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Graphic Swim: 2D and 3D Printing in Glass Casting

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Abstract: This document is a report on developing processes to encourage flow of the graphic image in kilnformed glass. It is also a description and reflection on a body of artworks in glass in which new visual qualities were exposed through a mishap and turned into an aesthetic choice. The research links 2D print approaches to 3D printing and their integration in cast glass. It updates the author's practice-based PhD research, a study that utilizes glass printing, cutting and fusing processes to combine the printed image within the glass object. The outcomes of the study can be organized under two approaches that have been developed, one appropriate to practical workshop teaching, and the other for the conceptualization and fabrication of new personal artworks.

Keywords: glass art; kilnforming; screenprinting; lost PLA casting; glass casting; 3D printing

1. Introduction

This research is an exploration of a combination of 2D and 3D approaches to print with the visual effects of movement through melting produced in kilnformed glass. First mentioned in a handbook on glass and print (Petrie 2006, p. 64), the possibility of 'graphic swim' has not been explored explicitly in creative glass research. This author's PhD study speculated on a working approach: 'The dynamic movement of the graphic image within the glass form might be achieved through methods that encourage the loosening of control over the printed image' (Sarmiento 2011, p. 169). The opportunity to do such research came in an artist residency and the creation of a new workshop at Bullseye Glass Company, a glass manufacturer which is also influential in exhibition, research, and education. It is embodied in new artworks by the author, whose research is from the perspective of an artist working in glass.

1.1. Background

First developed in 2007, *Encyclopaedia* (Figure 1) is an on-going body of artwork made through printing and kilnforming processes. It consists of book-shaped rectangular solid forms in glass arranged in multiple units, a visual nod to the volumes traditionally found on library shelves. Within each form, the pages have been replaced by sheets of printed glass, upon which images, text and patterns are layered, remixed, and fused together. This dense collection of visual information is intended as an expression of the artist/researcher's collected experience of life as a perpetual foreigner. *Encyclopaedia* uses transparency in glass to express the idea of seeing all the layers of information at once. Glass has historically been used as a surface for the painted, etched, and photographic image. In the modern practice of kilnforming glass, one working approach is to work with the permanent image on, or in, a piece of glass.

Figure 1. Jeffrey Sarmiento, *Encyclopaedia* (*Volumes*), 2012. Screenprinted, fused and polished glass. Photo: David Williams.

The images in this work are made by screenprinting a variety of ceramic on-glaze enamels and glass powders onto sheets of glass, sintering the image permanently in a kiln. In this particular body of work, the embedding of multiple layers of printed glass is achieved through fusing a stack of glass sheets held in place by kiln bricks. The fusing results in a homogenous rectangular block of glass, which is then polished to reveal multiple surfaces and angles through which to view the embedded imagery. As each image is separated by the thickness of glass, a floating effect is achieved. Variations on this theme have included a series of small *Volumes*, consisting of eight screenprinted images embedded in a book-sized object; *Chapters,* a wall-based version of the works in which the imagery is both layered and laid out; and *Encyclopaedia,* in which 100 images are embedded within a 70 kg solid block of fused and polished glass.

1.2. A Big Mistake

This body of work has been improved in each iteration through refining the process. Examples include the addition of a vibrant transparent color palette in screenprinted glass powders in combination with the detailed, but opaque, prints created using onglaze enamels. It is possible to use exclusively analog techniques in the making of printed and fused glass. However, digital making processes such as scanning, image and vector applications play an essential role in the compilation, creation, and manipulation of the printed image; screenprint positives are output on toner or inkjet printers as opposed to drawing on film. Process CMYK halftones and complex multi-colored images and patterns have been applied to the glass using registration printing. Quality control is also a motivation in developing the making approach. For example, techniques have been improved in the alignment and screenprinting of glass sheets, which differ to paper in thickness, transparency, surface texture, and absorbance. To prevent the formation of large bubbles which ruin the work, a two-stage fusing process was introduced to casting of the large *Encyclopaedia*. An additional casting process is introduced, laying several fused units (similar in scale to the *Volumes*) into a refractory mold to contain the glass as it melts at a process temperature into its final form. These blocks sit on their long edge in the mold for two purposes. First, the orientation should allow air between the units to escape during the firing process. Second, as the thickness of the glass is a factor in the annealing and cooling of the work, this layout provides the least vertical height and the lowest temperature difference between top and bottom in the kiln. This strategy makes for the most efficient cooling cycle and the most stable final work in cast glass.

This insistence on control may improve quality, but also serve as a barrier to experimentation and progress. As curator Tina Oldknow explains in an analysis of technique and creativity in the field of Studio Glass, 'Glass is a technically demanding material, and because of this, there is always the threat

of artists (and, equally important, their viewers) becoming arrested at a level that focuses on mastery of skill' (Oldknow 2008, p. 29).

What brought this body of work its greatest leap forward (both creatively and technically) was in fact a big mistake; in this case it might also be considered a moment of serendipity. A mold was constructed from refractory boards and bricks to accommodate a large *Encyclopaedia*, made using fused 'volumes' as described above. This approach was being used as the intended form was straight sided, and unlike an investment mold the components are reusable and adjustable. A general rule was followed for such a setup: the weight of the glass in the mold was supported by at least an equal weight outside the mold. However, due to an error in the distribution of supporting weight, the mold failed during this firing and gave way to the pressure of the liquefied glass (Figure 2). The result was a loss of glass from the intended thickness having run off the long ends, which would later have to be removed as waste. However, this kiln 'disaster' gave an unintended effect: imagery within the pre-fused elements shifted dramatically from the center of the work out toward the open edges of the mold. When the glass was removed from the kiln, it was found to be intact and viable for finishing. With its faces polished, a graphic 'swim' was revealed as the result of the kiln mishap (Figure 3).

Figure 2. Kiln setup for failed fusing of *Encyclopaedia*. Photo: The Author.

Figure 3. Jeffrey Sarmiento, *Encyclopaedia* (*Swim*), 2018. Screenprinted, cast and polished glass. Photo: David Williams.

2. Methods and Approaches

As the bungled firing provided such surprising results, a change in direction of the work led to the current research; a new aim was developed to encourage, rather than eliminate, flow and movement of imagery within the glass. It combines approaches relevant to the layered fused imagery in *Encyclopaedia* with the natural movement of the glass that is common to Studio Glass. Gravity and inflation are used to change the shape of glass, and this transformation is recorded on and within the resulting objects. Contemporary examples include the 'weaving' of decorative cane patterns of Italian-inspired blown glass by Tobias Møhl, and the veiling between individual elements melting together in castings by British glass artist Colin Reid.

2.1. In Search of Graphic Swim

To begin testing, the initial failed firing was restaged at a smaller scale, with the intent of understanding the flow of the printed image and controlling the results. The approach to firing is informed by a process originally developed by Bullseye Glass Co. It is manifest in their fabrication of the large-scale glass works by Jun Kaneko (Kaneko 2007), and explained in web-based educational videos on 'Harnessing Flow' (Bullseye Glass Co. 2018). Building on their research, flow is applied to printed imagery in glass. In initial testing (Figure 4), a basic grid was printed to the glass, which clearly demonstrates and visualizes the movement of layered imagery within a fused glass block. These glass sheets were then cut down and fused together in several sections, which would then be set on edge inside a mold for a second fusing cycle. A mold of cut and kiln-washed refractory furniture was made to accommodate the target dimensions for the final fused object, and the amount of glass was measured by weight to achieve the correct volume. The displacement in the melting process shifts the imagery, and the movement is controlled by varying the layout and dimensions of the glass sections within the mold.

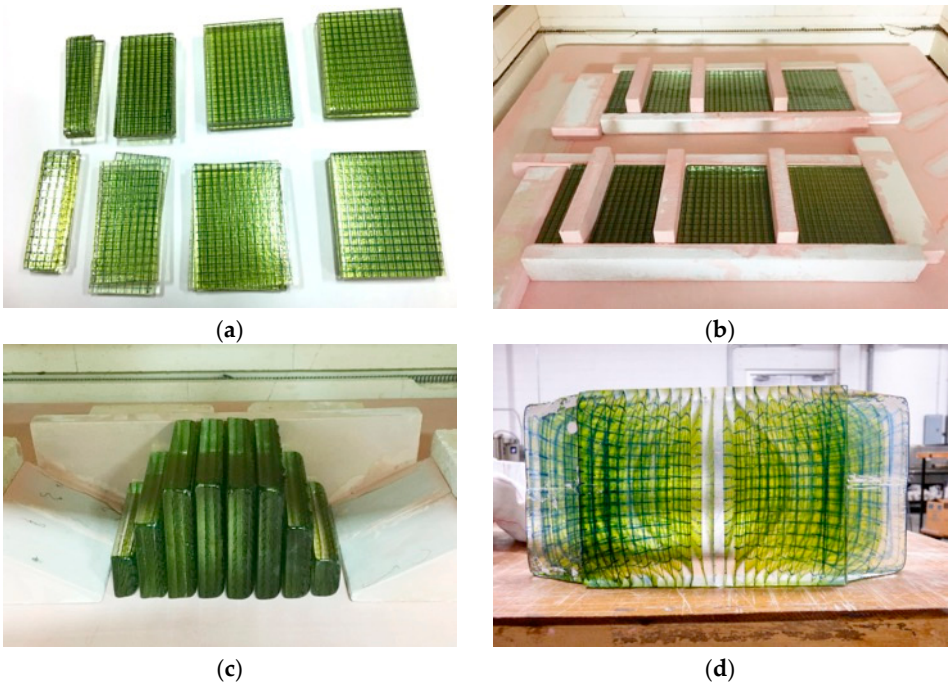

Figure 4. Process for 'graphic swim' test blocks. Glass screenprinted with a grid pattern (**a**) is stacked and fused into sections (**b**), which are then set on edge (**c**) for a second fusing cycle. Resulting fusing exposes movement of imagery (**d**). Photos: The Author and Bullseye Glass Co.

This process was then utilized as the center of a 5-day workshop at Bullseye Glass under the title Graphic Swim. The focus of the workshop was the transformation of layered imagery through the processes of screenprinting and kilnforming. Students were instructed and coached through the process described above, using a combination of imagery pre-selected for the class as well as their own graphic work. This provided an opportunity to see the effect of movement on different choices of graphic text, image, and pattern. Results of the workshop revealed several possibilities that encourage the direction of flow and the intensity of the shift of imagery (Figure 5). The direction of flow (outward, inward, or sideways) could be controlled through the placement of pre-fused sections. The intensity could be varied through varying the height of these sections, giving some imagery further to flow than others as the glass melts into a homogenous rectangular solid. Students were encouraged to consider their adaptations of the prescribed process, and in so doing they developed alternative layouts of sections to encourage assymetrical flow as well as combinations of still and shifted imagery. Their outcomes provided useful information that advanced an understanding of graphic swim.

Figure 5. Student work from Graphic Swim workshop. Variations are created through choices in image, color, and layout. Photo: The Author.

2.2. A Fusion of 2D and 3D Printing Approaches

Seeking possibilities beyond the glass block, the next phase of the project explored how printed imagery could be embedded into objects in the round. The mold structure for the *Encyclopaedia* artworks and the Graphic Swim workshops is simple. Four weight-supported walls hold melting glass in place produce a rectangular solid in which displacement is easy to predict. Replacing this with an investment mold of a three-dimensional form would encourage a dynamic flow of the glass and embedded images. Again, it is possible to use exclusively analogue techniques in the making of this work. However, in the same way that software provides precision and complexity in the 2D printed image, a similar approach was taken to incorporate emerging 3D printing techniques into the process.

Explored in depth by Thwaites (2018), a 3D print from a digital model is used as a single-use positive form in PLA plastic, which is then 'lost' through a melt-out of a refractory investment before being cast in glass or other materials. For the artist and craftsperson, the key advantages to this process are an expansion of possible forms through digital scanning and modelling; and the ability to bypass silicone and wax, two materials traditionally to create positives for lost-wax casting. In the early weeks of the artist residency, a silicone mold and waxes were made in the interest of time, for the sake of moving the kilnforming tests forward while the 3D printing process was being established. It was however quickly discovered to be untidy, costly, and time-consuming. The main disadvantage of analogue lost-wax is a lack of flexibility; resources must be committed to multiples or variations of specific forms, when in fact the goal in this project was to create a variety of forms to cast. A maker working with a 3D printer can alter the scale and correct forms as well as produce multiples, thereby engaging a workflow that allows for continuous development of the digital model and print. Its relative accessibility allows the author to take approaches to collection, variation, and collage used to cultivate uniqueness in his screenprinted glass work.

2.3. Building a Vocabulary of Things

The *Encyclopaedia* series involves the compilation and creation of hundreds of images, which could be considered a vocabulary of texts, shapes, diagrams, photographs. Considering the transformation in three dimensions of the image through graphic swim, it was also conceived that there could be a transformation not only of the image but also of the object. Is it possible to compile and build a vocabulary of 'things' to correspond to the imagery? The body of artworks created in the research and residency sought to work out these possibilities.

Much of the author's artwork including *Encyclopaedia* could be considered a form of self-portrait in that it records experience over time. In her interpretation of this body of work, Vigna (2007) writes, 'The richness of all of this information reminds us that personal identity is complex—something that goes well beyond (but does include) the tangible elements of a human being' (p. 20). An appropriate form to begin this experimentation was a literal self-portrait, albeit this one in three dimensions. A 3D scanner was utilized to capture a model of the artist's head. Portrait scanning is a trope in digital craft as photogrammetry is often utilized to create a 3D 'selfie' (Warnier et al. 2015, p. 34). It is also an obvious form to test detail in the outcome as an accurate likeness can be easily recognized. Furthermore, the choice was also practical in that considering the movement of glass, the imagery would need to melt into the form and would be distorted by any constrictions in the mold, and with few undercuts the form of a head is a relatively simple shape to cast.

From the resulting 3D printed heads, investment molds for glass casting were created. These are normally filled using a flowerpot with an enlarged hole as a crucible to contain the glass to be cast. As this method would force the screenprinted glass through a small aperture during firing, the imagery would become distorted to the point of complete illegibility. Therefore alternative approaches to filling the mold with glass were developed. Several tests were generated using these forms, exploring strategies for controlling the movement of the printed images. This would vary the distance the printed glass would have to travel as it melted as well as the amount of the void the melted glass would have to fill through the casting process.

The first setup (Figure 6) uses a simple block-shaped feed into which pre-fused elements are laid on edge. Using an indicative printed grid, the flow of the imagery could be seen clearly in the finished object. What became visible, however, is that during the melt, the glass becomes fluid. Imagery in the center of the fused sections would drop more quickly than imagery on the edges as the mold filled. Therefore, heavy distortion would lead to illegible graphics other than bold patterns.

(**a**) (**b**)

Figure 6. Process for loading kilnformed sections into lost-PLA investment. (**a**) In the first setup, a rectangular feed filled with printed glass sits atop the mold. (**b**) Image distortion is seen in the final result. Photos: (**a**) The Author and (**b**) Bullseye Glass Co.

Partial filling of the mold with printed glass sections offered the possibility of reducing this kind of distortion and would preserve some of the legibility of the images by preventing them from moving. The second setup utilized a single shape of a long cylinder consisting of stacked glass discs (matching the volume required to fill the mold) laid into the bottom of the mold and held by a ceramic pot as a feeder. The result of this test (Figure 7) was an increased legibility of the imagery directly inside of the mold. The flow into the form was still possible as the disc was only as large as the smallest opening and the printed images spread throughout the casting as it filled the cavity inside the mold. In the third version of the setup (Figure 8), contours from the 3D model of the head were taken to approximate the shapes that would fit more tightly, and glass was cut and fused to fit into the mold cavity. This test produced the least movement of all.

Figure 7. Jeffrey Sarmiento, *Encyclopaedia* Object 1, 2018 Screenprinted and lost PLA cast glass. A result of the second version of the setup, the mold was partially filled with a cylinder of stacked and screenprinted glass disks. Photo: Bullseye Glass Co.

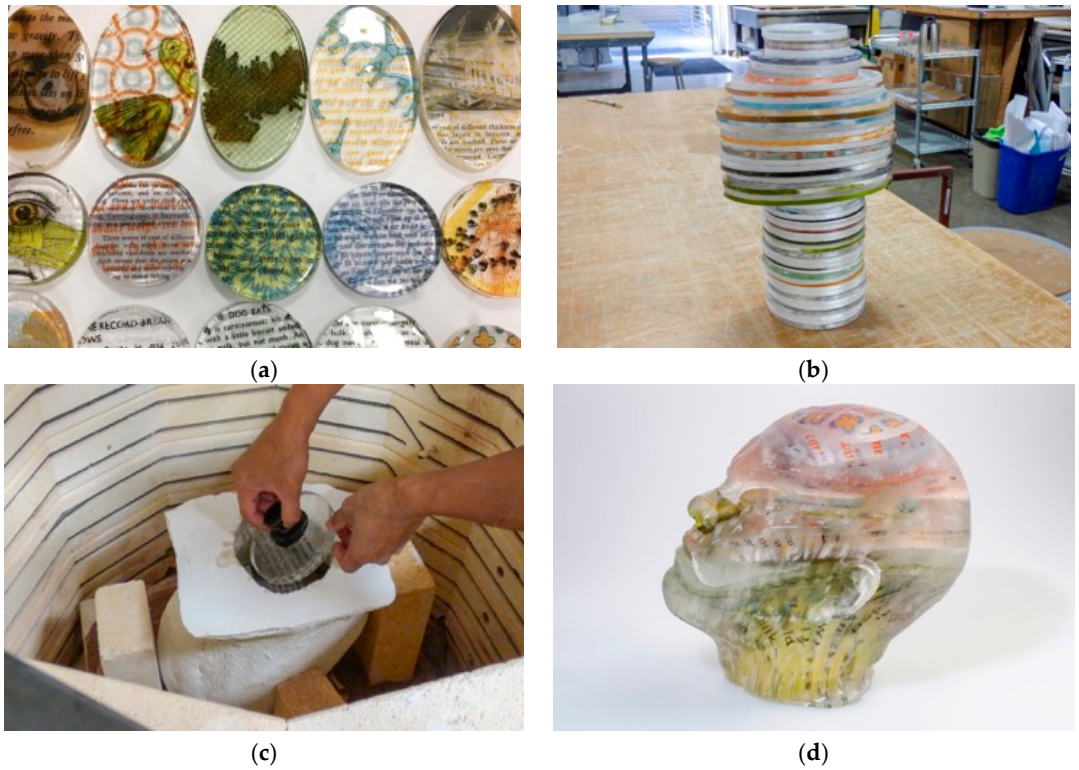

Figure 8. Process for loading kilnformed sections into lost-PLA investment mold. In the third approach, contours of the glass sheets are cut and fused together (**a**) to create a close approximation of the form of the target form (**b**). These pieces of glass are then loaded into the mould (**c**) to fill the void as tightly as possible. Resulting form reveals less distortion of the printed images (**d**).

3. Discussion

Following through on a failed firing with persistence, this research has yielded some new artwork as well as techniques for achieving visual effects in glass. It has responded to unanswered questions that remained after the completion of this author's PhD research. It explores possibilities for graphic swim in kilnformed glass, using a practical testing approach used to develop a workshop, and an experimental development of sculptural glass artworks. The following reflection is based on the artworks, student outcomes and consideration of the processes.

3.1. Outcomes

There has been positive response to the process as well as the new artworks. One artwork (Figure 9) was recently accepted through juried submission into Toyama International Glass Exhibition 2018, held in a new museum in Japan. Development of the body of work is ongoing. The success of the workshop could be measured by the way in which it provided visible evidence to improve an understanding of graphic swim. The workshop was also over-subscribed, and as evidence of interest there has been sufficient demand to repeat it three times in the coming year.

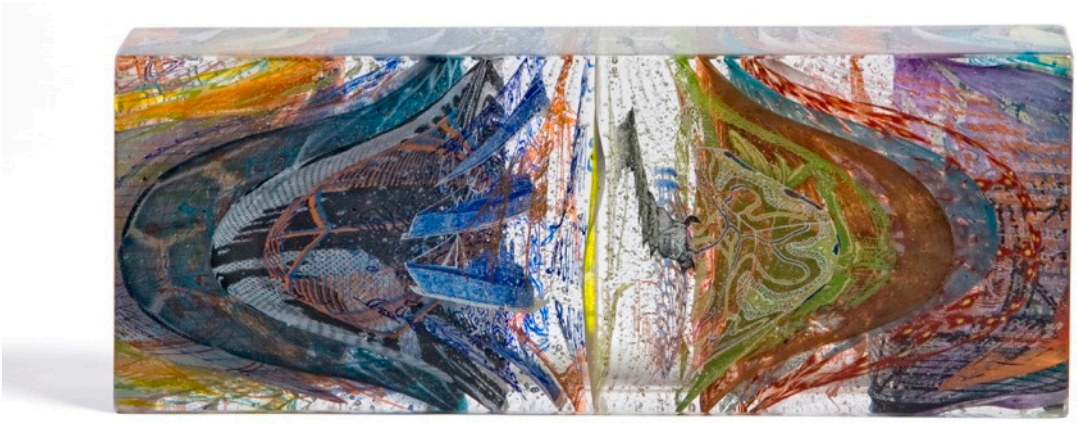

Figure 9. Jeffrey Sarmiento, *Encyclopaedia* (*Warp*), 2018. Screenprinted, fused and polished glass. Photo: David Williams.

The key accomplishment in this research is the articulation of one approach to the 2D image in 3D space, bringing together knowledge of screenprinting with glassmaking techniques. While there are other ways to produce a layered effect in sculptural glass through the use of multiple sheets of glass either mounted to a frame or glued together, the techniques to produce graphic swim activate in three dimensions the otherwise flat deposits of printed image cased within glass. It takes advantage of the natural response of glass to heat and gravity. Graphics are warped through the melting process, swimming within the glass. However, it should be acknowledged that the aspect of flow has been evident throughout the history of blown and cast glass, clearly indicated through decorative pattern and veiling. This history, along with the author's practical experience with glassblowing and casting, informs the investigation of the movement of glass in kilnforming.

On the subject of craft-based artists incorporating new and traditional technologies into their work, curator Emily Zilber finds that 're-tooling can be a rich source of inspiration for a work's very concept and content' (Zilber 2015, p. 17). It is possible to draw similar observations from this project. Processes and concepts of digital craft have informed this work, having a clear effect on the fabrication choices as well as potentials for interpretation. The use of 3D prints as a starting point offer an expanded vocabulary of forms that could be explored with graphic swim. This is more significant than removing the limitations of time and consumables found when using an analogue silicone and wax making process. Forms for casting in glass can be generated entirely through 3D modelling, or capture physical objects through scanning. They can be further transformed through the incorporation, collage, and modification of existing resources on the Internet. In this research, this approach to form finding and making relates closely to the strategies for working with self-made and found graphics in the screenprinting process. In the same way as narrative can be constructed through compositions of layered imagery, a relationship can be built between the objects that comprise a 'vocabulary of things' and the visual content held within.

In the resulting artworks, traces of the layered 3D print have been left as texture to show a level of detail that can be achieved through the 'lost PLA' method of glass casting. Exposing the marks of its manufacture, it was intended to draw a visual relationship between the layers of printed imagery within the glass and the strata of print on the surface. While graphic swim was an explicit aim for the artworks, the impressions of the developing work by others were somewhat surprising. In casual discussion, one reaction to the movement of the images within the object, a distortion of what had been clearly legible in previous works, led to an interpretation of the work as a commentary on the contemporary media environment. In another, it was mentioned that the flowing of the graphic image within the form also had a quality one might interpret as the movement of information or data. This may relate to Glenn Adamson's assessment of contemporary craft processes when he states, ' . . . the digital has changed the way that analogue makers approach their work . . . the characteristic features

of digital form—stretched distortion, filtered color and backlighting—migrate into analogue design as if unconsciously' (Adamson 2015, p. 288).

One of the drawbacks of the engagement with this process is that it has not (yet) helped to develop a more efficient practice. In exchange for new visual effects, complexity and autonomy, it draws heavily on material and energy resources. The glassmaking techniques of print, swim and casts from 3D printed positives are individually straightforward, but using them in combination results in a significant increase in production time. The possibility for improvements in this aspect may come through further practice in both 3D modelling and printing as well as the kilnforming techniques related to the process.

3.2. Mistakes Turned into Processes

A significant difference in the working approach in comparison to previous research by this author is the way in which the project has been led by an initial mistake that uncovered an effect that proved desirable. This was not only a welcome change from the focus on tight control on a technically demanding process; this research has revitalized a body of work which has been in production for more than a decade. The use of mistakes as a learning process is a positive response to an adverse situation, but the approach to the research overall does not deliberately engage elements of chance. Rather, the author's creative studio process allows for variation within a range of possibilities. This is already a part of the working process, in that the graphic imagery is often printed to the glass in a wide variety of colors so that choices can be made when creating a layered composition.

3.3. Opportunities for Further Work

Possible routes for development have been identified as a result of the research, and these will continue to be explored through both teaching and artwork development. Two potentials for control of imagery within the cast form involve the development of 3D modelling and digital fabrication. For example, using CNC or waterjet cutting to increase precision of the contours cut to fit inside molds would result in the least amount of movement of graphics within the cast form, but might allow for a more precise relationship between the printed interior imagery and the exterior form. Similarly, 3D modelling might be used to produce positives with part lines from which multi-part molds could be constructed. This would increase the number of mold elements to produce, but result in a tighter fit for imagery.

Further possibilities in the development of workshop teaching might include making 3D printing more accessible to the glass artist or craftsperson. Because 3D prints are relatively slow to produce and still require some specialist skills and facility access, the development of printing and casting techniques using flexible (and potentially reusable) 3D printed positives using alternative FDM printing materials might increase the viability of the processes by saving what is currently a single-use print positive. In terms of drawing a closer relationship between the 2D images and the 3D form that surrounds it, the focus could return to how a photographic printed image can be integrated into a low relief 3D print to provide an illusion of depth and a low relief sculptural surface.

Finally, it might be useful to further explore the opportunities afforded through calculated risk and a release of the tight control characterizing the approach to 2D printing in glass and the implications of 3D printing on traditional glass processes. By returning to earlier notions of materiality and action, and a consideration of the most appropriate process (analogue or digital) to obtain a result, the precision and gesture might be found to work well together.

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