting, fluxing, context. However this can be balanced against the idea that 'a revolution in thought can only use the language and the concepts that presently

exist or have already existed, and can only produce itself against the background and history of the present' (Grosz, 2005, p.120). Add to this a further layer of new materialist approaches re-thinking the object using a productive mode of action not an ideology,

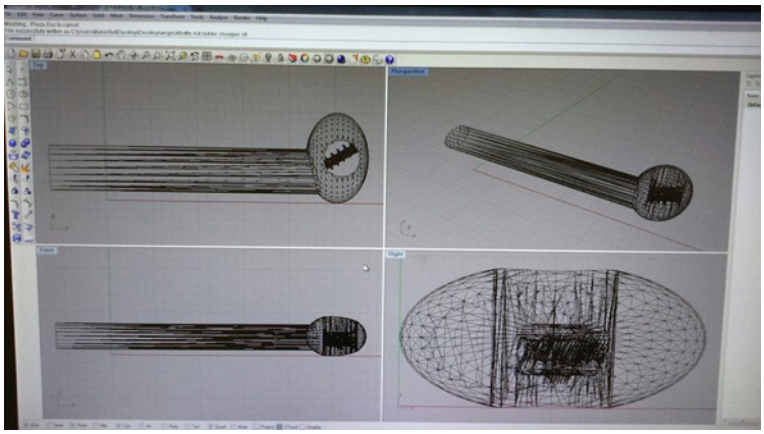
> *You can think and 'do' New Materialism without even knowing or being obvious about it, it has an invisibility… art enables research inquiry via practice via materiality for embodied, affective, relational understandings…[where you can] cognitively retrace the process through engaging with art works. (Lehmann, 2016).*

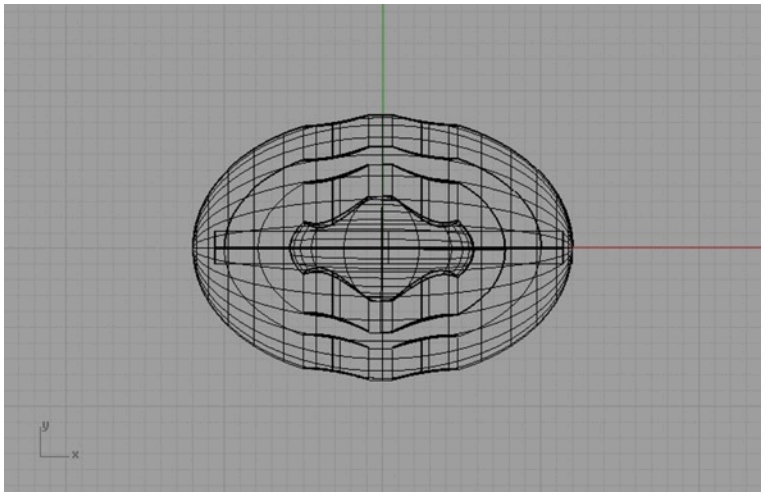
2016 saw the centenary of the birth of Dada, 'the anarchic art movement that signalled the end of nineteenth-century bourgeois naturalism and the beginning of the twentieth-century concept of the artist as miscreant and provocateur' (Abell, Stanford Arts, 2016). The 'material jolts' of Dada, which 'revelled in the chaos and the fragmentation of modern life', (Hopkins, 2004, p.4) echo now. Flux and fragmentation in contemporary society are imaged in Art and Media through digital technology which is used to re-explore methods and meanings of deformation, exaggeration and compression towards a renewed visual language. This can be read as an act of tracing, a re-treading of historic paths towards a new place: 'To trace is to repeat, to re-tread, to re-think, to re-imagine'… ' a reiteration, reframed by its re-ness..' 'To *re* is to produce new knowledge' (Liston, 2016, p.3).

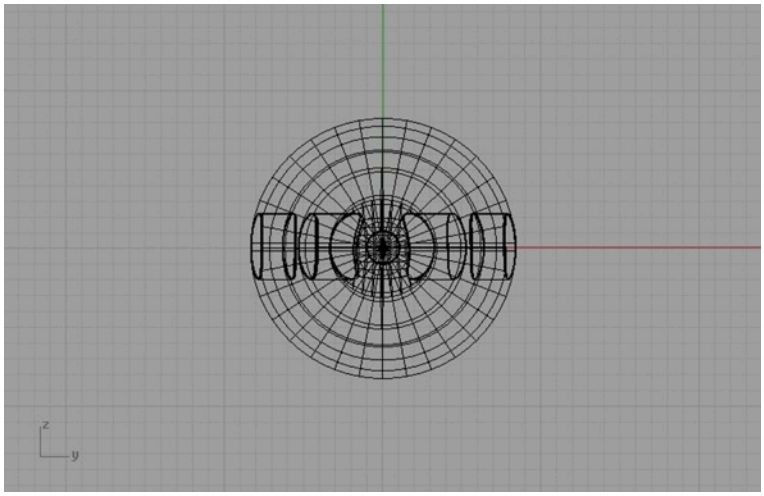
3D printing, which is still in its early years of development, links to these ideas of re-treading paths to create new knowledge through its nature. 3D printing recreates virtual, digital information in actual material form. The information often exists already in the form of open source files on websites such as 'Thingyverse', scanned information or 2D images which can be traced and developed into 3 dimensional forms. In any case the information can be changed either a little or a lot or anywhere in between, giving infinite possibilities for recreation and new knowledge gained through processing. Along this route are infinite options for exaggeration, compression, deformation, fragmentation all of which create multiple views, readings and meanings and connect directly to the qualities and principles identified in Cubism, Surrealism

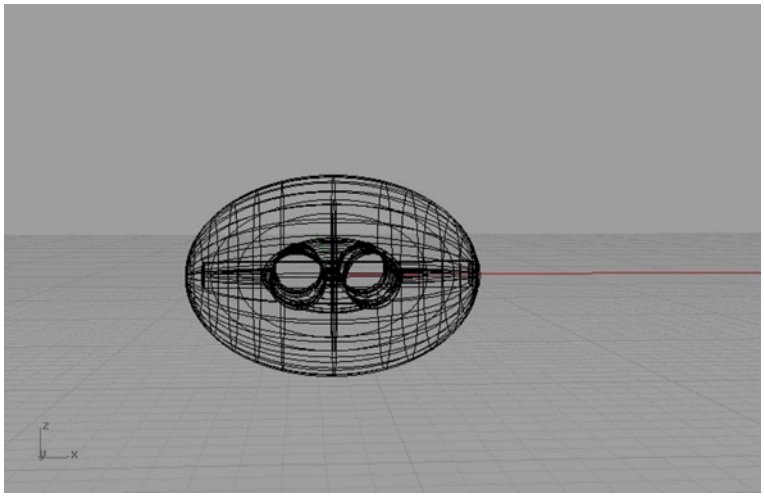
and DaDa artworks. These and the influence of Czech Cubism on the cast glass of Libenský and Brychtová are described in Chapter 3 of this thesis.

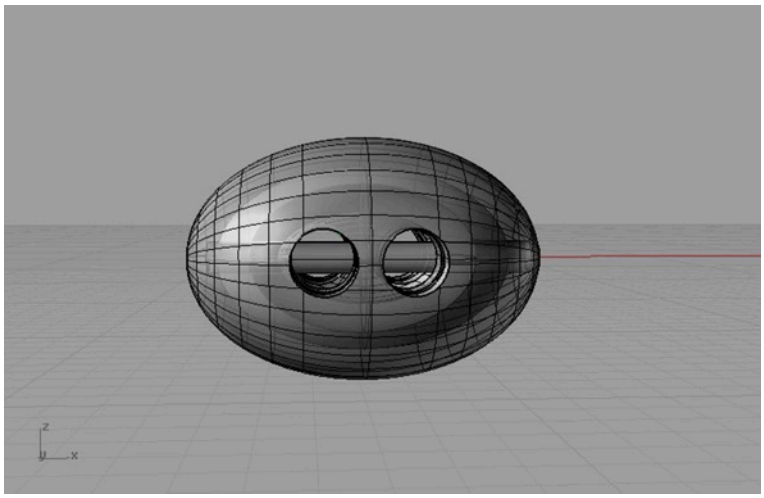
The work plane views of Rhino are to me, Cubistic by nature, giving simultaneous multiple perspectives of the idea being modelled. This goes way beyond hand making methods of modelling clay on a turntable or pouring wax in a to a master mould both of which have to be physically moved in order to explore each angle one at time – there is no possibility of simultaneous perspectives or views.







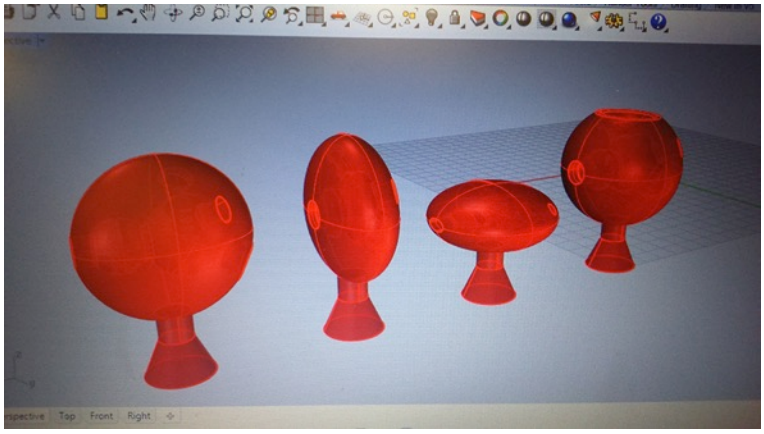




17. Image of rhino showing 4 views *Long tall eggy* and 17. A, b, c, d, rhino views of *Biclops*

Re - creation must also be considered alongside reproduction. 3D printing gives possibilities for reproducing a potentially infinite number of same or different objects with multiple ‘in between’ options of sameness or difference. I am using

the term ‘repeat with difference’ and this is explored as part of the practical experimentation described in Chapter 4.



17. e. Repeat with difference pre print *Globeys*

The potential to reproduce the ‘same’, or copies, leads on to key issues and questions arising on the changing nature of authenticity and authorship. Before looking at changing parametres in a digital age, the implications of ‘The Work of Art in the Age of Mechanical Reproduction’ written by Benjamin in 1936 will contextualise the contemporary discussion.

Benjamin’s detailed and influential essay explores changing values in the face of technological innovations. Many of the ideas expressed read as portents to the digital age. Written when innovative technology was photography and later, film, Benjamin describes the lens ability to ‘place the copy of the original in situations beyond the reach of the original itself’ (ibid p.232). This is certainly a forerunner to the power of virtuality and the screen experience of the digital era.

Benjamin goes on to describe reproductive technology as removing ‘the thing reproduced from the realm of tradition’ and substituting ‘for its unique incidence a multiplicity of incidences’ (ibid p.233). This theory could be applied to the internet where images and mimes echo, reverberate and are reproduced in many formats and contexts – a form of reproduction with difference similar to that possible with 3D printing.

At this point in time, I have a sense of the decline of Benjamin’s idea of the fading aura of an artwork where the secularisation of beauty which emerged out

of the Renaissance remained constant for about three hundred years. The advent of photography, coinciding with the birth of Socialism, liberates the work of art from 'its existence as a parasite upon ritual' (ibid p.237). The nature of art, its meaning and value change fundamentally. Firstly as a result of the clash between painting and photography, which set art 'free from its cultic roots', (ibid p.240) and later the evolution of film which 'portrays an event that can no longer be assigned to a single standpoint' (ibid p. 247). Enter the internet, youtube, contemporary journalism and digital art, all showing multiple viewpoints simultaneously through connecting instantly with a mass audience. The scale and reach of this multiple view simultaneity is a Cubo-surrealist's dream.

Architect and critic Sam Jacob, writing in 'Crafts' magazine, (2016, p.28) considers the meaning of copying and authenticity within current digital culture, with a particular focus on the implication for makers 'Digital tools are now completely embedded ... fundamental to the process of making. And the processes of copying that are native to digital culture are now second nature to us'. Jacob goes on to question whether the impact of increasing ease of copying digitally, and navigating between the digital and the physical are fully understood

> *in a digital age the copy and the original now inhabit the same space…ideas of the authentic, artisanal and hand-made co-exist with the multiple and the virtual....multiple conversations with the idea of the 'real', as if time has collapsed, telescoping back through reconstructions of the past..into the future (ibid, 2016).*

This challenges Benjamin's idea that 'Even with the most perfect reproduction, *one thing* stands out: the here and now of the work of art – its unique existence in the place where it is now' (Benjamin, 2009, p. 231). Once the copy and the original simultaneously co-exist in the here and now, a risk and a challenge emerge for practitioners of the 'hand-made' accompanied by an opportunity to expand existing practices in entirely new ways, encapsulating the main aim of this research.

Individual authorship and ownership of designs for making are being challenged significantly by rapid developments in 3D printing and open source soft and

hard ware. There are already more than half a million 3D printable files listed on the object sharing website Thingyverse (Barnatt, 2014 p.166).The potential impact of this is highlighted in a recent paper by Lauren England, ‘Copyright and Craft: incentive or interference?’ Rideout (2011, cited by England, 2015, p.5) points out that CAD files ‘ Although called drawings, in relation to IP they are classified as functional or ‘useful articles’ and therefore not protected by copyright’. The implications of this infer major change to professional, social and economic conditions for studio practitioners.

2.6 Social or un-social media?

Never has it felt so important to connect with and support other makers, to share knowledge and skill and to counter-balance the relentless push of big business into the interior spaces of people’s lives sometimes stealthily carried in via mobile phones and devices.

The average time a person spends on their social media is two hours a day and teens check their phones on average 150 times a day (Asano, 2018). This has both positive and negative implications for makers. In one way it has never been so easy to connect with others whether for social or business purposes, exchange or marketing. On the other hand it is increasingly difficult to prevent appropriating of ideas or even straight copying of designs if they are openly accessible. England (2015), debates the risks and benefits of making and sharing information whether it is digital files which can be used directly or images of work which can be copied. Holroyd (2012, quoted by England, 2015, p.7) also acknowledges the background values of a craft/making ethos that craft skills and techniques ‘are designed to be shared’. The use of the word ‘designed’ in the context of sharing suggests a more active responsibility towards passing on skill/knowledge than the somewhat over used phrase ‘tacit knowledge’.

The risk/benefit analysis England discusses is echoed by Amy Twigger Holroyd in her article ‘Why it’s important to be open’ (Holroyd 2014) where she writes

that her ‘commitment to openness is primarily about the future’ and that ‘openness is a growing movement, which is challenging conventional systems and hierarchies in many fields of life’ (Holroyd 2014).

Sterling in his essay ‘The future of Making’(2011), states that ‘Commerce has its stern patents and copyright, while Making enjoys louche, tolerant open-source and ‘copyleft’’ (Ibid p.68) while Petry locates the idea of ‘artists as a distinct class’ in the sixteenth century and that from this period the debate around artworks being ‘authentic’ grew (ibid 2014, p.2). In the spirit of this thesis which aims to unite historical and contemporary practices, I connect these statements simultaneously to Benjamin, as discussed above, and to historic description of Czech glass makers in medieval times having special status (Vondruška,1991 p.26).

2.7 Object making, media and technology

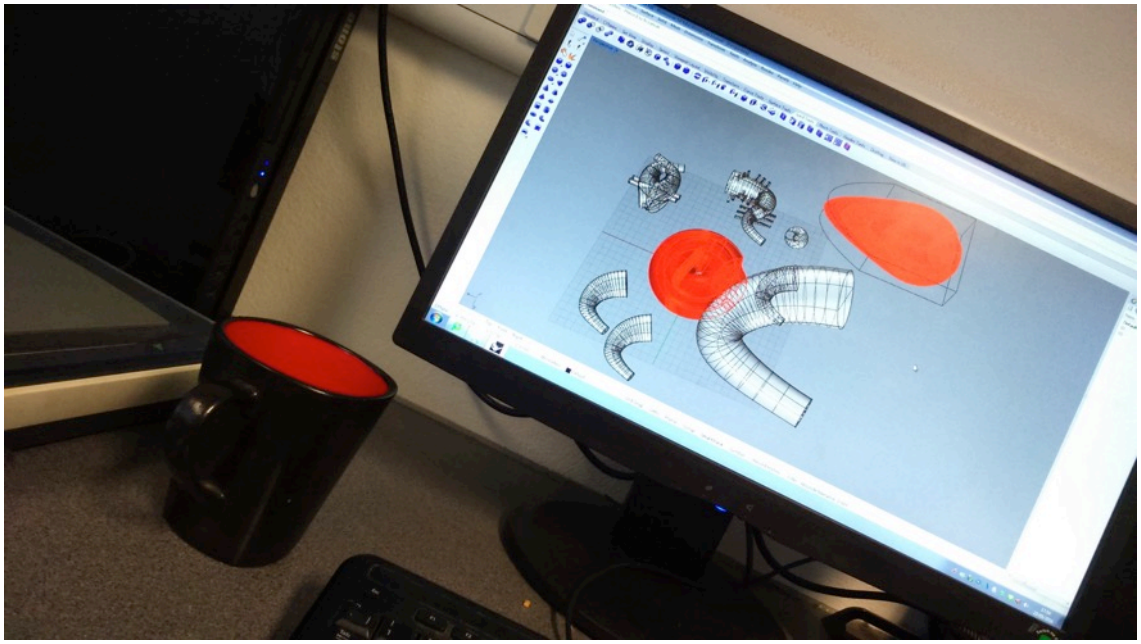
In 2017, the beginning of Trumps Presidency in the USA, coining the phrases ‘post truth’ and ‘alternative facts’ (Conway, 2017) there is a back and forth tussle between advertising as part of capitalism and media reportage of politics, and the re-subversion of media strategies back into art and culture through social media and digital technology. Key example of this re-subversion is celebrity artist Grayson Perry described as ‘one of the most astute commentators on contemporary society and culture’ and ‘drawing his subject matter from his own childhood experiences within a context of wider social issues encompassing class, politics, wealth distribution, sex and religion’ (Serpentine Gallery, 2017).

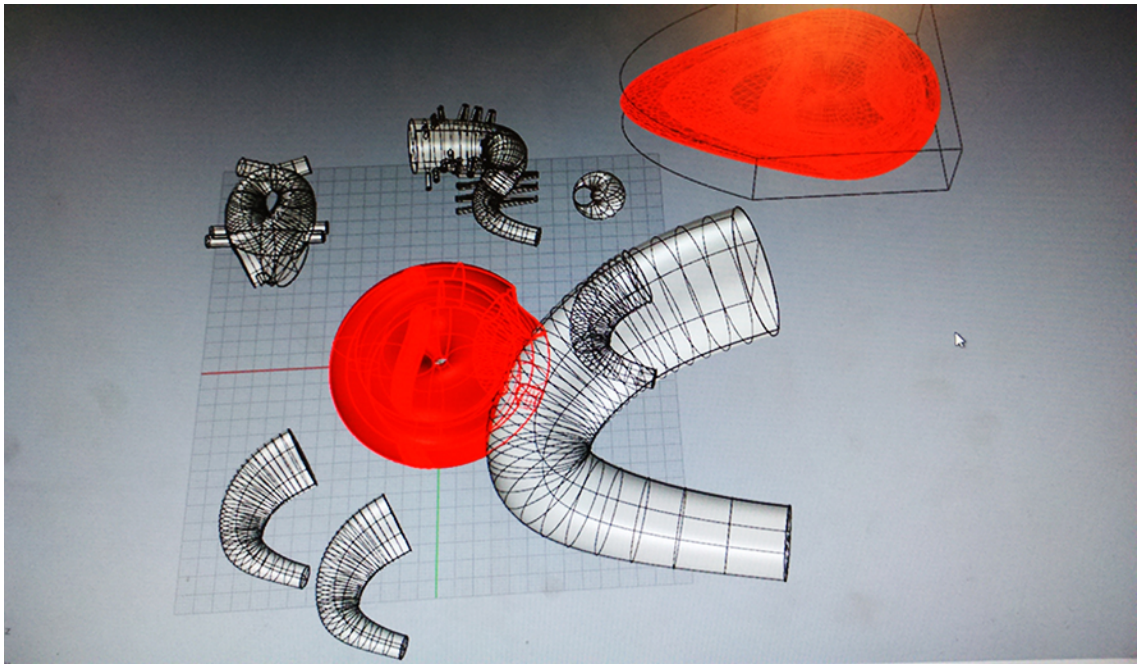
Perry’s artworks are made using a mix of traditional techniques and digital imagery and span popular and academic audiences of contemporary art. Using television as well as social media, Perry set out to capture the diversity of popular opinion in the UK after the EU referendum of 2016. Channel 4 made a documentary, ‘Grayson Perry: Divided Britain’ which followed him as he created a new work for the Serpentine show. ‘Harnessing social media, Perry invited the

British public to contribute ideas, images and phrases to cover the surface of two enormous new pots: one for the Brexiteers and one for the Remainers' (Channel 4, 2017). As well as ceramics, large scale wall hung tapestries were shown with the same dense, complex imagery from digital and drawn sources, layered and combined in a way which reflects the intense, fragmented experience of 21st Century viewers.

Jonathan Openshaw, in his book 'Post Digital Artisans' (2015) raises key questions as to 'how digital tech changes our approach to tactile craftsmanship' (Openshaw 2015, p.5) He goes on to ask 'Is this change infectious?' 'Is there a divide between real and virtual?' Then describes the expectations which have been formed by screen and internet in generations born after 1989 and how the 'disproportionate focus on the digital native perhaps obscures a more important observation: 'we're all post-digital now…in our networked world, the logic of algorithmic processing is the undercurrent of our existence' (Ibid p.5). Going on to explain what he means by post-digital, Openshaw concludes 'a digital mindset is inextricably entangled with our existence, whether or not the digital *technology* is actually present' (Ibid p.5). He highlights visual art as an area which has successfully 'tackled' digital 'through the idea of a 'New Aesthetic' that permeates everything from advertising to design and architecture. (Ibid p.5)

Bridle (2011, quoted in Openshaw, 2015, p.5) defines what is meant by the 'New Aesthetic' we are exposed to in our everyday experiences: 'what we're seeing is being filtered through the screen; flattened, juxtaposed, hyperreal'. This reflects vocabulary from Cubism and Surrealism: the strategies of distortion, compression, exaggeration, juxtaposition, disorientation are the same, but the means and methods are different - and the radical shift in depiction, from real to virtual. In fact there is no space between the two, which leads towards further questions about authorship and authenticity.





18. Rhino models in progress *Horns, Bagely, Rock Lobster* 18. a. Modelling using ‘pipe’ and ‘cage edit’ in Rhino

Connecting these ideas and questions around authenticity with expansions into an increasingly post disciplinary environment in the art world, Adamson and Bryan Wilson (2016) interrogate materiality and the way art is being made now. They describe their deeply searching questions as ‘not merely semantic. They cut right to the heart of the way that art is understood either as a disciplinary matter, with clear rules and limits, or, alternatively, as a free zone of exploration’

(ibid 2016, p. 28). The existential nature of this discussion is reflected in concluding comments in Chapter 5.

2.8 Shifts, confusions, craft and raw energies

In the UK, once autonomous and supportive organisations such as the Crafts Council, struggle against a background of expanded, stretched and endlessly reforming territory, so it is not surprising that there is confusion.

In the 1970s when the Craft Council was first set up, it was funded and had a clear remit ‘to advance and encourage the creation and conservation of works of fine craftsmanship and to foster, promote and increase the interest of the public in the works of fine craftsmen’ (Craftscouncil.org.uk). Between then and now there has been ceaseless argument over ‘Craft’, as a word, as a set of values and approaches, as a lifestyle even; not much has been agreed and wave upon wave of change has dispersed the energy for this debate.

This dispersion of energy has laid open ground for brands and big business to push into the territory formerly inhabited by craft practices. Platforms such as the ‘Make:Shift’ Conference, Manchester, 2016, where many presentations were given by non-makers and key space/time was given over to Global brands who used the opportunity to advertise mass produced items derived from ideas appropriated from craft contexts. This feels a long way from the current Crafts Council value statement

> *We believe that craft plays a dynamic and vigorous role in the UK’s social, economic and cultural life. We believe that everyone should have the opportunity to make, see collect and learn about craft (Craftscouncil.org.uk)*

By comparison, ‘Making Futures’, ‘a research platform exploring contemporary craft and maker movements as ‘change agents’ in 21st century society’ (2017) is providing firmer terrain for deeper discussion and consideration with a clearer view of making culture now. Keynote speaker Cameron Tonkinwise, (Making

Futures, 2015) exposed the rampant take-over of big business in our everyday lives and gave a call to arms for activism to re balance this situation. Glenn Adamson has a related viewpoint, describing

> *what is happening in a wider context [a]s a turn away from consumerism, globalisation and technology-as-ultimate-solution to a resurgence of humanistic values and concern for environment and the planet Earth; a re- focussing on values of material, skill and longevity of resources/people/things (Making Futures 2017).*

Recent trends in ceramic practices include hacking programmes and machinery (Keep-art.co.uk) and new concepts in design and manufacture of jewellery, exemplified in the work of Stanley Lechtzin, featured in the publication 'crafted: objects in flux', (Zilber 2015) who states 'if we wish to speak to and about our time is there a better medium to use than the technology developed in this highly industrialised society?' Clarifies the potential within this research for the embodiment of what is termed the 'unmakeable' that will drive forward kiln formed glass practices into the 21st Century and beyond. This territory has been explored through combinations of digital and traditional technologies specifically CAD 3D modelling software, 3D printing and kiln casting glass techniques.

Markus Kayser, through his ground breaking solar sinter project, starts to address questions arising about energy and material usage and the future contribution of technology:

> *In this experiment sunlight and sand are used as raw energy and material to produce glass objects using a 3D printing process, that combines natural energy and material with high-tech production technology. Solar-sintering aims to raise questions about the future of manufacturing and triggers dreams of the full utilisation of the production potential of the world's most efficient energy resource - the sun. Whilst not providing definitive answers, this experiment aims to provide a point of departure for fresh thinking (Etherington quoting kayser 2011).*

Now part of the Mediated Matter team at Massachusetts Institute of Technology (MIT), USA, which focuses on 'how digital and fabrication technologies mediate between matter and environment to radically transform the design and construction of objects, buildings and systems,' Kayser and the team are developing the 3D printing of hot molten glass. The project, titled G3DP,

represents ‘a first of its kind optically transparent glass printing process,’ (www.matter.media.mit.edu) and the group led by Neri Oxman, goes on to say ‘that glass could one day be printed to create ‘a single transparent building skin’ (Howarth quoting Oxman, 2015)

2.9 Post human

André Breton (quoted in Benjamin, 2009, p.277) says that ‘A work of art … has value only in so far as it trembles with reflections of the future’. The ‘Anthropocene‘, a term coined by Paul Crutzen and Eugene Stoermer in 2000 ‘conceives humans to be a geologic factor, influencing the evolution of our globe and the living beings populating it’ (Crutzen 2012). This concept has to some extent been superseded by that of society being ‘post human’ already. As significant progress is made in Artificial Intelligence (AI) and robotics, the role of the human being is changing irrevocably. Dialogue includes the notion that in the near future many people will not need to work and will receive a ‘citizen salary’ to keep them alive while robots carry out the tasks and do the jobs they would formerly have done.

In their play R.U.R (Rossum’s Universal Robots,1923) the brothers Čapek foresee the future of the world as taken over by robots (from the Czech ‘robota’, drudgery, corvée; Poldauf et al, 1971). Reading this play in 2018 is an uncanny experience as it prophesies the mankind and the end of the world through over exploitation of natural resources at the hands of out of control robots. ‘The period of mankind has passed away. A new world has risen. The rule of the Robots’ (Ibid p.90). And later the robots themselves are in crisis and turn to remaining man to implore him for help

> *Terror is coming upon us [the Robots]. We have intensified our labour. We have obtained a million million tons of coal from the earth. Nine million spindles are running day and night. There is no more room to store what we have made…Eight million Robots have died within the year. Within twenty years none will be left. Sir, the world is dying out. Human beings knew the secret of life. Tell us their secret – if you do not tell us, we shall perish (Ibid p.93).*

As well as science fiction in literature, there is already a history of automata in art and theatre. Examples from ancient Chinese Han dynasty (206BC-220AD) mechanical orchestra, water and astronomical clocks, through to Tinguely (1925-1991) and on to contemporary robotic performance art, the implication of the involvement of robotics and Artificial Intelligence (AI) for art and artists is a topic for continuing speculation and the seeds of the near future are already growing.

19. Angela Thwaites, 1983, in front of Orloj, astronomical clock, Old Town Square, Prague, built 1410, figure of death added 1490

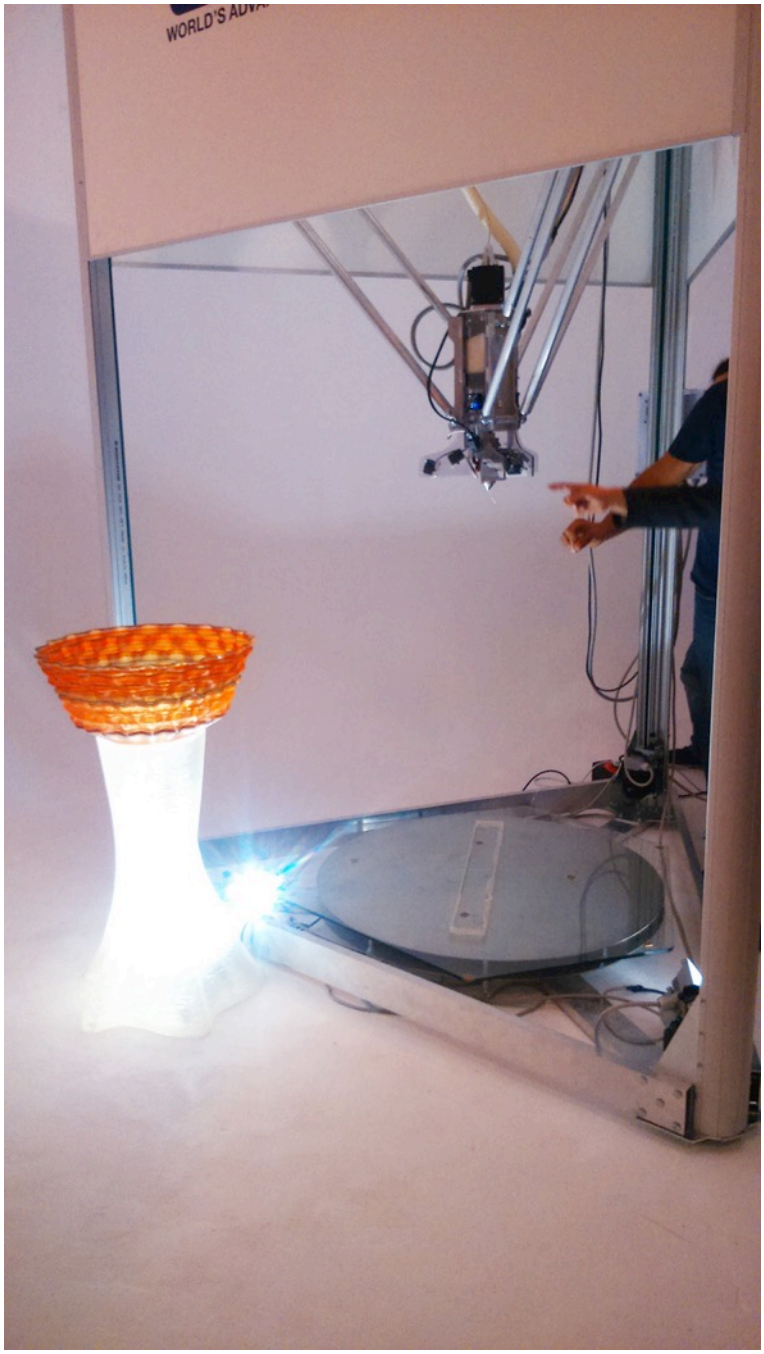
20. Model for *After the Fire*, 2016

21. Angela Thwaites, 2016, *After the Fire*. Photo D. Lawson

21a. Angela Thwaites 2016, *After the Fire*. Photo D. Lawson

> *'...Thwaites's dystopian After the fire uses cast off elements from 3-D prints as a mold positive to create an artifact reflective of a ' post digital post human world' with 'beauty in destruction''(Silbert, 2017,p.66).*

Make:Shift conference, (2014) presented drones drawing in virtual space to create architectural models and designs. On a recent visit to the Fine Print Research facility at University of West England (UWE) in Bristol, a researcher was working with a robot to overcome the obsolescence of an 'old' 3D printer. The printer was about 10 years old and parts are no longer made for it neither does it have support from its manufacturer who has been bought out, so the robot is the solution - a new 'brain and hands' with which to print. This type of collaboration between human and robot making together heralds the next phase of 'digical' (The DIGICAL show, imakr 2016).



22. *Delta WASP* 3D printer at Imakr Digical 2016

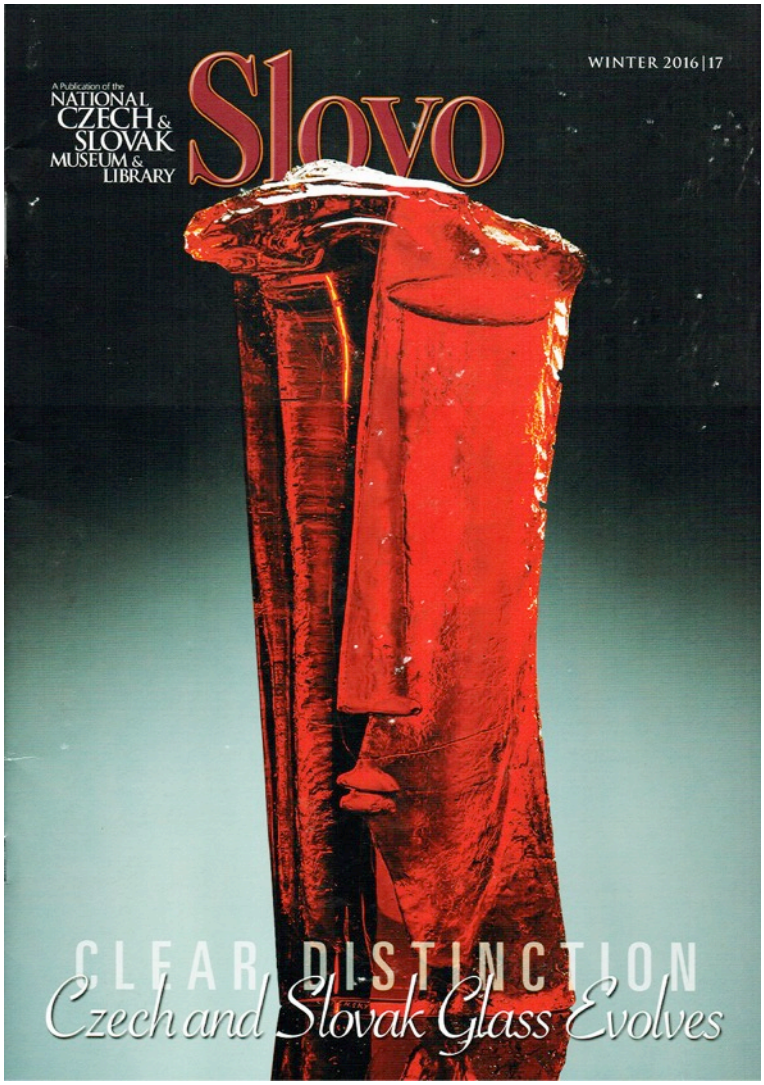
Chapter 3 Creating a Context: Engaging Czech Heritage in New Kiln-formed Glass

3.1 Introduction

The aim of this chapter is to locate this PhD project in relation to Czech glass heritage and its influence on kiln formed studio glass, within which I will define the context for this PhD and the background and development of my own practice, research, and teaching. These have been heavily influenced by my study in communist Czechoslovakia with the artists Stanislav Libenský and Jaroslava Brychtová, whose work exemplifies the sculptural use of glass. Translucency, tonal variation of colour and response to light are key qualities in their work.

> *Inner space as a motif runs through all periods of Libenský and Brychtová's work. On every level we meet it as something ungraspable… where simple structure and minimal construction are the framework for the potentialities of light and form within glass (Vlček, 2002).*

Libenský and Brychtová's teaching and artistic philosophy is embedded in this research, evidenced by a review of my learning and professional experience. This study considers traditional practices in kiln casting glass in tandem with digital fabrication techniques. This chapter closes with a gathering and reflection on current thinking on the subject of making, bringing a contemporary perspective to craft and research. This chapter draws from and elaborates on papers written as part of the PhD: 'Glass in a restless Age' and 'Space [in Glass] as the Setting for Life', (2016, Appendices).



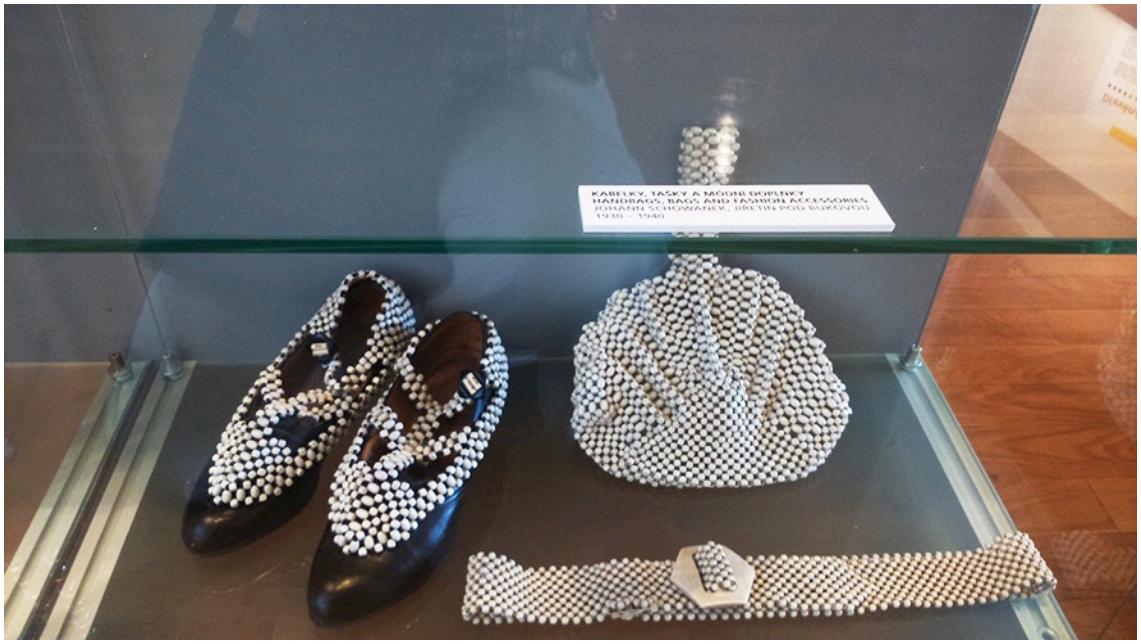
23. *Slovo* magazine, 2016-17

3.2 Overview of Czech Glass History and Heritage

Glass plays a unique and important role in all aspects of modern daily life, however its history and importance go back millennia.

> *Glass is among the most important discoveries of humankind (Langhamer, 2003, p.13).*

An overview of the history of Czech glass casting explores this unique context and shows how it continues to influence and connect practices across an international context.



24. Image of beaded shoes and accessories and 25. image of pressed glass buttons , Jablonec Museum of Glass and Jewellery, Czech Republic.

3.2.1 Glass/art connections 20th Century

Connections between glass making and the artistic movements of the late 19th and early 20th Centuries allowed makers to begin to assert their individual creative identities rather than as simply anonymous craftsmen. Evidence can be seen in the influence of Vienna and the inclusion of glass in the Czech Cubist movement. A line of influence can be traced through the architect Otto Wagner (1841-1918) and his students Jan Kotěra (1871-1923) and Pavel Janák (1881-1956) as well as the Viennese/ Bohemian glass factory Lobmeyr. This influence led to 'extraordinary creations' including the engraved work of sculptor Jaroslav Horejc that 'eerily combined neo classical rigor and expressionist feeling' (Olivié,1989, p.13).

Czech Cubism had a 'style in its own right, unmatched in its scope and cohesiveness of concept by any other country' (Koenigsmarkova, 2015, p.5). It emerged at the turn of the 20th Century out of a complex philosophical and theoretical context in a world of rapidly changing social, political and economic landscapes in short it was very much a product 'of its time'.

3.2.2 Czech Cubism and volume in space

Before World War One, activity and energy in the arts was interrogating theoretical ideas and questioning previously accepted principles around artistic creativity. As part of this, Cubism 'brought a radical change in the way reality was depicted in the visual arts' based on 'deformation, visual compression and exaggeration' (Lessons in Caricature : Cubism, 2016). As often happens in times of socio-political uncertainty, the imperative is for a clear, dependable direction and Czech artists in the early 20th Century were looking for answers 'in absolute values and order, derived from the immutable dictates of rendering volume in spatial relations' (Vlčkova, 2015, p.11).

26. Otto Gutfreund, 1913-14 *Kubistické Poprsí* (Cubist Bust), exhibited at the House of the Black Madonna, Prague, 2016

This idea of ‘rendering volume in space’ links directly to a key aspect of this research which uses 3D modelling software, based on ‘absolute values and order’ of geometry, to create volume and render it visually in virtual computational space so that it can be 3D printed as a physical model and then cast in glass.

Form was of primary concern to the Czech Cubists and this led to a move away from existing artistic traditions of representation into theories of perception and sources of inspiration from natural science. An understanding of how matter was formed in space was seen as key and the Czech Cubists aimed to achieve an ideal form that would reflect the absolute values of eternity and order (Vlčkova, 2015, p.11). My own research aims echo this idealistic quest, the

desire for a sense of timelessness in object making can be traced and linked to this notion of an enduring aesthetic.

Czech Cubist theories evolved around the perception of space as dynamic, ‘visualized by the depiction of disintegrated planes and isolated sections’ (ibid p.37) which was developed further by the introduction of ‘equilibrium : the oblique plane’ seen as ‘analogous to natural gravitational forces and express[ing] human action that is regarded as the spirtualization of matter ’ (ibid p37). The resulting forms which relate to French Cubist painting and formal abstraction also compare closely with artistic intentions expressed by Libenský and Brychtová. Forms with a distinctive, ‘fragmented morphology’ employing a simultaneous view from various angles and an abstracting of elementary signs, which found expression in the concepts of spatial arrangement and the structural tectonics of the whole’ (Ibid p.37).

Central to the evolution of Czech Cubism is the work of architect Pavel Janák which stems from the idea of a totally integrated system with the crystal, ‘a natural form *par excellence*’ (ibid p. 38) at its centre. The crystal form has a long tradition in Central Europe representing ‘the ultimate subjugation of the amorphous masses’ resistance while symbolizing order’ (ibid p.38). Largely as a result of Janák’s theoretical writing, the crystal became ‘the central component of the [Czech] Cubist morphological repertory’ (Ibid p.38). To Janák crystalline shapes represented ‘the ultimate aesthetic’ (Ibid p.38) and were used decoratively as well formally. Alongside writing and architectural design for grand interiors, Janák designed for ceramics and his crystal shaped, lidded box, 1911, is viewed as one of the emblematic works of Czech Cubist design.

27. Cubist ceramics and cabinet, House of the Black Madonna, Prague, 2016

3.2.3 The Czech Glass Movement

Within the Czech Cubist group, which included artists, architects and theorists, there was no boundary or hierarchy between applied and fine art or material, genre or scale. This meant that glass, ceramics, and furniture were ‘presented at Cubist exhibitions on a par with painting, sculpture and architecture.’ (Koenigsmarkova, 2015, p.5). ‘Aesthetically charged formalism pushed the question of function into the background,’ but the production of objects, buildings and particularly furniture was seen as important ‘because it dealt in practice with the much debated aspects of construction and form’ (Vlčkova 2015, p.11) and lent itself to an experimental approach, a practical testing out of the theories. This focus on form, object and on theory as a basis from which to develop these, can be described as a research based approach. This was not in evidence in applied art in other European countries at this time.

To summarise, the particular developments of Czech Cubism gave rise not only to paintings but also to objects, furniture and architecture designed and made to a Cubist philosophical rationale. This transition into design/object is uniquely Czech and was not seen in the Cubism of Picasso and other Cubist artists of the period.

The rationale of non-hierarchical values between fine and applied art, passed down through teaching and example, has had a unique and significant impact on the development of Czech glass. This influence has also passed to me during my education at VŠUP in the 1980s and provides a basis from which this research develops.

3.2.4 Post World War Two, the Libenskýs, their context and influence

As the relationship between glass and art became closer, a generation was educated in an open post World War Two environment by enlightened professors including Josef Kaplický. A sculptor who occasionally worked with glass, making the connection between technique, creativity and imagination ‘Kaplický always emphasised that building of a glass shape is a thing as arduous as building an architectonic shape’ (Vlček 2002, p.4). Making these connections between technique, creativity and imagination led ‘the simple practice of glass making to a unique plastic expression in glass’ (Olivié 1989, p.14). This is reinforced by the acknowledgement that ‘Firmness of expression was the goal … and the Josef Kaplický studio witnessed the new rise of thought and spirit (Libenský quoted in Petrová, 2002, p11).

From the 1960s onwards, students of Kaplický, Stanislav Libenský and Vaclav Cigler and other key figures in the canons of Czech glass, were responsible for the continuity of this philosophy and the cultivation and growth of glass as an expressive art form in Czechoslovakia. Both Libenský and Cigler have exerted massive influence in the development of glass as an artistic medium, not only through their own art practice, but also as educators in Prague and Bratislava respectively.

Libenský fostered an abstract approach which gave greater possibilities for freer expression without attracting negative attentions from the Communist regime. This form of abstraction referred heavily to Kaplický, who's roots were directly in Cubism. The Cubist notion of observing reality and translating it into multi aspect views in one image at one time has had great impact in terms of abstraction of the real into the formal. These ideas underpinned Libenský's teaching which

> *Was focused on the cultivation of artistic expression, artistic creativity, creative thinking, and experimentation…Students of school were encouraged to see their artistic activity as a part of the general visual culture. They were taught to understand glass as an element combining spatial-plastic, optical-light, and colour-painting dimensions (Petrová, 2002, p.75).*

Describing his experience of becoming Professor on Kaplický's death, Libenský says that he

> *tried to create a methodological and pedagogical order to the studio from which resulted a complex execution of glass creation based on continuous studious efforts (ibid, p11).*

The history of Czech Glass cannot be written without considering the impact of Jaroslava Brychtová. Daughter of a glass-maker, Jaroslava trained as a sculptor and began to experiment with pâte de verre glass making techniques with her father in the late 1940s and early 1950s. Libenský, a painter, who had learned to work with form, space and volume under Kaplický's teaching at the Academy of Applied Arts in Prague, met Brychtová in 1954. Libenský and Brychtová began to collaborate combining their skills and understanding through a unique approach to glass as a sculptural mass. This led to a life-long partnership, which resulted in monumental cast glass sculpture and glass for architecture unlike anything made before. Their work captured the attention of an international audience as well as founding another generation of ambitious, highly skilled and aesthetically developed Czech glass artists.

28. Libenský paintings and *Cube in sphere* 1980-1, at Libenský and Brychtová's Museum, Železný Brod

Libenský and Brychtová were based in the North Czech town of Železný Brod, an area steeped in glassmaking history. The Libenskýs were early adopters of a research based approach, evident both in their practice in the Železný Brod studio and in Libenský's pedagoical philosophy. The Libenskýs and their specialist team in Železný Brod, pioneered the research and development of monumental scale glass casting across aesthetic and technological areas, and this even before the advent of computerised kiln controllers on which practitioners have relied since the late 1980s. At the Academy of Applied arts in Prague, the Libenský pedagogical philosophy reflected this research approach which has had a direct bearing on my own early career interest and lasting commitment to research spanning aesthetic/ technological concerns in glass art.

The Libenskýs were able to work in the nationalised Železnobrodské glass factory on State commissions and to 'immerse themselves in technological questions of glass art' (Šetlik, 1994, p.29).

Underneath this 'technology cover' they were able to pursue their shared artistic vision wholeheartedly. Objects in glass which would have previously been rejected by the State as an expression of Western 'formalism' could now be produced and accepted (ibid p.29). Once again glassmakers were able to enjoy

a sense of freedom despite the confines of their client, in this case the Communist State. It is interesting to reflect back to the unique position of the glassmakers in feudal society described earlier and to compare this with a contemporary environment where material based art practice can give voice/draw attention to a range of issues.

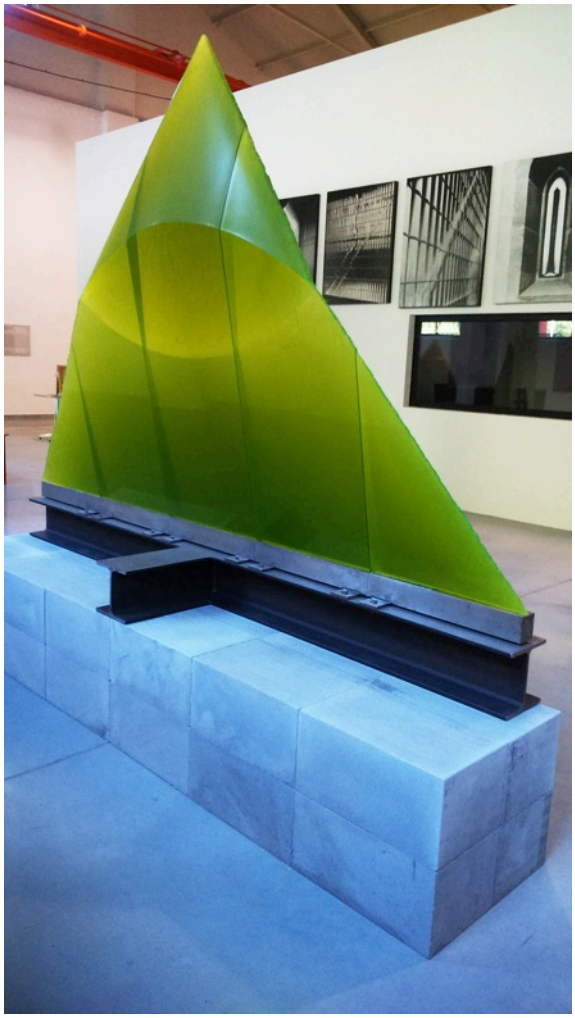
Alongside Libenský and Brychtová, a highly specialised and skilled team developed at Železný Brod. The team worked intensely together experimenting and developing technical expertise to realise the ideas and ambitions of the Libenskýs. Together they were able to produce many of the iconic Libenský / Brychtová works that now reside in Museums and collections all over the world. Translucency, tonal variation and response to light are key qualities in their work. Thick and thin areas of glass within abstracted massive forms comment on the human condition and these works and their meaning have impacted a whole generation of glass artists, including me, who have followed and developed their principles.

Šetlik (1994) writes that the Libenskýs were artistically 'impelled to rediscover and to express in their work the artistic influences of Expressionism, Cubism and Surrealism, which had been realized in earlier Czech painting, sculpture and graphic design'. Later he writes that they 'were particularly attracted to Cubism which opened new concepts of shape and space' (Šetlik, 2002, pp. 25-7). They expanded on and applied Cubist concepts in order to create large scale cast glass sculpture and glass for architecture. Šetlik goes on to describe how 'Cubist theory made a comeback in the Libenský and Brychtová's geometric and stereometric compositions of the 1970s and 1980s' (ibid pp.25-7). Their relationship with Cubism was 'As a formal point of departure, as well as concise philosophical reference,' and 'Color value, in relation to light, became a means of expression, ranging from high density to transparency. Libenský and Brychtová also employed elements of Cubist construction to evoke the impression of simultaneous viewing from various angles' (ibid pp. 25-6). This particular combination of colour value in relation to light expressing and exploring form and philosophy of Cubist construction and simultaneous views underpins the Libenský/Brychtová approach to making glass art. The use of

glass as the expressive medium and its translucency and reaction to light is a key difference to the mainly two dimensional approach centred on pictorial space of other Cubist artists and predecessors of Cubism including Picasso, Braque, and Cezanne.

The experience of being taught within this philosophy has left lasting impact on my own approach to research and making amongst a group of well-known Libenský graduates. It has in turn influenced my own teaching of glass casting and therefore subsequent generations of students in the UK and other countries in which I have taught, as well as having lasting impact in Czech glass education.

My own approach in practice and as an educator has and continues to follow a unique path of influence. No other non-Czech students taught by Libenský during the soviet regime, (and there were only one or two from others countries), have carried on developing their artwork and/or teaching based on Libenskýs philosophy in the way that I have. Experimentation with recipes and methods for refractory mould making, and continued research, exploration and innovation pioneered by the Libenskýs in glass casting, has shaped my own development. I have used digital technology as an addition to physical making techniques to challenge the scale, complexity and fineness of form; pushing forwards the boundaries of what were previously ‘unmakeable’ shapes to produce micro scales of artworks.



29. Libenský / Brychtová, *Green eye of the pyramid*, 1993, at Libenský and Brychtová's Museum Železný Brod

30. Angela Thwaites 2016, *Tiny Amber Biclops .* Photo D. Lawson

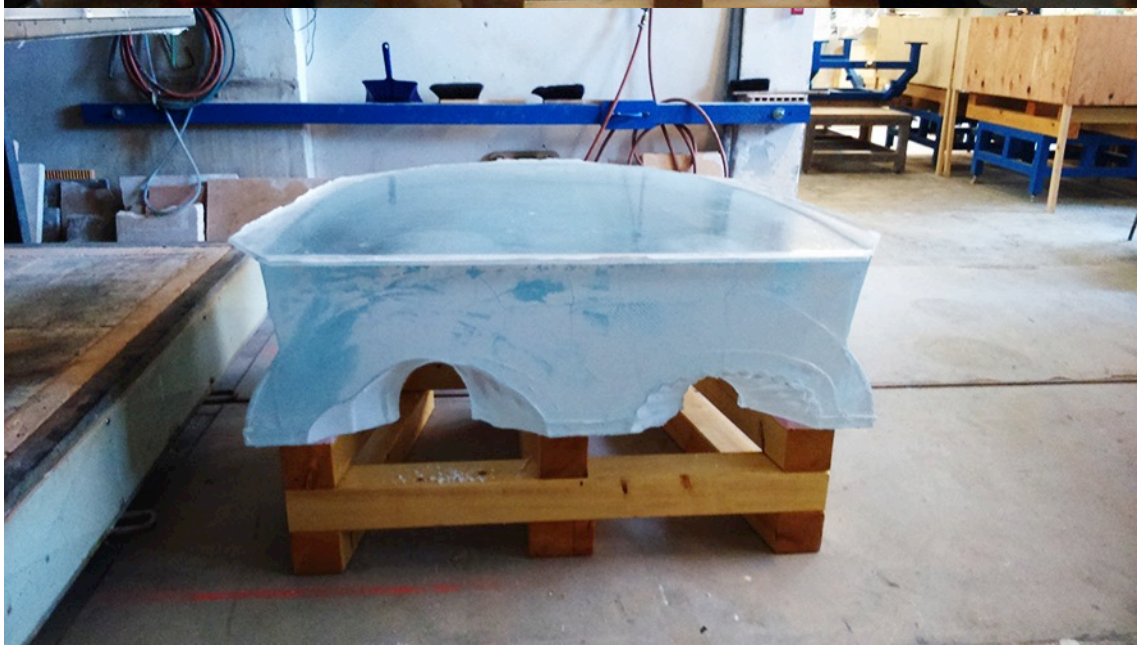
3.2.5 Czech glass Education and post Velvet Revolution

Skill acquisition and practice were key to the Czechoslovak education system. These skills were nurtured in young students who started to specialise in glass at middle school, at the age of about 14. This education could lead in several directions, technical, artistic, academic. Those students who desired to become artists applied to the Academy and often had to apply numerous times before being accepted. The study was usually for six years, during which time students continued to develop their skills whilst also studying drawing, design aesthetics and the philosophy and history of their subject. The breadth and depth of this educational approach has given generations of artists an incredible body of knowledge and experience from which to develop their practice. This has continued to feed back into the education system as well as outwardly into studio and industrial glass production and into academic and research fields.

Aspects of this pedagogical methodology relate to that of the Bauhaus, which existed in neighbouring Germany. The Bauhaus; founded by architect Walter Gropius in 1919, based his school of art and craft on a radical core concept: ‘to reimagine the material world to reflect the unity of all the arts.’ (bauhausmovement.wordpress). This utopian vision for a total union of art and design evolved new pedagogical approaches which have had far reaching influence in art and design education across the 20th and into the 21st Century. The Czech system, reflecting this ideal, takes students from a younger age and focuses their attention on one specialist material skill and knowledge area at this key early stage of their education and development. One of the key Schools for glass in Železný Brod was founded in 1920 very close timing to that of the Bauhaus.

After the Velvet Revolution in Prague 1989, everything changed again. The state was no longer in control, glass workshops and factories could produce and trade freely, and individuals could work as freelance artists, designers and makers. The management of the special casting workshop founded by Libenský and Brychtová in Železný Brod was taken over by Zdeňek Lhotský in 1994, one of Libenský’s own students from Prague. Lhotský s.r.o continues to develop its reputation and business in an international sphere through the legacy of

specialist skill and knowledge of casting of glass on a massive scale. It also continues to innovate both through the use of technology and process and also in aesthetic terms in collaboration with artists nationally and internationally and in co-operation with other regional glass companies and producers.



31. and 32. Lhtoský s.r.o., 2016, casting the Royal Danish sarcophagus

Although change affects everything, including education, Glass schools and Academies (Bratislava, Brno, Kamenický Šenov, Nový Bor, Prague, Železný Brod, Zlín) continue to teach glass programmes and the Libenský legacy is still tangible. Glass factories are recovering from the fierce competition from

cheaper Chinese labour and production costs. Artists are still producing and exhibiting glass art with expressive and contemporary qualities. Based on strength and success over more than a thousand years, Czech and Slovak glass is alive and developing through current restless times and on into a digital/post-digital era.

33. Klára Horácková, *Vénec* (Wreath), 2012, at *Femme Fatale* exhibition, Museum of Glass and Jewellery, Jablonec nad Nisou, Czech Republic, 2016.

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33.a Studio Dechem, 2012, *Pan Plaminek*, (Mr Flame), exhibited at Museum of Glass and Jewellery, Jablonec nad Nisou, Czech Republic, 2016.

3.3 Personal context: previous research and practice

The sections above outline the key influences of Czech glass history and the impact of major artistic movements, particularly Czech Cubism and its effect on Czech glass and the work of Libenský/Brychtová. The following sections outline the connection and importance of this history to my own education, practice, research and to the evolution of this PhD project.

3.3.1 Early education

My early art education in the UK was predicated on pedagogic principles from the Bauhaus, Modernism, and the work of iconic sculptors including Henry Moore (1898-1986) and Barbara Hepworth (1903-1975). Both of these world

renowned artists have exerted significant influence across subsequent generations of sculptors working with casting.

Hepworth's sculptural forms are described as relating to but 'never describing' real things such as the human figure and landscape. The distillation process of real to abstract form is portrayed in a film made by John Read on Barbara Hepworth, (BBC, 1961) in which Hepworth states 'what one does springs from a profound response to life itself' and 'I the sculptor am the landscape'. Connections can be made between this approach and that of Libenský and Brychtova through to my own working methods of developing form.

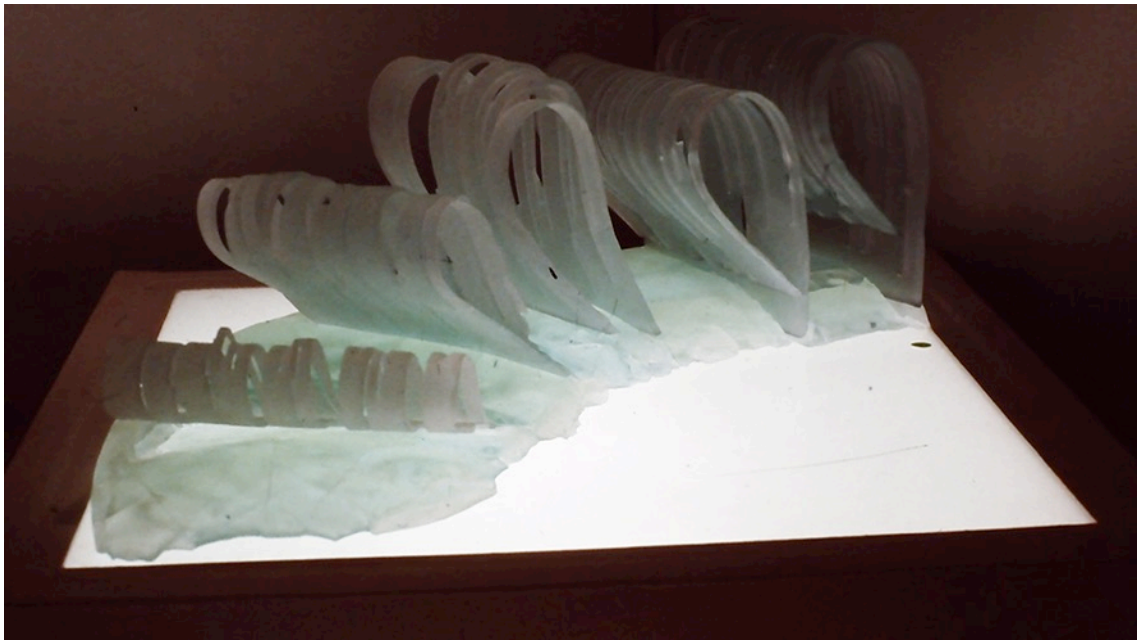
34. and 35. Image of Barbara Hepworth Plasters, Hepworth Gallery, Wakefield. (Photo, A.Thwaites, 2018)

As part of my approach to sculpture, I was initially very interested in the potential of clay as a medium and enrolled at West Surrey College of Art and Design (WSCAD, now UCA Farnham) on a BA (Hons) in 3 Dimensional Design (1979-1982). The first year I worked with clay, glass, metal and wood from which I selected clay and glass to explore for the remaining two years of the course. Much of the ceramics I was exposed to as a student was heavily reliant on an aesthetic borrowed from historical Japanese and Chinese production,

carried on through the Leach tradition. Technical achievement was often privileged over expression or innovation.

After working with clay, glass was fascinating, mercurial, particularly in relation to light, and the potential of transparent and translucent colour. It offered a vast range of creative and expressive possibilities which even the finest porcelain could not match.

36. Angela Thwaites 1982, *Wrapped Vessel*, Hand built Porcelain with inlaid colour, salt glazed, approx. 40cms high



37. Angela Thwaites1982, *Wave*, Slumped, saw cut and slumped again, float glass, approx. 100cms long

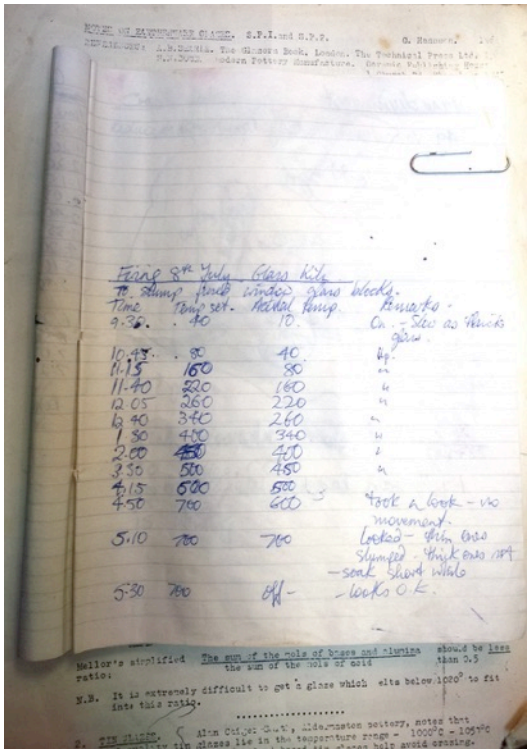
38. Angela Thwaites1982, *Hemisphere Bowl*, kiln fused cane work embedded in blown glass, approx. 25 cms diametre.

This was the late 1970s and the studio glass movement was still new and small, although it was quickly gaining momentum internationally. One of its main attractions was the free and lively use of material as an expressive medium.

The studio glass movement centred on the immediacy of hot glass with an ‘anything goes’ attitude to form, colour, and technique. Although the energy and expressiveness of this approach appealed to me as did the fluidity of glass as a material, the amorphous forms and attitudes did not fit my aesthetic aims nor my preferred way of working. So I chose the lesser-known and more challenging direction of kiln formed glass where I identified greater potential for exploration of subtleties of form, surface, colour and light play.

In the UK, Keith Cummings, who was teaching at Stourbridge (now University of Wolverhampton) and Charlie Bray in Sunderland, were the only known practitioners to be experimenting with and teaching kiln formed glass processes in the late 1970s early 1980s. At this point there was little knowledge or experience of casting glass at WSCAD and no ‘off the shelf’ materials produced for kiln forming in the UK although Bullseye Company was just beginning to manufacture sheet glass in USA.

I had access to glass from the furnace and window glass at the College, and I could buy a limited range of sheet glass made for stained glass purposes. There was little or no information on compatibility, annealing and cooling or model and mould making for casting glass. Keith Cummings first book, ‘The Technique of Glass Forming’ published in 1980, was the sum total of printed text to which I had access as I started on the long journey of learning to kiln form glass. Due to this lack of information, many of the kiln forming experiments I carried out initially were unsuccessful. As a result I quickly developed a systematic practice of experimentation and detailed documentation in order to build my own resource. Thus the basis for my interest in research was formed early in my education, though ‘research’ as a defined term was not used in Art and Design in UK Higher Education Institutions until the 1990s.



39. Angela Thwaites, 1981, kiln firing notebook

39a. Angela Thwaites, 1981, Coloured paper collage

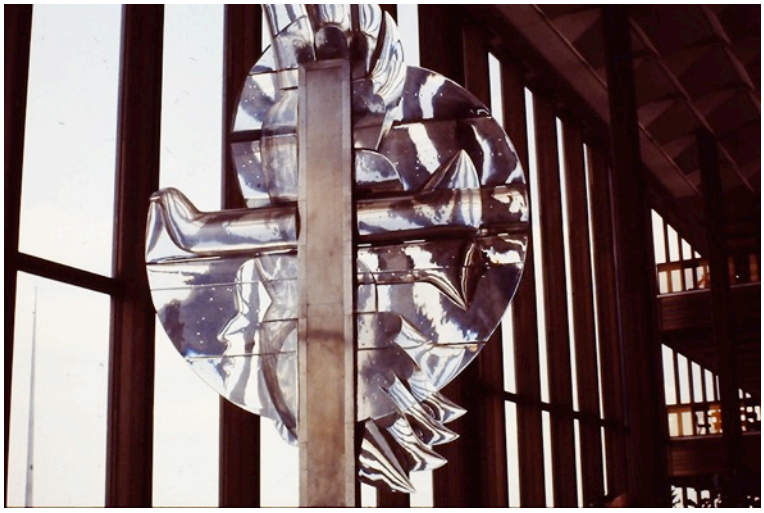
Ray Flavell and Stephen Procter, my tutors in glass during the 1980s, were established, internationally active artists themselves, and brought this perspective to WSCAD through the many international artists who came to demonstrate, lecture and work with students. So it was from early on in my student experience that I identified the need to explore further afield in order to develop my practice.

Encouraged by Flavell and Procter (1946-2001), I attended a master class in kiln formed glass taught by Klaus Moje (1936-2016) at the Pilchuck Glass Summer School Seattle, USA in 1981. Pilchuck itself was only a few years old, having been established by Dale Chihuly (1941-) and a core team in the late 1970s.

As well as benefiting from Moje's experience and teaching, which had a significant impact on what I was able to achieve during and after the class, I also encountered the very early hand based production of Bullseye sheet glass in Portland, Oregon, developed specifically for kiln forming processes. This amounted to clear and about five colours of hand rolled sheet glass which were inter-compatible with each other. For the first time it was possible to work with combinations of transparent colours including red, a holy grail in glass making terms. This radical shift opened up new possibilities for successfully designing and making stable glass objects, without losing transparency or colour and without stress cracking through incompatibility.

40. Angela Thwaites1981, fused Bullseye glass made at Pilchuck,, Masterclass with Klaus Moje.

After completing the masterclass at Pilchuck, I travelled around the USA and visited the Corning Museum of Glass, New York state. It was here that I first encountered the monumental glass sculpture of Libenský and Brychtová. The powerful presence of these monolithic glass forms, cast as one mass into one mould, still fascinates and inspires artists, glassmakers, collectors and historians decades later. This encounter with ‘Meteor, Flower, Bird’ (1980) proved to be the single most important influence on my practice and its impact continues to resonate throughout this research project.



41. Libenský and Brychtová 1980, *Bird* 290cms high

Once back in the UK, I reflected and acted on the experience from USA, understanding that there was so much more to be explored and achieved in

cast glass. So I started to plan for the next stage of my education and development, searching for funding and an appropriate location to do an MA.

3.3.2 Masters study in Prague, Czechoslovakia

I graduated in July 1982 and in Spring 1983 was awarded post graduate scholarship funding to attend the Academy of Applied Arts (Vysoká škola uměleckoprůmyslová, VŠUP) in Prague, (now using the title in English of Academy of Art, Architecture and Design, AAAD) under the tutelage of Professor Stanislav Libenský. As a student of VŠUP, I not only had access to studio and facilities at the academy but was introduced to the Libenský/Brychtová studio at Železnobrodské Sklo and various other glass factories, studios and artists working in what was then Czechoslovakia. With support from the state owned factory, including a team of technicians, Libenský and Brychtová had researched and innovated highly successful methods of casting glass on a monumental scale for sculptural and architectural installation.

Šetlik (2002, pp. 25-7) describes how Libenský and Brychtová's geometric and multi view point compositions of the 1970s and 1980s reflected their relationship with Cubism through form, philosophical reference, and colour density in relation to light, which became a means of expression, ranging from zero transmission to full transparency. They expanded on and applied Cubist concepts in order to create large scale cast glass sculpture and glass for architecture which resulted in a completely new visual vocabulary for glass and sculpture.

42. Angela Thwaites, 2005, *Dawn and Dusk*, from *Czech and Slovak Glass in Exile*, photo Robert Taylor (catalogue .p83)

In the context of studying in Prague, drawing and making gave me a language in a country where I had to start from scratch verbally. My own visual language, with an emphasis on 'real world' starting points distilled into abstract form, devoid of superfluous decoration, the formal use of planes, crystalline shapes, deformation and compression and the principle of 'one mould one melt one colour' developed as a result of Libenský's teaching. His philosophy, based on principles from painting, sculpture and architecture across cubism, constructivism, and expressionism has been a strong influence on kiln formed glass practices and several generations of his students, including me. This is documented by historian and authority on Czech Glass, Dr Sylva Petrová, in the catalogue accompanying the exhibition 'Czech and Slovak Glass in Exile' (2007- 8) which she curated;

> *Although Angela Thwaites is internationally known as an English glass artist, she has always had a strong personal relationship to Czech glass. She was quite exceptional among non-Czechs who attended Libenský's studio at the Academy (Ibid p.80).*

3.3.3 Back in the UK

Returning to the UK from Prague, in 1985, after two years living and studying under a Communist Regime, I was faced with the immediate and stark contrast of Thatcher's Britain. Establishing my identity and voice as an artist against this background was problematic. No-one in the UK had any experience or indeed any idea of what Czech glass really was and the new aesthetic with which I was working was misunderstood and in some cases regarded with suspicion. I started in a studio alone but very quickly sought shared situations not only to survive financially but to find like-minded company with whom I could share ideas, knowledge and artistic values. The first shared studio was in East London with Gayle Matthias and three others, and later with Emma Woffenden in south London.

A few exhibitions and galleries gave me the opportunity to show, though time and again my work was rejected as it did not fit in to an 'English' notion of Craft nor of Fine Art. I avoided these hierarchic descriptors and the limits they

imposed and my practice grew in the space between ‘the central reservation of the motorway’ spanning craft and art practice seamlessly. It was in this ‘in-between’ space in the early 1990s that I met Max Jacquard, Gaby Kienle, Matt Durran and others who had similar thinking and approaches to their glass art practice. Glass as an art-form has lain outside the realm of the fine arts and is never wholly within the crafts tradition (Jacquard, 2004, p.4).

As a result, New London Glass (NLG) formed as an independent platform to develop and exhibit, and together the group initiated, curated and staged a number of highly successful exhibitions and events. The first exhibition which launched the name ‘ New London Glass’ was at Candid Arts in Islington (1998) and included works in glass and mixed media from about 35 artists.

NLG worked closely together for about 10 years creating a distinctive portfolio of events and exhibitions including two in Barcelona, two for Gloucester Road underground New Platform for Art initiative, a large scale intervention at the Great Eastern Hotel and the ambitious Anglo-Hungarian Collaboration ‘Fragile Cargo’ which toured five venues across four European countries (2004-5). The works made for these exhibitions and sites varied enormously, presenting challenging opportunities for me to create and show a great range of artworks and to expand and master techniques beyond those of my studies.

43. Angela Thwaites, 2000 *Deadly Aspect*, exhibited at *Sub-Urban*, New Platform for Art, Gloucester Road Tube station.

3.3.4 Teaching and research, ‘Mixing With The Best’

Alongside development of my own practice as an artist, teaching across many different contexts and institutions over nearly thirty years, has given continuous opportunity to apply and to re-examine Libenský’s teaching and artistic philosophy. After teaching in Adult Education, I became a lecturer at University of Wolverhampton, during which time I gained a more detailed understanding of Keith Cummings work and pedagogical legacy. By this time Cummings was a Professor and research was established in art and design in a Higher education context in the UK, and the Arts and Humanities Research Board (now Arts and Humanities Research Council, AHRC) had been set up.

In 1999, I was appointed as a researcher at the Royal College of Art, funded by the AHRB. The project I worked on was an ‘Investigation and Comparison of Contemporary Working Methods and Mould Making Materials for the Kiln Forming of Glass’ which was published as ‘Mixing With the Best (MWTB)’ in 2002. As well as practical research, testing and documentation, a key part of this research was an International survey of contemporary practice. This

included face to face visits, phone calls, interview by email and paper printed questionnaires.

Visiting some of the Czech glass casting studios for the project, now more than a decade after the Velvet Revolution had ousted the Communist Government was a revealing experience. In some ways everything had changed, however, regarding materials and practices, not much had or indeed has, changed. This came as a surprise as the Libenskýs were such innovators, though, of course, with the overthrow of the regime so went the state funding for research. Workshops became privately managed and materials and commissions could be sourced from an International market. However, many practitioners continued to use the same methods and materials from the 1980s.

Ten years after MWTB, I was commissioned by A & C Black (now Bloomsbury) to write a book based on my research which was published as 'Mould Making for Glass' (2011). Writing the book coincided with my being in an academic post at De Montfort University (DMU) which, as a Polytechnic, had been one of the first Higher Education Institutions to run a glass programme in UK. Although Design and Architecture programmes at DMU already embraced digital technologies, the question of how to engage Design Crafts students, who were focussed on making by hand, towards working digitally, was unanswered.

In 2013, Jonathan Keep came to DMU to give a lecture and demonstration and I saw 3D printing, live, for the first time. This experience and the need to build and expand on what was possible using the Libenský's philosophy provided key impetus for the overall question posed by this PhD project.

3.4 The importance of making

As seen in the previous sections of this chapter, making does not exist or evolve in a vacuum: It lives within its own time as well as building on its past. Key learning from my Czech experience was the impact of politics, hand in hand with social and economic factors, on the life of an artist/maker.

As part of my practice and expressive voice as an artist, it is important to define the position from which I am working. To show this in more depth, I want to explore the key qualities of and issues around making which frame my unique identity as an artist working in glass in a contemporary environment.

3.4.1 *The Power of Making*

> *Making is the most powerful way we solve problems, express ideas and shape our world… It is one of the strongest of human impulses and one of the most significant means of human expression (Charny, 2011, p.7).*

The clarity and strength of these statements by Daniel Charny, curator of the seminal exhibition 'Power of Making' (2011-12) sums up the enduring importance of the role of making in the 21st Century. The exhibition included over 100 objects and artefacts drawn from a broad range of contexts. The accompanying catalogue fast became a key academic text which further interrogates and develops Charny's opening statements, firmly placing making at the heart of modern society. The essays in the catalogue echo and balance each other under the overall title, while expanding on sub-themes and discussions: making as research, making as well-being, making as agent for social as well as personal change, and the future of making and its role in shaping the world.

All of these areas can sit easily under a heading of 'politics': 'the science and art of government' (Pocket Oxford Dictionary, 1984, p.569). The use of the word 'art' feels significant here indicating the need for a creative approach to the functional imperatives of managing public life and affairs, just as an artist/maker employs a creative approach to the 'what' and the 'how' of making artworks. The etymology of the word politics is modelled on the title of Aristotle's text 'Politika' meaning - 'affairs of the city or state' (etymonline.com). The backdrop of city/state affairs has ever presented the artist/maker with an edgy mix of risk and opportunity and a key role in shaping, shifting and influencing urban environment and culture.

3.4.2 Making as wellbeing

Martina Margetts, in her essay ‘Action not words’ (Power of Making, 2011, pps. 39-43) describes making as ‘a revelation of the human impulse to explore and express forms of knowledge and a range of emotions’ and concludes that this is what shapes human action and the world we create (Ibid p. 39). Margetts expands this into the territory of well-being through making achieved through ‘ the recognition of making as in itself producing happiness, ‘flow’ and pleasure, experienced by the maker and transmitted through the work to the viewer’ (Ibid p. 39). This involvement with and impact on the audience as well as the maker is echoed by Adamson, where attention becomes commodity (Making Futures, 2017).

3.4.3 Making as Research

The broadsheet accompanying the ‘Power of Making’ continues ‘The knowledge of how to make - both everyday objects and highly skilled creations - is one of humanities most precious resources’ (Charny, 2011).

The theme of making as research to extend knowledge, capabilities and ideas is reiterated by Margetts: ‘The role of making is a sequence of actions that set in motion a curiosity to go beyond what is already known’ and ‘The hand’s sensitivity, developed over time, allows it to take the mind beyond its plan’ (ibid 2011, pp.40-43). Charny also reflects that ‘Applied thinking lies at the core of creating new knowledge of all kinds, and the sensibilities of making should increasingly be made a part of our future’ (2011, p.7).

Sir Christopher Frayling’s essay ‘We must all turn to the crafts’(2011, pp. 29-33) takes its lead from this now infamous statement from Walter Gropius, head of the Bauhaus, where the mistranslation ‘return’ has often been used to justify a nostalgic rather than forward looking view of making. Frayling, using the corrected translation ‘turn’, quotes Gropius’ ambition for craft as ‘research work for industrial production, speculative experiments in laboratory-workshops where the preparatory work of evolving and perfecting new type-forms will be done’ (ibid p.29). Frayling presses the argument forward on the necessity of

'com[ing] to terms with modernity - with the possibilities of digital technologies (for example 'industries of one')' within a contemporary context where 'the shifting borders of art [are] at one end and design at the other' (ibid p.31).

3.4.4 Making The Past And The Future

For thousands of years, makers have been developing respect and a system of values around making and materials. A value system existing around material origin and use, recycling and sustainable practices, described as a 'cradle to cradle' approach (Braungart and McDonough, 2002). This value system has history and continuity. It is shared, taught, passed on in a multitude of ways and contexts.

People becoming makers, regardless of age, background or experience, make a deliberate choice, and a political one, whether consciously or not. The backdrop against which this choice stands is stark and stormy in many ways as global economic and political bubbles flux, ferment and burst regularly. Moving through a highly industrialised, 'high tech', capitalist society, sharp light falls on the meanings and importance of making. According to place and circumstance both individual and societal, making in the 21st Century becomes a subject of much speculation, shifting paradigms, contradictions and in some instances chaos. This atmosphere is summed up by Bruce Sterling, science fiction author and techno-culture speculator, in his essay 'The Future of Making', (The Power of Making, 2011, pp.67-70). Sterling sees the handmade as 'stand[ing] out more sharply now, against a gaudy background of modern high-tech production - what might be called the 'Total Work of Commerce'.' (ibid p.67)

3.4.5 Making as Agent For Social Change

The voice and existence of individual makers and small scale making spaces can and does stand out bright against the current background of big business domination. As social media is increasingly used not only to inform and connect but to market and instigate change, it

> *'goes beyond a strategy to gain more business or respect, and relates to a more fundamental conviction … integrally linked to sustainability,*

> *presenting a genuine alternative to the 'closed' systems which created the environmental and social problems we face' (Holroyd 2014).*

The role and identity of a 21st Century maker as one of agency for change, discourse, connecting and bridging disparate opinions and communities is reflected in the strap line of the 'Making Futures' conference : 'Crafting a sustainable Modernity- towards a maker aesthetics of production and consumption' (2017). Keynote Adamson spoke of the importance of making and material interest in a digital age and this further builds the image of the maker as a powerful agent within society. He stated that 'craftsmanship as a tool to define new social formations' and 'making from the ground up' as key to 'slicing through the commodity chain'. He goes on to lay out new territories and responsibilities for the maker using 'Craft making as a channel for public attention' where attention is a commodity. There is no romance here, the maker cannot be an innocent bystander: 'when you are making you are never alone, you are surrounded by contingencies and issues - all materials, tools, etc come to us charged with political content'. 'How do we work with this and hold our own making in the balance?'(ibid 2017).

Towards answering this, I would add the issue of time, as while we are making we are accompanied by the past the present and the future and our courses of action need to be informed by an appreciation and understanding of these simultaneously. Anthropologist Daniel Miller discusses the need to understand history in order to understand contemporary contexts

> *no suggestion that we should forget long centuries of skill and labour. Indeed, these artisanal traditions are juxtaposed with contemporary decorative arts … this single object, the 3D printer, represents perhaps the most profound challenge to what we today call 'crafts', because we will be able to make things with it that presently can only be created by hand (Ibid p.15-16).*

The level of responsibility here starts to feel heavy, but Adamson responds with 'do not be demoralised by the scale of the problem' (2017). It cannot be carried or solved by the individual but by a sharing of values and appetite for change - a group sense of responsibility and an atmosphere of openness and transparency.

An aspect of this responsibility can also be shared with the audience. Using objects to draw their attention to wider issues, Adamson cites Clare Twomey's redirection of public attention at points in the commodity chain. Through the making and exhibiting of blue ceramic birds with the phrase 'Do not touch, take', at the point where Wedgwood jasper ware was about to become extinct, Twomey poetically and precisely focuses attention on a raft of issues: the demise of ceramic manufacture in the UK, the loss of skilled jobs and specialised knowledge, the loss of history of Wedgwood and its context. The implication of all these things is condensed into, and ripples out from, small clay objects: the power of making and meaning through making in action.

3.4.6 Making and the post human

In this increasingly post human world, where technologies are fast enabling automation and robotic production of all kinds of things from everyday goods to precision medical and engineered parts, the act of making takes on poignant significance:

> *The explosion of robotics has given the demand for UBI [unconditional basic income] renewed currency. Credible estimates suggest that it will be technically possible to automate between a quarter and a third of all current jobs in the western world within 20 years. At the very least, this will accelerate the trend toward the precariousness of jobs and income. At worst, it will make a sizeable share of the population redundant (Skidelsky 2016)*

This prediction represents a massive shift in a short space of time which could be seen as a threat to human livelihoods, role and existence in the world. However, change presents opportunities as well as potential threats. A sense of the present the future and 'the new' in glass, a field which has lost much of its once glorious industrial production is given by

> *'new directions as ways of understanding and developing the heritage of glass in new - e.g regional, entrepreneurial, or artistic - contexts, which challenge our perception of identity and authenticity.' (Johnsen, 2016, p.9)*

This positivity is echoed in curator essays in the same exhibition catalogue, 'European Glass Context 2016', 'Glass as a literal and metaphorical lens into

culture, provoking new ways of seeing' (Sarmiento, 2016, p.146) and 'Even in an abstract form, glass can function on the same level as paintings …The repeatedly postulated boundary between applied and fine art is eradicated here' (Hauschke, 2016, p. 128). It is interesting to note that this lack of hierarchy was already in place in Czech glass heritage as described above and has deeply affected my own understanding and approach to working with glass.

3.4.7 Conclusion to this section

So in this thesis the word 'making' is used to locate discourse in an environment where making is going on with the hands of, and controlled by, one person covering all aspects of the process of creating an artwork. Placing importance on 'doing all the making' is one of seats of the 'Power' described above, giving access and control across all aspects of process which builds empirical skill and knowledge in the maker. It also allows for 'live' change and development of the idea/design and importantly can have cost and time saving implications.

This description can be extended to encompass historical and theoretical knowledge. Without an understanding of the past, the present and the future have no substance. In short, the maker needs to be multi skilled in every aspect and process from idea through realisation to market of an artwork.

In summary, material knowledge and skill are of key relevance and importance to all making. Skill can be seen as a broad range of knowledge, practice, method and philosophy applied consistently and rigorously towards clear artistic goals as an expression of the human condition. It is Makers and Artists who continue to be responsible for the perpetuation of skill and the sharing of ideas and knowledge across all borders whether they are economic, political, cultural or all of these. Innovation across technology and artistic areas is continuous and exerts influence now as it has always done in the past. In a post-industrial, post digital, post human climate, never has it been such a strong political, economic and social statement, to be a maker and to share and impart knowledge and skill.

3.4.8 Other views

As well as the focus on individual making, it is important to note other important making contexts. These include collaborative practices, socially engaged and participatory practices and the art of 'Not Making' where an artist/artists have an idea and others are employed to do the actual making or realising of the artwork. This is the territory defined in 'The Art of Not Making' (Petry 2012). Employing the labour of others is necessary in particular circumstances, for example the production of very large scale artworks, short time frames for realisation or where the acquisition of specialist skills is not feasible.

Increasing levels of abstraction in the everyday world where human observation is of perpetual change without finish or end, constant transformation and evolution without outcome. These experiences link to ideas of new materialism and nomadic lifestyles and working practices of the 21st Century.

This inconclusive, constantly changing atmosphere that is all pervasive in everyday living has resulted in a paradigm shift in art. Focus has gone from object to subject, from outcome to process. A prime example of this is 'Glasstress,' 'Not necessarily an exhibition, but rather a process in which the show is not a definitive outcome' (Berengo, 2013, p.9).

Zilber (2015) in her essay 'The object in Flux' describes the dramatic shifts which have taken place across the landscape of contemporary craft in recent times. She goes on to define the object as 'passive' and states that 'the very notion of autonomous, unchangeable and docile objects has shifted towards the consideration of crafted objects as informing and being informed by larger practice' (ibid 2015, p.9).

This shift away from object/outcome has, in certain current trends in glass practice, led to anti-craft notions, leading to a never ending loop of process and amorphousness: an existential crisis in making. Although these trends as a product of their time can have a legitimate role in provoking debate, they miss key points. One of these is the lack of understanding of and recognition of the importance of the roots of studio based making. Without this, re-inventing the

wheel is taking place which diverts attention away from bigger issues such as the future of making itself. It is not making just for the sake of objects that matters but the reason for making that matters. Projected onto a larger scale, making reflects the reason for living. I firmly believe that an understanding of history is vital, as without it, significant loss of knowledge occurs and mindless, needless re-invention takes place.

Not everyone agrees however, Berengo, creator of the international extravaganza 'Glasstress', is in some ways, 'anti-history'. He talks in a negative way of 'aesthetic stereotypes that have accompanied this material [glass] for centuries' and 'Here in Venice the history of glassmaking is long and glorious, scattered with changes and innovations that through the weight of tradition, inhibits our perception of it [glass] as an artistic medium' (ibid 2013, p.12).

Although this applies to Venetian tradition, it does not apply to other glass traditions. I would describe the legacy of Czech heritage in kiln forming glass as archetypal rather than stereotypical. As previously discussed, the Libenský/Brychtová artworks have a universality of form and meaning. Devoid of superfluous decoration and grown out of a humanistic starting point, the qualities of Libenský/Brychtová's sculptural work in glass

> *transfer[s] the influence of these works from the limited certainties of modern constructions to [the] broader context of our new age perception of the world. When such ideas and things come together, there emerge motifs, which go to the depths of cultures of many places and many times (Vlček, 2002).*

Berengo's vision for the future of Venetian glass is one fitting the attention economy of the present. He wants to bring back attention, re-focus knowledge and experience. To build again where once were jealously guarded secret formulas within families and the results of new experiments increased knowledge, 'Glasstress aims to be the quantum leap in this increase in knowledge, utilising the experience of extraordinary artists' (ibid 2013, p.13).

In my opinion this is anti-evolutionary, it undoes the unifying of maker/artist which has brought such liberation and depth to much 20th Century artwork, and

reinforces a renaissance type hierarchy of artist over artisan. Glass makers with the knowledge to create the actual work are not even named in ‘Glasstress’ and the ‘artist’ who may have had no responsibility beyond the initial concept of the work takes all the credit. This can only be seen as a backward step and is not an opinion shared by historians and academic authorities on glass:

> *The creation of glass objects without previous experience of glass execution seldom brings outstanding results: it is attractive rather than convincing (Petrová, 2002, p.13).*

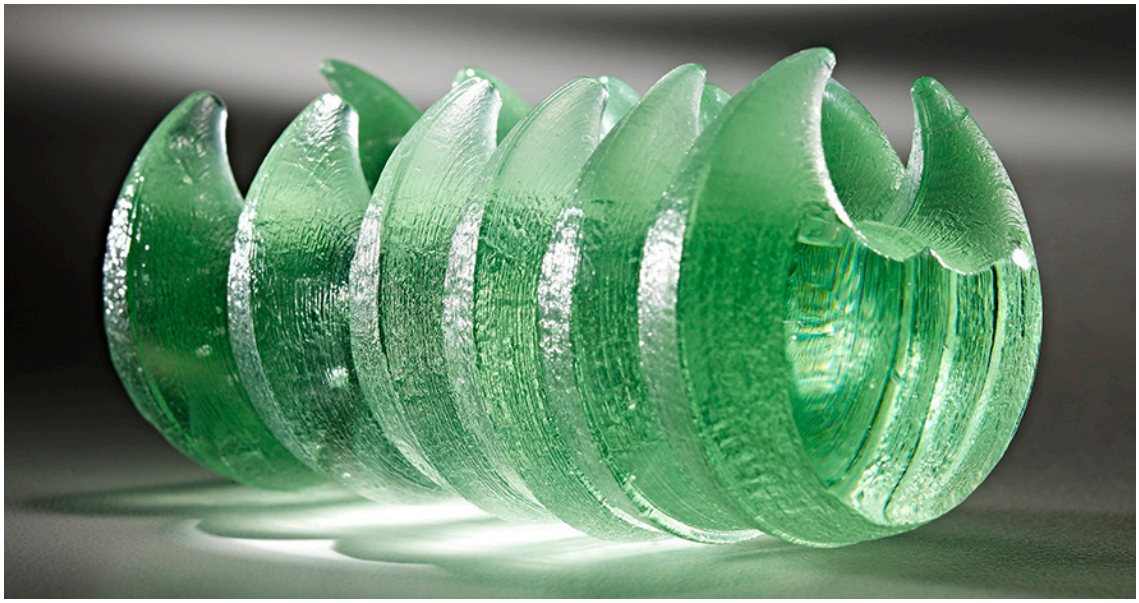
It is important then to consider the effects of adding digital methods into the historical analogue system of kiln forming glass. As well as liberating new content and language, this combination can also take us further down the road of open ended process. What was once an identifiably linear process has been replaced with a complex network of simultaneous, infinite choices, decisions and direction. This is exciting and risky at the same time. Clear intentions and decisions are essential to maintaining focus and not becoming lost in layers of complexity with no way out and no outcome. Several of the series of artworks created as part of this project are physical embodiments of this layered complexity and can be read metaphorically as warnings against losing the way in process – an indication of the boundary of the truly ‘unmakeable’.

‘Collaboration through Craft’, (Kettle, Felcey, Ravetz, 2013) analyses the philosophies, politics and practicalities of collaborating through making. The book itself is a collaboration and includes essays by established makers, curators and writers. Internationally reputed anthropologist and author Tim Ingold of Aberdeen University, says of the book:

> *Nothing is ever made without collaboration. Yet we continue to believe that every work is the product of a single hand. This book turns the belief in single-handed creation on its head. It shows that collaboration is not incidental to the crafting of things but the very power that drives it forward. Together, the contributors succeed in raising craft from its backward-looking association with traditional skills to where it belongs, as a dynamic, generative principle at the core of social and cultural life (Ingold 2013).*

The following images 44-47 show examples of glass artworks made as part of this PhD research investigation. All of them were modelled using Rhino then 3D prints were made which were used to cast glass. They conclude this chapter of the thesis on Creating a Context : Engaging Czech Heritage in New Kiln Formed Glass by providing aiming to reflect key qualities of Czech glass heritage : colour, form and monumentality, demonstrated on a miniature scale produced using digital technology as well as analogue processes. These artworks represent new methods and ideas in making kiln formed glass and refer to opinion I have offered in this chapter on the power and importance of making, the re-assertion of the object in art and the role of history and heritage.

44. Angela Thwaites, 2016, *Croissanty*. Photo D. Lawson



44. a. Angela Thwaites, 2016, Detail *Croissanty*. Photo D. Lawson

45. Angela Thwaites, 2016, *Blue Flat Globey*.Photo D. lawson

46. Angela Thwaites, 2016, *Amber Globey*. Photo D. Lawson

47. Angela Thwaites,2017, *Red Vessel*. Photo D. Lawson

Chapter 4 Methods and Approaches: Developing a Strategy for Making the Unmakeable

4.1 Introduction

> *The more man comes to know and understand glass, the greater is its degree of modernity and ability to interpret contemporary ideas (Libenský quoted by Kehlman, 2002, p.85)*
>
> *… established artists tend to push the boundaries of new technology into new interesting areas … rather than simply creating artefacts that are primarily products of the technology. (Hoskins, 2018, p.12)*

Putting the above quotations together, one from an artist focused on sculptural expression with glass as the medium, the other from an academic understanding of the potential of 3D printing in the arts; helps to map out my research towards making the 'unmakeable'. Although Hoskins goes on to describe 3D printing as a 'disruptive technology' he also comments on the slow rate at which this disruption is occurring through industrial manufacturing into desk top scale 3D printing and 'I can safely say at this point that currently no process offers what the user requires' i.e. a finished object straight from the printer (Hoskins, 2018 p.11). This aligns with the starting point of my research: to explore 3D printing as one part of the process of realising artwork in combination with analogue process. The combinations I have explore have made possible the creation of contemporary sculpture in glass with forms and structures which it would not be possible to make by analogue method alone.

This chapter records and reflects on the practical work carried out for this PhD study. Detailed documentation of projects and series of artworks are presented here as case studies of the practical investigation and experimentation carried out and relating to the contextual review. The approach taken to practical research has been developed using my prior experience as articulated in Chapter 3. The direction of the practical investigation, and decisions taken regarding testing and development of projects and series of objects created within it were guided by the methodologies described in chapter 1 and informed by the contextual review.

4.2 Technical Approaches

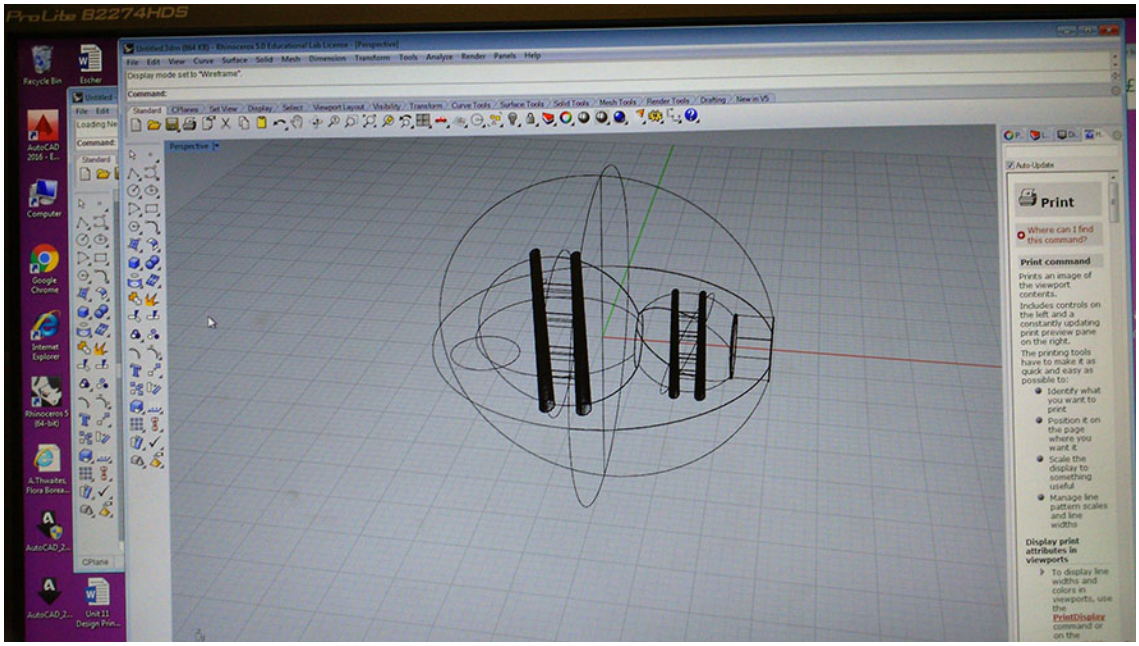
4.2.1 Drawing and modelling

Before starting this research, my practice had been entirely analogue. Starting to make had involved translating from drawings/sketches into three dimensions by taking a lump of material usually clay or wax and shaping, modelling, carving and refining it into a form. However, on a small scale, it very quickly becomes impossible to work the inside of a material model, simply because the human hand and hand tools cannot physically access the space inside the object. Working on the surface of wax or clay, once you have smoothed it over, the marks have gone forever, and even if a master model and mould are made, subsequent impressions or copies taken are never identical as the nature of the process involves many variables which will never be exactly repeated in the same way. Print is new to my practice. I started by exploring 2D as well as 3D print in relation to glass. This helped me to define what a print is and how to approach it as a process to explore new ground for 3D kiln formed glass.

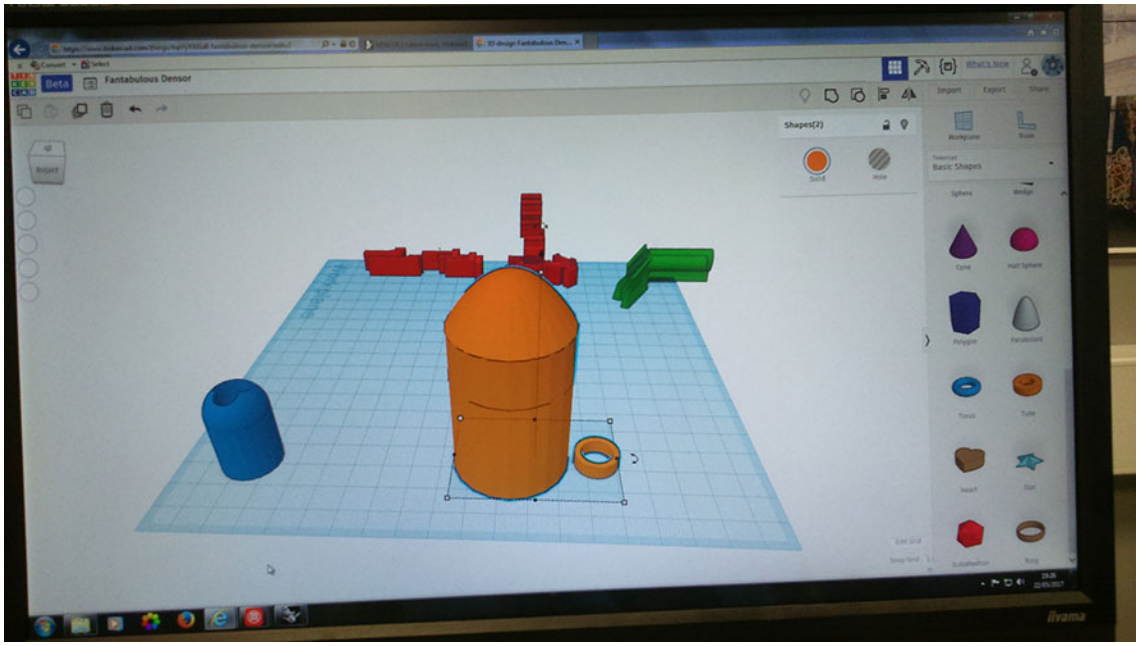
Royston Brown talks of ‘transpos[ing] an image into the physical world of materials and objects’ (ibid 2011, p.3) to describe his process working from a 2D starting point into a 3D outcome using print. The use of the word ‘transpose’ most usually associated with music, indicates change of a more subtle level than ‘transform’ which indicates a larger scale and type of change, from one form to another – a shape shift. The transformative potential of glass in its unique physical properties is a key aspect of my research and practice.

Using Rhino as part of this transformative process can be experienced as a point of division in thinking/making. CAD requires a completely different set of skills, knowledge and understanding outside of studio kiln formed glass practice, a practitioner therefore needs to be able to work in a very different way with Rhino or similar CAD software in order to be able to create original files to 3D print and transform into glass.

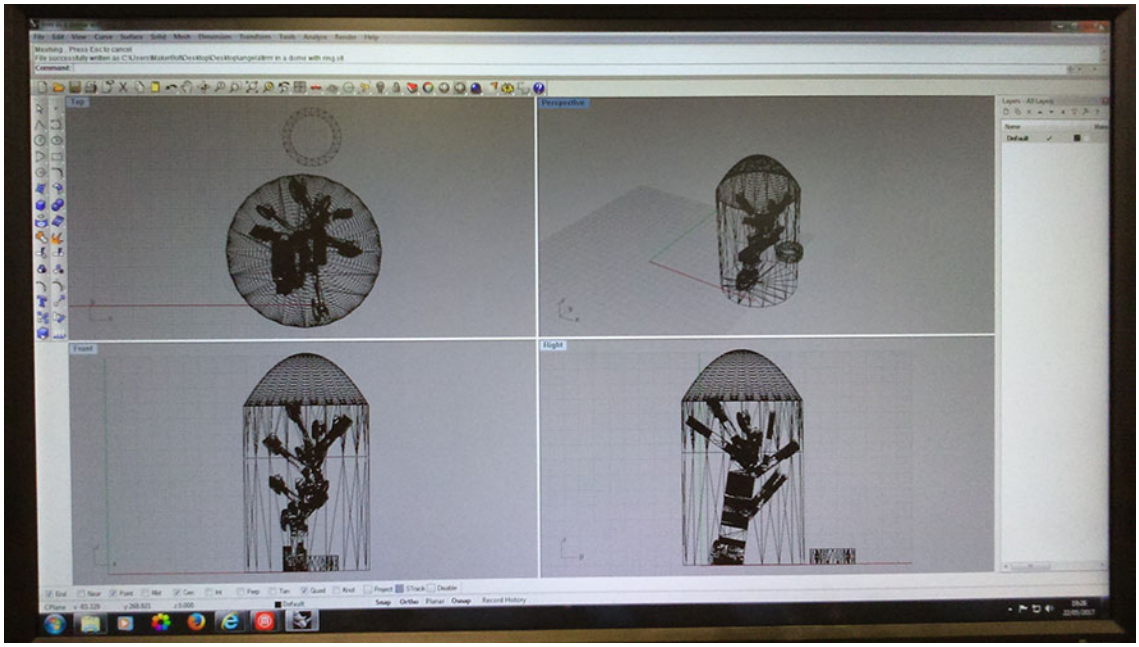
48. Hand drawn image in Sketchbook,



48.a. Transforming the hand drawn sketch through modelling in Rhino.



48.b. modelling on TinkerCAD

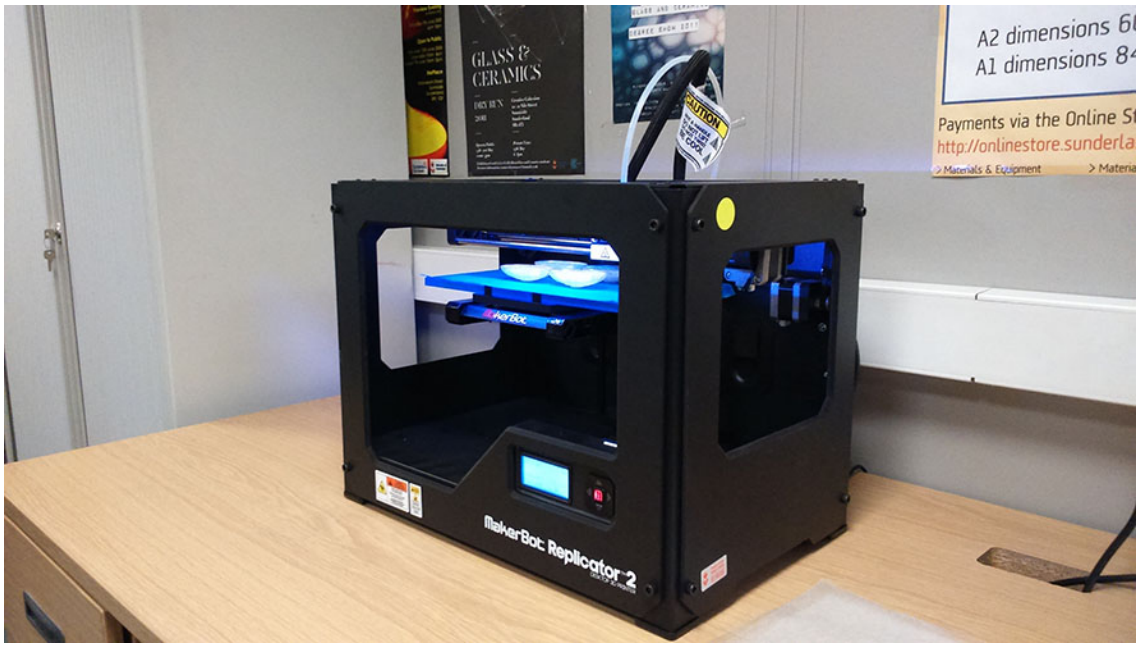


48.c. opening the TinkerCAD file in Rhino

4.2.2 3D printing

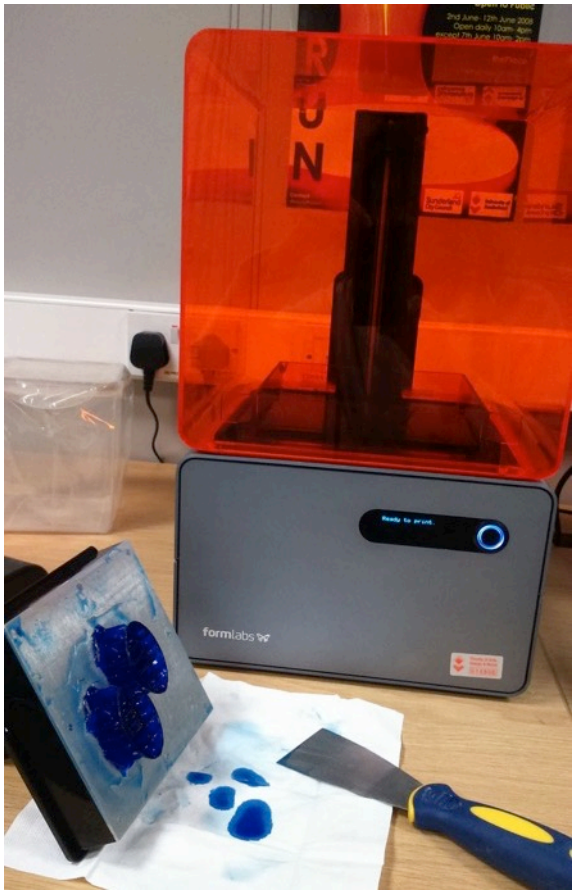
For this research, Rhino and TinkerCAD have been used to generate digital models, which have been realised physically using two main types of desktop 3D printing. These main methods can be understood by likening them to the formation process of stalactites and stalagmites, the first forming upwards and the second forming downwards. Makerbot and Ultimaker 3D printers used in

this project employ a process usually called FDM (Fused Deposition Modelling or FFM fused filament modelling or FFF fused filament fabrication). The print is formed by material extrusion creating an object in layers by depositing a heated thermoplastic from a computer controlled print head nozzle. The print forms upwards from the build platform which itself moves downwards to engage the next layer of the build.

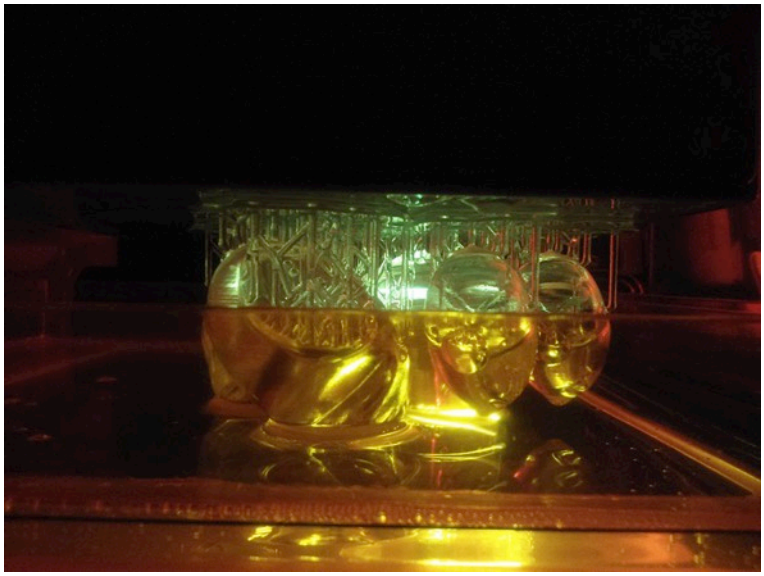


49. Makerbot Replicator 2, University of Sunderland,

By contrast, the Formlabs 3D printers used in this research are stereolithographic (SLA - StereoLithograph Apparatus). Stereolithography, the first ever 3D printing process, uses a computer controlled laser beam to build an object within a tank of liquid photopolymer (Barnatt, 2015, p. 52). The direction of the build platform is upwards. As it moves it dips into the liquid and a UV laser beam situated underneath the tank, traces the shape of the layer of the object. The platform peels away and shifts upwards to engage the next layer of the print. This results in a high level of accuracy and a smooth surface to the printed object.



50. Formlabs printer, University of Sunderland



51. 3D printing in progress, Formlabs clear resin

The rationale for using each printer was to achieve different levels of detail and resolution defined by the scale and complexity of each series of artworks developed.

Each of the different 3D print materials and printers has its own characteristics, properties and distinctive surface qualities, which I am describing as a ‘digital footprint’. From the filament printers this was fine and linear, showing the path of the layers of the filament from which the form has been built up. The Formlabs 3D printer results in an overall smoother, more neutral surface than that of the filament print and the print path and orientation are harder to see.

Supports are generated pre-print to facilitate prints with undercuts/overhangs. The 3D printers I used print only one material at a time, though there are now desk top 3D printers which can print two materials simultaneously. This gives options for using one material for the print itself and a second for the supports which could be printed in a water soluble material and washed away before mould making.

The main materials used for practical research were PLA (Polylactic acid) filament and Formlabs castable resin version 1 and later version 2. These materials were selected for their combustible properties which makes them suitable for a direct investment and burn out process. There are many types and brands of PLA, but the general melting range lies between 210-230 ˚C so it is easily removed from moulds at lower temperatures than the Formlabs resin. PLA is also documented as a safe material:

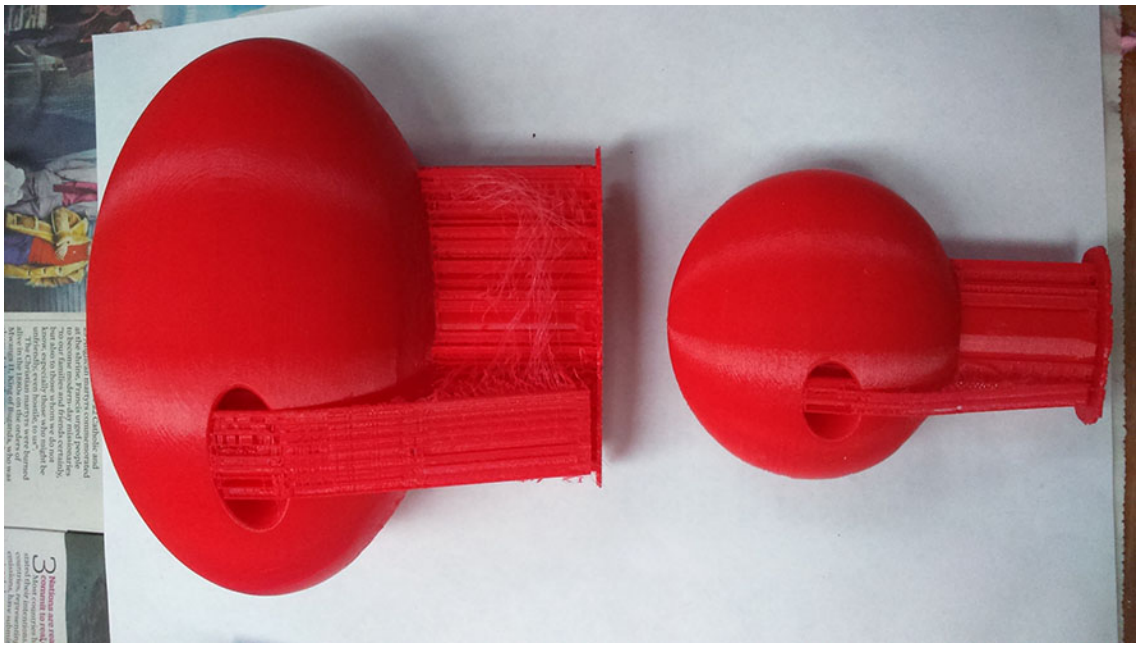
PLA tends to be the favoured build material in educational establishments as it does not emit any toxic fumes when melted (Barnatt, 2015, p.149).

The decision to use this sacrificial, burn out method was based on contextual review and previous research which showed that twice fired moulds resulted in superior surface qualities to the cast glass over a single firing approach (Thwaites, 2002 and 2011).

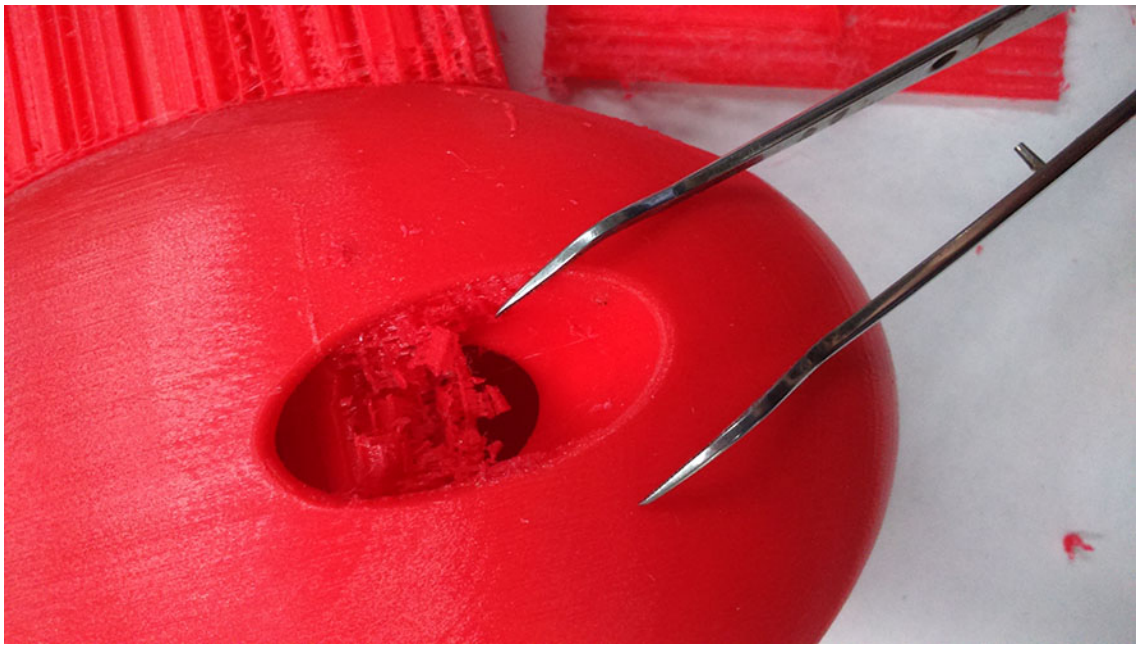
4.2.3 Mould making and casting

Once 3D prints have been removed from the printer, they are prepared for refractory mould making. This involves removing any imperfections and refining the surface if required. Experimentation has shown that using diamond files to

remove flaws works well. This is based on researcher knowledge transferred from glass making practice where diamond files are used to finish glass in a similar way.



52. *Eggys* with supports still on



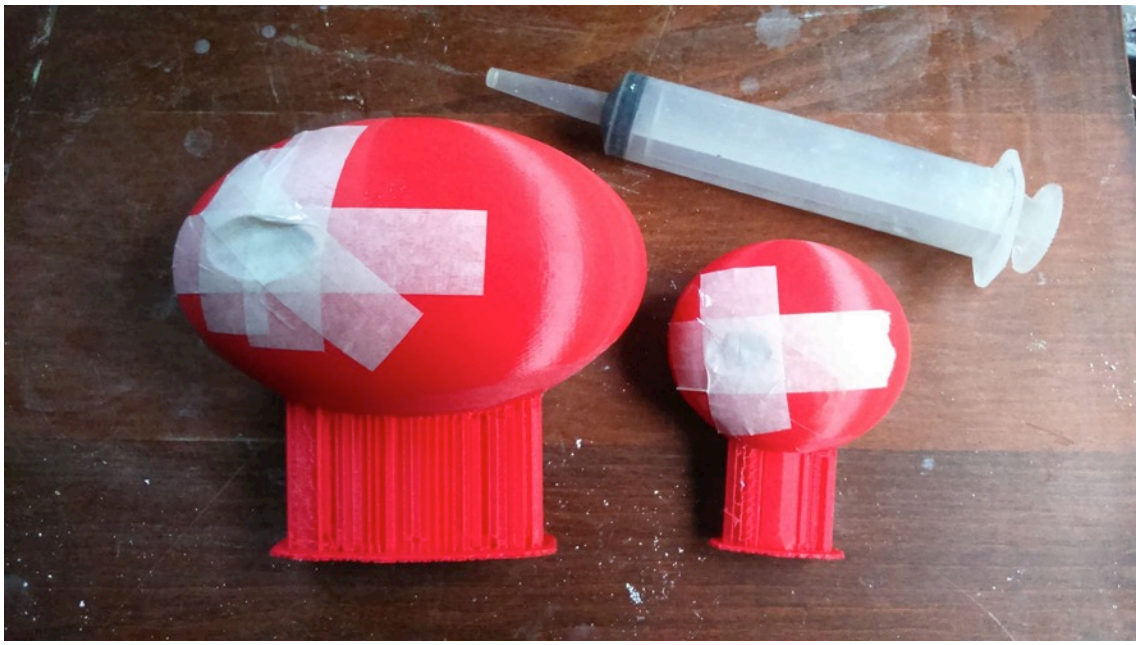
53. *Eggy* with supports being removed

The 3D prints are then set on a board using plasticine, a non-drying clay based material, modelled by hand and easily removed after mould making. The board with 3D prints firmly attached is then placed on a banding wheel or small

turntable allowing rotation, which facilitates even application of mould mixture. Plaster and powder refractory materials are measured out, dry mixed and added to a measured amount of water. The powder is allowed to settle, then stirred to combine thoroughly, preventing settling of the heavier powders and promoting the reaction of the plaster. Once the mixture starts to thicken and coats the back of the hand it can be applied to the model. The following application methods were tried.

1. Brush and spatula application
2. Cottling and pouring
3. Injection into inner cavities using a plastic syringe

Images of mould making in progress:



54. *Eggys* with taped openings and syringe

55. *Eggy* with mix inside

56 *Eggy* with first layer of mix applied

In each case a layered mould was constructed as findings from previous research showed these to be the most stable during repeat firings (Thwaites, 2002 and 2011). Various recipes from previous research and practice were adapted and developed to make refractory moulds.

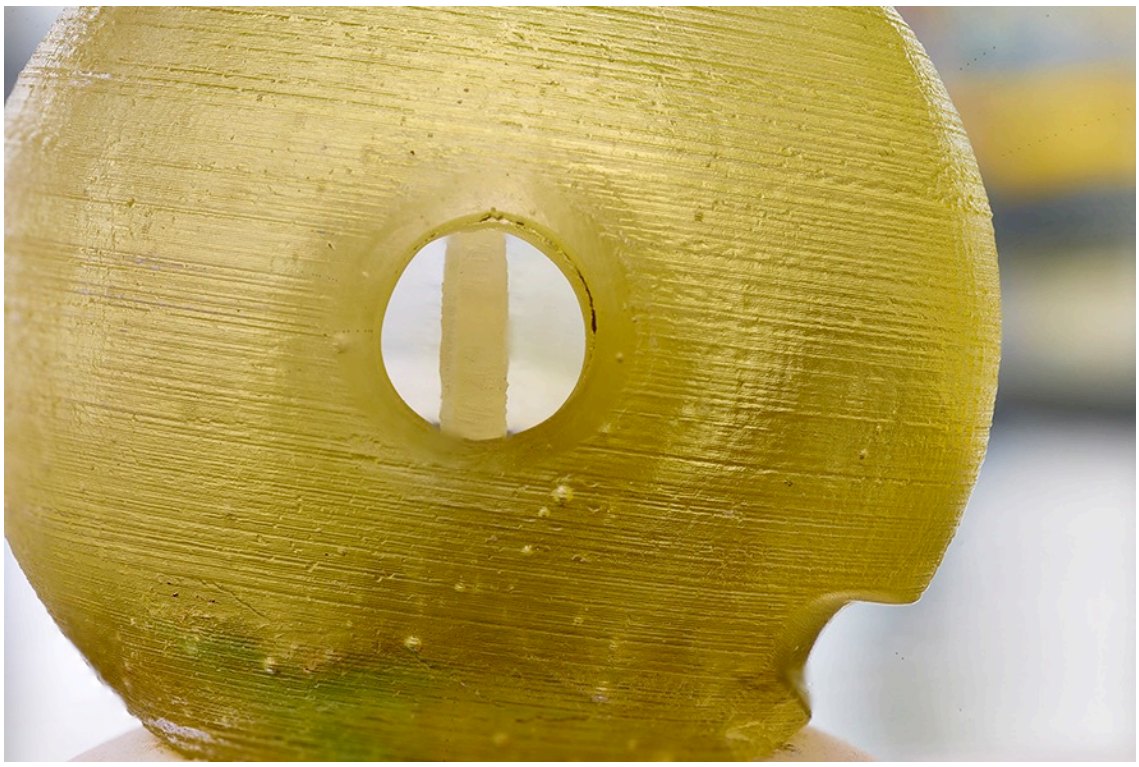
Once the refractory moulds had set, they were placed in a kiln and fired twice. The first firing was to ‘lose’ the 3D print and pre fire the mould. Moulds were placed upside down on pieces of refractory and the temperature was raised to the point where the PLA/castable resin melts and vaporises or burns away, leaving a clean and accurate cavity into which to cast glass. The second firing is to melt and cast the glass into the cavity of the mould, taking up the shape and space which the 3D print occupied. Various types of glass have been used some of which were new and some recycled from previous samples. Type and colour of glass has been carefully selected for each individual form and firing.

Approximately sixty firings have been carried out during this research across burn out and glass forming. Where at all possible, the same kilns have been used to reduce variables and ensure consistency of results and information derived from the firings. Firing schedules have been carried out taking account of the scale, complexity of form and type of glass. Results have been carefully documented and analysed, details are given in the Appendices.

4.2.4 Series, titles and taxonomy

Titles for each of the series and individual names for each piece evolved as the objects themselves developed. Words, their meanings and word play have been of interest to me for as long as I can remember. Trigger points for titles can be words or phrases from a wide source of reading from academic sources through to advertisements. Playfulness and associations grow between words and forms, not unlike the Dada Surrealist free association and automatic writing. Hence oval forms became *Eggys* and as the forms were developed the next generations became ‘Flat Eggys’, ‘Eggys with leg’, ‘Eggy with leg and ladders’. As the ovoid morphed into spherical the *Eggys* developed into *Globeys* and became part of the *Worlds within Worlds* series.

57. Angela Thwaites, 2016, *Eggy with leg*. Photo D. Lawson



58. Angela Thwaites, 2016, *Citrine Globey* with ladders detail. Photo D. Lawson

59. Angela Thwaites, 2016, *Eggy with scaffolding*. Photo D. Lawson

This approach to taxonomy helped document and describe the system of repeat with difference and to differentiate between series, second generations and individuals. Some of the forms were part of limited series, for example, the ‘Rock Lobster’, which was printed and cast only four times. Apart from changes in scale, form and proportion were not altered from the original CAD model so they all carry the same title plus an extra descriptor to indicate the size or orientation, for example ‘hand stand’.

Each series explores defined criteria of the research. *Coracle* and *Biclops* were created as initial control models. *Coracle* was a simple, open form to test and establish a basic working system. *Biclops* was a more complex form to test to core casting using the basic system. *Worlds within Worlds* series explores key criteria of repeat with difference, scalability and changes in proportions. ‘Wearable glass’ explores orthodox and improvisational approaches, the use of colour and tonal variation through mass and space.

4.3 *Coracle* and *Biclops*

Coracle and *Biclops* were initial models designed to test and develop the practical research method combining digital and analogue processes. The two models were designed to demonstrate the key qualities of the Libenský's glass casting heritage. This can be summed up as: essential form with no superfluous decoration, cast in one melt in one colour, with different thicknesses, spaces and mass showing tonal variations of colour when light passes through the body of the glass.

Coracle is a simple open form taken from the shape of a small, lightweight one person boat. *Coracle* was designed for ease of reproduction through casting and as an initial test to experiment using various combinations of physical and digital design and making. The initial scale ranged from 6mm to 110mm to facilitate rapid making and results to be analysed and feed information forwards quickly into further experimentation.

Biclops was a form I had designed prior to this research which had proved impossible to cast using the lost wax method, so ideally suited to digital experimentation towards making the 'unmakeable'.

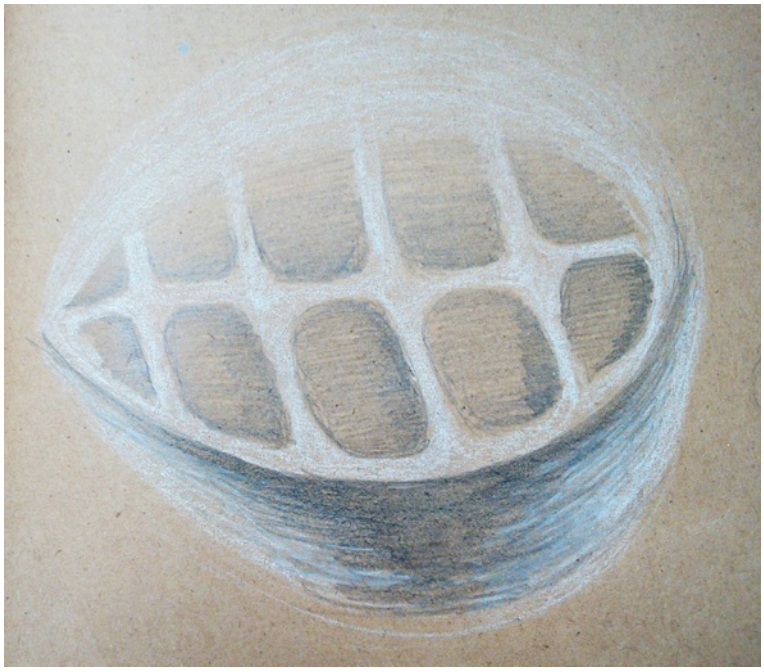
60. Angela Thwaites 2012, ‘unmakeable’ *Cyclops*, approx.55cms high

4.3.1 What was made and how / Physical digital combinations

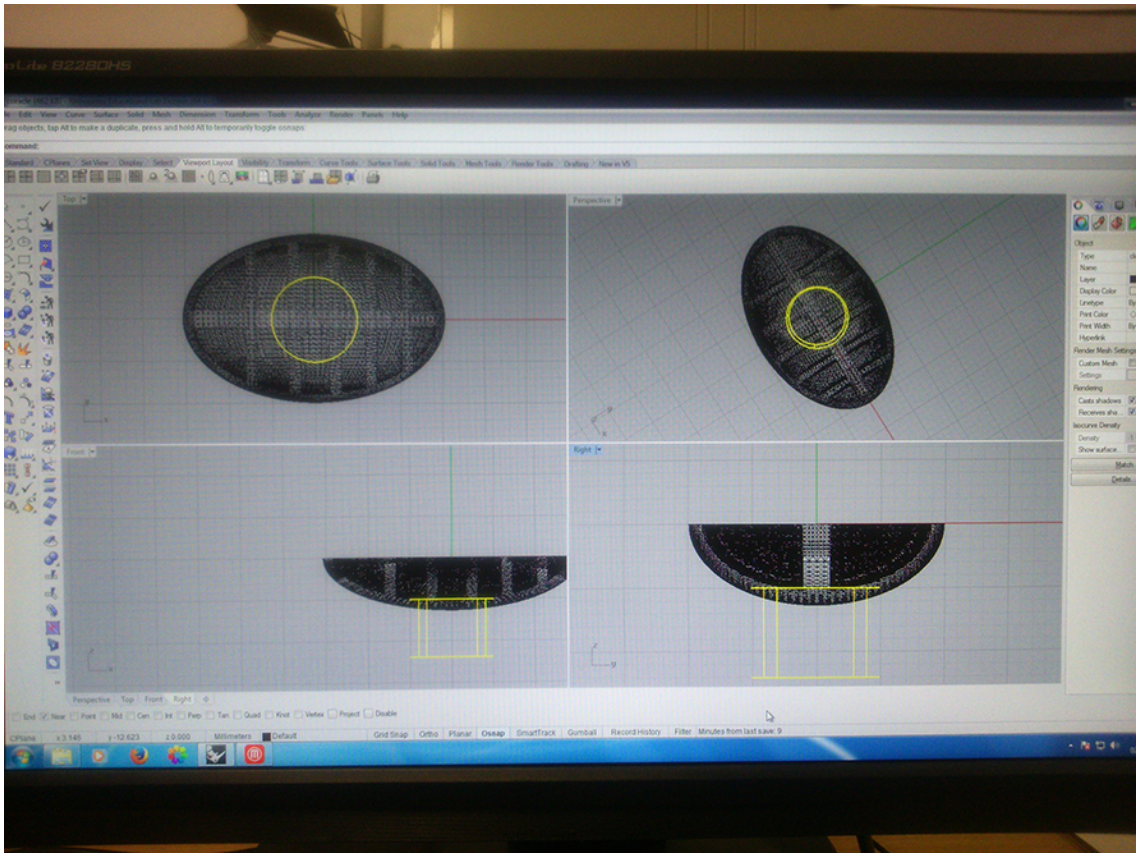
Coracle was an oval boat-like shape with ribbed interior. *Biclops* was an ovoid with eye-like apertures onto a central column connecting its double layered mass and inner spaces. Designed specifically for casting in translucent/transparent colour, both forms had variations in thickness and mass. Once cast in glass this variation shows a tonal range of colour: where the glass mass is greatest, the density of colour is deepest and where thin, the mass

shows the lightest tones, or even appears colourless. Both models were designed to work across a range of scales.

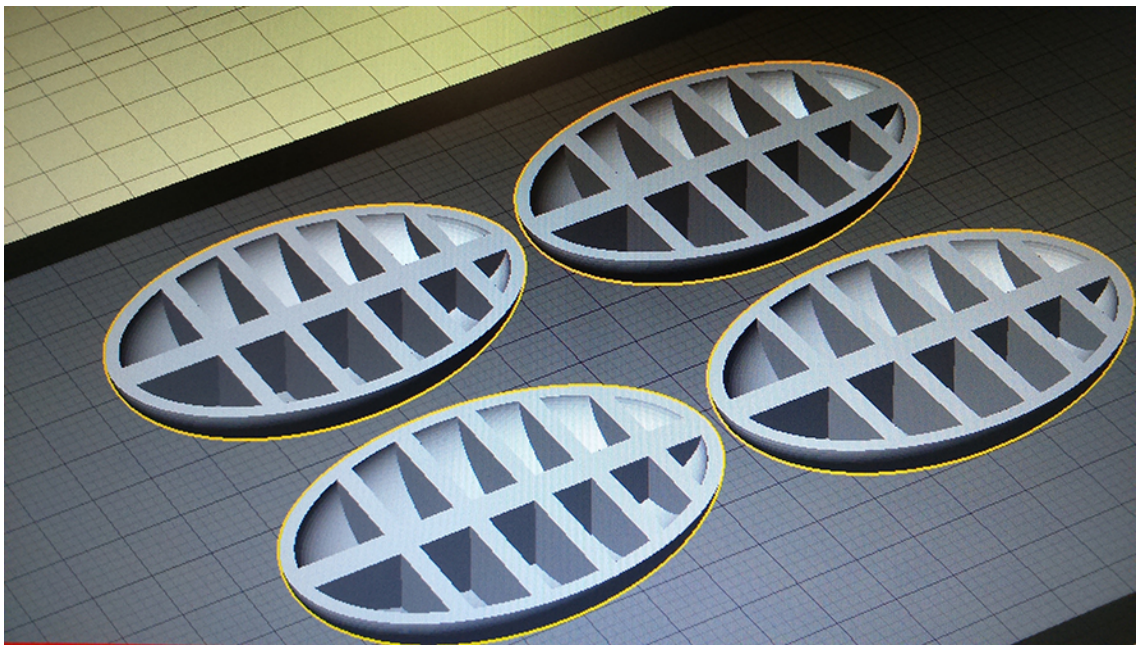
Coracle and *Biclops* were drawn by hand in sketchbooks and then modelled in Rhino to create 3D printable files as my first experience of working with CAD. This was on a masterclass at University of West England (UWE) in 2014, just before starting the PhD. Images of stages of making *Coracle* and finished glass:



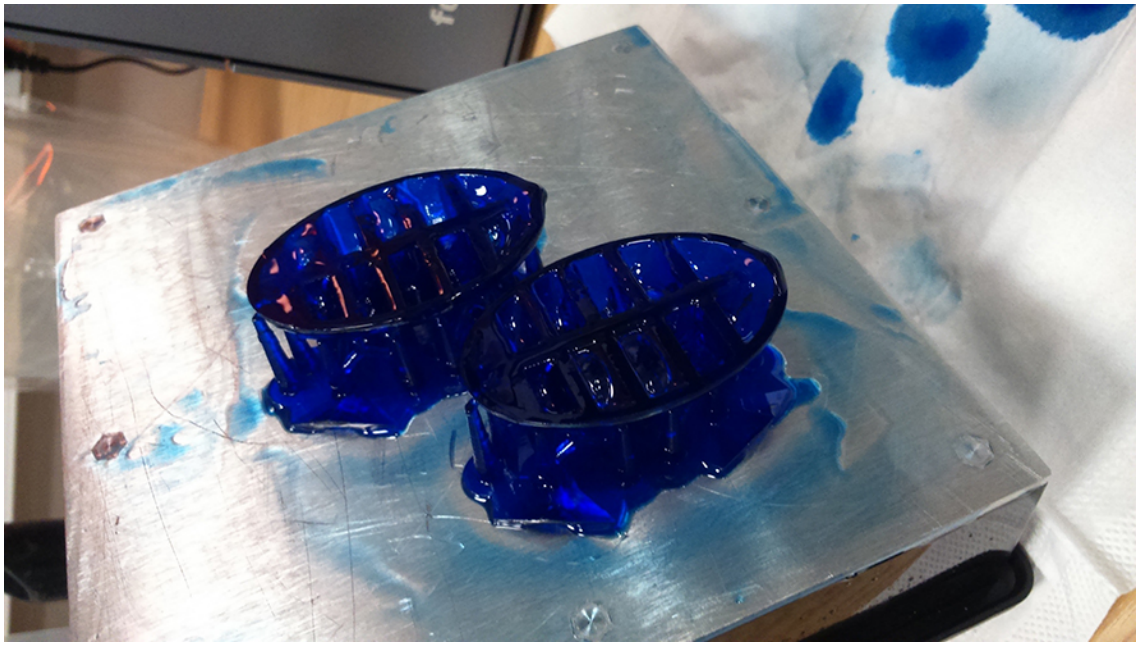
61. *Coracle* sketch



62. *Coracle* modelling on Rhino,

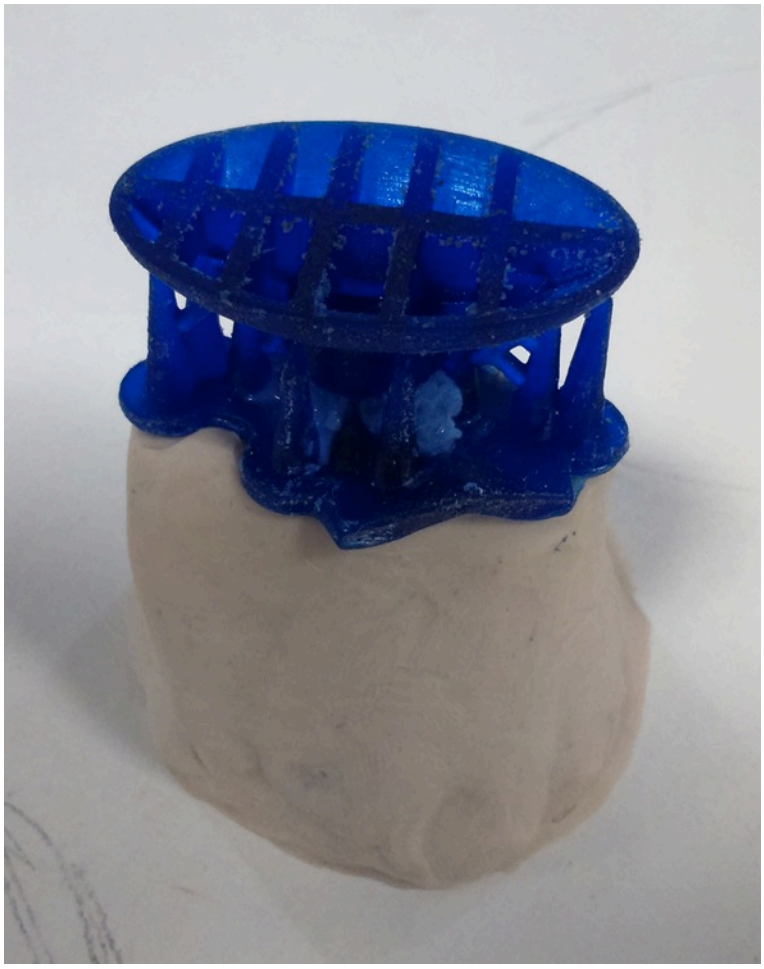


63. *Coracle* Pre-print,



64. *Coracle* Formlabs 3D Prints

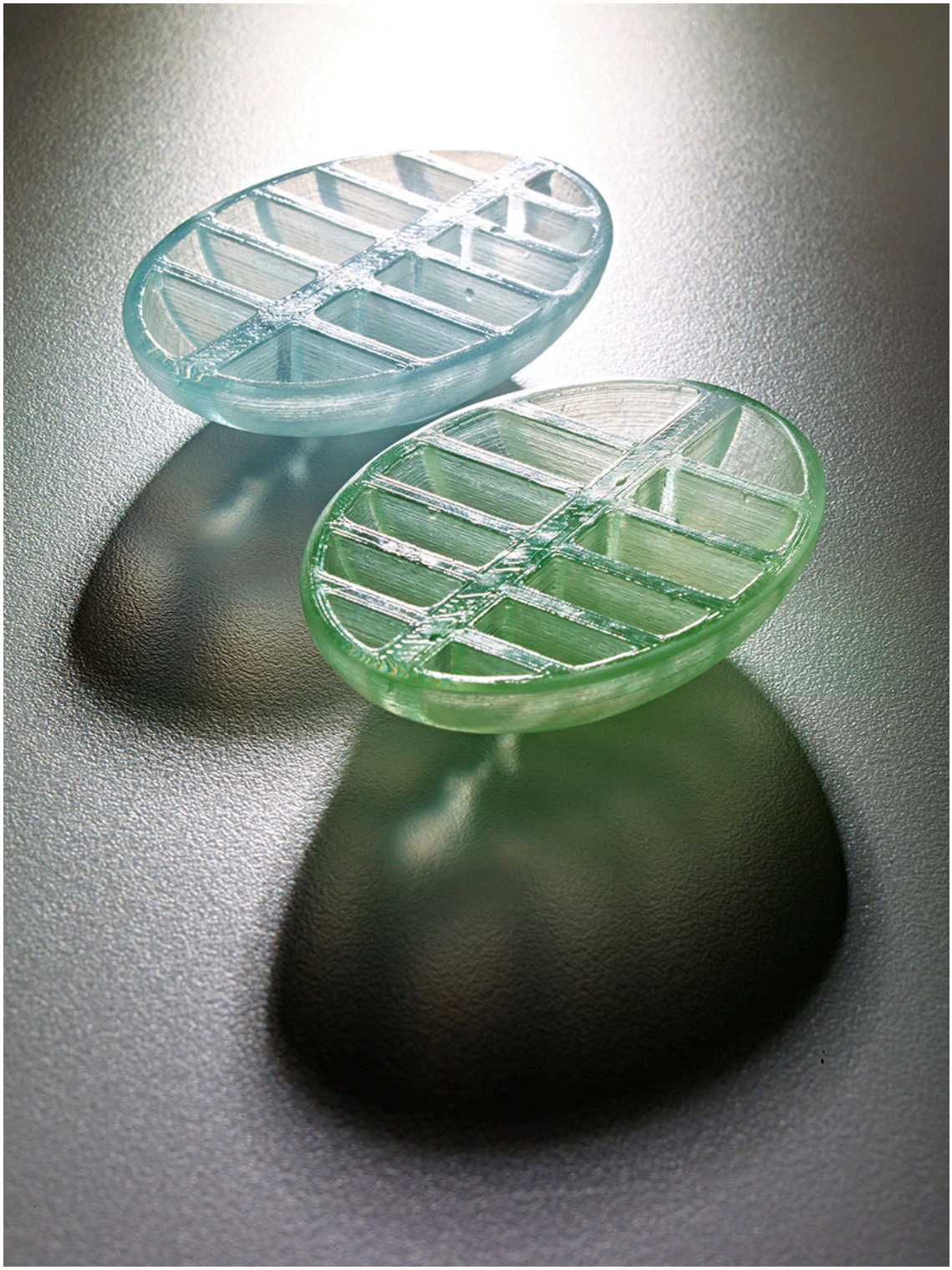
65. *Coracle* and *Canoees*, Formlabs 3D prints



66. *Coracle* set up for mould making

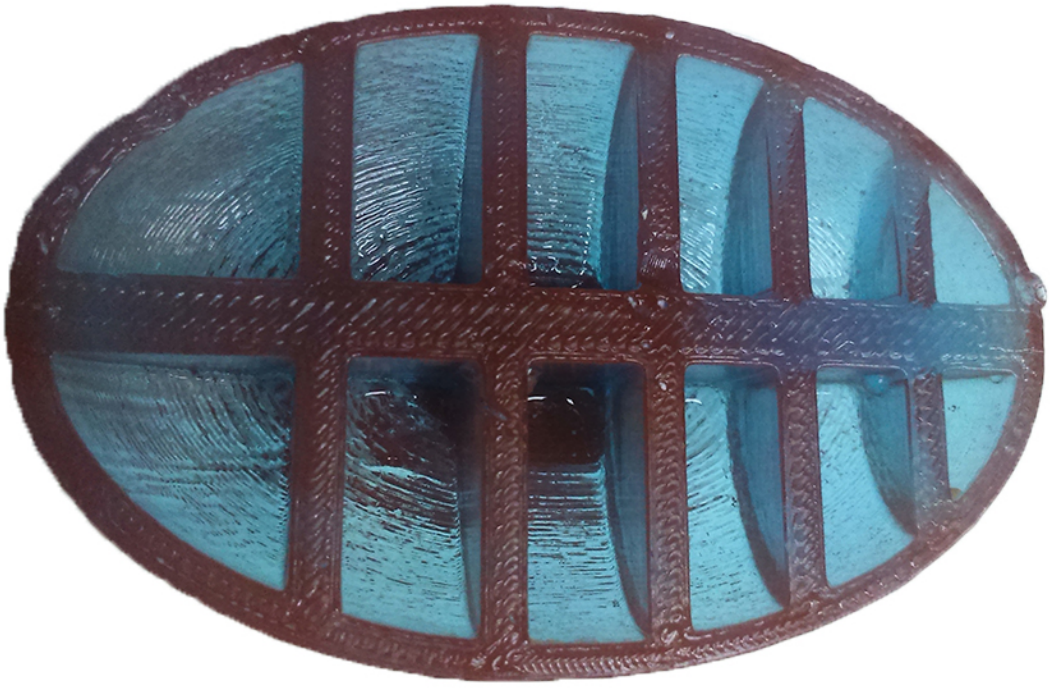
66.a. stretched *Coracle*s set up for mould making

67. Angela Thwaites, 2016, Stretch *Coracle*s. Photo D. Lawson

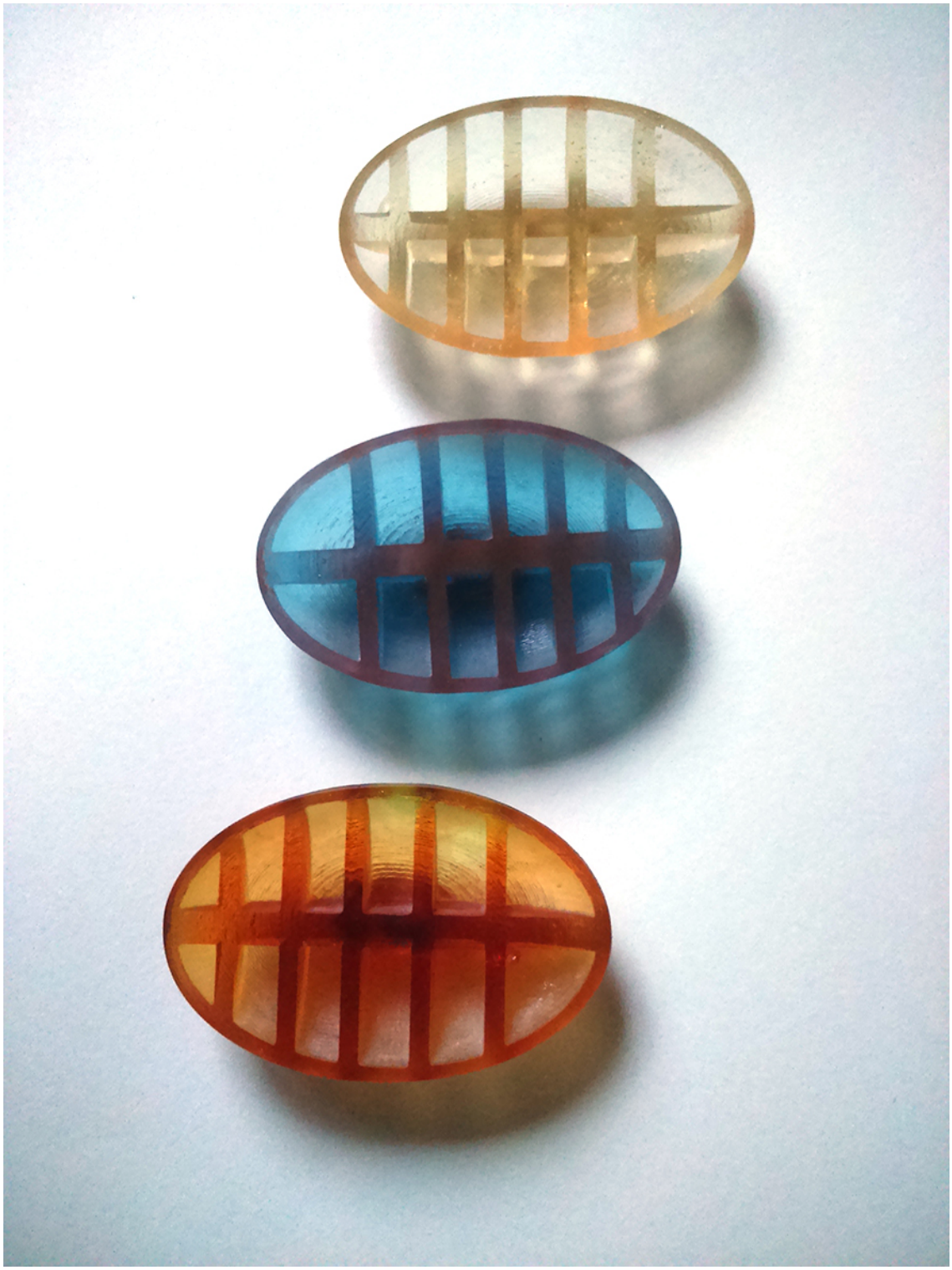


68. Angela Thwaites, 2016, Light blue and green *Coracle*s, photo D Lawson

68.a. Nano scale cast glass *Coracle* in Erin's hands



68. b. Angela Thwaites, 2016, Safarin *Coracle*

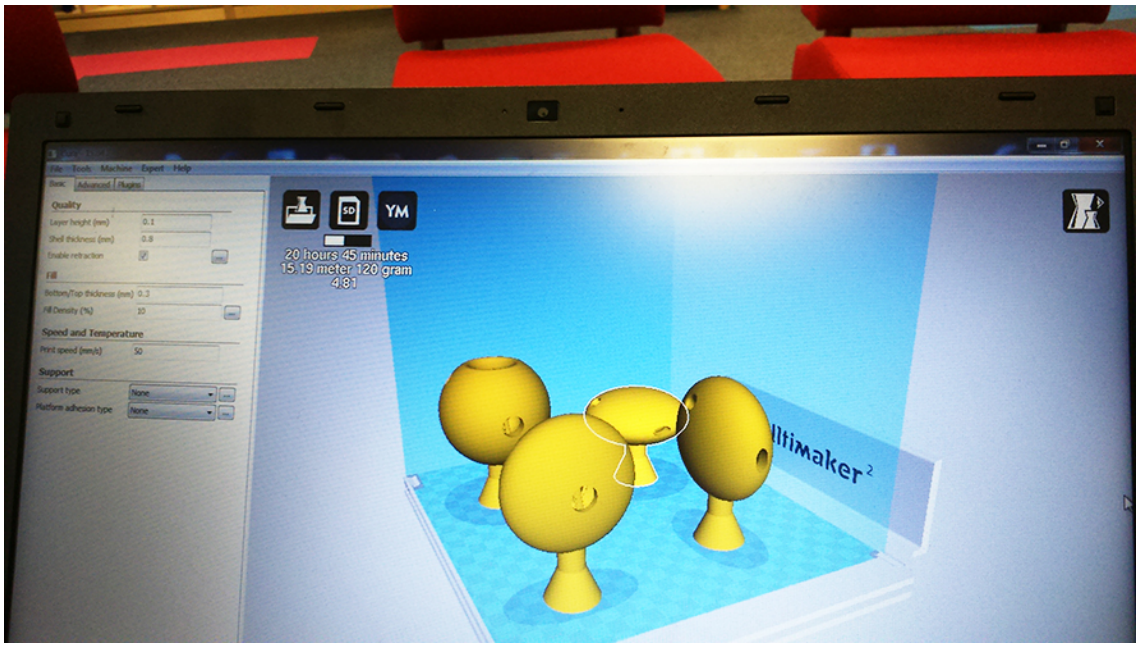


68.c. 3 Angela Thwaites, 2015, *Coracle*s in coloured glass

4.3.2 3D printing

Once the Rhino files were created and uploaded as a printable '.stl' (stereolithographic) files, pre-print software enabled choices and changes to be made. Experimentation was carried out on 3D printers using several different

types of PLA, PVA and Formlabs photopolymer resins. Various settings on 3D printers include print orientation, layer height, wall thickness, support structures and raft, and lay outs of single prints or groupings. Results were documented and analysed to frame the next set of tests, trouble shoot and develop understanding of the impact of the various settings. Repeat prints of the same model across different scales and proportions were initiated at print set up stage. The impact of changes in scale and proportion on 3D printing were carefully observed and results recorded to develop control of the process. Comparisons were drawn between filament and resin printing methods and results including the 'digital footprint' created by the different types of 3D print process.



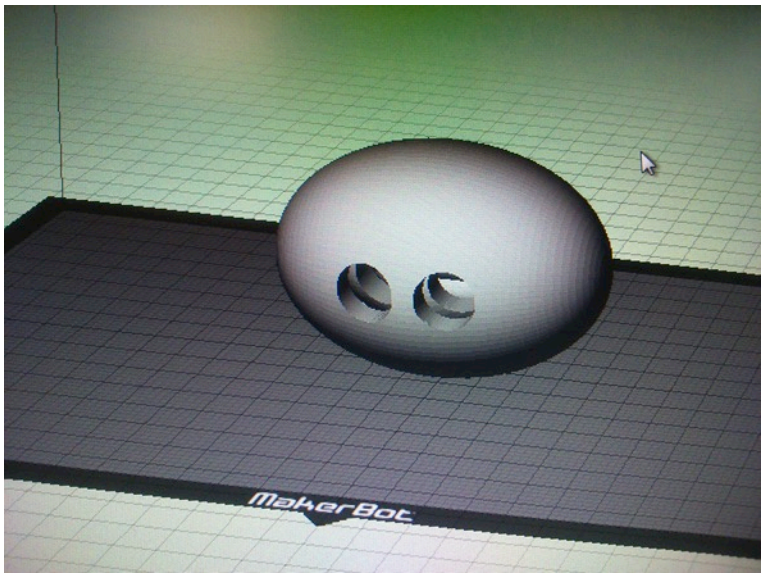
69.*Globeys*, pre-print on Ultimaker, Fablab University of Sunderland

4.3.3 Casting from 3D prints

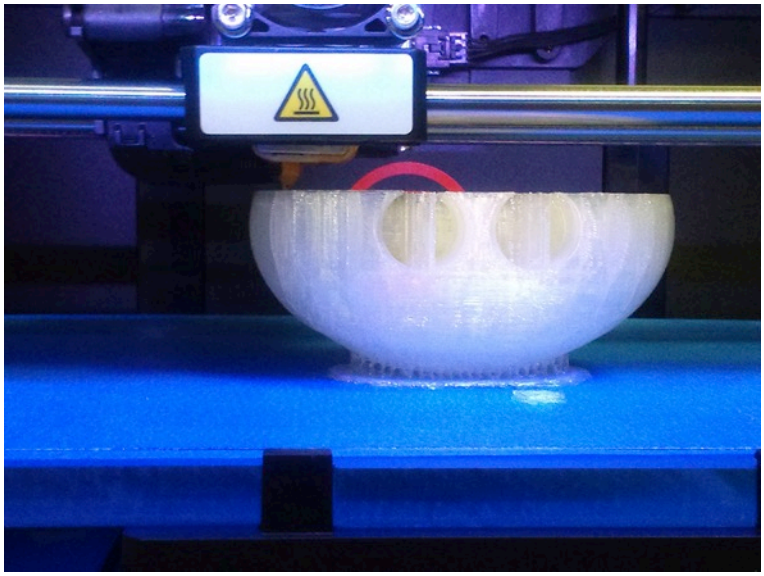
Over the course of the PhD, '*Coracle* and *Biclops* were re-printed numerous times scales and proportions and cast in different types of glass. Mould making and casting were relatively straightforward for *Coracle*. The decision to work on a small scale was taken for aesthetic reasons as well as practical ones. Practically working small saved kiln time and material. Shorter kiln schedules meant results were available faster for analysis and reflection and the full cycle of production could be considered, understood and adjusted quicker.

Biclops was more complex to 3D print and to cast in glass. Comparisons were made between cottled and poured and hand built mould making methods and combinations of both tested. The challenge was to ensure the full shape was captured in the mould and in the casting. The first step was to eliminate air trap in the mould mix. The first *Biclops* prints were dipped to fill the inner cavities. This was partially successful. To improve on these results, a plastic syringe was used for the next set of moulds and this was a more successful approach.

70. *Biclops* sketch



71. *Biclops* pre-print, from Rhino model



72. *Biclops* printing

73. *Biclops* and 3D print set up for mould making

The challenge of casting on a small scale was in the flow of glass into the miniature mould cavities. Early results showed air bubbles in the glass and loss of definition, particularly edges, corners and extremities. This showed that a long soak time at top temperature was required to ensure the glass was very fluid on entering the mould. Further experimentation showed that adding extra glass and venting using cotton thread which burns away gave improved results. The extra weight of glass added facilitated complete casting and pushed air out of the tiny channels created by the thread vents. This practice of essentially overfilling the mould's reservoir had a positive outcome regarding cold working. As the cast objects were so tiny, the extra glass which cast into a cone shape in the reservoir, facilitated cold working through ease of holding and control. Removing this extra glass after cold working the actual form resulted in cone shape cut offs which were a neat fit when placed into the next mould's reservoir for recycling into another casting.

74. *Biclops* showing reservoir for cold working

75. Angela Thwaites, 2015, Red *Biclops.* Photo D. Lawson.

4.3.4 Approaches and what issues they engage

The approach was to design two contrasting models, with particular characteristics, which could be repeated relatively easily and developed as the practical research progressed. The models had to be suitable for reproduction across a range of scales and changes in proportion and castable in various types of glass. *Coracle* and *Biclops* were used as ongoing ‘control’ models to chart the consistency of the materials and processes involved in making and to test variables, such as new types and colours of glass and to establish accurate reproduction. *Coracle* and *Biclops* were also used to test ‘repeat with difference’ through engaging digital technology to replace traditional methods which necessitate the making of individual master models and moulds for each incremental change in scale or proportion. *Coracle* and *Biclops* were my first experience of working on Rhino. Although they were essentially simple shapes they still presented challenges as well as providing an entry point for learning to navigate and operate the software.

76. *Biclops* repeat with difference 3D prints, PLA

As the experimentation progressed, scale became a focus of interest. Investigation was partly inspired by ancient glass objects seen on visits to the Bodrum Museum of Underwater Archaeology, Turkey, and partly through feedback from a contemporary gallery show, which identified increasing client demand for small artefacts. The next experiments involved taking the *Coracle* form already cast in glass from a 3D print model and embedding it into a wax box-frame. A new refractory mould was then created around the box form, the wax steamed out, the mould dried and then fired to melt new glass in. The results showed an interesting combination of traditional and digital qualities. Showing the pieces to a selection of kiln formed glass practitioners, they were asking what the digital element was? This demonstrated that through this combination of digital and traditional processes it is possible to make objects/ artefacts which do not look ‘digital’ in appearance.

4.3.5 What I did and the data to substantiate

Repeat prints were made of the two models to test and compare results and create a secure path of accurate reproduction. Ongoing use of *Coracle* and *Biclops* as 'control' models enabled analysis and comparison at all stages of making. This covered accurate reproduction of form, surface and detail. The models were printed using both types of 3D print process available. Repeat of the models facilitated experimentation and developed confident use of printer settings, orientation and supports. It also facilitated the establishment of methods of recording and documentation for analysis and comparison between results.

3D prints were set up for casting at several different angles and orientations. This was done to minimize air trap in refractory mould mix and to explore efficient flow of molten glass into the mould cavity. Choice of set up and reservoir entry point for molten glass affects flow of glass and is seen in the 'digital footprint' left on the surface. Reservoir entry point and surface marking from glass flow also determines the necessity for finishing and cold working of a casting. If molten glass flows over a finely textured mould surface for a long period of time, wear and loss of detail can occur to the surface of the mould material. This results in loss of quality and sensitivity of reproduction in glass and necessitates finishing/cold working.

Results from initial castings were overall successful in terms of complete reproduction of form but included imperfections in the cast glass. This was mainly small pieces of investment material which had detached from the mould and floated into the glass during melting, and some tiny traces of ash from the burn out process. To address this issue, models were very carefully checked for any porous areas or minute holes where the plaster based mould material could leak inside the hollow models, where it would remain as loose material which could then float into the glass during casting. Print defects were painted over with combustible materials (PVA, Shellac or Tirranti's combustible, low carbon, red wax), allowed to dry and checked again before investment, which greatly improved results. Consideration was also given to particularly vulnerable mould details in relation to the flow path of the molten glass and refinement of form

carried out at the CAD stage. Analysis of the effects of two firings on the moulds had been done in previous research so knowledge developed using organic models for casting was applied to combustible 3D prints (Thwaites, 2002 and 2011).

77. Red wax used to fill flaws/defects

4.3.6 Themes and content

An old magazine cover showing Tom Rogers, from the last family of *Coracle* makers in Britain, c.1905, provided a starting point for the *Coracle* idea.

78. Image Tom Rogers, *Coracle* maker in central England.

Coracle has several qualities which suited specific aims and carried meaning . A coracle is a one person boat for river and lake transport. It is made from lightweight materials, can be paddled and and then lifted and carried by one person. It is a traditional design which has been recreated over centuries in Wales and Central England where there are numerous navigable waterways. .It's function as one person transport related strongly to my own experience of travelling between home in South London and University in Sunderland, carrying everything I need on my back. The simple form has been repeated over centuries using basic materials and methods: makeable by one person for one person. This resonates with my own practice, the idea of accessibility which has run through this research with the aim to establish clear, repeatable making methods which can be handed on. As an object from the everyday environment, of minimal form and decoration combining organic and geometric characteristics, the *Coracle* also fits well to the principles of Czech glass casting underpinning this research. *Biclops* was originally part of a series of ovoid forms derived from egg and eye shapes from previous research into vision and perception. Ovoids were designed with complex interior spaces, variable mass

and apertures in the surface allowing light and views inside. Variation of mass and space gives a high level of tonal variation once cast in translucent coloured glass, a key principle from Czech glass heritage. Before starting this research, I had attempted to make forms similar to *Biclops* on a larger scale using the lost wax method. Technical issues thwarted its resolution at all stages, from creating the model and mould, through steaming the wax out, let alone trying to see inside the mould to check it was clean before loading the glass. The results were unsatisfactory so *Biclops* was created as an ideal starting point to test potential combinations of digital/physical processes towards making the 'unmakeable'.

4.3.7 Scale, colour, mass and space / Finishing and presentation

Coracle and *Biclops* were printed in a range of sizes and proportions and cast in different types of glass: Gaffer, Bullseye, Uroborus, Czech lead based glasses, and Chinese casting glass. The smallest '*Coracle*s', 6mm long, had minimal mass and even the darkest blue/ green glass appears pale and translucent. A pair of light green '*Coracle*s', stretched pre-print, 110mm long, show consistent pale colour. The original shape, cast in Gaffer and Czech amber glasses, gave the best results in terms of easy glass flow into the moulds and highest level of tonal variation of colour. Recycled cut off pieces of Czech 'Safarin' a dichroic colour gave pleasing variants from blue to pink at 6-10 mm thick and denser blue to brown at 15-30mm.

The smallest *Biclops* 7mm long, cast in translucent amber, transmits some light but is surprisingly dense for such a small glass object. The largest *Biclops*, approx.150mm long, shows a range of red, pink through to almost colourless tones at the thinnest parts. This fits well with one the aim of working with single colours/ maximal tonal variation, in accordance with the Libenský's glass casting tradition.

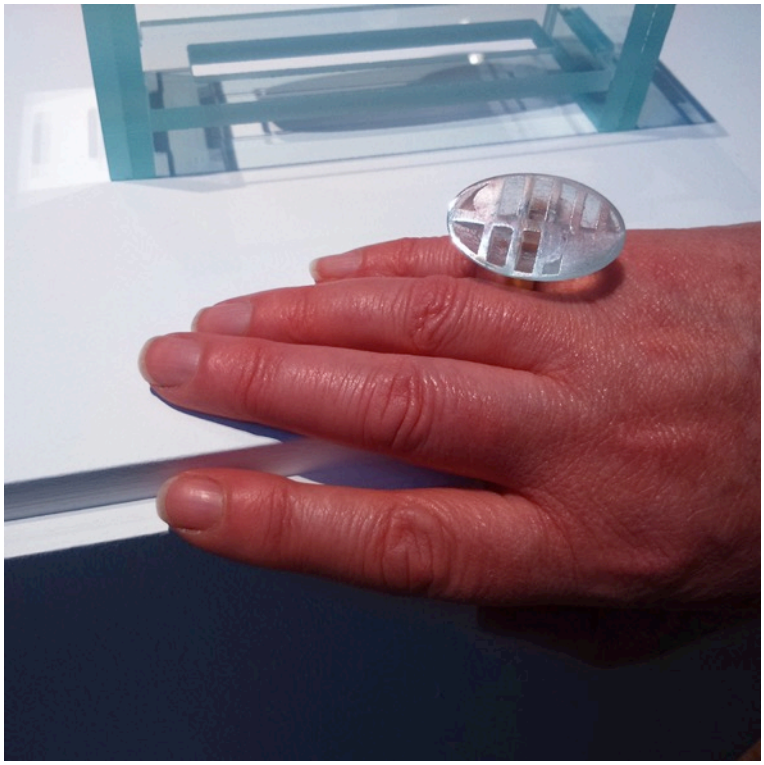
Once cast in glass, each piece was finished using a range of cold working techniques. Some of the first 3D prints had been imperfect so I polished the top surfaces of these casts entirely to erase blemishes. Print quality was resolved through developing an understanding of the method and requirements of the

printers, and also by smoothing any blemishes on the 3D prints before mould making. Cold working and polishing became a choice rather than a necessity. After identifying the need for more weight of glass to facilitate casting small objects, (described above) I used the resulting reservoir of glass to hold on to while cold working. This made any flatting of the glass surface much easier to control whether using the flat bed machine or lapping by hand. I could subsequently cut the extra glass off and finish the underside of the objects afterwards.

I chose to develop *Coracle* during the 'Jewellery: Wearable glass' project which is described in detail below. The first iterations were used the original proportions and were 3D printed in PLA and Formlabs castable resin. The 3D prints were invested, burned out and cast in various colours of glass including safarin, turquoise, a darker blue/green and amber. The first of these were drilled and suspended as simple pendants.

For 'Jewellery: Wearable Glass', *Coracle* was developed so that it could be attached to a ring shank. Re-working the model on Rhino, I added a short round column to the centre of the base. As well as providing a point to attach to a ring shank, this improved the original by facilitating the set-up of the 3D print for mould making. The concept of the *Biclops* form went on to be developed in the next series called 'world within worlds'.

79. Angela Thwaites, 2017, *Coracotta* ring being worn



80. Angela Thwaites, 2017, *Coracotta* ring being worn

4.4 *Worlds within Worlds*

My intention was to create three dimensional sculptural forms with multiple layers and complex structures inside, to express a sense of ‘Worlds within Worlds.’ Initially inspired by research into the artist M.C. Escher (1898 -1972), the concept developed further through encountering text by Grosseteste describing what has been termed a ‘Medieval multiverse’ or ‘Medieval big bang’ theory. This is described in more detail below and in the Appendices.

Forms of this complexity had previously proven to be ‘unmakeable’ using the lost wax method. These ‘multiverses’ were therefore an ideal starting point from which to explore combinations of traditional and digital technologies towards making previously impossible forms and structures and radically developing new content and approaches.

Developing consistently accurate and efficient reproduction and mass individualisation, or ‘repeat with difference’ as I have termed it, were also areas

for experimentation aimed at extending existing possibilities in kiln casting glass.

4.4.1 Approaches and what issues they engage

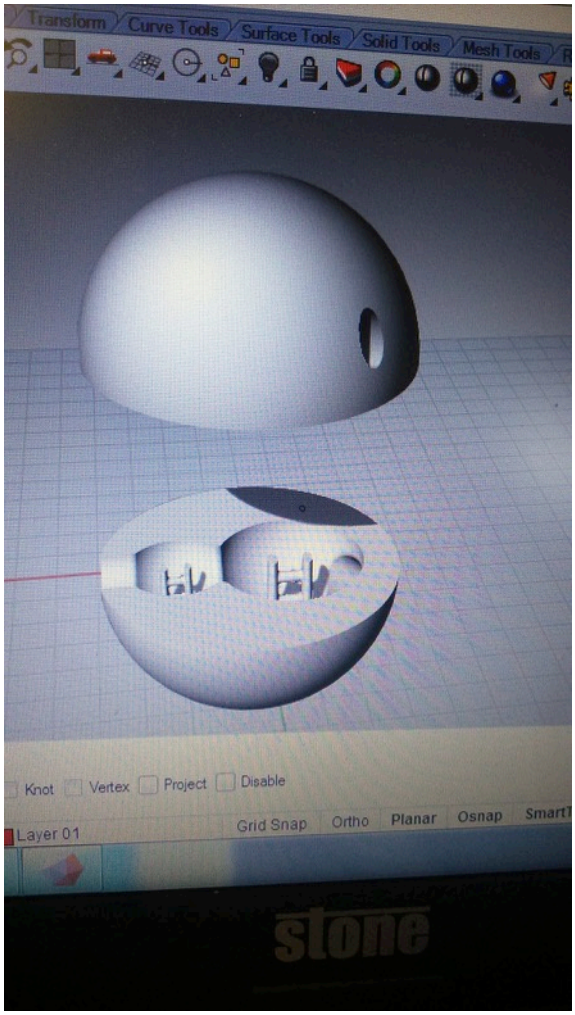
A series of related forms was developed to test the breadth and limits of the ‘unmakeable’ using physical and digital methods of designing and making. A circular system of modelling, 3D printing, mould making, casting, analysing and documenting results was employed. Reflection on and analysis of results was used to inform the next ‘revolution’ of experimentation starting again with modelling.

A series of hollow ovoid and spherical forms were modelled using Rhino to be made as core casts in glass. Inner cavities were created with different proportions to the outer forms. This was designed to give a differing wall thickness to the overall form so that once it was cast, the variation in thickness of glass would show a tonal range of colour through differing light penetration. This approach is rooted in the Czech glass casting philosophy of Libenský/Brychtová which is described in detail in Chapters 2 and 3.

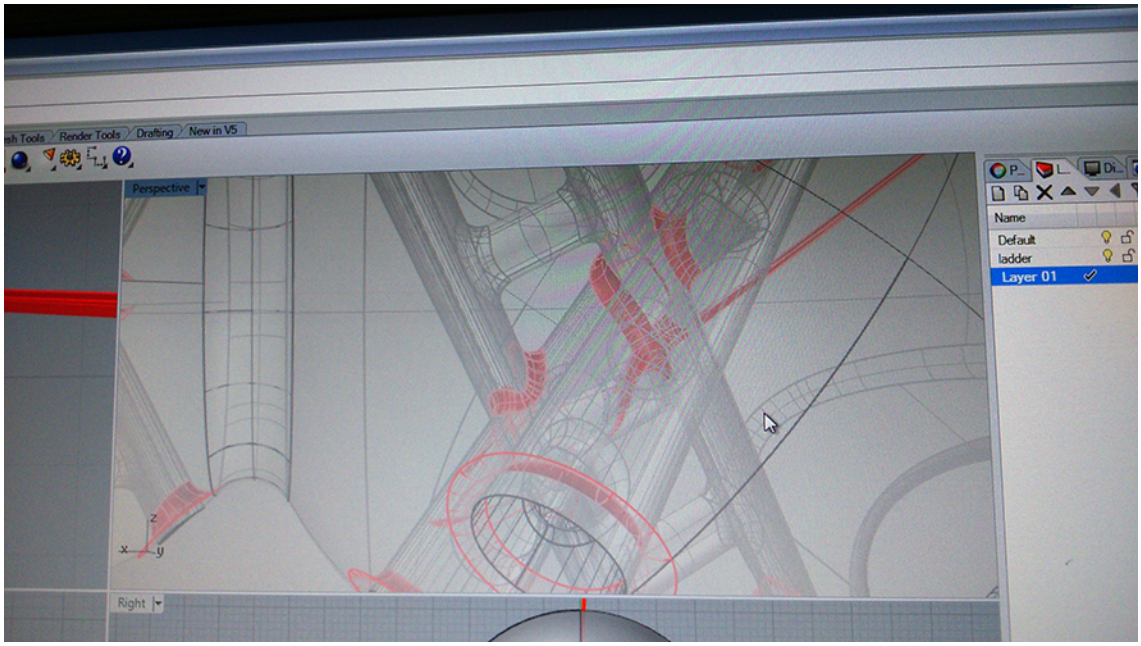
4.4.2 What was made and how

A series of about twenty objects was created over a period of a year. The first generation of hollow ovoids were *Eggys*, which rested directly on their long sides, relating to *Biclops* described above.

Using Rhino, I created a number of 3D printable models with an outer ovoid shape and hollow core. Later, spherical forms had layered interiors of varying complexity, interlinked inner spaces and mass of various thicknesses. Some of the designs had very complex interiors including ladders spanning and connecting the interior spaces.



81 Rhino images of *Globeys* model development



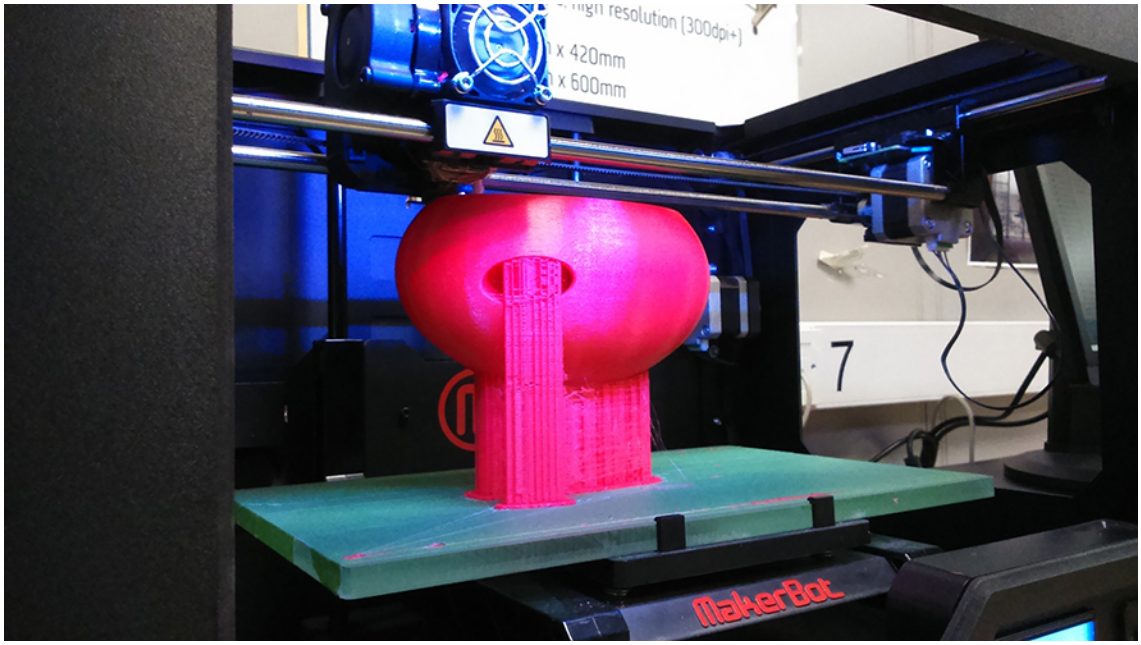
82 Rhino images of *Globeys* model development

4.4.3 3D printing / Casting from 3D prints

The Rhino models were saved as '.stl' files and 3D printed using PLA. A smaller number were printed in Formlabs castable resin. The models were developed initially through variations to scale and proportion, 'repeat with difference', in the 3D printing process.

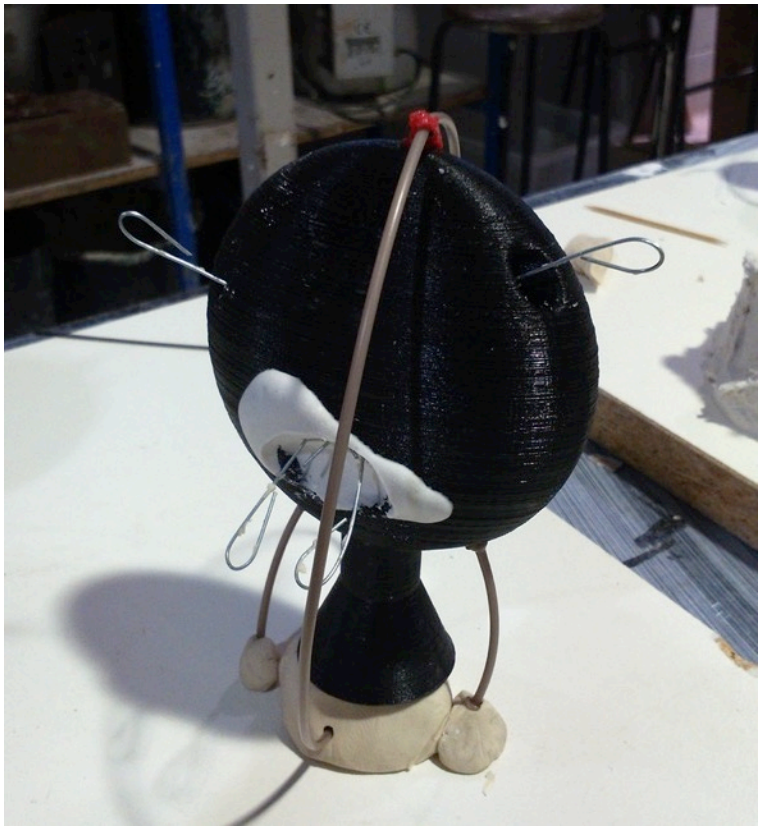
The first batch of *Eggys* and *Globeys* were made using 3D prints which had been printed as whole forms. Some of them had surface flaws from lack of support for over-hanging areas of the form. Experimentation was carried out to repair these flaws using combustible red wax and shellac varnish. Both of these worked however extra vents were needed to allow vapour from the red wax to evacuate the mould during the burn out process. Without vents residual ash lingered in the mould cavity was picked up by the flow of casting glass resulting in debris on the surface or worse, inside the body of the glass.

Refractory moulds were hand built using a combination of dipping and syringing to fill the insides of the 3D prints with mould mix. However, the handling involved in this method dislodged cocktail stick vents so scraps of PLA filament were fused onto the print before mould making using a candle was used to heat the filament. This practice proved successful and was carried forward into the next round of mould making.

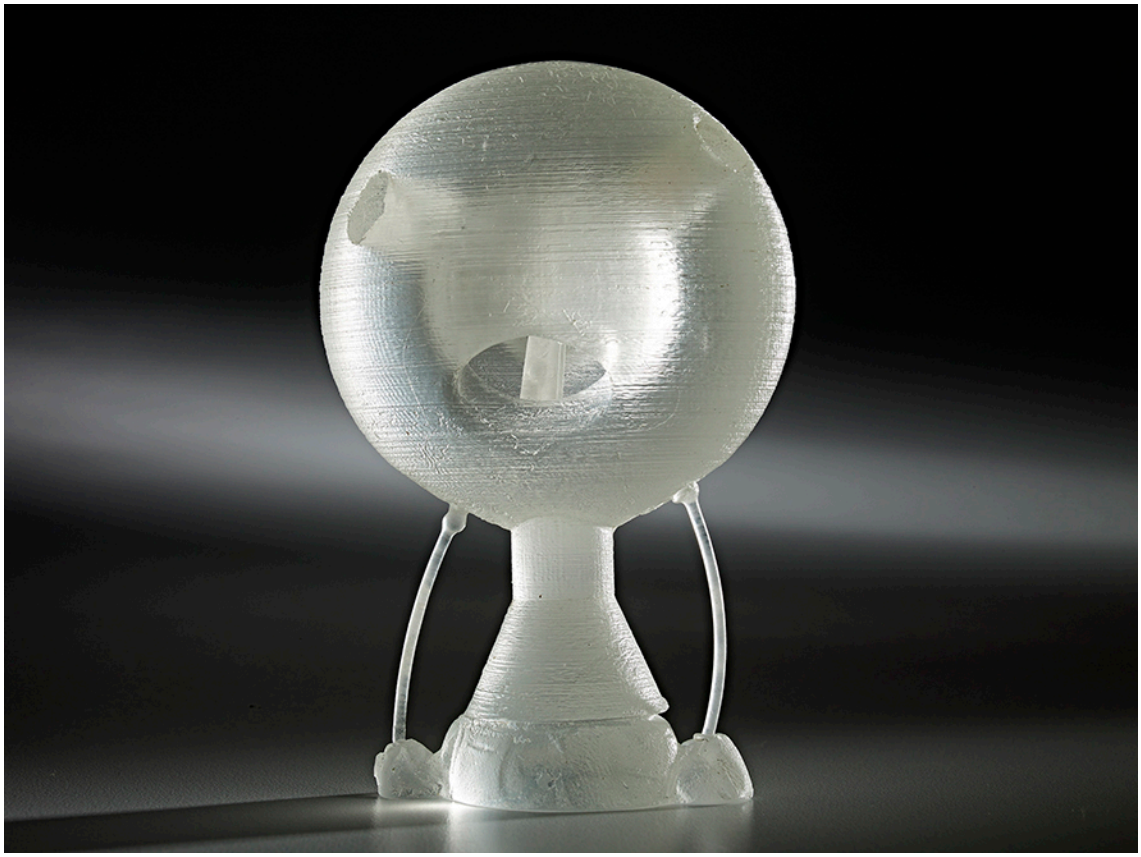


83. *Eggy* printing on makerbot

84. Flattened *Globey* with vents.

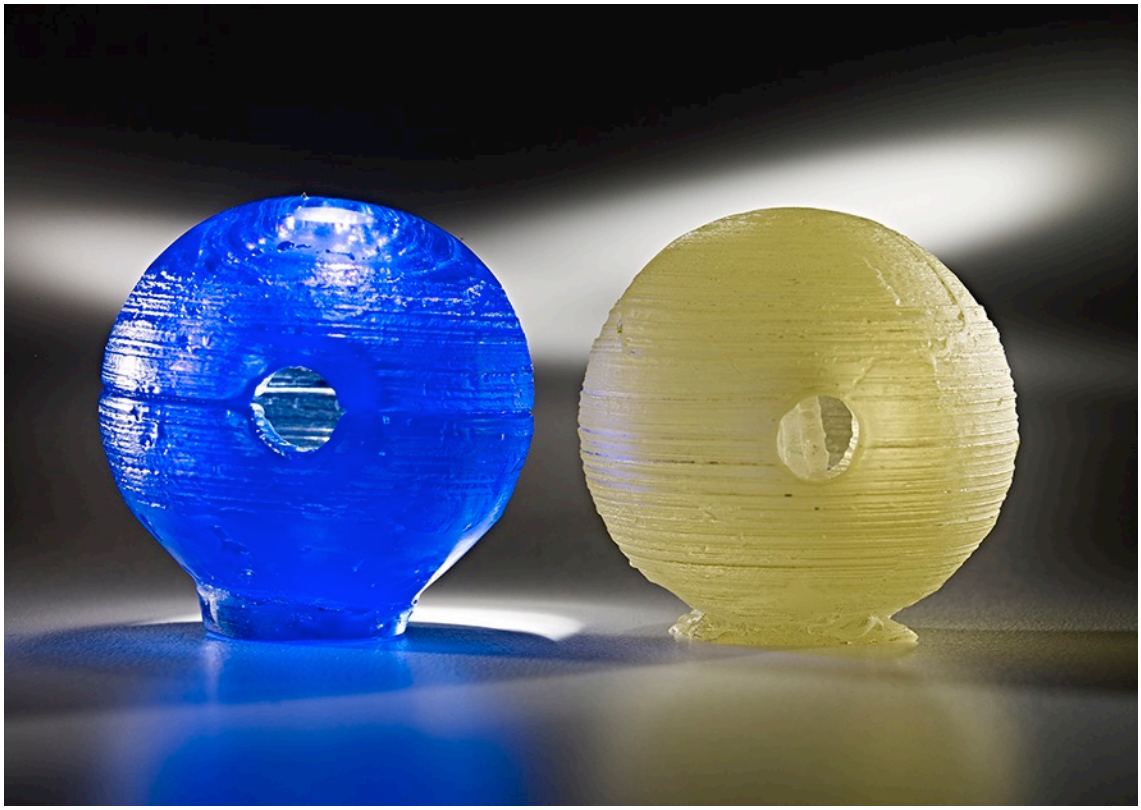


85. Mould making flattened Globey



86. Angela Thwaites, 2016, *Flat Globey with ladders*. Photo D. Lawson.

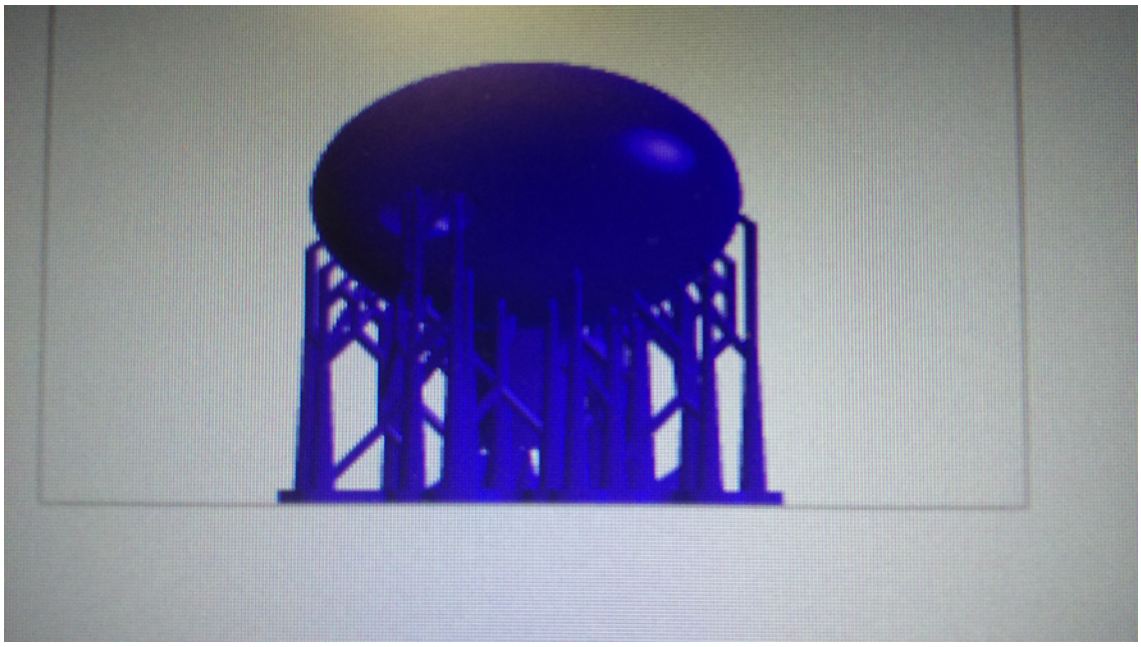
The shape, size and position of apertures into the outer surface controlled the viewpoints into the interior spaces giving an increasing sense of secret, inner worlds. Once 3D printed, these apertures provided a means of accessing the inside spaces to fill them with refractory mix and to clean the mix out again after casting. As experimentation progressed, the apertures facilitated the insertion of miniature scale reinforcement to prevent pieces of mould material breaking off during casting. Fine copper, steel wire paper clips stretched out, fibre glass strand and fine brass mesh were tried as reinforcement materials, all worked. Apertures modelled into the spheres are simultaneously functional and aesthetic. They facilitate the strengthening of a refractory mould and the removal of mould material after casting, provide viewing points inside the forms, and allow light to penetrate the inner spaces and masses, without which it would not be possible to see inside. The inseparability of inside and outside and simultaneous view of and through the surface of the glass into the inside of the form has its roots in Czech Cubism via Libenský/Brychtová's philosophy of creating sculptural form in glass.



87.Angela Thwaites, 2016, *Citrine and Blue Globeys*. Photo, D. Lawson

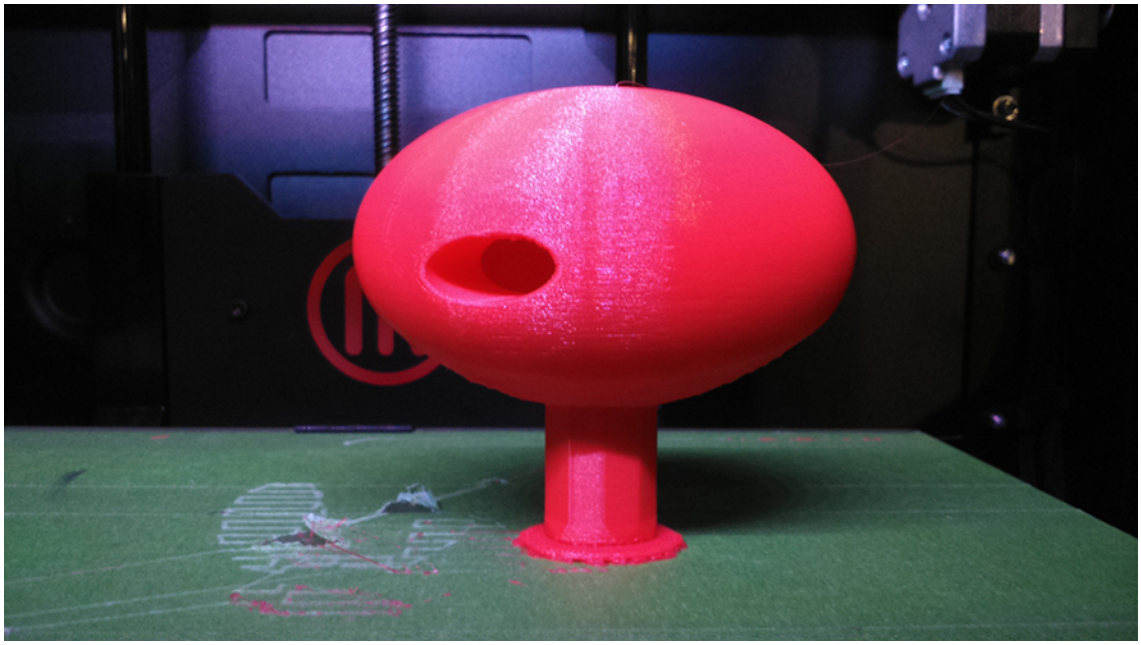
4.4.4 Physical digital combinations

The first series of *Eggys* was followed by a second. Adaptions and developments of the forms revealed the touch point between analogue/digital manufacture and the need for a craft approach. An addition to the initial Rhino file was made, of a slim, columnar leg digitally modelled on to the underside of the basic form. This raised the ovoid/sphere shape up, letting more light into its interior and making it easier to see inside, facilitated the mould making set up and reduced the need for finishing as the area of the base became small and easily cut, ground and polished. This minimised loss of the 'digital footprint' of the surface which is an important characteristic resulting from careful translation of digital to physical.

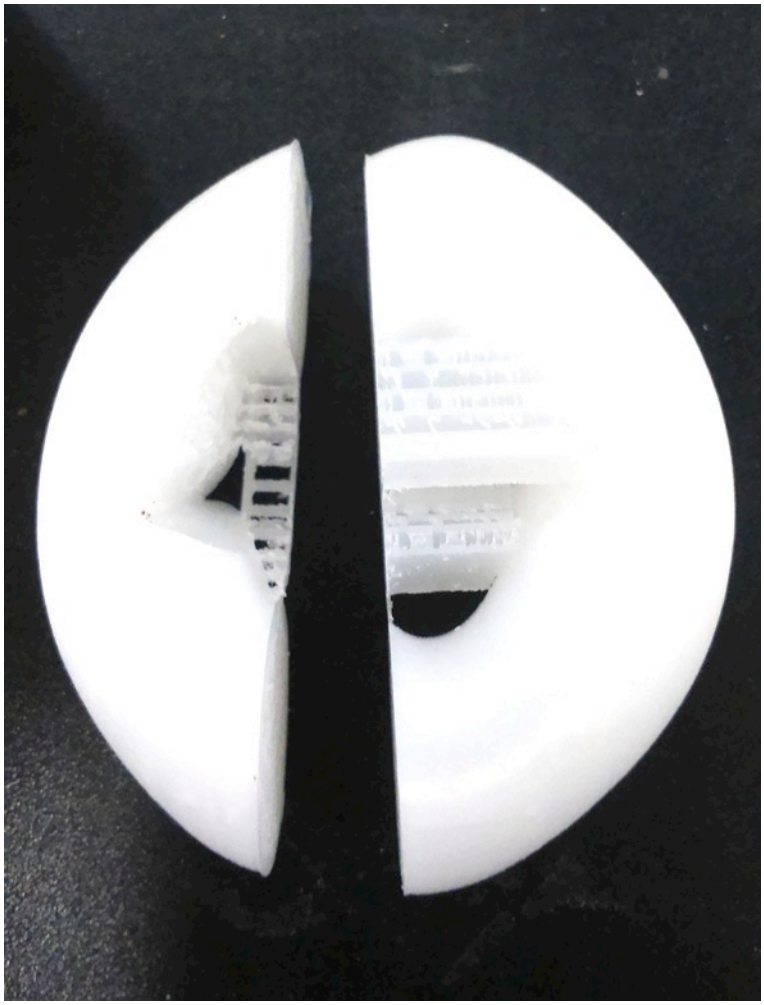


88. *Eggy with leg* and scaffolding, Formlabs pe-print,

After making the first series of *Worlds within Worlds* the next stage was to address the issue of flaws from unsupported over hangs and interior details. In order to realise the desired forms fully and without defects, a digital solution of importing the Rhino file to Cura (slicing software), cutting the model in two and positioning the halves flat face down to print. This gave two improvements: it avoided unsupported overhangs and also facilitated adhesion of the 3D print to the build platform. This method was also used for printing 'Rock Lobsters.'

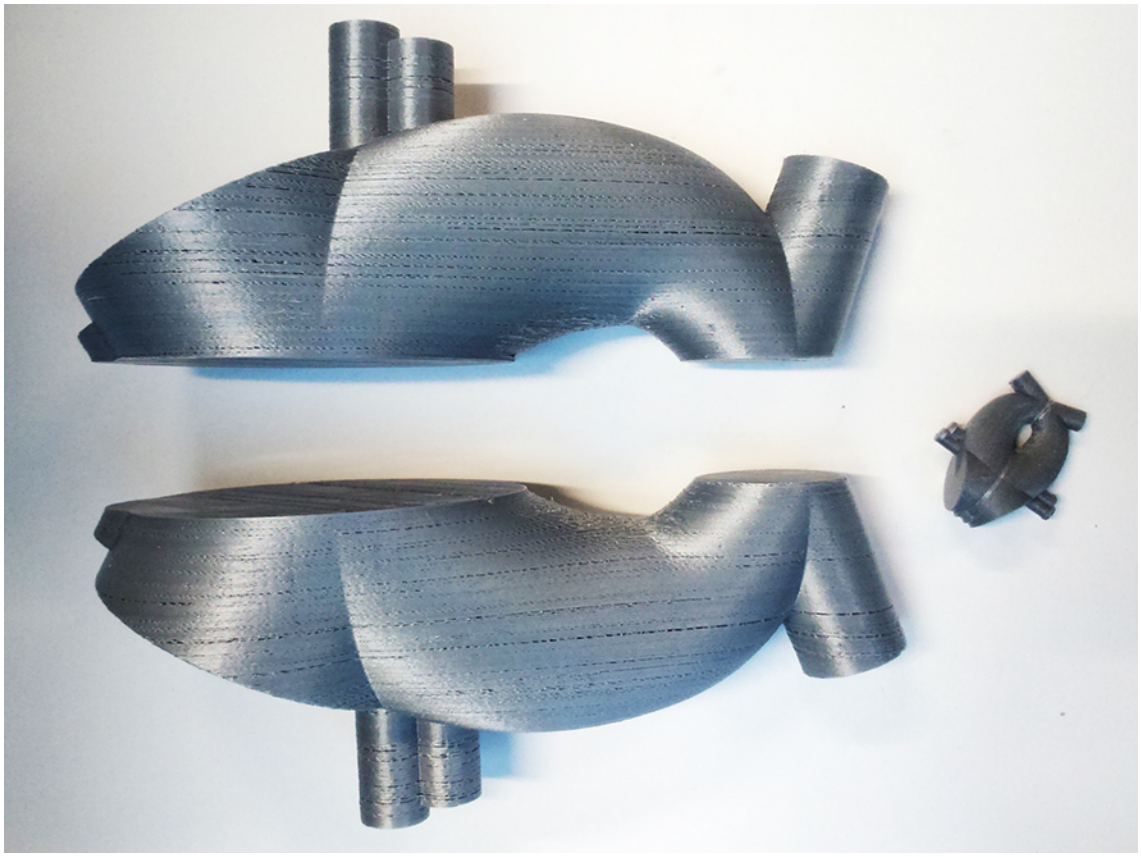


89. *Eggy with Leg* PLA print



90. Oval Torus 3D printed in halves

90.a. Angela Thwaites, 2016*, Oval Torus in Pink.* Photo D.Lawson



91. Angela Thwaites, 2017, *Rock Lobster printed in* two halves.

91. a Angela Thwaites, 2017,. *Rock lobsters* halves cast in glass

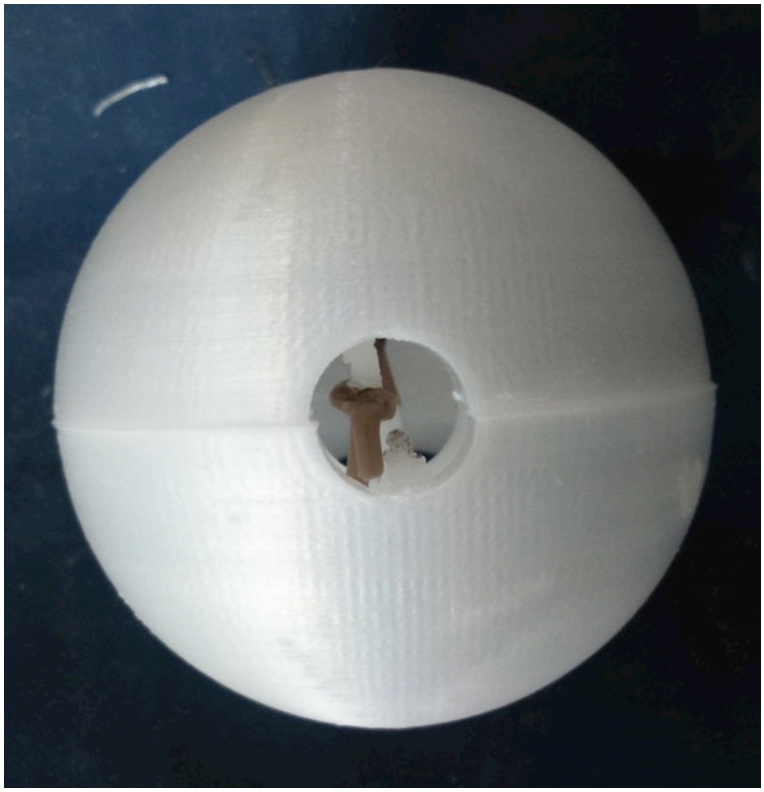
92. Angela Thwaites, 2017, *Rock Lobster*

Two further sets of physical tests were then carried out developing and applying craft approaches. The first bonding the two half 3D prints together before mould

making. The second casting the halves in separate moulds and then kiln fusing the glass halves together. Both these methods were successful with slightly different surface qualities and characteristics visible in the final pieces.

93. *Globey* 3D prints in halves

93.a. Hemisphere adding ladders



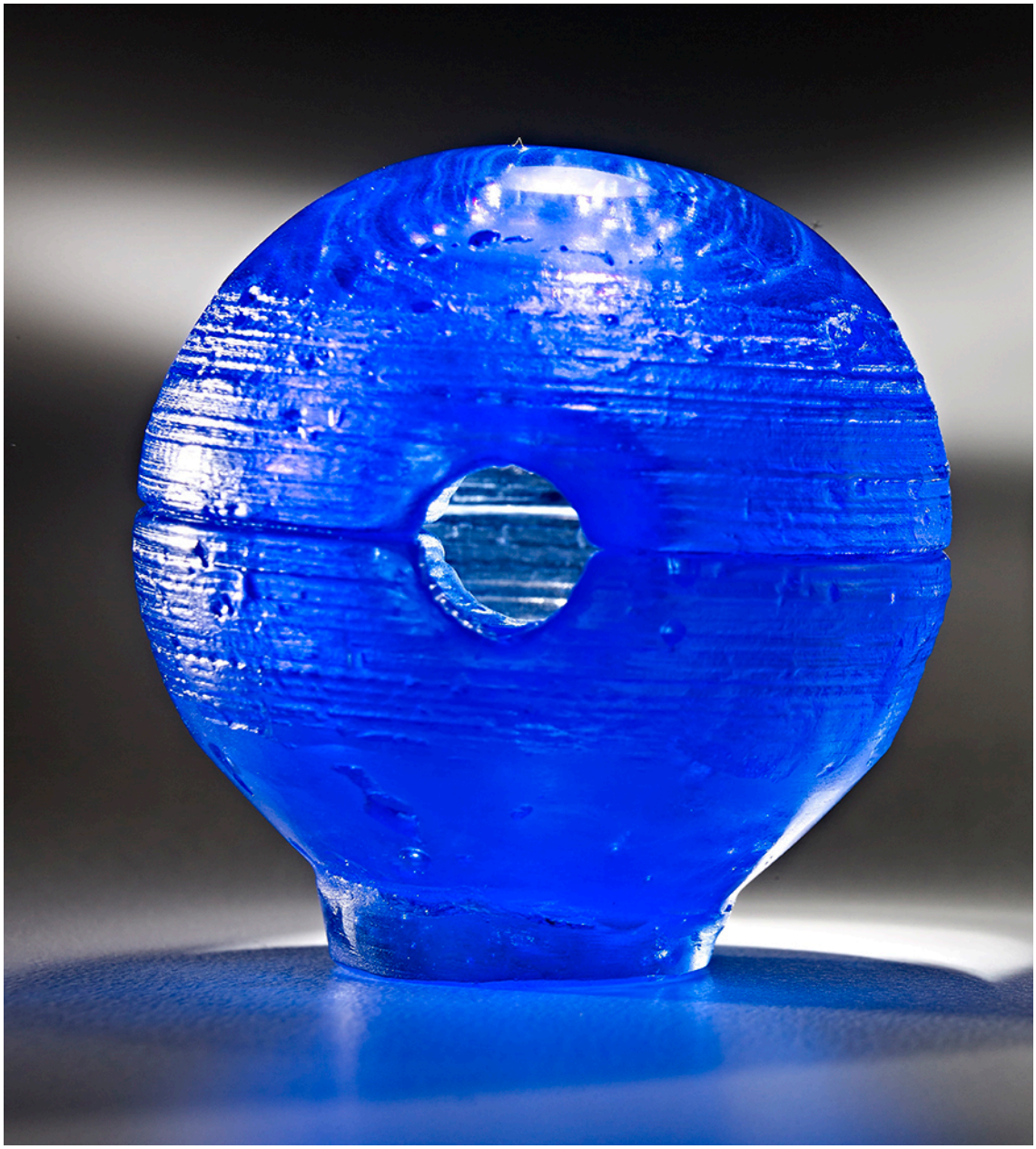
94. Bonding halves

95. Blue halves being packed with ludo inside

96. Packed with ludo outside

97. Fused *Blue Globey*,

98. Angela Thwaites2016, *Flat Blue Globeys* and *Eggy*. Fired mould fragment in foreground. Photo D. Lawson



99. Angela Thwaites, 2016, *Flat Blue Globey*, Photo D. Lawson

4.4.5 Themes and content

The theme of *Worlds within Worlds* evolved out of previous attempts to cast hollow forms with complex interior structures with the additional influence of new contextual research. Seeing an exhibition of M.C. Escher's work and reading about his precise, mathematic approach to creating graphic imagery with a sense of illusion in space and geometry, I considered architecture as a basis for ideas for the inside spaces of the spherical forms. Escher took an individual approach with a Surrealist aspect to it, working with what appears to

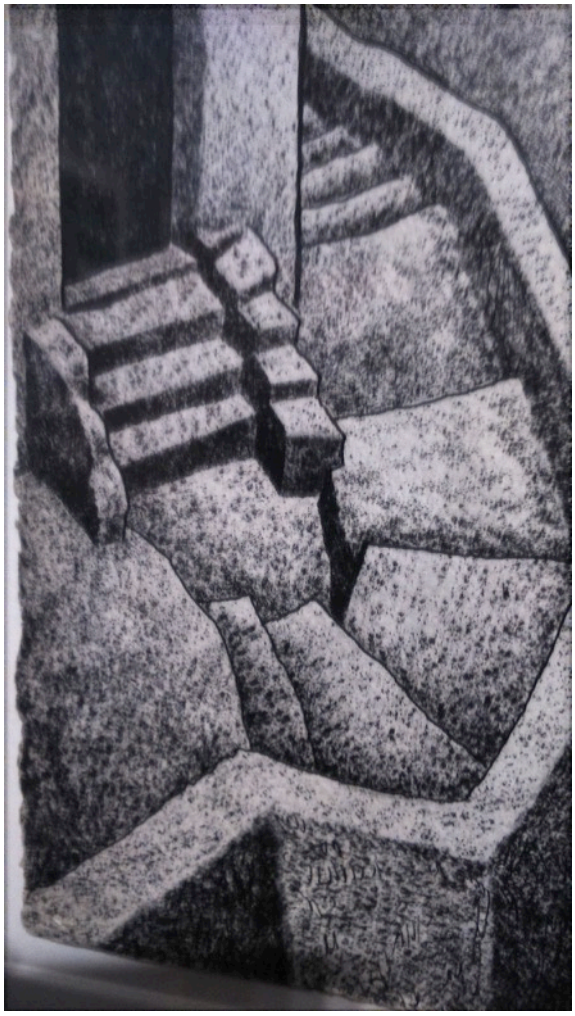
be plausible 3D form and space but on closer inspection is impossible, a blurring of inside and out. He drew staircases that lead up, down and back around to their own beginnings in an infinite twisting movement, like a Mobius strip. Escher played with two dimensional surfaces to create perceived three dimensional depths where stacked books become part of a building, defying any sense of scale. These illusionist impossible geometries inspired me to use real imagery inside the objects I was making to play with the light through layers of glass and space, to create unexpected optical illusions. I decided to create ladders, increasingly complex connecting inner spaces and apertures in the otherwise enigmatic spheres to control the viewing points inside and to let light in. Further reading about space led me to Bachelard's 'The Poetics of Space' which resulted in questions about how the viewer could experience the spaces inside and influenced decisions on spatial relationships and the architecture of the inside of the spheres.

I started to model inter-connecting spherical chambers with ladders bridging and connecting the spaces inside. Some of the ladders were created through the digital modelling process and others made manually using left over support material. Ladders developed layers of meaning as well as practical significance. In the real world, ladders infer impermanence as they may be moved at any moment indicating change however they also provide access where it would otherwise not exist. Ladders connect two otherwise separate points or places and have minimal mass compared to the solid, block-like stair cases in Escher's artworks. Modelled inside another form and cast in glass, ladders permit light to enter around and through their delicate structure with minimal obscurity of view adding to the ephemeral atmosphere. Having facilitated the flow of glass the ladders are themselves transformed through casting to become permanent, connecting the flow of mass and space inside, giving a sense a stable, unchangeable inner world.

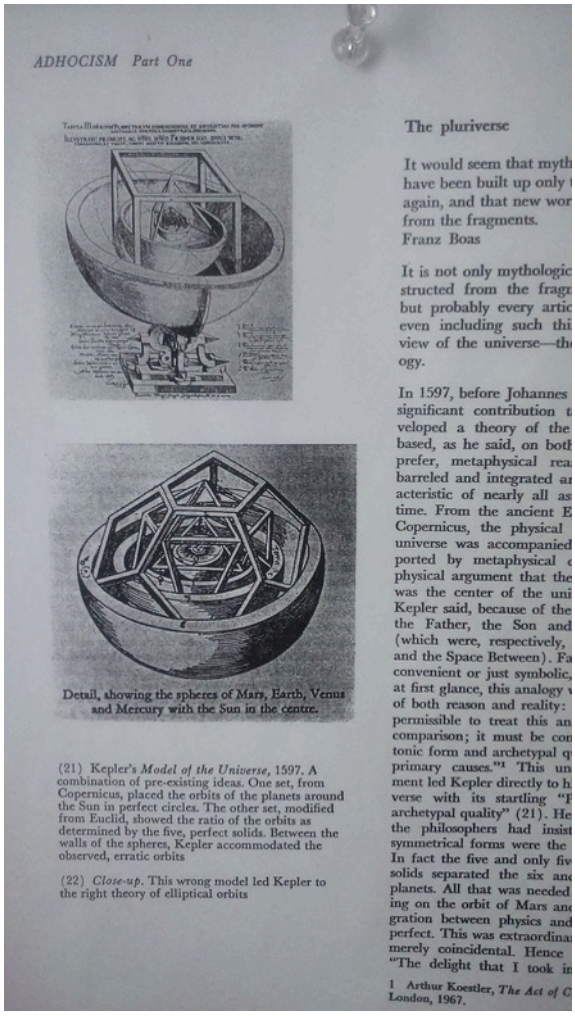
The theme of *Worlds within Worlds* developed further through association with the Ordered Universe project. Colin Rennie and Dr Cate Watkinson, senior academics and researchers in Glass at University of Sunderland, connected to this international, interdisciplinary project via Durham University. A group

reading of treatises by Bishop Robert Grosseteste, about whom the project revolves, took place at the NGC. The text ‘De Luce’, about light, has been described as a Medieval version of the big bang theory as Grosseteste writes about spheres of light forming within other spheres, to create a ten layer multiverse. Responding to this idea I started to model more complex spheres within spheres. Modelling ten layered spheres within spheres in 3D is made possible through the use of digital technology. Casting a ten layered 3D form in glass has yet to be achieved and therefore still represents the ‘unmakeable’.

100. M.C. Escher, Hand with reflecting sphere, 2015, Dulwich Picture Gallery.



100.a. M.C. Escher Stairs detail, 2015, Dulwich Picture Gallery. Photo A.Thwaites .



ADHOCISM Part One

The pluriverse

It would seem that myth
have been built up only
again, and that new wor
from the fragments.
Franz Boas

It is not only mythologic
structed from the fragr
but probably every artic
even including such thi
view of the universe—th
ogy.

In 1597, before Johannes
significant contribution t
veloped a theory of the
based, as he said, on both
prefer, metaphysical rea
barreled and integrated a
acteristic of nearly all as
time. From the ancient E
Copernicus, the physical
universe was accompanied
ported by metaphysical
physical argument that the
was the center of the uni
Kepler said, because of the
the Father, the Son and
(which were, respectively,
and the Space Between). Fa
convenient or just symbolic.
at first glance, this analogy
of both reason and reality:
permissible to treat this an
comparison; it must be con
tonic form and archetypal q
primary causes."[1] This un
ment led Kepler directly to h
verse with its startling "F
archetypal quality" (21). He
the philosophers had insist
symmetrical forms were the
In fact the five and only fiv
solids separated the six and
planets. All that was needed
ing on the orbit of Mars and
gration between physics and
perfect. This was extraordina
merely coincidental. Hence
"The delight that I took in

Detail, showing the spheres of Mars, Earth, Venus and Mercury with the Sun in the centre.

(21) Kepler's *Model of the Universe*, 1597. A combination of pre-existing ideas. One set, from Copernicus, placed the orbits of the planets around the Sun in perfect circles. The other set, modified from Euclid, showed the ratio of the orbits as determined by the five, perfect solids. Between the walls of the spheres, Kepler accommodated the observed, erratic orbits

(22) *Close-up*. This wrong model led Kepler to the right theory of elliptical orbits

1 Arthur Koestler, *The Act of C*
London, 1967.

101. *Pluriverse* , image from Adhocism: the case for improvisation

102. Angela Thwaites Design board for Grosseteste project, *Being Human* day at Durham University.

4.4.6 Scale, colour, mass and space

The *Worlds within Worlds* series comprised a range of forms cast on various scales. I experimented with colours and types of glass, the selection of glass

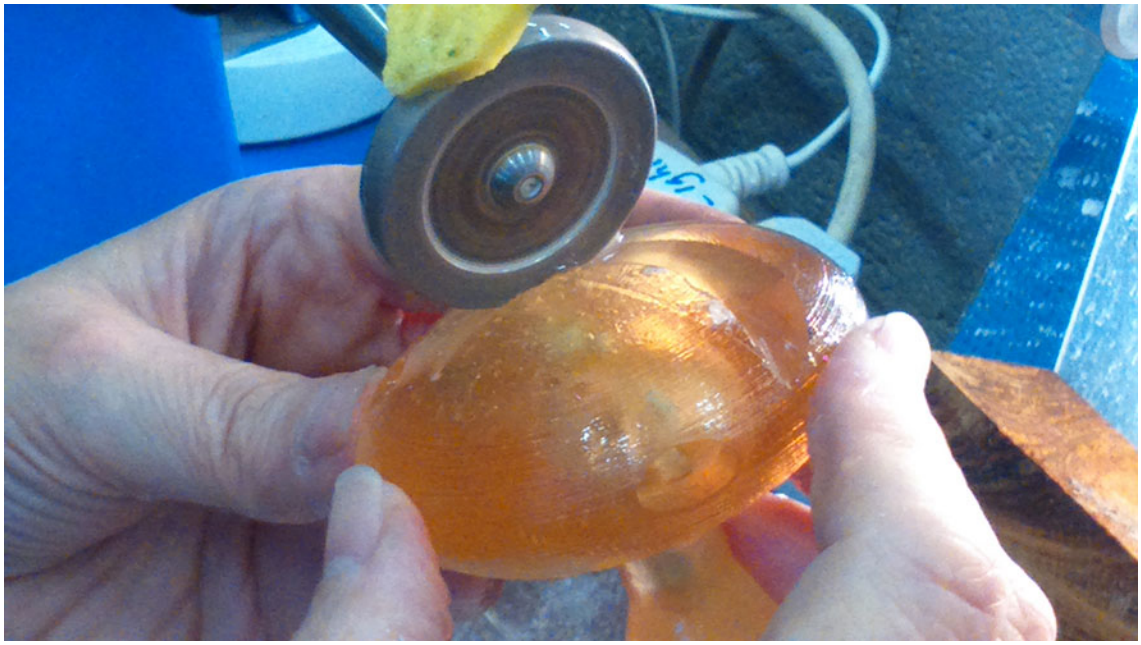
type being informed by knowledge and experience from previous practice and research.

Some of the initial simpler forms cast well in amber and dark blue/green glass but these colours were too dense to transmit much light, so restricted visibility of the interiors. As I developed the complexity of the interiors, high lead content lightly coloured or tinted glass was used. In combination with adjustments to soak times at top temperature, this soft glass ensured full casting of the form and reproduction of fine details and surface qualities and transmitted plenty of light to enable views of the inside.

The most successful group of *Worlds within Worlds* was cast in ‘Champagne’ coloured transparent glass. This allowed light to penetrate the interior spaces through the body of the glass as well as through the apertures in the outer surface.

4.4.7 Finishing and presentation

A couple of early casts were cold worked and polished to a high gloss finish but the resulting transparency worked against the idea of a veiled and mysterious view of the inside spaces. Polishing selected areas provided intriguing viewing points and still allowed enough light to penetrate the interior spaces. As the series progressed, the surface texture of the outer skin of the spheres was left intact and greater emphasis given to the shape, position and size of the apertures in it. This created distinct viewing ports into the object interiors and also drew positive attention to the distinct ‘digital footprint’ of the surface texture translated into glass through the casting process.



103. Engraving/ cold worked surfaces showing digital footprints

104. Engraving/ cold worked surfaces showing digital footprints

105. Angela Thwaites, 2017, *Flat eggy/globey* engraved and polished. Photo D. Lawson

105.a. Endoscopic image inside showing ladders

Collaborations, exhibitions and special projects

The *Worlds within Worlds* series, along with other pieces from the first two years of this research, were exhibited in the Research Gallery at the National Glass Centre (NGC) in Sunderland during the summer of 2016. This was central to my Year 2 annual monitoring submission and gave an opportunity to consider presentation, document the work through professional photographs and reflect on progress as a whole.

106. Angela Thwaites, *Worlds within Worlds*, 2016, at National Glass Centre, Sunderland. Photo D. Lawson

107. Angela Thwaites, *Worlds within Worlds*, 2016, at National Glass Centre, Sunderland. Photo D. Lawson

108. Angela Thwaites, *Worlds within Worlds*, 2016, at National Glass Centre, Sunderland. Photo D. Lawson

In 2018, I was invited to take part in ‘Science, Imagination and Wonder’ (SIW) at Pembroke College, Oxford as part of the ongoing ‘Ordered Universe’ project. As well as giving a presentation at the SIW Conference, I created a new installation of *Worlds within Worlds* using a range of colours and sizes of sphere and re-imagined a scientific experiment documented by Grosseteste concerning the lens like quality of water. Further details are provided in Appendices.

109. Angela Thwaites, 2018, *Worlds within Worlds* at *Light Embodied* exhibition part of *Science, Imagination and Wonder* conference, Pembroke College, Oxford, 2018

110. 110.a. and 110.b. Installation *Worlds within Worlds* at *Light Embodied*, Pembroke College Oxford, 2018

4.4.8 What I did and the data to substantiate

The *Worlds within Worlds* series provided opportunities to expand and develop approaches identified early in the practical research process. Initial ‘Eggy’ and ‘Globey’ forms were vehicles for exploring various aspects of digital modelling

and 3D printing. Being able to save, revisit and change the original Rhino files facilitated incremental layers of complexity to be modelled which increased learning and confidence with software. This also led to new levels of challenge in the physical processes of mould making and glass casting.

The form of the plasticine reservoir base (used for setting up the 3D prints for mould making) reproduced in glass and provided an extension of the original form. This led to the practice of adapting models at the Rhino stage to design and control the size and shape of this reservoir base in order that it seamlessly became part of the final form in glass. Strands of PLA which were attached to the 3D prints were also reproduced through the glass casting process. This was also taken forward in practice and deliberately applied in a way that it became part of the final form. A key question arose here as to the whole idea of a piece being 'finished' and the role of the object in 21st Century art. These questions were addressed through reading on new materialism and post digital contexts. This led to 'Un-object', the theme for the Pilchuck masterclass (2016) which aimed to explore systems and process without the necessity of producing 'finished pieces'.

4.5 Jewellery

My intention was to design, make and exhibit a new collection of jewellery comprising two related groups of pieces, one wearable and one sculptural, both made on the same small scale. I wanted the two groups in the collection to have contrasting characteristics and qualities. One group was to have unexpected combinations of form and content with figurative and humorous characteristics. I used methodological approaches from music and dance practices, described in detail in Methodologies, Chapter 1 and research from the contextual review into Surrealism and Dada to inform a spontaneous and playful 'Improvisational' approach.

The second group based on an 'Orthodox' approach was to have simple pared back, clear forms with organic and geometric qualities to be cast in one piece in

one translucent colour. This approach related to Libenský/Brychtová philosophies and principles rooted in Czech Cubism.

111. Angela Thwaites, 2017, *Turquoise ring thing*, *Wearable Glass* exhibition, Ruthin Craft Centre

4.5.1 3D printing / Casting from 3D prints

Rhino and TinkerCAD were used to model simple, 3D printable ring forms and elements. Rings were 3D printed in several wearable sizes and one or two were printed on a larger scale as bracelets. Both PLA and Formlabs Castable resin elements were printed, some were cast in one piece and others created from separate forms and collaged/constructed together.

Initial moulds were hand built in layers around both PLA and resin prints. Dipping of some of the finely detailed forms was used to create a face coat and subsequent layers of mould mix built up by hand using a spatula.

Both types of 3D prints burned out easily and any ash residue was removed using gentle vacuum cleaning. The first results in glass showed a few areas of missing detail. This coincided with thicker areas of the mould wall, so making the next set of moulds I marked the setting up boards and monitored each layer thickness to prevent excess building up.

Forms were composed and constructed using separate elements of both types of 3D print and other combustible materials glued together. These were dried and then invested in refractory mould mix as before. During this stage of experimentation various adhesives were trialled to find the best for construction, to withstand handling and mould making and to be safely combustible in the kiln. PVA glue was the best option and tiny amounts of super glue were used where necessary. The use of a candle to fuse strands of PLA was also used to add vents as described above.

The first castings were one piece one colour. As the series developed colour tests and blends were carried out for the two jewellers I was working with on the ‘Wearable glass’ project. Experiments with specific placement of colour in the mould reservoirs, based on a pâte de verre approach, resulted in subtle blends and colour transitions. This practice was then used in subsequent pieces of my own to good effect.

112. Angela Thwaites, 2017, *Gold ruby/apricot ring thing* with colour blend, *Wearable Glass*

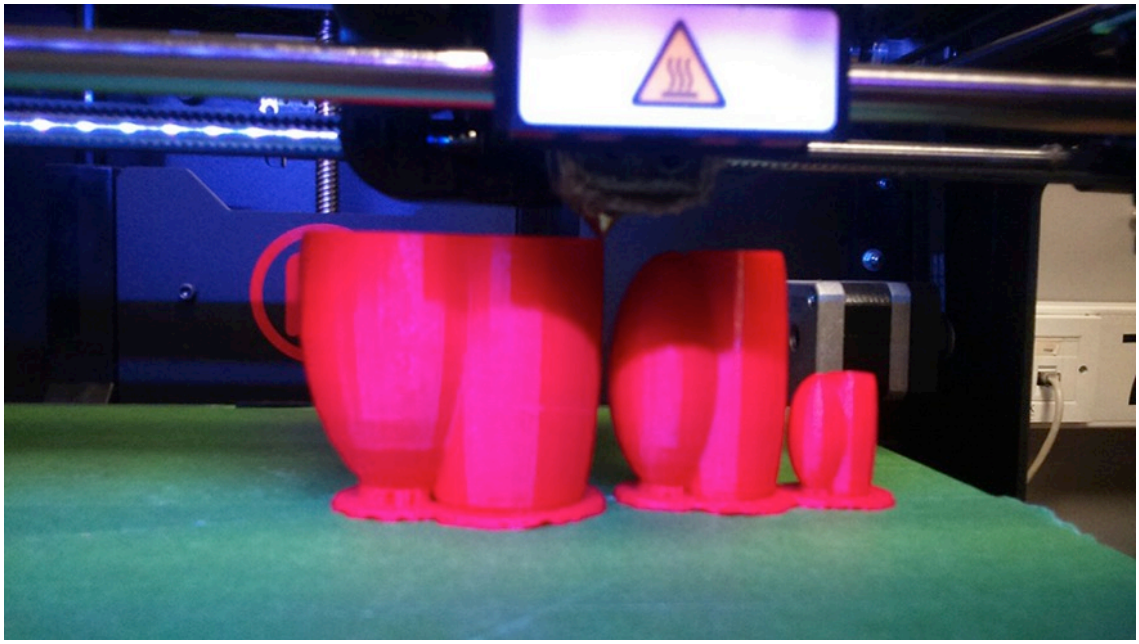
4.5.2 Approaches and what issues they engage

The development of wearable jewellery and portable sculpture provided an opportunity to engage methods identified from the previous stages of practical research experimentation and to explore and expand these further. Two main approaches developed and were employed for the rest of the PhD: ‘Improvisational’ and ‘Orthodox’.

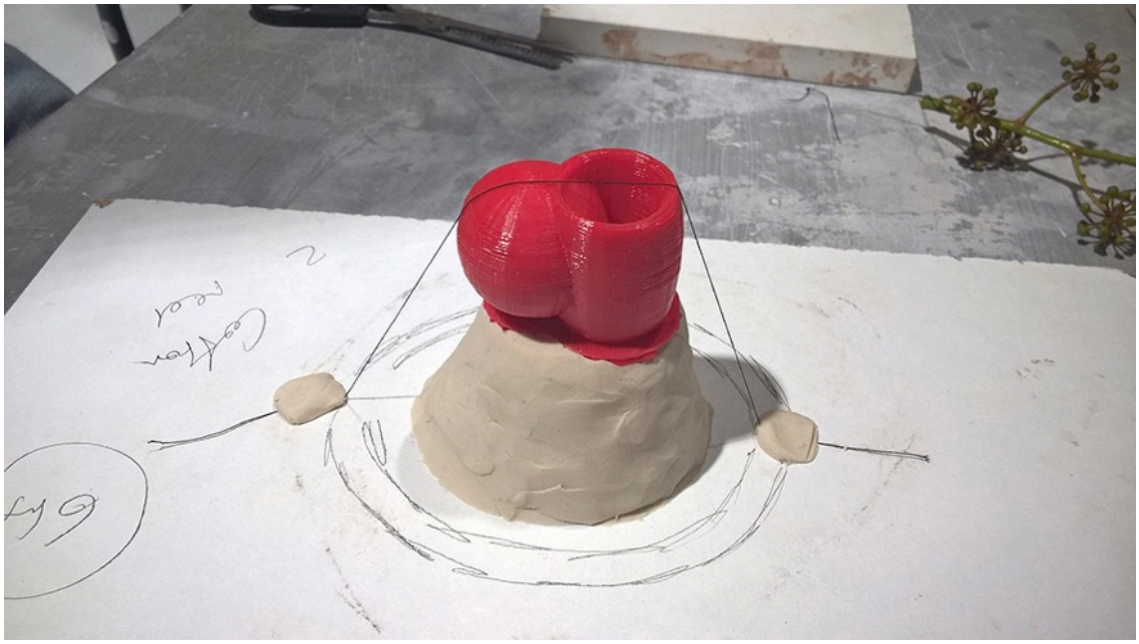
‘Orthodox’ established earlier, followed a linear path of digital modelling, 3D printing, casting and cold working. ‘Improvisational’ which grew out of and alongside ‘Orthodox’, enabled the spontaneous development of form and content which could not be realised via a linear approach. Spontaneous and instinctive decision making allowed for rapid changes, including reductive as

well as additive model making. This method of ‘Improvisation’ gave rise to a third approach which was the introduction and inclusion of other media which further expanded possibilities at the model stage and at the resolution stage in terms of ‘wearability’ and durability.

These approaches were simultaneously applied, continued and developed into the next stages of practical research. To sum up: ‘Orthodox’ = linear path of conception and making; one model one print one cast. ‘Improvisational’ approach 1. = constructed model, one cast. ‘Improvisational’ approach 2. = construction after casting, re-fired or bonded.



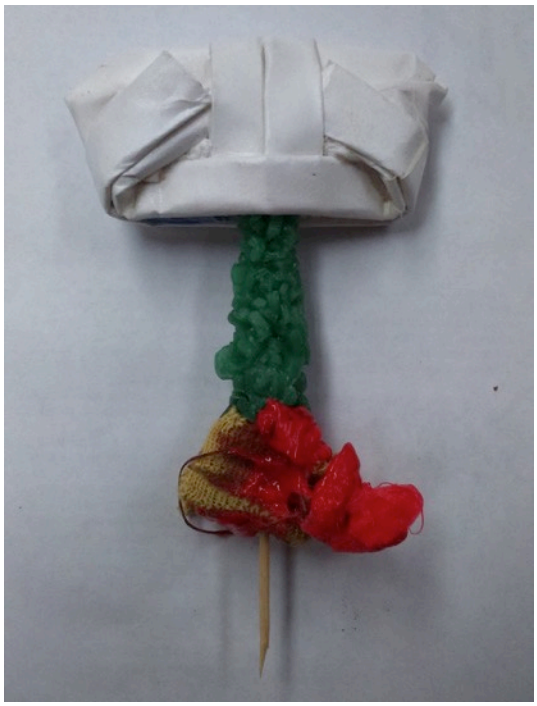
113. ‘Orthodox’ method, *Ballcyls* printing



114. *Ballycyl* set up for mould making

115. Cast as *Red Ballcyl pendant bead*. Photo D. Lawson

'Improvisational' method 1.



116 *Turban tree* model

117. Angela Thwaites, 2016, *Turban tree* Glass. Photo D. Lawson

'Improvisational' method 2.

118. Angela Thwaites, 2017, *Opal red ring*. Photo D. Lawson

119. Angela Thwaites, 2017, *Gold turquoise ring*. Photo D. Lawson

4.5.3 Physical digital combinations

The ‘Improvisational’ collage/construction approaches liberated ideas and overcame limits of process and material. The first stage of this was that it was no longer necessary to model and 3D print a complete form from one digital file. This meant I could use models imported from Rhino and TinkerCAD together in one object through 3D printing them as separate elements and then combining them physically. This process enabled the creation of forms which would be difficult to support and print in one piece and forms where different parts required the use of different types of 3D print material. It also opened up the idea of using other combustible materials in combination with the 3D printed forms at the modelling construction stage.

Mixed media constructions were created using 3D prints, waste 3D print material, and paper, card, fabric and plant/wood fragments. Using this approach opened up new possibilities regarding form, texture and potential ‘wearability’.

119.a. Angela Thwaites, 2018, *Black Croissanty ring*, cast from model constructed from separately printed elements

120. Angela Thwaites, Roker Rock Ring, 2017

121. Angela Thwaites, 2017, *Roker Pendant*. Photo D. Lawson

A further level of the ‘Improvisational’ approach was developed after casting. Glass elements were cast, cold worked and then bonded or fused together. In some of the jewellery pieces ceramic and metal elements were also added at this stage. This added further possibilities regarding form, colour and texture and facilitated cold working of separate elements before final construction. Other materials and techniques were also used to create a mounting system for the presentation of the work.

122. Water jet cutting ‘bunk bed’ stands for *ring things*

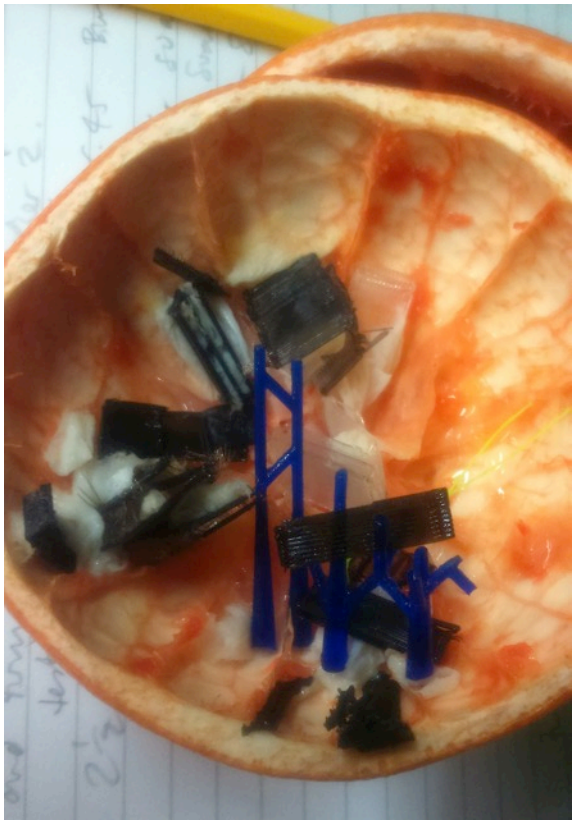
4.5.4 What was made and how

During the second year of the PhD, I was invited to take part in a special project, entitled ‘Jewellery: Wearable Glass’. Seizing the opportunity to develop aspects of the processes I was researching for the PhD and inspired by interaction with the jewellers, I produced a new collection involving various combinations of 3D printing, casting, cold working and mixed media.

An approach to constructing models was evolved informed by further contextual research into improvisation, ad hoc and ‘DIY’ methodologies including influences from Surrealism and Dada. This included Schwitter’s (1887-1948) technique developed under the title ‘merzbau’, of three dimensional collage (from the French word “coller”, to glue) based on the combination and construction of a mix of materials and forms assembled together to create a new whole form. Using this approach was an important step which speeded up some aspects of making, opened up other strands of the ‘unmakeable’ involving the use of construction methods and other materials leading to new forms which could not be produced using the linear application of digital followed by physical process.

123. and 123.a Schwitters *Merzbau Wall*, at Hatton Gallery, Newcastle

124. Building Grapefruit collage



125. Building Grapefruit collage

126. and 127. Angela Thwaites, 2015, *Grapefruit gazer* in glass. 126. Photo D. Lawson

Post casting construction was used to create ‘Akrobatiky’, a group of three pendants and a further series of ‘Ring Things’. This resulted in forms with a duality of geometric and organic characteristics designed and made using digital modelling, 3D printing and physical casting, cold working and construction together, along a non-linear process path.

The ‘Orthodox’ approach was used to create parallel series of forms with different functions/outcomes. One series was based on various iterations of a very simple form of a sphere and a cylinder compressed together during digital modelling. This form ‘Ballycyl’ was used to explore ‘Repeat with Difference’ in various ways. It was repeat 3D printed in a range of scales, stretches and proportions and cast in various types and colours of glass. The 3D prints were set up to cast so that the interior space could be open at each end to create a tube or closed to create a vessel. For ‘wearable glass’ the forms were cast as open ended beads which could be strung as pendants/necklaces.

The second series created from the same TinkerCAD model, was 3D printed and cast with the inner space closed at one end, forming a vessel shape. ‘Repeat with difference’ was engaged in terms of scale and stretch at the pre-print point to create ‘Vessel line-up’ cast in a range of colours. This demonstrated the tonal variations created by light transmission through differing thicknesses of glass – the colour ‘volume principle’ of Libenský/Brychtová, applied on a nano-scale.

128. Angela Thwaites, 2017, *Vessel line up*. Photo D. Lawson

129. Angela Thwaites, 2018, *Vessel line up*, for *Loud and Clear* exhibition, Harley Gallery, Nottinghamshire.

4.5.5 Themes and content

My response to the over-arching theme of ‘Wearable glass’ was to create a new collection that included some pieces that could be worn and some that related to the idea of being worn, but were essentially miniature or nano-scale sculptures. The decision to use rings as the focus for this collection was inspired by the two jewellers who had chosen to work with me on casting. The choice to work with rings and nano-scale sculpture was also informed by images of ancient amulets and miniature artefacts examined during the contextual review process. The collection was to include some ‘found’ as well as modelled forms. Files of miniature sofa designs were sourced from ‘Thingiverse’, 3D printed and added to other elements of my own design to create unexpected combinations and forms of a humorous nature. The unexpected meeting of a Queen Anne style sofa with a croissant, for example.

130. Angela Thwaites, 2017, *Ring things* with sofa and croissant

130a. Angela Thwaites, 2017, *Ring thing Allis*. Photo D. Lawson

This playful approach was developed in the next series of pendants entitled ‘Akrobatiky’.

131.Angela Thwaites, 2017, *Akrobatiky Trio*. Photo D. Lawson

132. Angela Thwaites, 2017, *Akrobatiky no. 2*, photo D. Lawson

4.5.6 Scale, colour, mass and space

The rings were made on a direct wearable scale by defining measurements during the CAD process. The ring shanks and ‘gemstone’ equivalent were 3D printed separately and bonded either before mould making or in some cases after casting. After casting and beginning to cold work the light transmission affecting the colour intensity was seen to be much reduced if the reservoir was cut off. Further experiments were carried out modelling the reservoir shape with the intention of leaving it as part of the final cast form. The results showed much richer colour and tonal variation so a series of sculptural ‘ring things’ was created using this method and exhibited at ‘Liquid to Solid: The Mutability of Glass’, 2017-18.

133. Angela Thwaites, 2017, *Dark blue green ring thing* on reservoir base showing colour intensity. Photo D. Lawson

4.5.7 Finishing and presentation

In order for the rings to react with light, and to be seen in a clear and dynamic way, I devised a simple effective mounting from which they would be visible from all angles. Using clear float glass and designing a system with slots so that the rings could stand up and be seen through it and from all angles, echoed a Cubist principle relating to form and multiple simultaneous viewpoints.

The initial idea for the mount system was a sketch on paper, based on the idea of stacked bunk beds. I designed it with interlocking sections and slots in the horizontal plane in which to hang the rings. This sketch was drawn out on AutoCAD and the float glass was water jet cut. The edges were lightly finished by hand and the slots softened and widened to fit individual rings using a diamond file, also by hand.

134.and 135. Images from ‘Wearable glass’ showing Rings Things in bunk beds

The ‘Ballcyl’ beads were minimally cold worked by smoothing the ends where the reservoirs had been and lightly brush polishing to leave the digital footprint of the surface.

136. Angela Thwaites, 2016, *Clear/copper Ballycyl pendant* Bead showing unworked digital footprint on the surface. Photo D. Lawson

4.5.8 Collaborations, exhibitions and special projects

‘Jewellery: Wearable Glass’ was a project devised by the curator of the National Glass Centre (NGC), Sunderland in collaboration with Ruthin Craft Centre. Four glass practitioners working across four technical areas were teamed with two mid-career jewellers each to facilitate the making of new work in glass. Collaboration with the two jewellers inspired me to develop jewellery outcomes as part of my research. The final pieces from all participants, along with photos and film footage of the collaborative process, were exhibited at NGC Sunderland and then toured to Ruthin Craft Centre in Wales and Studio Fusion in London. A catalogue was produced and a number of pieces were sold.

‘Akrobatiky’ started with the idea of the body as a building site and led to combining and abstracting visual sources of inspiration from architecture and acrobatic performance along with elements from digital models I had already created. ‘Akrobatiky’ and ‘Ring things’ resulting from this key stage of practical research were also shown in a group exhibition, ‘Liquid to solid: The Mutability of Glass’, London, 2017-18.

4.5.9 What I did and the data to substantiate

The introduction of other materials and found objects in combination with cast glass expanded the wearable and sculptural possibilities of the jewellery pieces. The incorporation of found ceramic and glass elements, small stones and pebbles sourced from local Roker beach in Sunderland and metal leaf enabled form and content to expand in a more spontaneous way than digital modelling, 3D printing and casting alone.

I collected various pieces of material and natural stone and selected from these to complete the forms of some of the jewellery collection I was developing. Criteria of form, colour, size, weight, durability and physical limits of construction were used to select the found objects/materials. Several of the natural stones and ceramic fragments were cold worked in order to be bonded together with glass. For examples the turquoise-blue ring in image 130. shows a small ‘gem’ of contrasting colour glass which has been shaped, polished, gilded and bonded to the glass sofa which is the top of the glass ring. Image 135. shows two rings which have been constructed using terracotta ceramic shaped into rings. The right hand ring has a cast glass coracle bonded onto it and the left has a sliver of found glass which has been shaped as a miniature plinth to on which is set a natural stone from Roker beach, gilded on the reverse side.

4.6 Conclusion

To conclude this chapter I have created a tool for reflection based on experimental methodologies described in Chapter 1. This tool takes the form of an imagined conversation between myself, Libenský and Brychtová. Putting myself and my research into this conversation compresses time and connects themes of timelessness and 'scalelessness' to the making of 'unmakeable' artworks in glass described in this chapter. This dialogue interrogates my underlying approaches and aesthetic concerns and articulates their relationship with the philosophy and practice based approach of Libenský and Brychtová. Re-iterating my aesthetic aims and focus on form, the qualities and characteristics I wanted to achieve, why I have chosen glass as my primary medium for artistic expression, and how to further develop contemporary dialogue with the philosophies and artworks of Libenský and Brychtová.

Libenský and Brychtová's responses are taken from a discussion in the catalogue accompanying one of their final exhibitions 'The inner light: sculpture by Stanislav Libenský and Jaroslava Brychtová', (Kehlmann, 2002).

AT: Your live's work has been studying the technology of glass not as a path for making beautiful objects but as a means of inquiry into ideas. (Kehlmann, 2002, p.14).

Libenský: 'there is no sense in producing objects. Creating ideas is what makes sense.' (ibid 2002 p.86).

AT: This philosophy you taught, where sculpture is not only a physical outcome but a means of developing an understanding of the world, has had massive impact. It became the basis for my own practice and research, including this study.

Let's talk more about the choice to work with glass, a key part of your philosophy.

Libenský: 'The more you know about glass, the more you are able to take out of it what is really essential. Your work is more contemporary because of your ability to draw out the essential.' (ibid 2002, p.85).

AT: This focus on essential form has indeed maintained its contemporaneous quality. It still resonates in a timelessness way across an international field of kiln formed glass. Time and timelessness are important factors in your artwork and I aimed to carry this forward in this research project in an actual and a metaphorical sense.

Brychtová : 'the fourth dimension, time, is as important to a work as its height, width or depth' and 'The element of time expands an object's or a building's presence to include the viewer's experience of it. It is no longer simply a fixed entity in space.' (ibid 2002, p.10)

AT: That's an interesting perspective and chimes with contemporary thinking, to include the viewer's participation as part of the artwork, echoing the idea from earlier, that the object is not 'fixed' as an outcome, nor necessarily the primary concern.

Brychtová : 'Naturally perception is subjective, but it's also gradual…a sculpture that stands in space is perceived gradually.' 'The viewer's experience becomes a part of the work itself' (ibid pp. 77 and 89)

AT: Kehlmann also highlights the 'scalelessness' emerging from Libenský's drawings into sculpture 'that allows them to be reduced or enlarged, suggesting they have no single ideal measurement' (ibid 2002, p36)

Taking these principles of 'timelessness' and 'scalelessness' which you worked with monumentally, I have applied them through the use of digital technologies on a miniature scale. This constitutes one aspect of the originality of my

research. Scale becomes almost irrelevant if the work absorbs the viewer and has presence in space.

Brychtová: ‘the space inside the sculpture meets the space outside. The sculpture becomes one with the space’ (ibid p77).

AT: Space, mass and the relationship of light to glass sculpture have guided what I have made throughout this project. This unity between inner and outer form and sense of dematerialisation, are intriguing qualities to pursue digitally and in miniature, and are, as discussed earlier, timeless.

Brychtová: ‘All sculpture is defined or viewed by the reflection of light, but only glass sculpture is defined by light penetration’ (ibid, 2002, p.25).

AT: That sums it up clearly. Light and space in glass create a sense of abstraction of scale. The object appears to dissolve into the space outside itself; to dematerialise.

Libenský: ‘organizing light in the inner mass, concentrating it in the inner volume of the pieces’ (ibid, 2002, p.89)

AT: Yes it’s designing and making forms which focus light in this particular way so that the ‘inner morphology’ as you describe it, is made ‘of light and planar intersections’ (Brychtová, ibid, 2002, p.25)

This relates back to Czech Cubist ideas about the subjectivity of perception and intent for simultaneous views without the loss of form.

Brychtová: ‘The Cubists wanted to make everything visible from one point of view, and that’s something glass does quite naturally. This view which encompasses all that’s contained in a sculpture must be respected. We must always be aware of the quality of glass.’ (ibid. p.77)

AT: Kehlmann talked of clear glass as giving ‘expansive and restful geometry. Fewer fractured planes’ and enabled us to ‘see the whole at once’ (ibid, 2002, p.32). This connects to Cubist ideas with which you and Professor Libenský

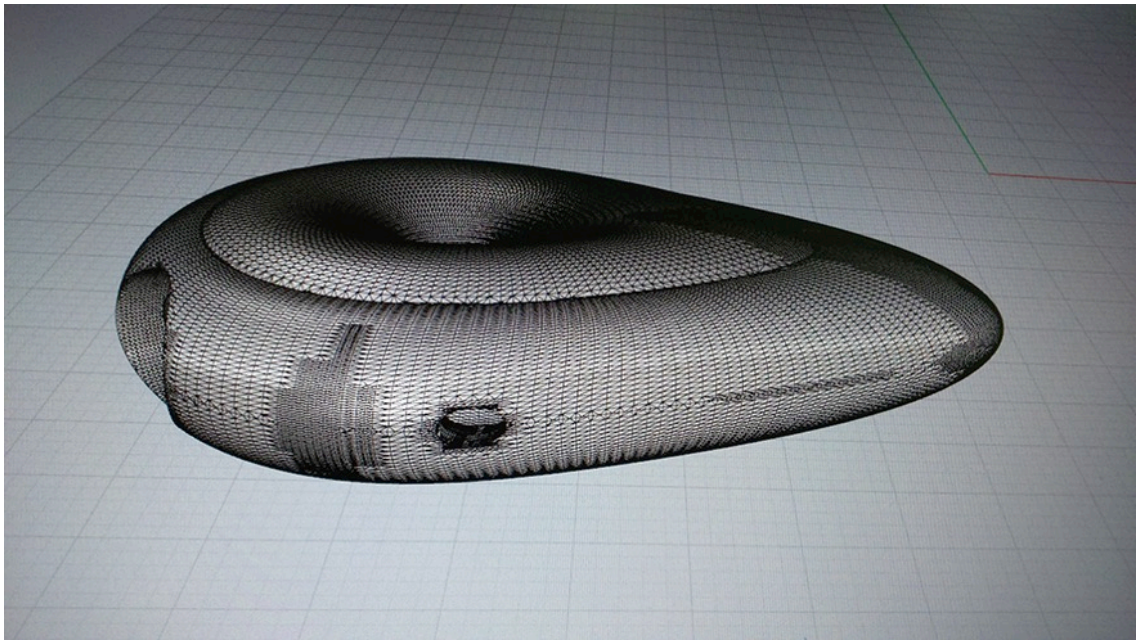
worked and taught, and which have suffused my own practice. These ideas and principles are crucial to my research and are perennially relevant in the context of contemporary studio making.

Brychtová: 'It [Cubism] was a simple, basic form of expression. It was something pure' (ibid p.77)

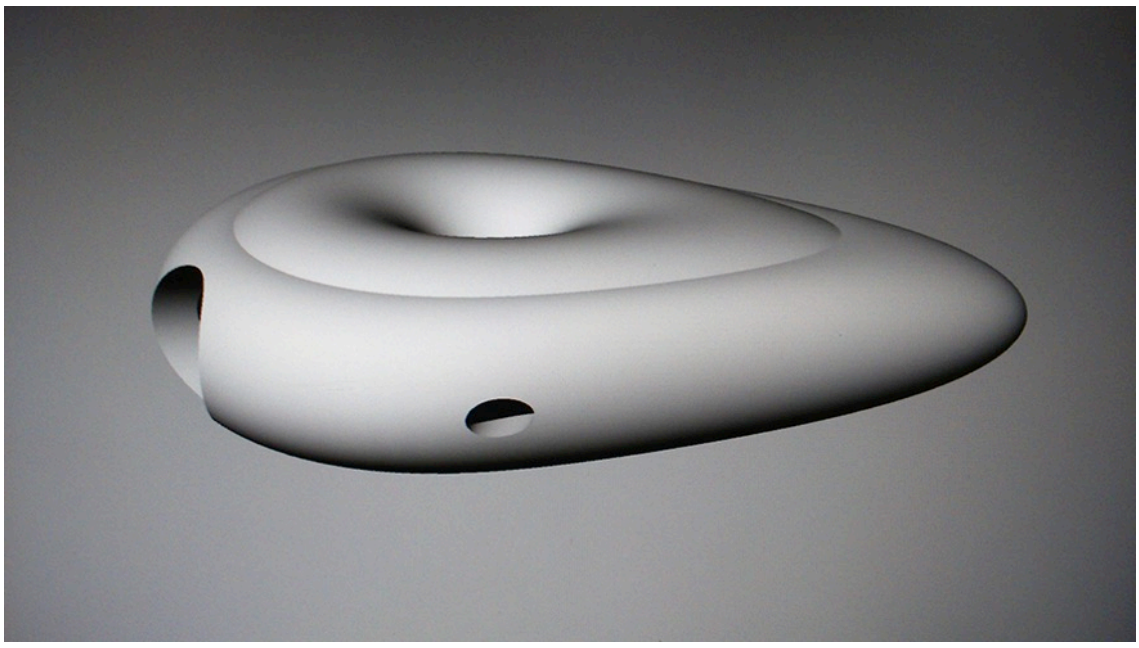
AT: This sense of pure, undecorated, essential form, directly connected to real life, is of great importance. Jiří Harcuba, who was a student of Karel Štipl, explained this clearly 'Even if the design was abstract, we believed that you have to get everything from life, and so the proportions are human' (Oldknow, 2002, p.67). Without this root, the idea and meaning of the artwork can be become lost or diluted.

Libenský and Brychtová : ' [we] have investigated the intangible in the tangible, the immaterial residing in the material, and the inner light within corporeal being.'(Kehlmann, 2002, p.14).

AT: You have used sculpture to seek answers to complex existential issues which are as relevant today as they were thirty or a hundred years ago. Sometime after I had started to use the description 'unmakeable' I found that Kehlmann had used the term 'unfeasible' to describe your final 'Imprint of an Angel' series (ibid, 2002, p.17). Taking this end point of your combined life time's research as the starting point for my own, I set out to explore and expand on the boundaries of what is 'makeable/unmakeable' in cast glass.

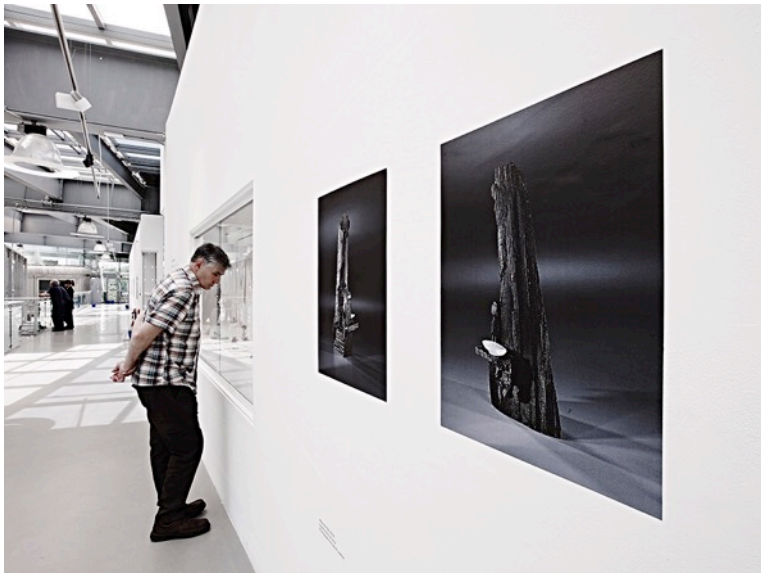


137. *Bagely stretch* Rhino wireframe



138. *Bagely stretch* Rhino, pre-print

139. Angela Thwaites, 2016, *Bagely stretch, Croissanty* and other works, National Glass Centre showcases. Photo D Lawson



140. Angela Thwaites, 2016, *After the Fire* large photos, National Glass Centre. Photos D. Lawson.

141. Angela Thwaites, 2016, *Eggys with legs* in showcase NGC. Photo D. Lawson

Chapter 5 Conclusion

This concluding chapter reflects on all aspects of the research and its outcomes, its contribution to knowledge and potential areas for further research investigation. The intent is to provide a framework for practice covering broader concerns that inform thinking as well as making. This thesis brings together historical and contemporary attitudes to making to counter balance rapid loss of content and heritage in a digital age. This study highlights the importance of the application of craft skills within digital design and fabrication. Not only practical skills but attitudes, thinking and approaches rooted in craft practice.

Reflection on the research aims and questions is considered through the artworks produced and the written thesis together. The contribution to new knowledge offered is embodied in the artworks produced and in this thesis. Practice based experimentation centred on making the ‘unmakeable’ in cast glass through combinations of contemporary digital and heritage analogue techniques, approaches and philosophies of making. This was carried out utilising CAD, 3D printing and analogue casting techniques in new combinations to create unique artworks, and through the development of original methods and approaches in the production of miniature scale glass sculpture which expresses principles from Czech glass heritage.

Both technical and creative aspects of the study add to existing knowledge, to the context of glass art and potentially to a wider field of art, craft and design. Areas for further investigation include opportunities for extending the application of 3D printing across a broader range of applications and scales. The Appendices include a detailed list of exhibitions, papers, presentations and participation in events as part of this study.

5.1 Reflection on research questions

This research explored combinations of digital and analogue practices through the creation of artworks in glass, inspired by everyday starting points and

responding to Czech glass heritage. This section of the thesis reflects on how the following questions have been addressed through this research. (See 1.4)

How can analogue and digital processes be combined to produce previously ‘unmakeable’ artworks in cast glass and create new ways of thinking and approaches to making?

How can Czech glass heritage inform contemporary kiln formed glass making?

How is kiln formed glass practice being affected by a culture of open source and shared information?

5.1.1 How analogue and digital processes are combined to produce previously ‘Unmakeable’ artworks in cast glass and creating new ways of thinking and approaches to making

The making of the ‘unmakeable’ in cast glass has been achieved through experimentation and practice based research carried out for this study. The use of CAD as a design tool and 3D printing as a means of materialising were found to open up previously ‘unmakeable’ forms for casting in glass. Complex layered forms and structures were modelled using CAD softwares Rhino and TinkerCAD and materialised through 3D printing to create models which could then be invested in refractory moulds to be cast in glass. These types of complex forms were not previously possible to make using analogue processes alone.

In order to achieve the making of the ‘unmakeable’ in glass, experimentation was carried out across a range of digital and analogue process combinations and approaches. Through research and experimentation, I have identified many possible ways that analogue and digital processes could be combined and also many points along the path of design-to-making at which either or both can be applied for technical and/or creative reasons.

Through this research, novel approaches were developed and applied to making the ‘unmakeable’ I have called ‘repeat with difference’ ‘improvisational’ and ‘orthodox’. The artworks made for this study which most clearly embody the ‘unmakeable’ and demonstrate the application of ‘repeat with difference’ and ‘orthodox’ are *Biclops*, *Worlds within Worlds* and ‘Vessel Line–up’

5.1.2 How Czech glass heritage can inform contemporary kiln formed glass

This thesis provides a description of my long term relationship with Czech glass through personal experience of study and highlights the lasting influence of the artists Libenský and Brychtová. Their influence is international, covering several subsequent generations of artists working with glass as an expressive medium and like many of their artworks, monumental in scale.

Although there are numerous artists across the world who have been significantly influenced by and have taken up aspects of glass casting developed by Libenský and Brychtová, the approach I have taken in this study relating to their philosophies is unique. It aims to connect with and continue their influence into new generations through the artworks and thesis produced. Re-addressing scale through a miniature approach to the interplay of mass and space in glass sculpture with the action of light on glass colour, pioneered by the Libenskýs, has two effects. It refocuses the importance of their achievements of monumental scale glass casting and lays down a challenge regarding the need for ‘big’ statements in glass against a 21st Century context.

5.1.3 How Kiln formed glass practices are being affected by a culture of open source and shared information

In studio kiln formed glass the use of contemporary digital technologies has been initially slow to develop compare to other areas of art and design. This was due to lack of access to digital facilities and expertise outside industrial and academic contexts and to a general lack of understanding regarding potential benefits.

This is changing, and a number of studio glass practitioners are now pursuing digital modelling and 3D printing. Initially the availability and cost of equipment and software was limiting. At the time of writing this thesis (2018), the cost of a basic desk top 3D printer has gone down to around £200-£300. Access to and engagement with software is a changing scenario too and low and no cost options on line provide starting points for trialling digital modelling and 3D printing which can be out sourced through various bureaus and maker spaces. Online resources such as Youtube provide information, tutorial input and answers to questions and trouble-shooting open to all in a reflexive use/contribute way. As open source and professional software continue to develop at speed this may give access to further levels of the ‘unmakeable’ regarding scale and content.

5.2 Reflection on research aims

By considering context and methodologies, and identifying the use of CAD, 3D printing and analogue casting techniques to create formerly ‘unmakeable’ artworks in glass, this study has addressed the key aims of the research as described in Chapter 1.

To reiterate the original research aims from 1.5 for reflection:

To consider the language and significance of form, colour and scale in kiln formed glass against the background of Czech glass heritage

To consider a democratic context for contemporary practice in kiln formed glass encompassing social, critical and technological change

To use CAD and 3D printing in combination with analogue glass casting processes to make the ‘unmakeable’

5.2.1 Considering the language and significance of form, colour and scale in kiln formed glass against the background of Czech Glass Heritage

The language and significance of form, colour and scale in kiln formed glass have been considered in this research against a background of the heritage of Czech glass, particularly that of Libenský/Brychtová.

Responding to the Libenský's principles of evolving sculptural form and language which were rooted in Czech Cubism, I have applied a 21st Century perspective on fragmentation, crystallisation and abstraction of three dimensional form. This has been explored through digital modelling to develop new forms for casting glass. Taking the Libenský's 'colour volume' principle as a starting point, I have applied it to miniature rather than monumental scale. These qualities and approaches are embodied in the series of artworks produced notably 'Vessel line-up', 'Croissanty', 'Rock Lobsters', *Worlds within Worlds* and 'Wearable Glass', which are described in detail in Chapter 4.

5.2.2 Considering a democratic context for contemporary practice in kiln formed glass encompassing social, critical and technological change

Through practice in glass and by providing accessible documentation, this project considers ways into the digital field for studio glass makers wanting to expand on traditional practices.

Considerations of accessibility have guided the development and documentation of this research including the writing of this thesis. Finding ways of clearly documenting the thinking and the making as equal, simultaneous partners in the research process presented new challenges. My response is reflected in the way the writing has evolved to create an unconventional PhD thesis and can be summed up in relation to the artworks by the recent comment: 'we've never seen anything like these before!' (CAA, 2018).

Studio glass has for many years focused on producing larger and larger scale work regardless of process and in many cases regardless of audience or context. This study challenges this through the creation of miniature scale artworks which could be termed nano-sculptures in cast glass. This is set

against a rapidly changing environment where questions around making and an increasingly post-human, post digital context arise. This is discussed in more depth in Chapters 2 and 3.

5.2.3 Using CAD and 3D printing in combination with analogue glass casting processes to make the 'unmakeable'

Additions and extensions to existing glass practices have been made possible through the use of CAD and 3D printing. These are demonstrated in the development of formerly 'unmakeable' forms and structures, particularly hollow forms for core casting with complex cavities and inner detail. Examples of the embodiment of this are *Biclops* and *Worlds within Worlds*.

The miniature scale on which I have created and developed these forms also offers extensions to analogues practices as digital design and 3D printing gives access to this scale which analogue materials and methods would struggle to produce. Detailed recording and documentation have enabled development of an understanding of technical and creative implications of changes in balance between the digital and the analogue and to explore approaches to navigating this balance.

Accuracy of reproduction of formerly 'unmakeable' forms and structures is achieved through both digital design and materials new to the field of studio glass. This includes the use of advanced settings at point of print to define layer height, orientation, speed, bespoke design of support structures, and layout on the print bed. All of these can be used creatively as well as for technical accuracy.

PLA prints and Formlabs Castable resin, the two main 3D print materials used in this study, can reproduce complex hollow forms, structures and surface detail to a higher level of accuracy and fineness than analogue materials. Direct investment and burning out of 3D prints resulted in finer surface reproduction and better release of glass from the mould surface, than the analogue method of lost wax. Steam removal of wax can result in erosive damage to surface, detail and water log the mould body to detrimental effect. The technique of

investing and burning/melting out from 3D prints is now being called ‘Lost PLA’. However I consider this to be a limited term as it excludes the Castable resin and could mislead practitioners into thinking that 3D printing is a direct replacement for lost wax, instead of a radical extension.

5.3 Contribution

The contribution to knowledge which this research offers is centred on the making of what I have described as the ‘unmakeable’ in cast glass. This is embodied in the artworks and in the written thesis. The bodies of artworks demonstrate that through the carrying out of this research, the ‘unmakeable’ has become makeable. This is due to unique combinations of CAD modelling, 3D printing and casting techniques resulting in hand held scale glass sculpture. Although the miniature scale is a fresh approach, the sculptural principles of colour volume, and methods of creating and developing form and visual language are firmly rooted in Czech glass heritage.

The approaches of ‘orthodox’ and ‘improvisational’ to create original forms, translated using digital modelling and 3D printing into the medium of cast glass, are a part of the contribution to knowledge in the field of kiln formed glass. The methods and approaches developed potentially offer addition to knowledge across a broader range of art, craft and design practices.

The thesis also offers new knowledge as a reference not only for practitioners in glass but with extending relevance into other areas of art, craft, design and model and mould making. The attention given to the importance of historical understanding and context and the power and meaning of making also offer new insight from a practitioner perspective.

The unconventional approach to writing the thesis combining documentation of research and practice contextualised against previous experience and research may also provide a useful model for future reference. The thesis indicates

avenues for further research and development of practice and pedagogical approaches which are described in more detail below.

5.3.1 Scholarship

Taking the working studio as the central point from which to address the research questions; the approaches, method and artworks created during this research offer practitioner insights and solutions back into the field of studio glass. This has been achieved through the development and documentation of the method and approaches and the impact these have on concepts and content.

Building on the knowledge, skill and experiences of the past using digital as an additional tool, not a replacement for analogue techniques, I have extended potential content and evolved new visual languages for kiln formed glass.

As well as liberating new content and language, the effects of adding digital methods into the historical analogue system of kiln forming glass have been considered and documented. What was once an identifiably linear process has been replaced with a complex network of simultaneous, infinite choices, decisions and directions. This complexity and multiplicity can lead further down a road of open ended process. This thesis deeply considers the importance of history as a counter balance to this existential tendency and points towards a reassertion of the object in art.

5.3.2 Artwork

The research carried out for this PhD is embodied in the production of series and bodies of new artworks created using combinations of CAD modelling, 3D printing and analogue glass casting techniques. These explore, demonstrate and express the key aims and research questions regarding the ‘unmakeable’ in cast glass. The artwork has and will be exhibited and the new knowledge produced as a result of this research will be shared with professionals, practitioners and in educational environments.

Several of the series of artworks I have made for this project are physical embodiments of this layered complexity and can be read metaphorically as well as literally. Layers within the forms indicate layers of meaning, mass and space equate to absence and presence, loss and gain, connecting to ideas explored in the research and writing of this thesis, existential questions around ‘losing the way’, boundaries of the truly ‘unmakeable’.

5.4 Thesis as model for approach

By building on and expanding themes from my previous practice and research, as well as developing new approaches and content, this research project has developed and extended what it was possible to make in kiln formed glass at the outset of the PhD. This has been achieved through combinations of traditional and digital approaches and processes which expand the expressive potential of kiln formed glass practice from where it is now into the future.

New modes of practice integrating traditional and digital approaches for the making of kiln formed glass sculpture have been identified, tested out and documented. This has contributed to the advancement of both technologic and aesthetic possibilities in kiln formed glass.

The approach taken during this project and methods of experimentation, documentation and reflection developed, offer new insights to the field of studio glass. The exploration and development of form and content within this project will be of value in a field where there is limited critical evaluation of the relationship between digital and traditional technologies applied to kiln formed glass.

Compared to other areas of art and design there is very little detailed and accurate documentation about glass making materials, processes and practice and less about glass and digital technology though this is a growing field. What comes across to a practitioner/researcher is the key importance of documentation written from the perspective of an in depth skill, knowledge and

understanding of materials and processes being used and discussed as well as accessibility and potential application of the written information. This was a major factor in previous research and writing of ‘Mixing With The Best’ (Thwaites, 2002) and Mould Making for Glass (Thwaites, 2011) on which this project builds. Transparency and accessibility of information were key features of these publications. The impact of this kind of writing is not only practical/ technical, but also aesthetic and conceptual. So it is across these areas that this project seeks to stimulate discussion and contribute new knowledge in the form of documentation and method which can be taken and used in a studio context as a basis from which to engage with digital technologies hand in hand with analogue practices.

These findings highlight the need for further experimentation, documentation and publication of clear, reliable and repeatable practice using 3D printed models for casting in glass if this is to become a viable practice for glass makers in the future.

5.5 Outcomes

The research covers a range of outcomes including novel approaches termed ‘improvisational’ and ‘orthodox’ which are detailed in chapter 4. The artworks made during this project embody and demonstrate the development of new approaches to concept and process through the physical combination of traditional and digital making methods to produce previously impossible forms and structures in cast glass.

Dissemination of this research was ongoing throughout the PhD which took the form of conference papers, presentations and exhibitions as well as teaching and peer discussion. Papers and presentations covering practical and conceptual aspects of the study have been presented to specialist and interdisciplinary audiences, evidencing the wider reach of the research. Exhibitions and publications through jury selection and invitation in a variety of

locations and contexts also reach out beyond a glass community to broader audiences.

The use of 3D printing in this study has facilitated the making of previously impossible forms and structures, realised in glass through analogue casting techniques. This has been achieved through practical experimentation using CAD as a modelling tool, 3D printing to materialise these models and analogue casting techniques of mould making and cold working to realise these models in glass. The series of artworks produced using these combinations of processes and approaches reflect on the original research question regarding making the ‘unmakeable’ and what 3D printing has to offer kiln formed glass practice now and into the future.

5.6 Reflection/interpretation

Before starting this PhD predictions of 3D printing as the next (post-industrial) revolution were in full swing. Christopher Frayling extolled the transformative role of digital technologies stating that ‘the subsequent making of the prototype is becoming purely mechanical’ (Frayling, 2011, p.136). However this is not the case with desk top 3D printing and the practical experiments documented in chapter 4 clearly demonstrate the necessity and application of hands on craftsmanship to ensure quality and success in 3D printing processes. There are many other makers and projects which reiterate the need for hands on skills and approaches (Ver Bruggen, Openshaw, VanderStukken).

Prior to this research, my practice has seen a continuity of approach and methodology starting with 2D drawing and designing on paper, followed by translation into 3D form through modelling using hand making techniques and traditional materials such as clay and plaster.

Expanding on this analogue basis, I have taken images and ideas gleaned from the everyday as starting points for modelling. I used paper sketches, digital

photographs translated through CAD (Computer Aided Design) to create virtual models physicalised through 3D printing.

My own knowledge and skill, a prerequisite for this research, has helped to foster confidence and ability to learn and apply new skills. As digital fluency has developed across design and production in terms of 3D print processes, new horizons for creative expression have opened up.

Artworks cast from 3D prints resulted in initial small groups of *Coracles* and *Biclops* shown as part of ‘Changing Practices’ at the Contemporary Applied Art gallery in London. The work was well received by gallerists, peers and public, including positive comments about the miniature scale of the works which was encouraging as this was an area of new exploration in contemporary cast glass.

During 2016, an exhibit of *Worlds within Worlds* was set up in the Research Gallery at the National Glass Centre (NGC) in Sunderland. By the time I was to set up a great number of tests and experiments had been carried out resulting in a series of works under the *Worlds within Worlds* heading. Various designs had been repeated with differences in form and scale and types of glass. Having to edit from the series focused reflection on progress to date and pin pointed issues for subsequent stages of investigation.

Key questions arose here on the notion of a ‘finished’ piece and the role of the object in contemporary art. Further contextual review and peer discussion ensued. Out of this grew the idea for the Pilchuck masterclass, ‘Un-object’. The aim was to explore combinations of analogue/digital processes in an experimental and open ended way. It presented a high level of challenge for the students who enrolled on the class. Prior experience in cast glass ranged from none at all to professional level across the group, and two students had no experience of working in three dimensions, either design or fabrication. This led to further reading and consideration of the existential trap of process without end or outcome.

Researching and writing the papers ‘Glass in a Restless Age’ and ‘The exploration of space [in glass] as the setting for life’ contributed to the

contextual review, particularly the overview of Czech Glass History and its legacy which has contributed significantly to Chapter 3. Giving the paper at European Glass Context also engendered useful response from peers across an international field, some of whom expressed opposite views to my own about the future of making. This led me into further research and re-considering of the role of the maker in 21st Century. Both of these papers have therefore supported the development of the thesis overall.

‘After the fire’, a unique piece, cast from a composite 3D print/carved wood model exemplifies the improvisational approach developed in the research. The unity of digital and analogue making is harmonised in the characteristics of form, surface and detail of the sculpture. This work received particularly positive attention and endorsement in the UK and Internationally. The piece was selected by all four jury members for publication in the International New Glass Review, 2017 and was also selected for exhibition at the British Glass Biennale, 2017.

The piece selected for ‘Vessel’ at Vessel gallery was a clear example of the ‘orthodox’ approach. It was a refined and simple hollow form, scaled up and re-proportioned from a Tinker CAD model and made in glass as a classic core casting. This involved the investment of a PLA 3D print, which was then burned/melted away in an initial kiln firing, glass was then cast into the resulting hollow investment mould. The response to the piece was very positive from peers and the gallery who sold it on the opening night.

This led me to the creating of ‘Vessel Line up’ which shows ‘repeat with difference’ at its best. The same TinkerCAD model described above was re-scaled, re-proportioned and re-printed. Once cast in glass, they become a linear series of related but unique pieces showing the evolution of the form across a range of sizes and colours of glass. These pieces also demonstrate a miniature scale application of the Libenský/Brychtová principle of light through thickness of glass resulting in a variety of tones and hues described as colour volume (Brachlow, H., 2012, p.19, quoting Albers).

Taking part in the ‘Wearable glass’ project and touring exhibition had a dynamic and positive impact on practical experimentation. The two jewellers I worked with on the project explored lost wax process, leaving me free to develop my own approaches and outcomes for jewellery to be exhibited alongside. I started exploring the potential of rings and bracelets through further development of the improvisational approach. Simple ring forms were modelled on Rhino and TinkerCAD and re-scaled to a variety of ‘wearable’ sizes using the pre-print software. A number of rings were then 3D printed in PLA and Formlabs castable resin and three dimensionally collaged together to be cast. The printing of separate elements allowed for combinations to be made across both types of print and also the inclusion of tiny amounts of other organic/combustible materials. This approach also gave the opportunity to use open source CAD models as part of the jewellery designs. I downloaded STL files of sofas from ‘Thingiverse’, scaling them down, so that they could be used as ‘gems’ for the rings. The use of open source STL files parallels that of the ‘found object’ developed in Cubist, Surrealist and Dada art. The final compositions evolved through trial and selection from a range of elements to find aesthetically pleasing and surprising forms to be cast in glass. The resulting body of new work was very well received with useful and encouraging peer critique as well pieces starting to sell once the exhibition toured.

My previous experience of computer based work had been basic and functional, not creatively focussed. I had never spent my days sitting at the screen for long periods of time learning to master complex new software to model forms. The main challenge I faced was the interface with Rhino. I found the particular mathematically based vocabulary and complex, multi layered menus and commands of Rhino initially intimidating. So, like learning Czech language from scratch, 30 years before, I started to grasp it word by word, click by click and build up from there.

At the start of this research, there was a dearth of information relating to the burning out of PLA as it is a new practice, and no formally published information had been on the details of casting glass from 3D prints. The making of initial tests showed that PLA (poly lactic acid) filament, a bioplastic made from

agricultural products such as corn starch, can be effectively burned or melted out of a mould. Especially on the small scale used for tests and artworks during this research, and the open matrix nature of 3D prints, the amount of actual material combusted is minimal so there is almost no fume during a burn out firing. The safety of this process has been indicated and PLA is clearly defined as more environmentally friendly than other petroleum based filaments (Barnatt, 2014).

'Lost PLA', is a term now being applied to this process of burning/melting out as used in this research. However I consider this term to be limited in scope as it does not encompass the other types of 3D print material for example the Castable, combustible resin from Formlabs and similar products now coming onto the market from other companies.

5.6 Areas for further investigation

New questions arise constantly as a result of rapid advance in technology. However, there are a number of potential areas for further research identified as a result of carrying out this research.

Using the research carried out as a basis from which to scale up and further explore 3D printing models in sections which can be assembled before investing and using other types of digital fabrication e.g. CNC, laser cutting to create larger scale models for model and mould making for casting glass.

Further testing to explore the effect of pigmentation/colouration in PLA on the burn out method and mould surface. This question arose out of 3D printing with a dense black PLA which left some residue on the refractory mould surface after the burn out firing and which then left residue on the surface of the glass.

New types of filament for 3D printing are coming onto the market all the time. Wax and PVA have been identified as having potential qualities to be tested

and compared with materials documented in this research. Questions arising include:

- use of easily removable support materials if these are used as secondary print materials next to PLA on printers that can print two or more materials simultaneously
- ease of removal through use of water if PVA is used either as a support or main print filament
- Creative carving potential of wax if it is used to create the 3D print

Exploration of combinations of 3D printing in clay combined with analogue mould making for direct casting. Seeing the Wasp 3D printer printing in clay led me to the question of what the potential might be for creating both master moulds and refractory moulds using a piece or part mould approach taken from clay 3D prints. Questions of the perceived benefits of this could be

- ease of removing clay from plaster based moulds,
- directness of translation from 3D print to mould,
- potential for repeat production through reintroduction of lost wax technique

Exploration of 3D printing in e.g. bronze, and other compatible metals, Egyptian paste, bone china, to create inclusions for glass: the question here is regarding the creative potential for compatible inclusions within kiln formed and other hot glass making methods.

Exploration of further combinations of glass and other 3D printed materials through construction e.g metals. The question here is creative potential of mixed media through possibilities of:

3D Printing two materials simultaneously on one printer: Using CAD to create elements which fit together or complement each other which can then be 3D printed and cast in different materials without loss of accuracy and fit.

Exploration of potential of Jesmonite for 3D printability to create elements for construction with glass: the question of whether Jesmonite can be prepared as a printable material for use on the Wasp clay 3D printer and the results incorporated into sculptural outcomes along with glass elements.

5.7 Closing Remarks

At the beginning of this research I thought that I would create a new paradigm for casting glass. Now I am at the end, I can see that what I have achieved is not only about connecting 3D printing to glass casting in terms of making, but a reinforcement of thinking through making and the importance of history. Re-considering and developing an in depth understanding of history and heritage, both personal and contextual, has refocused my relationship with what it means to be a maker and to work with glass as a means of artistic expression. This frames me in a different way than others currently involved with digital technologies in the fields of glass, art and making. Through the research and writing of this thesis I hope to offer thoughts and practical processes to others who are looking to embrace ‘digical’ and extend their own glass/art practice.

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Appendix A Indicative Firing Schedules for 3D print removal from refractory moulds

Various schedules were tested to find the most effective time/temperature for removing PLA and Formlabs Castable resin prints. Factors under consideration were clean and complete removal of 3D print material, integrity of mould after firing, length of firing.

In all firings moulds were set up open face downwards with edges resting on small pieces of kiln shelf for support. This allows air flow and any ash/residue to fall out.

PLA Melt out: Kiln 5, NGC
3 Small moulds, upside down on pieces of kiln shelf over a baking tin to catch the melted PLA.

*C per hour	temperature	Soak time in hours/mins	total time /mins hours	comment
100	250	45mins		Kiln vent partly open No visible melting
999	260	45 mins extended to 1hr 30 mins		Closed vent. Eventually PLA melted
200	400	1hr 30 mins		Removed baking tin. Reset temp. Vent 1cm open
			8hrs	Allowed to cool to ambient. Clean moulds

Shellacked prints, black PLA: NGC kiln

*C per hour	temperature	Soak time in hours/mins	total time /mins hours	comment
250	400	1hr 50 mins		Vent partly open
				Left overnight.
				Next morning PLA half melted out, moulds quite

				brown in appearance reprogramme d
250	400	3hrs 45mins		Next day half PLA out reset again
250	500	3hrs 45mins		Next day, PLA and residue still visible. Took moulds to London and refired

Re-firing London Kiln:

*C per hour	temperature	Soak time in hours/mins	total time /mins hours	comment
200	775	15		Finally clean

NGC kiln 18
6 moulds, prints black and clear PLA and Formlabs

*C per hour	temperature	Soak time in hours/mins	total time /mins hours	comment
150	570	10 mins		Vent partly open. Soaked at 570 as per Formlabs recommended schedule. Had a look at 700*C atmosphere in kiln black and smokey as materials burn.
999	775	15 mins		Left to cool. Moulds not clean. Refired
300	800	15 mins		Finally clean.
				Mould around Formlabs print cracked, need to repair mould so its useable.

NGC Kiln, adjusted Formlabs firing to address mould cracking issues

*C per hour	temperature	Soak time in hours/mins	total time /mins hours	comment
100	200	30		
150	735	1hr 30 mins		
100	482			Clean but cracked!

Issues of castable resin expanding during firing resulting in mould cracking.

Ballycyl tinkerbead PLA (for red/orange Bullseye frit – see appendix B)
Mould made of 50/50 Crystalcast and potters plaster. Cottled and poured with a graphite stick to support the core.

*C per hour	temperature	Soak time in hours/mins	total time /mins hours	comment
150	400	2hr 30 min		
150	150	end		

Burn out in hot shop kiln NGC.
Red PLA rings and berry piece cottled and poured. Formlabs ‘croissanty’.
Potters plaster 1 and half cups and crystalcast two and half cups to two and a half cups of water. Strong mix to fire at high temperature for long time to get detail reproduction for jewellery pieces.
Burn out based on temperatures and times for Formlabs Castable resin.

*C per hour	temperature	Soak time in hours/mins	total time /mins hours	comment
100	180	30 min		
120	735	1 hr 45 min		
100	480	1 hr		

Formlabs moulds cracked but repairable.

Burn out. Kiln 4 NGC. 7th December 2016
6 moulds which have dried for 5 days to see what difference this might make. Formlabs prints - 4 croissants, one hanger, one multi egg. Mould mix 1 part each keramicast, sieved ludo, crystalcast and quartz with fibre glass tape between layers. This should be a strong and flexible mix to withstand the expansion of the formlabs castable resin.

*C per hour	temperature	Soak time in hours/mins	total time /mins hours	comment
100	180	30 min		
120	732	1 hr 30 min		
100	480	1 hr		

Reduced top temp a couple of degrees and 15 min. 3 larger Moulds still cracked, one of them into two halves. Wrapped them in fibre glass tape and added another layer of mix using grog as an addition of 1 part to 3 parts each plaster, ludo, crystal cast and 1 part quartz. Thick mix which set super fast.

Burn out PLA. Kiln 12 hotshop. Jan 2017
Jewellery pieces ring things.

*C per hour	temperature	Soak time in hours/mins	total time /mins hours	comment
100	100	60 min		
150	150	3 hr		
150	380	3 hr		
50	150	end		

This was ok. Some slight residue in deeper/ bigger moulds.

Rock lobster, in two halves grey PLA from Ultimaker at Fablab, for Clone exhibition Kiln 3 NGC. Late Feb 2017.
Moulds cottled and poured using potters plaster and crystalcast 50/50. Cotton thread air vents.
Burn/melt out schedule based on Pilchuck experience.

*C per hour	temperature	Soak time in hours/mins	total time /mins hours	comment
100	100	1hr		
100	150	2 hrs		
150	380	3hrs		
50	150	1 hr		

Short of time so one step firing. Little surface residue which I removed with a soft brush before loading glass. Glass to be recycled light amber Banas (from Ivana) see appendix B.

Burn out formlabs and PLA London kiln R, 12/3/17
Rings and things moulds plaster, crystalcast grog ludo.

*C per hour	temperature	Soak time in hours/mins	total time /mins hours	comment
75	100	30 mins		Bung open
100	720	2 hrs		
75	500	30 mins		

Took them out hot so could load glass to cast. Hairline cracks only otherwise all ok.

Burn out London Kiln R 16/8/17

1 x formlabs double ring
1 x improv ring, PLA with sofa and formlabs mini croissant added
1 x improv ring PLA with Queen Anne sofa added
Cottled and poured mix keramicaast, ludo quartz and crystalcast.

2 stoppers from PVA
4 horns PLA red

*C per hour	temperature	Soak time in hours/mins	total time /mins hours	comment
75	150	20 min		Bung open
120	500	1 30 mins hrs		

Tiny amount of residue otherwise good.

Appendix B Indicative firing schedules for casting

Casting firings: Various tests were carried out with minor adjustments to find reliable and repeatable results using the different types of glass. Issues under consideration were and form and scale and level of detail to be cast along with type of glass.

The following firing schedules were developed and carried out with minor changes across kilns at NGC and in researcher's own kilns in London.

Casting: NGC, Kiln 18, overhead elements only (not ideal but based on availability of kiln)

4 moulds from hemisphere prints- small

2 Chinese blue glass, 2 in Gaffer clear crystal

*C per hour	temperature	Soak time in hours/mins	total time /mins hours	comment
300	800	4		Vent tiny bit open, moulds already fired so no steam. Can also go up faster because moulds have been pre fired.
999	830	1hr 30 mins		
999	600	5mins		
50	546	3 hrs		
5	430	3		
25	318			

50	120			Left to cool to ambient before opening
			46hrs 15 mins	
				After demoulding one mould, ladders had not cast in Blue glass, so refired all of these. Need access to kiln with elements all round not just from the top.

Casting: NGC kiln 6 (top elements only, not ideal)

Topping up and re-firing

3 hemisphere moulds 2 with Gaffer clear crystal,1 with chinese blue.

*C per hour	temperature	Soak time in hours/mins	total time /mins hours	comment
300	845	3hrs		Vent covered. Moulds have been fired twice already so super dry, want to save time and energy too. Extended soak time to melt added glass into previously

				cast glass.
999	600			
50	546	3hrs		
10	430	3hrs		
25	318			
50	120			
			32hrs 20 mins	Left to cool to ambient

Casting: NGC kiln 13 full elements - (this firing was repeated numerous times at NGC and in London as it proved successful)

2 larger hemisphere moulds. Re-firing under filled hemisphere,Chinese champagne glass

*C per hour	temperature	Soak time in hours/mins	total time /mins hours	comment
150	600	1		Vent closed
250	830	3hrs		
999	850	1		Raised top temp to facilitate casting fine details
999	550	10 mins		
50	440	5		

10	318			
35	120			Slower as larger amounts of glass in these moulds
			35hrs 20 mins	Left to cool to ambient. Successful casts

Casting London, Kiln R. 7/4/16

Two globeys from PLA burn out moulds.

Flattened globey in semillion (later engraved with Catherine Coleman and exhibited at Clone).

Round globey in citrine Gaffer. 3D print had been dipped in shellac and blemishes on both repaired with Tiranti red wax which burns out. Plaster, quartz grog mix. Wires to support cores.

Burned out to 600*c as black PLA and can leave residue otherwise.

Thin mould walls supported with ludo blocks.

Estimated glass quantities – need to keep track of volume when 3d printing!

*C per hour	temperature	Soak time in hours/mins	total time /mins hours	comment
120	600	30 mins		Vent tiny gap open
200	810	4hrs		
Full	830	1hr		

300	500			
50	430	6 hrs		
8	318			
25	120	end		Slower as larger amounts of glass in these moulds

Good casting. Round citrine better than semiliion which had some bits of plaster mix floating in it where they had dislodge from mould cavity. Later engraved tehse out and polished.

Wires supporting cores worked quite well. Due to small scale some points wire touched glass. Mould mix was soft and easy to remove but has held up well and performs better than molochite mix at Uni,which is too hard for small cores.

Red wax used to fill tiny blemishes in 3D print has burned away cleanly.

Citirne under-filled so had to top up and re-fire which was fine.

Casting London, Kiln S. 11/4/17

6 moulds made in London

Large globey

Dished top globey

Full globey – citrine gaffer

Canoe

*Coracle*s

Half canoee and scaff

All have been water displaced to get volume for glass. Czech amber glass.

*C per hour	temperature	Soak time in hours/mins	total time /mins hours	comment
120	600	30 mins		Vent tiny gap open
300	800	4hrs		
Full	820	1hr 30 mins		
Full	500			Bung closed
150	430	6 hrs		
8	318			
25	120	end		

Larger globey had lost some of its ladders in burn out but all cast ok.

Casting Kiln 4 NGC. 1/12/16

Based on previous successful firing from October.

2 moulds from PVA prints 2 parts crystalcast to one part plaster, hand built in two layers.

Ballycyl tiny, recycled Gaffer grey, oval square cut (from PVA) F2 and Gaffer mixed, PLA red ring and berry, recycled semillion clear and black Gaffer, Formlabs Croissanty, Gaffer blue green recycled repaired Galleon mould, recycled Gaffer grey.

Temp *c	temperature	Soak time in hours/mins	total time /mins hours	comment
100	600	1hr		Vent closed

Full	830	4 hrs		
Full	850	1hr 30 mins		
Full	500	5 min		
50	430	5hrs		
15	318			
35	150	end		

Big Bracelet ring. Kiln 18 21/1/17

Burn out was clean from red PLA. A hair line crack in base following shape of ring. Mould has hollow centre. Cleaned up edge which was a bit flaky after burn out despite only going to 380*c.

Bullseye clear scrap cut into small pieces to fit into open ring shape mould cavity.

Temp *c	temperature	Soak time in hours/mins	total time /mins hours	comment
150	600	15 mins		
Full	855	4 hrs		
Full	865	30 mins		
200	660	30 min		
75	485	5hrs		

30	371			
50	150	end		

Cast well. Bit bubbly as Bullseye is!

Maud experimental Gaffer colour firing based on previous one. 23/1/17 Kiln 18 NGC.

Temp *c	temperature	Soak time in hours/mins	total time /mins hours	comment
150	600	60 mins		Vent open as Maud and Emmi moulds damp from steaming
Full	830	4 hrs 30 mins		
Full	600	5 min		
200	430	4hrs 30 mins		
25	318			
65	150	end		

This worked very well with lime green and lilac side by side in reservoir placed using a card divider which was removed for firing. Good colour combo. Repeated with two more moulds later.

Rock lobster in two halves for Clone. Kiln 3 NGC. March 2017. Banas Glass

*C per hour	temperature	Soak time in hours/mins	total time /mins hours	comment
100	600	1hr		Vent closed
120	850	3hrs 30 mins		
999	860	1hr		Raised top temp to facilitate casting fine details
75	600	10 mins		
75	475	5		
15	380			
45	150			Fast as need to get piece out to take home to finish and deliver to Hertford.

Cast well, just enough glass! Not much cold working.

Casting London kiln s 2/6/17

17 moulds

Bottom shelf on large props halfway up the height of the chamber. Sand on shelf in case of spillage. 3 moulds pendants steel blue Gaffer, blue Gaffer fine

frit, black bits and frit Gaffer for ‘hanger’ shape. Hanger at back in Banas light amber,

Ballycyls:

Large – gold ruby Gaffer

Bognor yellow

Semillion

Apricot

Tiny gold ruby recycled res

Black

Formlab canooes Chinese blue, bronze grey gaffer recycled reservoir and Bognor yellow

2 rings turquoise recycled gaffer and black Gaffer for Orleans House exhibition.

Big flat ring amber gaffer frit

Coracle on flat base

*C per hour	temperature	Soak time in hours/mins	total time /mins hours	comment
150	600	30 mins		Bung closed
Full	810	4hrs 30 mins		
Full	840	1hr		
Full	500			
100	430	6 hrs		
20	318			

50	150	end		

Cast well and all usable. Great!

Appendix C Outcomes from research

The range of outcomes from this research includes artworks, publications, presentations, exhibitions, documentation, workshops and masterclasses across a range of academic and public contexts.

Over the period of the study (2014-18) participation in thirteen public exhibitions was carried out in a variety of locations across the UK. New work produced using combinations of 3D printing, casting and using ‘orthodox’, ‘Improvisational’ and repeat with difference approaches were shown.

- “Fresh Air “and “Glass Glamour”, Quenington Old Rectory, Cirencester, 2015, UK
- “Changing Practices” at Contemporary Applied Art gallery, London, 2015
- “Black to white and back again”, London Glassblowing Gallery/CGS, 2015
- “Worlds within Worlds”, Research Gallery, National Glass Centre(NGC), Sunderland, 2016, UK
- “Being Human”, part of the International, “Ordered Universe” trans-disciplinary project, Durham University, 2016, UK
- “Clone-The Art of Replication” at Courtyard Arts, Hertford, 2017, UK
- “Vessel” at Vessel Gallery, London, 2017
- “The British Glass Biennale”, Ruskin Glass Centre, Stourbridge, UK; 2017
- “Liquid to Solid: The Mutability of Glass”, Stables Gallery, Orleans House, London, 2017-18
- “Jewellery: Wearable Glass”, touring from NGC, to Ruthin Craft Centre, Wales and Studio Fusion, London, 2017-18
- “Colour Theory”, at Contemporary Applied Art gallery, London, 2018
- “Light Embodied”, Pembroke College, Oxford, accompanying Science, Imagination and Wonder conference, part of the International, “Ordered Universe” trans-disciplinary project.
- “Loud and Clear”, Harley Gallery, Nottingham, 2018

September 2015, I wrote and gave a paper, “Towards Content”, at the “Extreme Glass Conference”, Northlands Glass Centre, Scotland, where I had taught a masterclass in August.

In 2015 I was commissioned to write a short article “Framing Devices” 3D printing - why would we be interested in this for glass?” for the Contemporary Glass Society magazine which was printed in the Autumn edition.

A number of presentations were given in a variety of academic contexts. These included:

- Baltic 39, 2014, 2015, 2016, 2018, Sunderland/Northumbria Cohort Development Training (CDT) programme Newcastle, UK

- “Skills Fest”, 2016 and artists talk “Towards Making the Unmakeable in glass : How can 3D printing inform studio based kiln formed glass practice in 21st Century? How did I get here?” February 2017, University of Sunderland, UK

- 2015, 2016, 2017 Annual Monitoring Reviews (AMRs), University of Sunderland, UK

- “Through a Glass Darkly” part of the international trans-disciplinary Ordered Universe project, 2016, University of Sunderland, UK

- Pilchuck Glass School, 2016, USA

- Plymouth College of Art, 2016, UK

- De Montfort University, 2017, UK

- “Science, Imagination and Wonder” Conference at Pembroke College, Oxford, part of the international trans-disciplinary Ordered Universe Project

Also in 2016, I was asked by the funding body Arts and Humanities Research Council to provide a case study of my PhD to date.

I submitted an abstract and was selected to write and present a paper at European Glass Context Conference, 2016, Bornholm, Denmark, entitled "The exploration of space (in glass) as the setting for life".

In August 2016, I co-led a masterclass entitled “Un-object” at Pilchuck Glass School, USA and I am invited to return, August 2018, to co-lead a second masterclass expanding on combined analogue/digital methods and approaches for glass.

The National Czech and Slovak Museum and Library in USA, commissioned me to write an article “ Glass in a Restless Age: The Importance of Czech Glass”, published in the winter 2016-17 edition of “Slovo” magazine under the heading “Clear Distinction, Czech and Slovak Glass Evolves”.

In 2017, the artwork “After the Fire” was selected and published in the international New Glass Review as well as exhibited at the British Glass Biennale.

Throughout the time frame of my PhD at University of Sunderland I also gave several practical demonstrations and workshops with BA and MA students in Glass and Ceramics

Appendix D Articles, papers and proposals 2015-6

Article 'Framing Devices' commissioned and published by Contemporary Glass Society in the CGS Magazine, Autumn issue, 2015.

3d printing - why would we be interested in this for glass?

"Digital technology dominates our waking lives … More people are probably gazing into a backlit screen right now than are looking out of a window - or any other framing device through which we perceive the world." 'Craft makers ahead of the curve', Financial Times June27th/28th 2015

My interest in glass is ongoing over more than 30 years. There's always something new to contemplate, whether it is a technical or aesthetic innovation or preferably the two hand in hand.

So I have, against all predictions, 'gone digital' or to be more accurate, I am in the process of going digital, though you never see signs saying 'in the process of going fishing' do you?

So what has led me here?

My starting point is a feeling that lost wax has lost its way. Originally a technique for making repeats of a form or an object, it is now mostly taught and used to create 'one offs' when applied to glass. However, like all practice, it can become a habit which is not questioned. So it is time to question and search out new solutions.

Part of my feeling of loss is about the wider field, not just glass. Deep concerns about shrinking world syndrome affecting 3D design and making in general echoed in Higher Education, which is loosing its footing. The focus on skill and depth understanding of material and process, preparing students for a practitioner/studio context, is being eroded. A great number of courses are unravelling before our eyes and there is no clear vision or direction for the future. Neither is there any idea how on earth the next generation will operate or make ends meet as professionals, particularly in glass which is such a specialist area.

Historical Background:

The materials and methods for kiln casting glass have not changed very much in 4,000 years. As I see it there have been two big innovations in that time.The first was electricity, particularly the establishing of national power grids which could be relied on to deliver stable and consistent energy. This meant that kilns could be set to run longer programmes making larger scale kiln casting glass a possibility. The second was computer technology which was applied first to kiln and furnace controllers making even larger scale casting with real time and temperature accuracy possible. These innovations resulted in massive

monumental scale kiln cast glass being produced for the first time. This was in the 20th Century.

What we see now, in the 21st, is an expanding range of digital technologies taking over the visual arts. Some of those particularly relevant for glass practitioners include water jet cutting, CNC milling and 3D printing (also called additive manufacturing). There is, of course, some academic debate about terminology. I prefer the basic descriptor “3D printing”. What attracts me to 3D printing in particular is the ‘print’ idea - repetition with scope for sameness and difference - similar to lost wax but with more options.

I started to see the possibilities directly relating to my own practice in a lecture/demonstration by Jonathan Keep, who 3D prints clay. I saw immediately the potential for model making for glass casting which is what I have started to explore in my research. A key benefit of 3D printing is that it makes possible certain forms which would be extremely difficult and time consuming or virtually impossible to fashion by hand. It is also very accurate and allows for both mass and individual customisation.

Like all tech, there is not necessarily a time saving factor, as some large/complex shapes need many hours to print out though while the printer prints you can be doing other useful things.

Scale is an interesting question: at the moment most desk top printers have a limited maximum size. So I am exploring small scale, right down to fingernail size. This is challenging my mould making and glass casting skill and knowledge too. The results are varied and very portable!

The process goes like this:

* Start with an idea for a form

* Draw it out accurately using CAD

* Save the drawing into an STL file

* Give the file to the 3D printer and print.

The more challenging part is the CAD. I’ve started to learn to work with Rhino which is complex and sophisticated software with incredible potential. There is other software available, some of which is open source on the web. There is also ongoing development of a haptic system (virtual 3D touch,) led by Ann Marie Shillito. I had a 2 minute ‘go’ on it at the London 3D print fair a few weeks ago - you ‘feel’ the material through a kind of large ‘mouse’ which draws your model on screen - great concept!

Once the design drawing is resolved, it needs to be checked to make sure it will print satisfactorily. If there are gaps or sloppy bits of drawing at the CAD stage

then these can cause problems during printing, resulting in an incomplete print or flaws in the printing process. An analogue equivalent could be examining a wax model for holes where unwanted plaster could seep in, or asking a glazier to cut to a template from a fuzzy line drawing and then when the glass arrives it's a couple of millimetres out. We've all been there!

There are now many different 3D printers and process variations on the market and as a result they are coming down in price rapidly. The one I have used the most so far is a MakerBot Replicator. It has been reliable and easy to use and prints using a heated filament which is deposited through a heated nozzle on to a moving bed. If you haven't seen this is action then imagine a hot glue gun or someone icing a cake and you can imagine how the model will be built up in layered filament.

There are now a great many different filaments and other materials available. I am using PLA which is corn starch based and burned it out of my moulds as I would organic materials. (Plug - you can see burn out method in my book). Other 3D printers use resin, wax, various plastics and you can 3D print in gold, stainless steel and wood too.

There is also research going on into printing directly with glass - a kind of pâte de verre approach,(USA); and 3D printing refractory moulds around virtual models (Gayle Matthias and Tavs Jorgensen, UK.)

So I believe the answer to my question of why we would be interested in 3D printing, is at the top of this article. With digital here to stay, I feel the urgent need to learn to work with it and connect it to existing methods of making so that 4,000 years of practice and history are not lost along the way but combined to shape new forms of practice and outcomes.

Reading and resources:

Cutler, V., New Technologies in Glass

Shillito, A M., Digital Crafts

Warnier, C., VerBruggen,D., Printing Things

Angela Thwaites is an artist and practitioner, educator and author of 'Mould making for Glass' published by A&C Black. She has recently started a PhD at University of Sunderland investigating 3D printing for kiln casting glass. Angela teaches in London and exhibits internationally. www.angelathwaites.com

PAPER submitted and accepted for European Glass in Context Conference, Bornholm, Denmark September 2016

Angela Thwaites

Glass artist, author and PhD Researcher, National Glass Centre, University of Sunderland, UK

Does the European contemporary glass scene really need the cultural heritage and tradition? Is it important that the process and craftsmanship is visible in the piece?

My response to these questions is emphatically yes! These two questions are intrinsically linked through the connection and application of making as artistic expression with material knowledge, skill and understanding. Technology dominates human life across Europe and the rest of the planet. This was summed up succinctly by Dries Verbruggen (2015), who described digital technology as giving ‘complexity for free’. At the same time I believe it is vital to maintain and expand cultural heritage, skills and craftsmanship.

Starting with the context of the Czech glass scene in the 1980s this paper will use my own practice and experience to explore the continuity of heritage through its influence and importance in 21st Century glass art. My research, practice and teaching have been heavily influenced my education with Libenský/Brychtova and the experience of communist Czechoslovakia. Today their teaching philosophy is a key point of continuity in my PhD study in Sunderland. My research considers the unity of digital and traditional practices in kiln casting though CAD drawing and 3D printing with a goal of making the unmakeable in glass.

Expressing the human condition, the Libenskýs exemplify the sculptural use of glass with ‘the exploration of space as the setting of life' (Setlik, 2002). Translucency, tonal variation and response to light are key qualities in their work. By expanding current themes as well as developing new approaches, my research aims to expand the expressive potential of kiln formed glass practice from where it is now into the future. Ann Marie Shillito (2013) states that ‘digital technologies enable us to produce new work that was previously impossible, extremely difficult or physically and financially unviable to make by hand’.

Exploring the theme of *Worlds within Worlds*, my aim is not the flawless regularity that digital processes appear to promise, but the material presence of the handmade translated through the casting process into glass. The heritage of Czech glass, particularly through the Libenskýs, has played a unique and deeply influential role connecting practice in glass across the European context as it evolves into the future.

Pop up proposal submitted to BID, for 251 High Street West, Sunderland

Angela Thwaites and Helen Pailing, June 2016

Who we are:

We are practice based PhD students based at the National Glass Centre (NGC), University of Sunderland. We are artists and makers and our combined experience includes specialist skills and knowledge focused on making and materials, creative conception and design, education and public engagement.

Angela's PhD study, entitled 'Towards making the unmakeable in glass' exploring the potential of desk top 3D printing for generating small and complex forms to be cast in glass.

Helen's project focuses on creating new artworks through the repurposing of waste materials from the various processes and makers at the NGC. Education and dissemination is a key part of our remit and this should include public as well as academic audiences and participants.

(Please see attached Cvs for further detail about who we are and what we do).

What we would like to do and why:

Our proposal is centred on bringing making back into the commercial centre of the city of Sunderland. We aim to engage public interest, connect with other businesses and creatives in the area and to inhabit the empty space with arts events and activities.

Our proposal is for an initial 6 week Pop up, with each week being curated individually to include making and creative workshops, exhibition and showcases, and arts events and performances. Art work will be made and shown on site but will no direct selling will take place.

The premises at 251 is large and varied in terms of its inner spaces and offers a variety of uses for our envisaged programme of activities and events. The upstairs is seen as potential studio/ workspace and the ground floor as open engagement space for exhibitions, events, art performances and show cases.

Participants potentially include students, staff and graduates from Sunderland and other local Universities and colleges, regional artists and makers and members of the public.

In order to make this happen we are looking for support from the University and both internal and external funding to cover water, electricity and heating, insurance and any other running costs iincurred through the duration of the pop up.

Context:

The bid for city of culture 2021 is a key focal point for everyone in Sunderland and the surrounding area. Our proposal is a key way of bringing people together from the University and the city to reflect Sunderland's long and distinguished history of glass making.

Proposal submitted, for GAS conference 2017, USA, Reflections from the Edge: Glass, Art, and Performance

"Practice makes Perfect?"

Panel discussion on How Action, Reaction and Reflection inform practice.

Moderator-Angela Thwaites, UK

Panellists- Mark Hursty, USA; Gayle Matthias, UK and Dr Sunny Wang, Hong Kong

This panel proposes to discuss innovative ways that glass is being used as a performative medium and how to continue developing the language and content of sculptural glass. The context is action research in arts practice and how performance can blend and inform process and concept in ways that impact on artists and their audiences in public and academic arenas.

Glass studio film clips and images of the panellist's action research will reveal their dynamic and individual approaches to performing with and reacting to glass and associated materials and processes. Ensuing discussion will show how play, improvisation and reflection on action inform practice.

The panelists are all professional researchers, practitioners and artists working with glass across a broad international spectrum. Each panellist makes a unique contribution to the field through their dynamic and individual approach as well as the outcomes of their research using glass as an expressive medium.

Highlights from the panel will include: Mark Hursty, (USA) early use of video, choreography and pneumatic textile sculptures, Sunny Wang, (Hong Kong) videos of hot glass action exploring studio glass art inspired by Chinese Calligraphy and framed by Buddhist practice; Gayle Matthias (UK) an intuitive way of employing digital tools while maintaining immediacy with low tech assemblage of materials. Angela Thwaites (UK) currently doing a PhD by practice entitled 'Towards making the unmakeable: How 3d printing can inform studio based kiln formed glass in 21st Century'. A central part of this is the development of new visual languages through shifting paradigms of practice and thinking.

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Practice statement to accompany research show cases NGC, June 2016

Angela Thwaites

Glass artist, author and PhD Researcher

National Glass Centre, University of Sunderland, UK

Towards making the unmakeable: how 3D printing can inform studio based kiln formed glass in the 21st Century

My PhD research considers the unity of digital and traditional practices in kiln casting glass. The recent addition of digital technologies to a practitioner's tool-kit has facilitated the creation of work which would be virtually impossible to produce by hand making methods alone.

It is not the flawless regularity that the digital process promises that I am interested in, rather its potential to combine with the material presence of the handmade, translated through the casting process into glass sculpture.

Regular train journeys between London and Sunderland provide a wealth of observable data which triggers ideas for shape and form. The translucent medium of glass is an ideal medium for blurring boundaries between this reality and illusion.

The theme of *Worlds within Worlds* is being used as this research open doors to imagined as well as real environments, extending sculptural language on a small scale through the exploration of void, mass and light in glass. Human presence is implied, with references to body within space, space within body in an abstracted, quirky and sometimes humorous way. Designed to draw the eye inside, the half secret voids and interiors play with one's perception.

My methodology synthesises the digital with the traditional: Images observed from the train window are sketched or photographed and then developed into three dimensional forms using CAD software and 3D print technology. The subsequent 3D printed models are then invested in a refractory mould material and twice fired. The first firing burns out the 3D model and the second casts the glass into the mould.

After the second firing, the mould material is removed and the final stages of refining and polishing are carried out by hand using traditional tools and processes.

Appendix E Pilchuck 2016

July/August 2016 ‘Un-object’ Masterclass, Pilchuck Glass School, USA. Co-taught with *Erin Dickson, teaching assistants Yoav Reches and Stina Bidstrup.*

Course Description:

We are now in transition from an *object-orientated* to a *systems-orientated* culture. Here change emanates, not from *things*, but from *the way things are done*.’ (Jack Burnham, 1968) Contemplating Burnham’s statement, students will engage in practice-based research and collect and analyse data from Pilchuck’s dynamic ecosystem. Findings will be brought back to the studio to be translated into kiln cast glass with the assistance of the 3-D technologies. Students will leave with a library of samples to inspire finished works.

Reflection

This was a test bed for digital/physical exploration and experimentation with a focus on process rather than object. The students on this course arrived with diverse levels of experience and some of them had no experience of 3D, glass or digital modelling. It was challenging within the 12 day time frame to build enough experience and confidence across all necessary processes to match the course aims, though individual students built their experience and achieved well within the time frame. An intense daily timetable delivered basic scanning and Rhino modelling, 3D printing, investment mould making, burn out and glass casting firings, kiln packing information and an introduction to cold working. Although most of the students wanted to produce tangible results in glass, three of those with higher level of experience and practice in art and design evolved more open ended concepts and explored ideas using digital image and projection, 3D modelling and printing as well as producing samples in glass.

Working on a small scale allowed for a building of experience in both digital and physical making and students were able to work on several projects to further test and refine ideas and skills. The kilns allocated were old and very slow to fire and cool so negotiation to use newer faster firing kilns speeded up casting in the last week of the course.

Appendix F Indicative 3D print information

Formlabs printer in bot room at University of Sunderland.

November 2014	Size mm	Size mm	Size mm	Printer & material	Model , Layout , set up comments	Layers	Support	Print success Yes/no	Print run time	Test type	Print destination
Print no.	x	y	z	Formlabs +1 castable	Stl from Rhino						jewellery
1.								n		Eggy	

Eggy Drawn on Rhino

First print of Eggy not quite complete. Think the tank is a bit fogged underneath ?
One side of the oval found in the resin tank whre it had peeled away from the print bed so removed it.

Set a 2nd print going with different orientation and supports and placed it to the right of centre to avoid the fogged tank area. Help notes say the right hand side is the 'hinge' .

Ultimaker, Fablab, University of Sunderland.

25th May 2016	Size mm	Size mm	Size mm	Printer & material	Model , Layout , set up comments	Layers	Support	Print success Yes/no	Print run time	Test type	Print destination
Print no.	x	y	z	Ultimaker Transparent PLA 'Verbatim' filament 2.75mm	Stl from Rhino						
1.				3.66gms		0.06 layer height Shell 0.8 Top/bottom 0.48 Speed 50	No support	Y	2hrs 15 mins	Croissantys	
2.				28gms each				y	Total 11hrs	Toroid with pipes x 2	
3.				24 gms		0.1 layer height Shell 0.8 Top/bottom 0.4 5% fill Speed 50		y		Rock lobster printed in two halves	
4.				25gms		0.1 layer height Shell 0.8 Top/bottom 0.4 No fill Speed 50		y	4hrs 15 mins	Horn	

Notes on set up and use of Ultimaker

Toroid halves and Rock lobster halves printed together.
Successful and transparent filament burns away cleanly in firing.

Makerbot printer in bot room at University of Sunderland.

10th December 2015	Size mm	Size mm	Size mm	Printer & material	Model , Layout , set up comments	Layers	Support	Print success Yes/no	Print run time	Test type	Print destination
Print no.	x	y	z	Makerbot PLA filament	Stl from Rhino						
1.			10.5	68gms			Auto	Yes/no	9hrs	Eggy	

			cms				supports and raft		45 mins	with leg	
2.			7cm				Long raft no support			Eggy with leg	

Eggy with leg re-drawn on Rhino

Print 1. not quite complete. Think computer has problems overnight as print stops!
Print 2. Smaller eggy ok.
Usable

Ultimaker, Fablab, University of Sunderland.

Feb 2016	Size mm	Size mm	Size mm	Printer & material	Model , Layout , set up comments	Layers	Support	Print success Yes/no	Print run time	Test type	Print destination
Print no.	x	y	z	Ultimaker Black PLA 'Verbatim' filament 2.75mm	Stl from Rhino						
1.			40 mm				supports and raft	Yes	34 mins	Tubey globey 2	
2.	40mm					0.15 Shell 0.8 Bottom/top 0.3 Fill density 8% Speed 50		Y	Total 3hrs 54 mins	2 x half globeys	
3.	70mm					0.15 Shell 0.8 Bottom/top 0.3 Fill density 8% Speed 50		Y		2 x half globeys	
4.	40mm					0.15 Shell 0.8 Bottom/top 0.3 Fill density 8% Speed 50		Y	16hrs 47 mins for 4,5,6 together		
5.	70mm					0.15 Shell 0.8 Bottom/top 0.3 Fill density 8% Speed 50		Y			
6.	110mm					0.15 Shell 0.8 Bottom/top 0.3 Fill density 8% Speed 50		Y			

Notes on set up and use of Ultimaker

Bed self -heats from underneath
Clean bed with water and then isopropyl alcohol
Possibly need to use bull dog as well as its own clips to hold glass bed in place
Coat the glass bed with pritt stick – thin layer to help adherence of prints

Clear tubing if filament breaks or is stuck. Take off the blue clips and press the white ring to release.
Use another piece of filament to push through and clear out the tubing

The dial has maintenance - advanced settings
Insert the filament – about 1 cms then hit ready and it should take it up. Make sure the tube is properly settled.
Select PLA

If the nozzle gets blocked, heat up and pusht the filament through

Software to prepare file is CURA.

Do not exceed two thirds of nozzle thickness for layer height so use 0.25 or 0.1
Shell thickness has to be a multiple of 0.4 (defined by the nozzle possibility). 0.4 creates a very flexible result, so 0.8 is stronger

Fill density (interior of model) e.g. 5% or 10% for a trial print
Support has to touch base
Print speed 80 = fast, 50 is normal
Check the file through mesh mixer.
Load file to SD card.

You cant print halves and whole on one bed together at same time if using supports as the halves will have extraneous stuff underneath.

Ultimaker, Fablab, University of Sunderland.

25th May 2016	Size mm	Size mm	Size mm	Printer & material	Model , Layout , set up comments	Layers	Support	Print success Yes/no	Print run time	Test type	Print destination
Print no.	x	y	z	Ultimaker Transparent PLA 'Verbatim' filament 2.75mm	Stl from Rhino						
1.				3.66gms		0.06 layer height Shell 0.8 Top/bottom 0.48 Speed 50	No support	Y	2hrs 15 mins	Croissantys	
2.				28gms each				y	Total 11hrs	Toroid with pipes x 2	
3.				24 gms		0.1 layer height Shell 0.8 Top/bottom 0.4 5% fill Speed 50		y		Rock lobster printed in two halves	
4.				25gms		0.1 layer height Shell 0.8 Top/bottom 0.4 No fill Speed 50		y	4hrs 15 mins	Horn	

Notes on set up and use of Ultimaker

Toroid halves and Rock lobster halves printed together.
Successful and transparent filament burns away cleanly in firing.

Makerbot printer in bot room at University of Sunderland.

October 2016	Size mm	Size mm	Size mm	Printer & filament	Model , Layout , set up comments	Layers	Support	Print success Yes/no	Print run time	Test type	Print destination
Print no.	x	y	z	Makerbot Red PLA	Stls from TinkerCAD	0.1mm Layer height					jewellery
1.	11.00	10.43	1.52			343 layers		Y	2hrs 40 mins	Bangle ring	

Temp set itself to print at 230*c

Printed well.

Makerbot printer in bot room at University of Sunderland.

May 2017	Size mm	Size mm	Size mm	Printer & filament	Model , Layout , set up comments	Layers	Support	Print success Yes/no	Print run time	Test type	Print destination
Print no.	x	y	z	Makerbot PLA - Red	Stls from TinkerCAD	0.1mm Layer height					Vessel exhibition
1.	50.91	31	67.75	Total 1,2,3 35.56gms				y	4hrs 52 mins	Ballcyl stretch	
2.	31.91	19.41	42.48							Ballcyl stretch	
3.	15.91	9.65	21.20							Ballcyl stretch	
4.	42.01	43.25	49.71							Bottle this is not	

Printed 3 Ballycyls successfully. Each different scale beside the other worked well, no threads of filament between them.

Bottle this is not ok too.

Formlabs printer in bot room at University of Sunderland.

13th 14th and 25th Jan 2016	Size mm	Size mm	Size mm	Printer & material	Model , Layout , set up comments	Layers	Support	Print success Yes/no	Print run time	Test type	Print destination
Print no.	x	y	z	Formlabs +1 castable	Stl from Rhino						
1.								Y / n		*Coracle*s and canoees	

*Coracle*s and canoes.

Problems with adherence and completion of prints.
Tank prep – scraped adhered resin from base of tank carefully and checked for fogging on the base of the tank.
Topped up resin in tank
Cleaned bed and checked it was clipped on carefully

Hinge side – seems to hold prints better. Small scale open *Coracle* form prints well. Others are problematic and keep tearing apart during printing.

Tried different set ups and orientation and customising supports . Weight of liquid resin inside pulls print away from bed. The only form which prints well is the *Coracle*. Printed successfully up to 45mm so tried larger at 50mm. Enlarged supports to 50%.
One of the canoes printed successfully. The other a sall piece of the side is missing and had to be removed from the tank.

Formlabs printer in bot room at University of Sunderland.

18/10/16	Size mm	Size mm	Size mm	Printer & material	Model , Layout , set up comments	Layers	Support	Print success Yes/no	Print run time	Test type	Print destination
Print no.	x	y	z	Formlabs +1 castable	Stl from TinkerCAD	0.1mm Layer height					jewellery

1.				6.90ml		120 layers	Density 0.63 Point size 52	Y	45 mins	Ring model no. 2 X 5	
2.					Cancelled twice before printed			No then yes	45 mins	Pendant backs x2	

Advanced settings: adjusting these shortened print time by 1 hour and worked well so used for 3 big rings.

Slope multiple 1.00
Base 1.00
Height above base 3.50

Drawn on TinkerCAD

Problems getting the pendant backs to adhere to the print bed. Cancelled twice then finally got them to print though the results were crude but usable with some repair work.

Cured under uv but short time and watched carefully so as not to peel layers.

Appendix G Article ‘Glass in a restless age’ 2017

“Glass is among the most important discoveries of humankind” (Langhamer p.13)

The aim of this article is to share a personal perspective on the continuing cultural importance of Czech glass in a restless age of rapid change: digital technology is changing the ways in which we do things, prompting fundamental discussion around the values of traditional material-based skills and knowledge, of which glass making is a particularly interesting example.

To understand its continuing cultural importance and to make the connections between then and now in Czech glass, we should look to its rich and deep history.

Evidence of early glassmaking exists from the Mediterranean countries, including Syria, Egypt and later in Europe. “Probably the earliest preserved glass object is about 5,000 years old, a greenish bead from Thebes” (Langhamer p.13). From the end of 2nd millennium B.C, glass beads were traded from the Middle East into Central Europe - so from that time onwards glass has had a presence in the Czech lands even though its actual production did not start until later.

Discoveries of unworked glass material from 400 B.C. support the belief that glass workshops existed in Czech and Moravia from this time. The first Celtic peoples appearing in Central Europe had high levels of artisan skill and were already working with a palette of glass colours, including cobalt blue, dark purple, amber brown, green and clear.

Archaeologists have also found the foundations of glass furnaces in some of the craft centres of the Great Moravian Empire of the 9th Century. It is thought that Benedictines continued some level of production in Czech after the fall of this Great Empire around 905AD.

By the late 13th Century, documentation indicates the first Bohemian glass houses appeared in the mountainous and forested regions of Czech and Moravia. The earliest products were beads, bulleyes for windows and later hollow ware.
Vlasitmil Vondruška in the book “Bohemian Glass Tradition and Present” (p. 14., 1991, Crystalex) describes Chřibská, in North Czech, as having “one of the oldest glass works in the world, operating without interruption from its foundation,” (cited as 1414), until at least the 1980s.

Timber was a key resource, both as fuel and to produce potash, one of the base ingredients for making glass. “According to old documents, the manufacture of one kilogram of potash required many dozens of kilograms of sound Beech or other wood” (Vondruška p.11). As the forests were depleted, glass makers moved deeper into the mountain and forested areas, to access new supplies of wood.

As well as timber, minerals were also sourced from the environment and used as raw materials for making glass, purifying its quality and developing colours. The North Czech area around Jablonec nad Nisou still has a vibrant industry and expertise in colour creation across a range of glass types required for a variety of functions -sculptural to utilitarian- including the ever present bead and button production.

From Medieval times through until the early Twentieth Century societies were essentially feudal. However, sited on the country estates of wealthy land owners, “Old glass works resembled small islets of freedom surrounded by the sea of serfdom” (Vondruška, p.26). Glass craftsmen had exceptional status as freemen, exempt from taking part in ‘corvee’ – the unpaid labour demanded by feudal lords – which all other tenants and serfs were required to do. The glass makers, however were required to respond to every demand made upon their skill and time by their clients - landlords, other aristocrats, the church and Royalty.
The reputation of Czech glass for its high quality in design and craftsmanship resulted in the growth of trade, nationally and internationally. This encompassed drinking vessels, beads, scientific glassware and later, glass for windows. The oldest written trade agreement dates back to 1376 between Nicholas Queysser, a glass maker from Vysoké and Hanuš of Hlohov, for the delivery of 3,200 glasses.

Image of Medieval beaker

As trade and reputation flourished, so did competition from Venetian glass which was, however, very different in material and character. The Czech, potash-based glass was a softer and more transparent, better suited to cutting and engraving than the harder, soda based Venetian glass.

However, the Czechs did not imitate the Venetian designs which tended to be thin walled ornate vessels with fine trails of added colour and decoration. Instead they created forms which responded most favourably to the character of their own materials - greater thickness and mass, refracting light in a different way, especially once cutting and polishing had evolved.

By the 1500s, there was established production of glass for windows, richly enamel painted ware; and in the forested areas, smaller workshops continued to produce the ever popular glass beads.
From the Middle Ages the Ore Mountains were a centre for advanced glass-making and in the 16Th century glass masters moved from Saxony to inhabit a wide mountain area stretching across Ore, Orlice, Jizera Mountains, South Bohemia, Moravia and Silesia.

By the end of the 16th century, division of labour between glass works began to appear with some creating glass and selling it on to others to refine. This could be seen as the beginning of the individual, highly specialised skill and knowledge which is still present in Czech glass making today and a move away from the medieval precedent where “glass makers were designers, artists and craftsmen all rolled into one” (Langhamer,p.19).

Around 1600, in Prague, Italian gem stone cutters at the court of Rudolph II are seen as instrumental in transferring stone cutting skills to glass - “the new art of cutting glass” (Langhamer, p. 37).
As glass making flourished in the Czech lands, development and innovation took place. Chemical and heat resistant glasses were developed through careful selection and refinement of materials and methods. This technological development eventually led to the production of crystal glass. The knowledge and skill around melting and furnace building also grew and “In 1765 a glass furnace was heated for the first time directly with coal” (Vondruška, p.16). This was crucial, as glass production was encountering difficulties in sales and in sourcing raw materials, particularly wood, which was increasing in price as estate owners became resistant to forests on their lands being felled.

At the end of the 19th Century, further technological innovation took place in the form of gas fuelled furnaces and trends changed - improving sales in an international market. Glass works were able to move down from the mountains into settled areas. Ease of transport, particularly roads became more important and wood was no longer a prime material for glass production. The quality of glass products remained high as there were fewer workshops which attracted the best glass makers with high levels of skill and experience.

The industrial revolution had little impact on Czech glass making: Hand skill was still of primary importance and was not replaceable with steam power as happened in other industries. It was not until the latter half of the 19th Century that major change took place, due to the introduction of indirect firing of glass furnaces using Siemens electric generators.

The next major wave of change came at the end of World War 1. The map of Europe changed significantly, with the creation of newly independent states, including the Czechoslovak Republic. Economic boundaries changed as well as political ones, affecting glass production and its markets. Before the war, up to ninety two percent of Czechoslovak glass production had been for sale within the Austro Hungarian Empire, much of this directly to the Monarchy. The war years severed many trade connections and unfavourable export conditions prevailed after peace. After the war the mismatch between production and the ‘home’ market was enormous.

Nevertheless, “In the course of a few post-war years, glass bearing the “Made in Czechoslovakia” mark found a firm place for itself on world markets” (ibid Langhamer, p.99). Glass in jewellery and fashion industries was particularly successful in the 1920s and export flourished to France, Germany, Italy, Great Britain and the United States where consumers appreciated “the outstanding qualities of Bohemian glass”(ibid Langhamer, p.99).

(Images of beaded shoes and image of buttons and press, Jablonec Museum)

Connections between glass making and the artistic movements of the late 19th/early 20th Centuries allowed makers to begin to assert their individual creative identities rather than as simply anonymous craftsmen. Evidence can be

seen in the influence of Vienna and the inclusion of glass in the Czech Cubist movement. A line of influence can be traced through the architect Otto Wagner and his students Jan Kotěra and Pavel Janak as well as the Viennese/ Bohemian glass factory Lobmeyr. This influence led to “extraordinary creations” including the engraved work of sculptor Jaroslav Horejc that “eerily combined neo classical rigor and expressionist feeling”. (Olivié, p.13). Enthusiasm for particular techniques and qualities has waxed and waned in glass as in other areas of art and design. Engraved glass has had several periods of great popularity and there is a current rise in interest amongst glass practitioners who are re-evaluating and experimenting with the vast possibilities, refinement and subtlety of mark making which engraving techniques can offer.

Two Images of ‘Dialogue’, Pavlína Čambalová

As the involvement of glass and art became closer, a generation was educated in an open post World War 2 environment by enlightened professors like Josef Kaplický. Kaplický, a sculptor, who occasionally worked with glass, made the connection between technique, creativity and imagination. Together they led “the simple practice of glass making to a unique plastic expression in glass” (Olivié, p.14).

From the 1960s onwards, students of Kaplicky, Stanislav Libenský and Vaclav Cigler and other key figures in the canons of Czech glass, were responsible for the continuity of this philosophy and the cultivation and growth of glass as an expressive art form in Czechoslovakia. Both Libenský and Cigler have exerted massive influence in the development of glass as an artistic medium - not only through their own art practice - but also as educators in Prague and Bratislava respectively.

This history cannot be written without considering the impact of Jaroslava Brychtová. Daughter of a glass-maker, Jaroslava trained as a sculptor and began to experiment with pate de verre glass making techniques with her father in the 1950s. Libenský, a painter, who had learned to work with form, space and volume under Kaplicky’s teaching at the Academy of Applied Arts in Prague, met Brychtová in 1954. They began to collaborate and were able to combine their skills and understanding through a unique approach to glass as a sculptural mass. This led to a life-long partnership, which resulted in monumental cast glass sculpture and glass for architecture unlike anything made before. Their work captured the attention of an international audience.

Libenský and Brychtová were based in the North Czech town of Železný Brod, steeped in Czech glass history. They were able to work in the nationalised glass factory on State commissions and to “immerse themselves in technological questions of glass art” (Essay by Šetlik, J. p.29. S. Libenský, J. Brychtová, A 40 year collaboration, 1994). Underneath this ‘technology cover’ they were able to pursue their shared artistic vision wholeheartedly. Objects in glass which would have previously been rejected by the State as an expression of Western ‘formalism’ could now be produced and accepted (ibid). Once again we began to see glass makers enjoying a sense of freedom despite the confines of their

client. It is interesting to reflect back to the unique position of the glass makers in feudal society described earlier.
A highly specialised and skilled team developed at Železný Brod. The team worked intensely together experimenting and developing technical expertise to realise the ideas and ambitions of the Libenský's.They "were particularly attracted to Cubism which opened new concepts of shape and space" (Šetlik, p.25). Together they were able to produce many of the iconic Libenský / Brychtová works that now reside in Museums and collections all over the world. Translucency, tonal variation and response to light are key qualities in their work. Thick and thin areas of glass within abstracted massive forms comment on the human condition and impacted a whole generation of glass artists following their principles. During this period, it was no easy task to comment on human experience, as art sanctioned by the State was expected to be of a Socialist Realist nature.

Three Images of Libenský / Brychtová works

Cigler, described as "A poet of rationalism" (Klivar, p.40) "played a decisive role in breaking with the past, releasing from blocks of glass the effect and movement of light" and "playing optical games and philosophical musings about the spatial metamorphoses of glass's reflecting surfaces" (Olivié p.15).The influence of this thinking is still tangible in work being made by artists today.

Skill acquisition and practice were key to the Czech education system. These skills were nurtured in young Czech students who started to specialise in glass at middle school, at the age of about 14. This education could lead in several directions - technical, artistic, academic. Those students who desired to become artists applied to the Academy and often had to apply numerous times before being accepted. The study was usually for six years, during which time students continued to develop their skills whilst also studying drawing, design and the philosophy and history of their subject. The breadth and depth of this educational approach has given generations of artists an incredible body of knowledge from which to develop their practice.
Generations of Czech and Slovak artists, too numerous to be listed, taught by Libenský and Cigler, chose to express themselves through glass as their primary medium where they could be beyond direct criticism of the State. As a result, we have been provided with an incredible wealth of world-class glass art work.
After the velvet revolution of 1989, everything changed again. The state was no longer in control, and glass workshops, and factories could produce and trade freely and individuals could work as freelance artists, designers and makers. The management of the special casting workshop in Železný Brod was taken over by Zdenek Lhotský, one of Libenský's students from Prague. Lhotský s.r.o continues to develop its reputation and business in an international sphere through the casting of glass on a massive scale. It also continues to innovate both through the use of technology and process and also in aesthetic terms in collaboration with artists nationally and internationally and in co-operation with other regional glass companies and producers.

Images Lhotský

Although change affects everything, including education, Glass schools and Academies (Bratislava, Brno, Kamenický Šenov, Nový Bor, Prague, Železný Brod, Zlín) are still teaching. Glass factories are recovering from the fierce competition from Chinese cheaper labour and production costs. Artists are still producing and exhibiting glass art.

Pic Klára Horácková, Wreath. ‘Femme Fatale’ exhibition Museum of Glass and Jewellery, Jablonec nad Nisou.

So is it in spite of or because of the endless tectonic shifts in economics, politics, society, technology, resources and environment that Czech and Slovak glass endures? This is open for debate.
What I can say is that I see material knowledge and skill as important and still relevant to all glass making and indeed all making, though this opinion is not necessarily shared by everyone. Skill, in terms of the history described here, can be seen as a broad range of knowledge, practice, method and philosophy applied consistently and rigorously towards clear artistic goals as an expression of the human condition. It is Artists themselves who continue to be responsible for the perpetuation of skill and the sharing of ideas and knowledge across all borders whether they are economic, political, cultural or all of these.

So my conclusion, is that based on strength and success over more than a thousand years, Czech and Slovak glass is alive and developing through current restless times and on into a post-digital era.

AThwaites Images

Angela was a student of Professor Stanislav Libenský from 1983-5 at the Academy of Applied Arts, Prague. Her current PhD research considers the unity of digital and traditional practices in kiln casting glass. “It is not the flawless regularity that the digital process appears to promise that motivates this research, rather its potential to combine with the material presence of the handmade, translated through the casting process into glass sculpture to produce previously ‘unmakeable’ forms and structures.” (Thwaites, 2016)

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Appendix H Transcript from presentation given at Science, Imagination and Wonder : Robert Grosseteste and His Legacy Pembroke College, Oxford, 2018

Worlds Within Worlds: Making the 'Unmakeable' in cast glass"

Image 1. Clear Globey with Ladders from "Worlds within Worlds", 2018.

Thank you for this opportunity to take part. Taking the permission Tom gave right at the beginning of the conference, saying 'there is no such thing as trespassing', as a starting point, I would like to share with you a mixture of imagination, some history and wonder a tiny bit of material science to weave an account both personal and professional.

My account will focus around working with glass as an expressive artistic medium, and to connect to particular ideas from Grosseteste, which I have taken as starting points from which to create the installed pieces here in "Light Embodied" in the Pembroke College Gallery.

Woven into my presentation are metaphors which I find useful to compress complex ideas into smaller spaces and times, because as you will see glass casting is time consuming so this is a necessary time saving counter point.

Image 2. Hand built porcelain discs, Thwaites 1982. The aim of translucency, almost, but not quite thin enough, to read a newspaper through.

By way of introduction to my current practice and research, my background is from working with clay, before encountered glass. Colour, translucency and mass were qualities which led me through porcelain and high firing ceramics to experimenting with kiln forming glass.

The studio glass movement which grew from the late 1950s in USA and across Europe focused mainly on blown glass and hot shaping on the iron. Kiln forming pre-dates blowing by some 1000 years but re-emerged in the late 1970s early 1980s. I was an undergraduate student at this point but there was only one text and none of my tutors were working with these methods so direct experiment and practice were the only way forward.

Image 3. Libensky and Brychtova, 'Bird', Monumental Cast glass sculpture, Prague,

After graduating at WSCAD (now UCA) I urgently wanted to continue to develop glass casting. So I applied for masters and gained British Council funding to study in Prague with Professor Stanislav Libenský who working with his wife Jaroslava Brychtová, developed monumental scale casting in glass and

championed glass as an expressive sculptural medium. This was in Czechoslovakia, when it was ruled by Communist government.

The principles with which Libenský and Brychtová developed their sculpture and teaching are centred on how light and colour 'work' through mass and space in glass to give tonal variation from dense dark, through to colour so light it appears almost colourless. All within one sculptural object, one melt of glass. This principle, which has been called ‘colour volume’ (Brachlow 2012) embedded itself into the development of my practice and my research. So when I had sight of the Grosseteste texts at the first 'Through a Glass Darkly' meeting there was an immediate resonance.

Image 4. Impression of Angel, 2000, Libensky/Brychtova, Zelezny Brod.

The work of Libenský and Brychtová described as “The exploration of space as the setting of life” Šetlik (2002) reflects their persistent interest in the exploration of the human condition and nature, developed through monumental scale spatial sculpture in glass. This basis from which I have developed my own research and practice feels resonant with some of the ideas expressed in Grosseteste’s texts and in other papers given in this conference.

Image 5. Orloj, Staromestske Namesti, Prague.
Life classes, Academy of Applied Arts, Prague, 1983-5

As Colin in his presentation yesterday, imagined walking and talking with Grosseteste, responding each from their perspective of artist and theologian, discussing colour in nature. Perhaps inter-disciplinarity is rooted in shared experience involving field work which can cross time as well as spanning across disciplines, subjects and locations.

Image.6. Rogallo, 1985

So I went to study behind the iron curtain for two years. In an age of easy global communication with English as a dominant language it feels like deep history to talk about an experience of arriving with no Czech language what a struggle it was to communicate. But I studied with my eyes, relying on visual and perceptual information while I learned to speak.

Participating in this conference led me to consider the ongoing nature of learning new languages whether that is a verbal or a visual language. I am also remembering Jim Al Kahlili's description in his keynote, of scholars going to southern Spain to learn Arabic in order to translate texts into Latin to broaden access to them. From an artist’s perspective I think here of the casting process as a translator, a unifier - one melt one colour one form with light as the active agent to bring life to the resulting from.

Image 7. Three images together indicating the path of idea to glass : 'Mala

Strana', photo; clay model ; resulting cast glass, Thwaites 1985. Cast in Zelezny Brod in Libenský and Brychtová's own studio.

So let's talk about what casting glass involves. It is an ancient set of connected techniques, examples of cast glass exist in Museums around the world, for example the Museum of Underwater Archaeology in Bodrum, Turkey. Where beads made approx 4,000 years ago look like they could have been made yesterday.

There are many stages of process and types of materials used to translate an idea into a cast glass object or sculpture. Until I started the PhD my method took a long and winding route from

idea →image/sketch → master model →master mould → soft model → refractory mould →casting →glass → cold working.

For 'Mala Strana' I used clay, translated through plaster to 'klih', a form of gelatine used in Czech before silicon rubber became easily available, to create a flexible model. This soft model can be withdrawn from a fragile refractory mould into which glass can be cast in a kiln.

Image. 8. '20 20', 1999, Caption: developing ideas around vision and perception

Back in the UK, I started my own studio with very basic equipment, determined to carry on working and developing ideas from the perspective of my Czech experience.

Image. 9. Mould making for Glass, Bloomsbury, 2011
launched at MELT exhibition, London Glassblowing

I worked with variations of this method, often using wax which is easily steamed out of a refractory mould,until I came up against forms I wanted to make which proved impossible. At this point I started to look for another way forward and became interested in the potential of digital technology.

Digressing for a moment, I have noted during the conference, that several people have shared memories of comments made that have challenged yet shaped them in their education for life. I'm sure we all have them. The one I would like to add is from someone I respected very much who called me a slow learner. At that moment I was stung. On reflection it has helped me tremendously, not only to understand my own way of learning but that of others too. I liken this slow, deep learning process to devitrification in glass. This takes place over time, as crystals of 'not glass' (which is what devitrification means) grow slowly around a particle of dust or minute droplet of water on the surface of glass during a kiln firing. This process, like learning is a transformative: glass becomes crystalline and it is therefore not glass anymore, the learner becomes transforms into a more structured being, growing knowledge around a nucleus.

Image.10. Flora Borealis I and II, 2012, reconsidering the analogue lost wax method

Lost wax is one of the most established ways of creating 3D sculptural form in glass. It enables the creation of forms which would be impossible to make using blown and hot glass techniques. However it too has its limits. Becoming frustrated with limitations of lost wax process I turned towards digital technology as a potential way to access the making of complex forms and details in glass. This was the starting point of my PhD and I already had long term relationship with University of Sunderland. My research considers the junction of analogue and digital making in Studio Glass at a point where making by hand is being questioned and re-evaluated in an expanded field of art, craft and design.

Image 11. Scaffolding in Prague and Newcastle and Tom Rogers, the Coracle maker, c.1905

Although many of the forms I create in glass are abstract with a fusion of geometric and organic qualities, everything has real world starting points. You can see here the last *Coracle* maker in England and scaffolding which I combined through drawing to make a simplified *Coracle* shape as a test form for combining digital and analogue processes. The sculptural forms and scale that I wanted to work on ‘the unmakeable’, referring to forms, structures and miniature scale that would be impossible or nearly impossible to make by hand.

Image 12. 3D virtual models created using Rhino software, 3D printed and then cast in glass. Three glass 'Coracles'

Image 13. Through a glass Darkly, evolving ideas, Grosseteste's medieval multiverse

Although I was initially drawn to De colore, it was De Luce that I became more sensitive to as I re-read the text and notes after the initial meeting.
Thinking about Grosseteste, the idea of the medieval multiverse, lux and lumen, I started to formulate a visual response.

Image.14. Modelling on Rhino

Image 15. Multiple simultaneous views

Image 16. Virtual Models created on Rhino materialised as 3D prints

Image 17. Refractory mould making using the 3D print as a sacrifical model

Image 18. From CAD models to cast in glass

Image.19. Worlds within worlds, version 1 at the National Glass Centre

Image 20. Worlds within worlds, version 1 at the National Glass Centre

Image 21. Worlds within Worlds' 2018, Pembroke College Gallery

Image 22. Mini Biclops

Towards making the unmakeable:
How 3D printing can inform kiln formed glass practice in the 21st Century

With glass as with people, the inside is as important as the outside - both have body, skin and inner landscape. Sometimes you can clearly see in, sometimes what you see is distorted, as through a lens, and sometimes translucency veils your view. Ideas around vision and perception and aspects of the human body, all have a part to play in the translation of feelings into tangible, tactile forms.