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Method& Critique *Frictions and Shifts in RTD*

Collaborative Craft through Digital Fabrication and Virtual Reality

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Abstract: This paper examines the collaborative practice between an analogue and a digital craft practitioner. It aims to illuminate ways in which digital tools can be used to translate handcrafted objects in collaborative craft practice and to address the following questions: 1) What forms of knowing and meaning making evolve in collaborative research through design practice? 2) What does it mean to explore material in Computer Aided Design (CAD) through Virtual Reality (VR)? Originating with a hand-knotted artifact, the study begins with the transformation of an analogue form into digital format using a range of techniques. These activities act as both a review of digital fabrication capabilities and an exploration of new thinking mechanisms offered by this emerging hybrid practice. The study broadens our understanding of the maker's role within the capabilities and limitations of digital tools. Each iteration of digitally-fabricated objects was documented and reflected upon. This collaborative practice acts as a catalyst for established disciplines within art and design to collide and interact. Outcomes include mapping workflows within digital and analogue material practice, and reflection on how the materials and methods used in digital fabrication have the potential to expand the meanings connected to the things that are produced.

Keywords: CAD; collaborative practice; digital fabrication; hybridization; new craft; virtual reality

Nimkulrat, Oussoren, Day Fraser, Doyle | 3D printed cups, Nithikul Nimkulart, 2017.

Introduction: Analogue and Digital Craft

Whilst craft is generally understood to be concerned with 'controlling the whole process from start to finish, adapting and improving tools as the need arises', the processing of digital technologies seems ''hidden' making understanding and controlling the process from concept to end product seem more complicated … and not craft' (Shillito 2013, p.9). This raises questions about the role of the controlling hand in 'machine culture' and CAD environments of industrial design where mechanised output has a close association with ideas of precision, reproducibility and certainty. '[A]gainst the rigorous perfection of the machine, the craftsman became an emblem of human individuality, this emblem composed concretely by the positive value placed on variations, flaws, and irregularities in handwork' (Sennett 2008, p.84).

Pye (2010, p. 342) gives a provocative definition of craft – relating it to risk-taking: '[Craftsmanship] means simply workmanship using any kind of technique or apparatus, in which the quality of the result is not predetermined, … The essential idea is that the quality of the result is continually at risk during the process of making'.

Traditional craftspeople make personal subjective decisions as they work with analogue materials to form artefacts; they have no digital history to retrack their decisions. Material artefacts act as the only documentation at the end of the process (Zoran and Buechley 2013, p.6). Today, craftspeople can access digital tools and digital fabrication, tapping in to processes whereby an object is designed on a computer, and then automatically fabricated by a machine. Craftspeople have the 'right approach, skills and mindset' to affiliate themselves with digital technologies (Campbell 2007) and explore the close relationship between digital work and craft practice (McCollough 1996). McCullough sees craft expanded by digital media, which has the capacity to 'reunite visual thinking with manual dexterity and practiced knowledge'. Craft researchers continue to widen their view from a traditional making practice to – as Dormer (1997, p.140) noted over 20 years ago – 'craft as knowledge that empowers a maker to take charge of technology'.

The subjective decisions of the maker remain necessary for the production of digitally produced artefacts, which in turn reflect their makers' skills, perspectives and values (McCullough 1996). In this sense, digitally fabricated work is at risk in a similar way to handcrafted work . The difference lies in the digital craft practitioners' accessibility to the resulting material artefacts and also a rich history in the form of editable digital files. This implies considerably less risk in digital craft than in an analogue one.

Digital fabrication and open-source tutorials on 3D modelling have transformed the practice of some designer-makers. However, some other craft practitioners seeking direct interaction with materials through handwork do not see digital interfaces as affording tools. This paper aims to illuminate ways in which digital tools can be used to translate handcrafted objects in collaborative craft practice, addressing the following questions:

1) What forms of knowing and meaning making evolve in collaborative research through design practice?

2) What does it mean to explore material in Computer Aided Design (CAD) through Virtual Reality (VR)?

The collaboration detailed in this paper took place at Emily Carr University of Art + Design over the period of 2.5 months, between an analogue craft practitioner (Nimkulrat) and a digital craft practitioner (Oussoren). Nimkulrat has worked extensively in textiles; her practice mixes experimental and traditional forms of hand-knotting to produce evocative three-dimensional artefacts. Originally trained as a glass artist, Oussoren is fluent in CAD and digital fabrication processes, and applies this digital skill to mould making for glass. Cross-disciplinary collaboration between Nimkulrat and Oussoren is taken as a *research through design* approach (Nimkulrat and Matthews 2017) to tackle the above research questions. The following sections will examine this collaboration using digital tools to evolve a form through paper string, knots, 3D scanning, CAD, Virtual Reality and 3D printing. Reflection on this collaboration is expected to shed light on how shared interdisciplinary making can contribute to the development of individual collaborator's methods of making and subsequent creative output.

Handcrafting Through Digital Tools

In order to understand digital processes through a craft lens, Nimkulrat constructed a small handcrafted artefact for further experimentation with digital tools available in the research labs at the university. The artefact was a knotted coffee cup with a saucer made of paper string, a replica of an artefact named *The Coffee Cup* (2007) (Figure 1).

Nimkulrat and Oussoren first used a high definition Polhemus 3D laser scanner to translate the analogue artefact into a digital format (Figure 2). Scanning required coordination between the moving hand and the eye focusing on the rows and columns of knots. The first scanning attempt was carried out with reservation and at the same time with curiosity as to how well the intricate knot structure and paper string could be captured. Scans of the cup showed a line quality resembling the characteristic of paper string and the handcraft. Nevertheless, the files of the scans were too large to process effectively in CAD, causing computer crashes on both the university's and the scanner manufacturer's platforms. This revealed that the properties and characteristics of the handcrafted object were beyond the capacity of this digital tool.

The next approach followed the idea of abstraction to simplify the degrees of complexity in working with digital tools (Campbell 2016, p.xxi). Freehand drawing on a photograph of the analogue artefact with a stylus on a WACOM tablet was utilised to produce a simplified model that avoided the unmanageable amount of data (Figure 3). Handling a digital tool to interact with the CAD program resonates with Clark and Chalmers's (1998) 'Extended Mind' thesis – the idea that the mind is not necessarily contained within the brain or physical body, but can extend to elements of the environment. In this case, the mind extends to the virtual software and the hand to the digital tool.

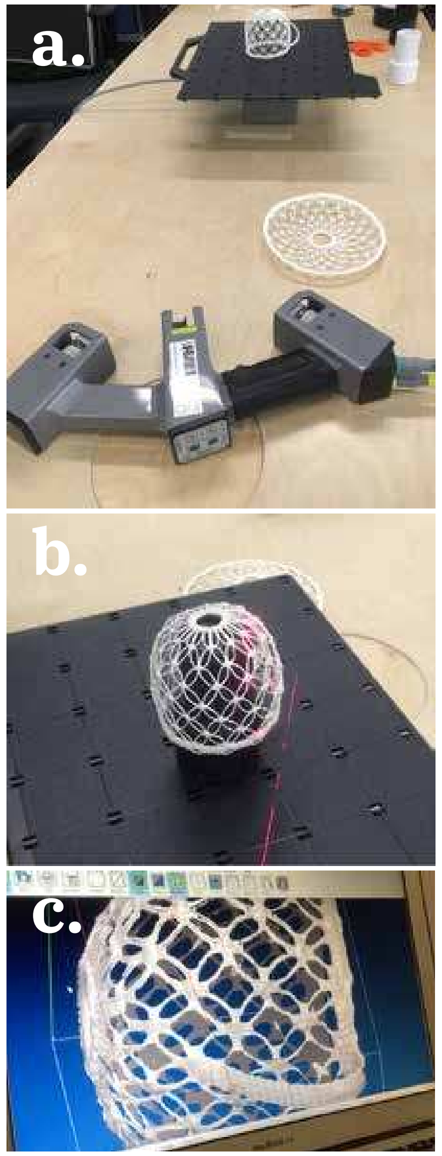
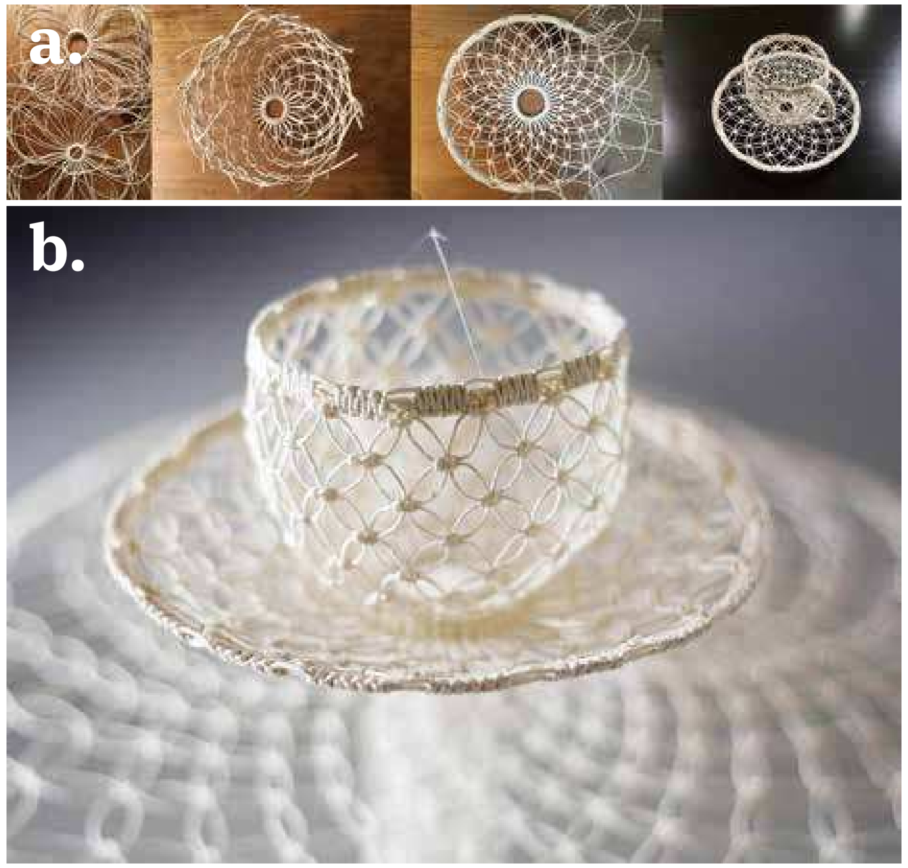


Figure 2. Polhemus Scorpion handheld 3d laser scanner (a), the scanning process (b) and the 3D scan (c).



<Figure 1. Process of making the handcrafted artefact, 2017 (a), a replica of an artefact made in 2007 (b).

A CAD model of a three-dimensional array of one section of the knotted pattern achieved a resemblance of the original knotted cup (Figure 4). Throughout the process of developing the CAD model using Cinema 4D, communication between Nimkulrat and Oussoren was crucial. Experts in their fields but having limited skills and knowledge in each other's domain, they had to continually find ways to understand intention and speculate on next steps in the process, e.g. through a demo, drawing, etc.

Objects created in CAD have been described as being confined to a programmed visual language, based on things that CAD does well, e.g. skew, duplicate, scale and rotate. The work, to this point, was a record of material manipulation according to analogue parameters or things that string does well, e.g. self-friction, knot and bend, translated into a prescriptive CAD language according to the parameters of the software. The development of the 3D model involved several hours navigating the restrictions of the software to achieve a model suitable for output.

Uncertainty and Imprecision in Digital Fabrication

This section describes the 3D printing process and the resulting prints of the CAD model in Figure 4. With little previous experience with digital output, Nimkulrat assumed that a high level of precision and certainty would be enabled through digital fabrication. However, digital processes presented challenges similar to those of craft materials and tools, and according to both physical limitations and novice digital fluency of the maker (Nimkulrat), imprecision and uncertainty were ever present in the process.

In order to refine and better understand the capacity of the materials and tools for production in relation to the delicate cup

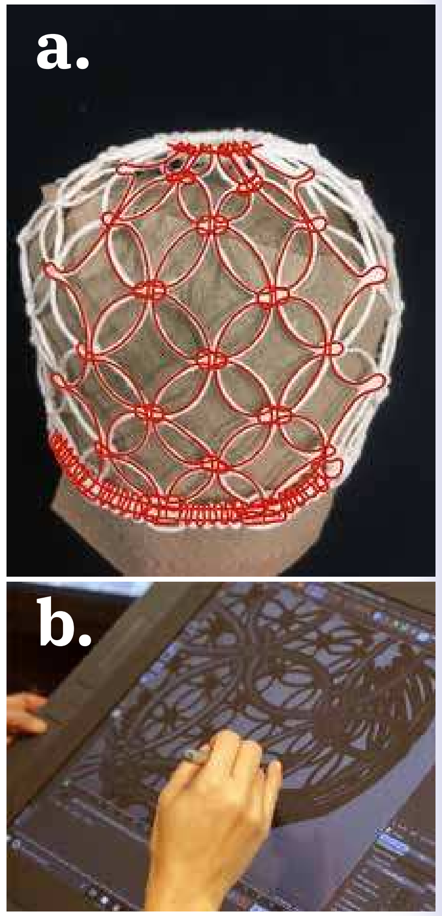
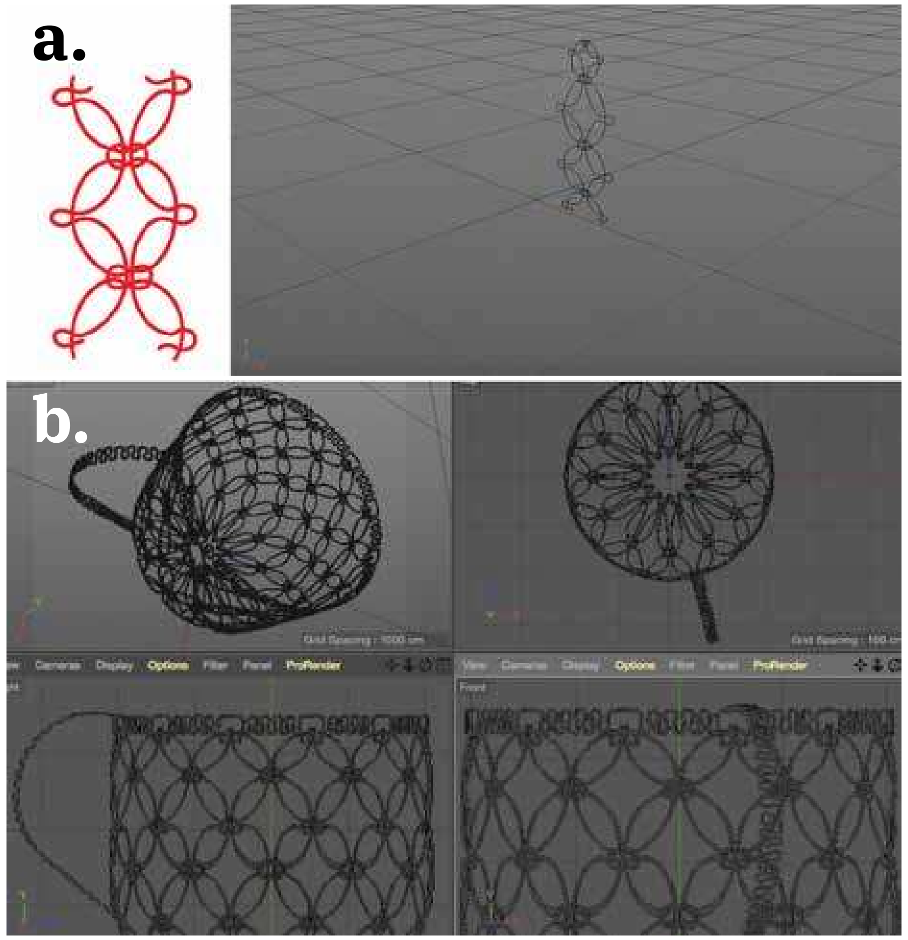


Figure 3. Tracing the knot structure on a photograph of the knotted cup (a). Working on WACOM tablet using a stylus (b).



<**Figure 4.** A section of knots imported to CAD for generating a three-dimensional array of the knot pattern (a), forming a 3D model that captures a likeness of the original knotted cup (b).

form, the authors explored 3D printing on a range of technologies and scales, including thermoset and thermoplastic material production systems such as the Stratasys Objet30, a large format Stratasys F370, and a desktop Tinkerine DittoPro 3D printer. Details of the CAD model were set as small as 0.4mm and used only partial support material in PLA (a thermoplastic) filament. The DittoPro printer managed to print the entire model, but the physical print was too fragile to retain the cup form (Figure 5).

The CAD model thickness was gradually modified increasing from 0.8mm, to 0.95mm, and eventually 1.2mm. Replicas of these thicknesses were test printed in PLA in order to find the thickness suitable to the capacity of the machine while preserving the characteristics of knots, likeness of strings and fidelity of hand-knotting. The authors compared the resulting prints and decided that the 0.95mm print was the most successful rendering and would be used for further 3D printing using PLA composite materials, including wood (approx. 30% wood, 70% PLA) and copper (approx. 30% copper, 70% PLA).

Printing the 3D model of the cup in various composite filaments allowed for a detailed comparison of the printed outcomes – and for the authors to consider how implicit material character potentially influences the form and meaning derived from the mediated artefact. As Sennett points out (2008, p.160), 'by making something happen more than once, we have an object to ponder; variations in that conjuring act permit exploration of sameness and difference; practicing becomes a narrative rather than mere digital repetition'. A close reflection on the printed cups revealed that each composite presented distinct material features (Figure on pp.2-3).

In experimentation with the selected composites, several iterations of setting parameters of the printer's slicing software were changed to explore the certain material properties of each type. Settings such as temperature, speed, density and angle of support material were modified in order to find a solution to successfully print each composite. Occasionally, the CAD model itself required further modification when adjusting parameters in the printer's software had not yielded successful results. For example, the speed for printing the wood composite was gradually increased to achieve a better flow of filament due to the material's fibrous property that caused clogging to the extruder nozzle (Figure 6a) and in turn calling for an easing of the model's geometry. Despite the revised parameter settings, the resulting prints were still missing parts (Figure 6b). After several iterations of machine parameter settings, CAD geometry and printing, the authors were satisfied with the outcomes having achieved an appropriate material fidelity in each composite.

This work has illustrated that the production of digitally produced artefacts still requires the maker's decisions (McCullough 1996), similar to how handcrafted artefacts do. This was due to the digital technologies being not as precise and certain as assumed. What was important here is 'craft' as a 'knowledge that empowers a maker to take charge of technology' (Dormer 1997). Nimkulrat reflected on her experience of encountering the uncertainty and imprecision of 3D printing: 'Digital fabrication is not accurate as it may seem. This probably is due to the fact that no judgement of the maker is being constantly made in process (unless the maker observes the machine absolutely at all time' (Nimkulrat, personal note, November 7, 2017).

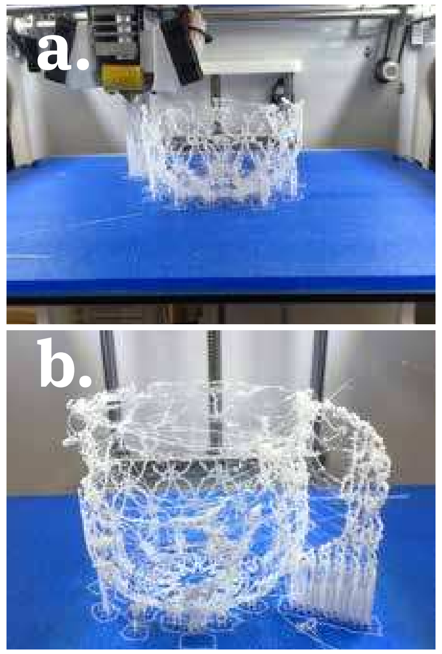


Figure 5a, b. The first 3D printing to test the capacities and limitations of the printer.

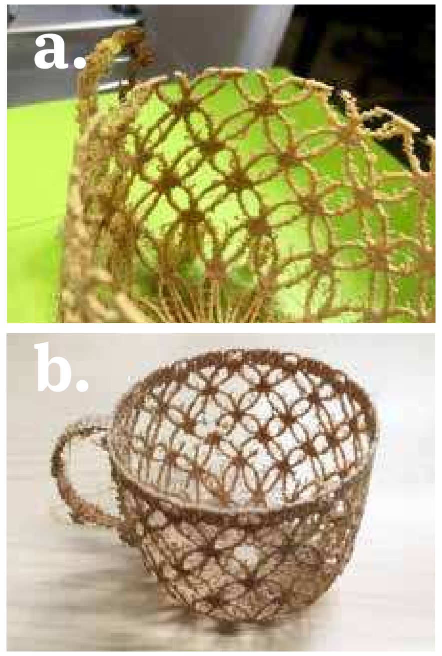
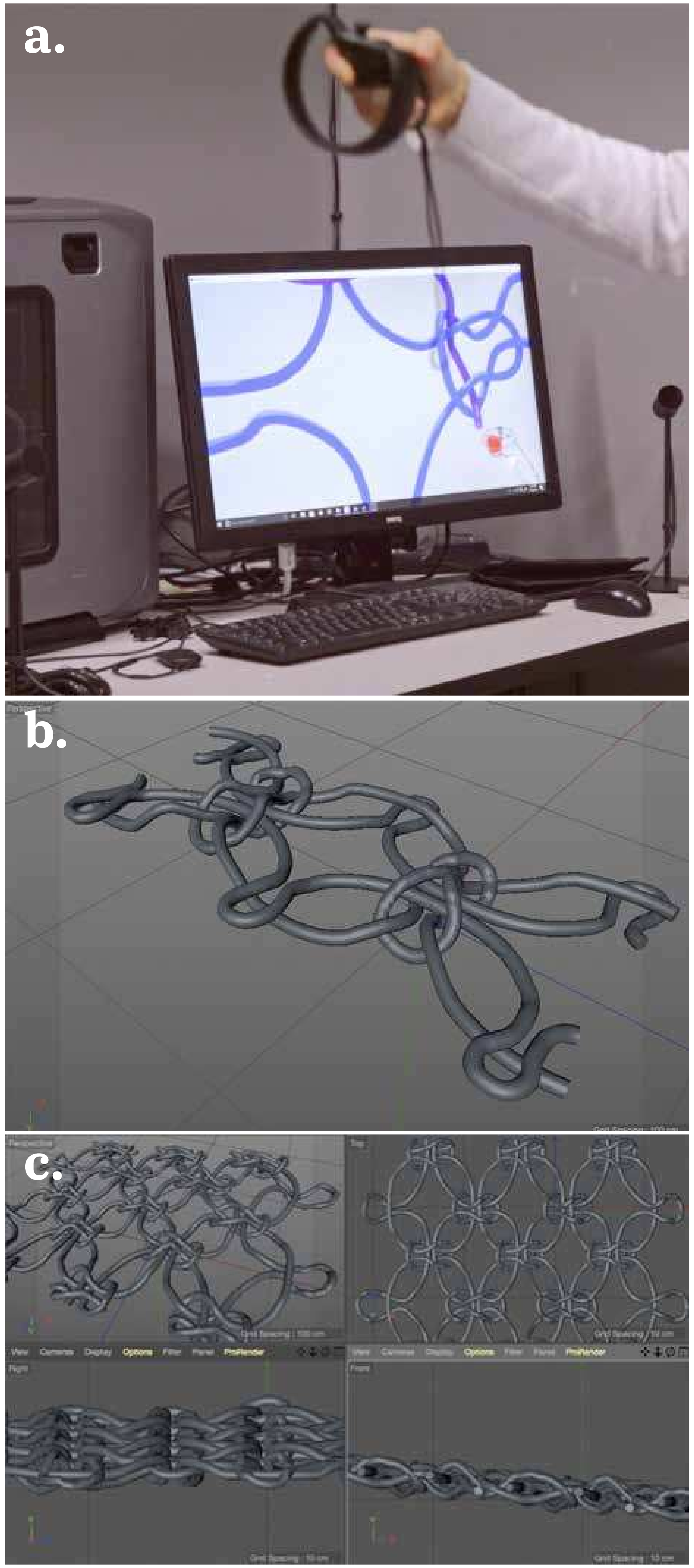


Figure 6. Experimentation with the wood composite. An incomplete print due to the clogging of the extruder nozzle (a) and a print with missing parts (b).



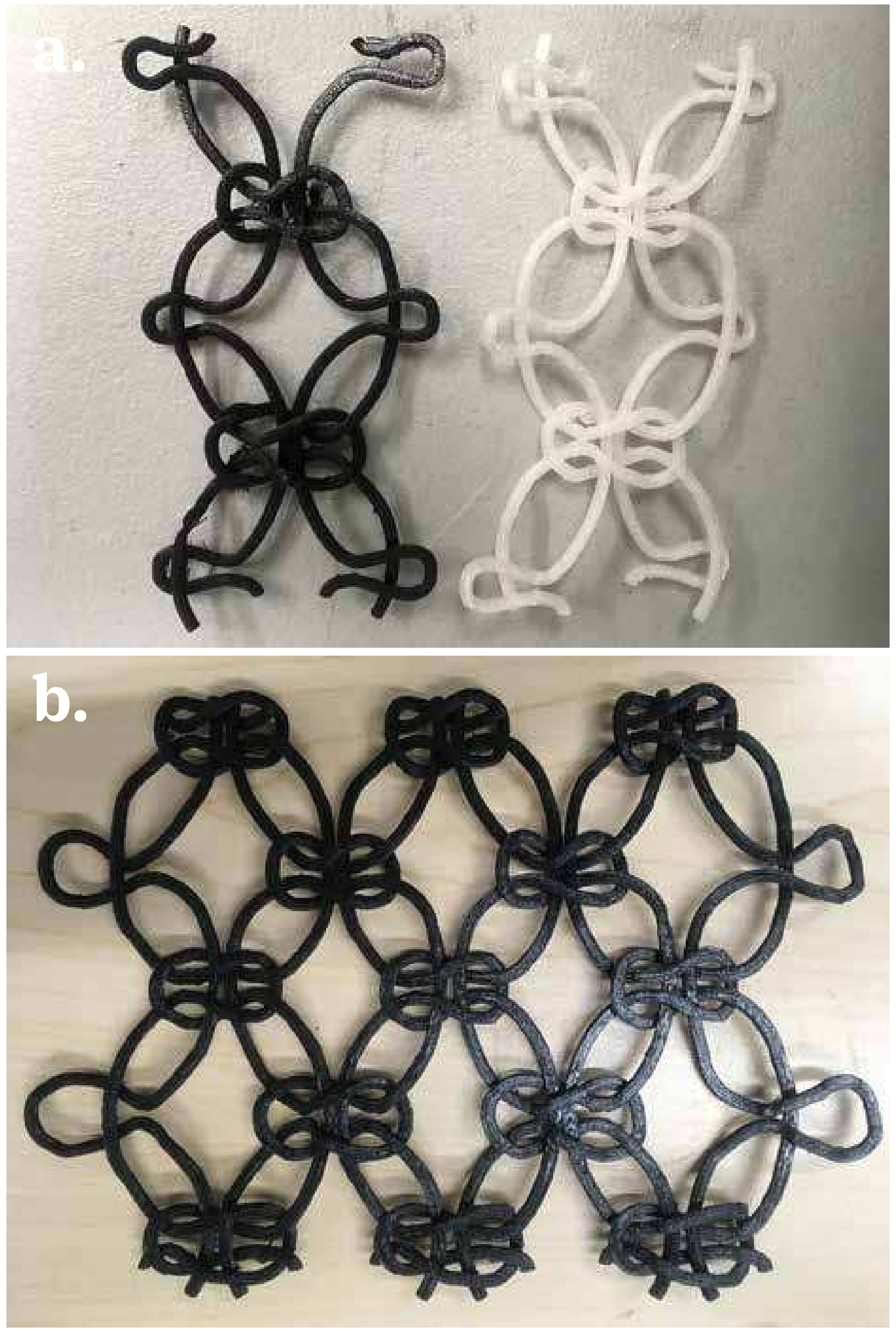
Handcrafting in Virtual Reality

Although the 3D printed cups could capture the likeness of the original hand-knotted cup, Nimkulrat felt that the physical characteristics of knots, including the continuity, flexibility and bendability of knots or things that string does well, were missing from the prints. To represent the nature of knots, Nimkulrat and Oussoren attempted to create a new CAD model of flexible, loose knots. A stylus was employed again to create a section of knot pattern for further 3D modelling. However, it turned out that virtually knotting on a 2D screen was incomprehensible for Nimkulrat, despite her long-standing experience of hand-knotting three-dimensional work. The use of a 2D screen to create a 3D model did not sufficiently depict or open up access to the positions and the interlacing of strands that construct knots.

Oussoren saw a possibility to resolve this obstacle through drawing in virtual reality (VR) space although he had no experience with it. Using a drawing program called Gravity Sketch and VR controllers, Nimkulrat drew scaled-up knot structures in a 3D VR space, imitating a gestural manner to real-world hand-knotting of string. CAD, as discussed by Sennett (2008, pp.42-43), is largely a disembodied or 'hands-off" practice because it disconnects simulation and reality and disregards relational understanding. However, drawing in VR recalled hands-on experience and relational understanding of positions of strands in 3D space that Nimkulrat has with hand knotting. The new experience in handcrafting in VR enhanced Nimkulrat's understanding of the positions of strands of knots in a three-dimensional space and helped her to find a solution for the making of a CAD model of a section of knots (Figures 7a and 7b).

<**Figure 7.** Crafting knots in VR (a) and CAD Models of a section of flexible knots (b) and multi-sectional knots (c).

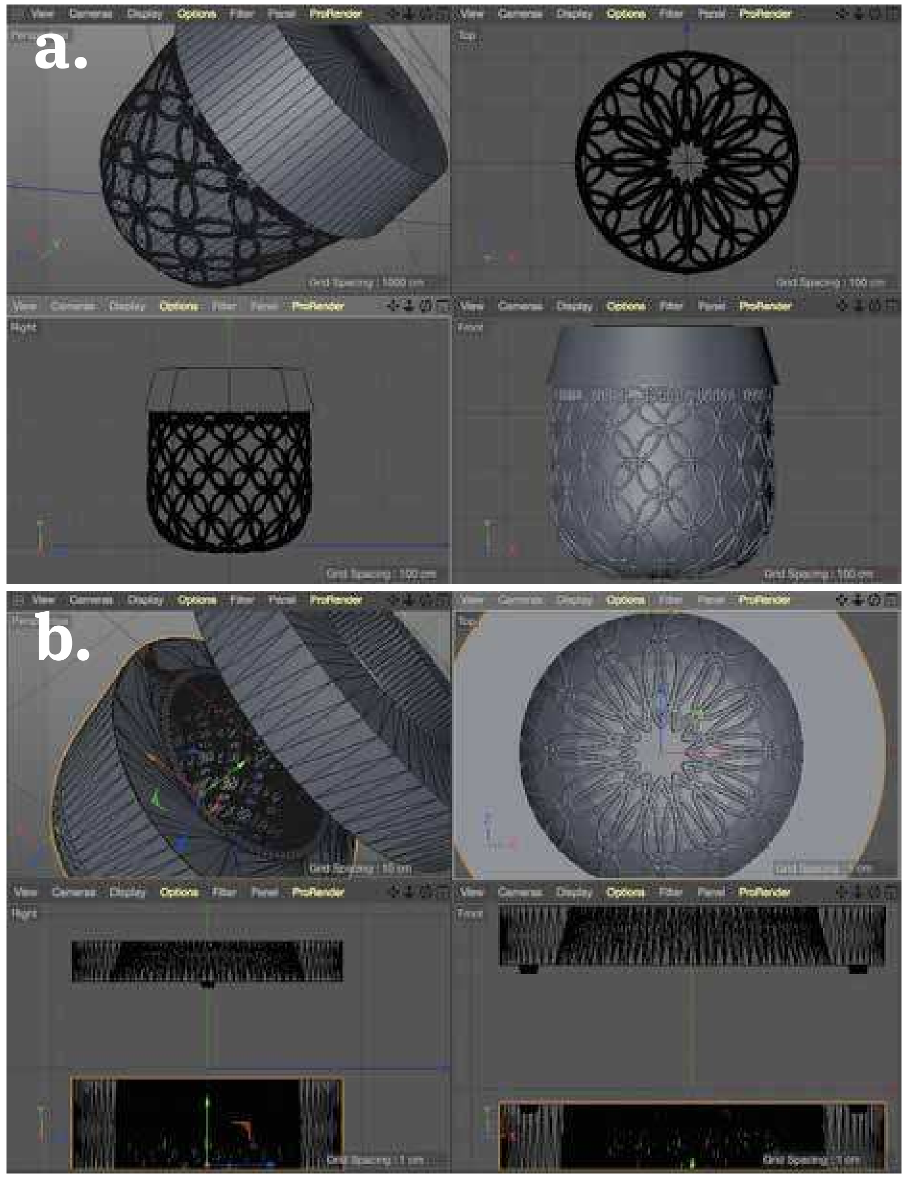
The next challenge was to solve the 3D printing process in which the printing nozzle irritated on a previously printed area with a steep angle and caused it to shift from its original position on the support material, resulting in the detachment of the next printed layer. Initial prints fell apart when their support material was removed, or, if they stayed whole, had a fractured, uneven surface. Two factors contributed to the printing problems: the machine and the parameter setting on the printer's slicing software. To test the first hypothesis, the same 3D model was printed on a different machine. The result improved, yet cracked surfaces still occurred (Figure 8a). This output suggested that the machine might partially influence the printing process. Next, the slicing parameters were set to generate a full grid of support material. A new print was successful, but the support material was too dense to remove. Having proven that the setting of slicing/printing parameters was the key factor, the support material was set to distribute throughout, strong but relatively easy to remove. The next stage of modelling and printing of multi-sectional loose knots also used this approach (Figures 7c and 8b).



<**Figure 8.** Comparison knots prints from different printers (a) and a print of multi-sectional loose knots (b).

New Craft: The Digital Meets the Analogue

Oussoren, Robbins and Doyle (2015) have employed powder-printing technology for mould making for use in the metal foundry, glass casting and slip-casting in previous projects. This 3D printing technology at first seemed unrelated to Nimkulrat's practice. However, having accumulated her 3D modelling and printing skills, She saw this 3D printing method as a new opportunity for giving function to her artefact. Although being a textile practitioner by profession, Nimkulrat had gained in her first degree in Industrial Design an understanding of the general principles of mould making for prototyping and traditional ceramics. Together with Oussoren who is an expert in CAD and digital fabrication processes of mould making for glass casting, Nimkulrat created a CAD model mould for slip-casting a porcelain cup that considered shrinkage and the removal process of the finished cast piece (Figure 9). The 3D modelling process started with making positive form of the cup with a relief surface of the knot pattern based on the 3D model of the knotted cup used earlier for 3D printing with PLA filament. The process continued with designing a one-inch-thick mould around the cup.



<Figure 9a, b. Process of making the CAD model of the cup mould.

Figure 10. The process of making a two-piece 3D printed mould and using it for slip casting porcelain.

The mould was then 3D printed on a Zcorp 310+ binder deposition powder printer, using custom in-house powder and binder recipes (Oussoren, Robbins and Doyle 2015). After being removed from the printer (Figure 9a), the mould was de-powdered with compressed air and misted with water (Figure 10b). This helped set the gypsum-based powder substrate, increasing its plasticity when dry. Porcelain slip was cast in the dry mould (Figure 10c). However, due to the different properties of the material of the 3D printed mould from those of the plaster one, using it for slip-casting porcelain could not follow the usual principles. For example, the cast pieces required a longer time to set because of the material's higher density. The cast cup had a unique texture that was the imprint of how the mould was constructed with powder layer by layer (Figure 11).

Figure 11. Cast porcelain cup from 3D printed mould.

Having been inspired by Nimkulrat's ability to generate complex knotted form in VR, Oussoren recognised new opportunities for form development in VR that could be translated into glass. Sitting on the outside watching Nimkulrat's gesture as she utilised the VR interface to generate knotted vector-line form led Oussoren to speculate on the connection between the gestural and fluid motion traditionally used in his own glass practice and the immersive gestural interface of VR. Oussoren began exploring a series of marks leading to the development of a series of three-dimensional glass forms comprising craft material and a captured gesture. Merleau-Ponty notes that gestures contain meaning and makes communication possible for human beings (Merleau-Ponty 1962, p. 213); gestures by one individual can outline an intentional object and bring perceptible points of the world to the attention of another. Gestural acts cross borders providing nonverbal invitations for others to take part in dialogue (Merleau-Ponty 1962, p. 215). In this case, Nimkulrat's gestures revealed opportunities to construct complex forms using VR; they invited Oussoren to explore these opportunities, making the communication between the practitioners possible. A glass-cast mould was designed in CAD (Figure 12). This particular design was derived from gestures captured while working in VR. The translated result (a mould for the form) was then 3D printed in a plaster like material suitable casting glass (Figure 13).

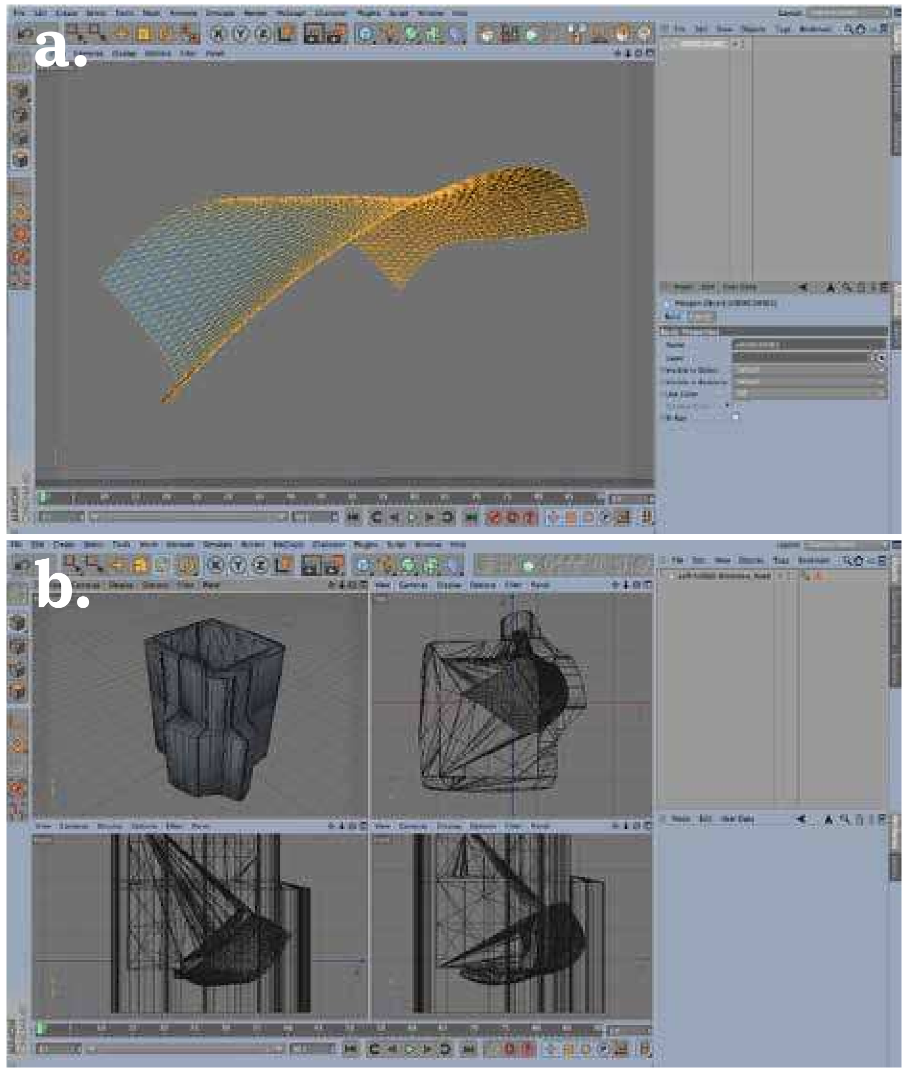


Figure 13. 3D printed moulds for glass casting, pre-firing.

<**Figure 12.** Gestural form captured in VR (a) and CAD design for mould based on VR form (b).

After 3D printing, the mould was post-processed by depowdering using compressed air, misting with water and applying a mould release ready for casting. Once the mould post-processing was complete and thoroughly dried, it was filled with crushed glass and fired to full melt temperatures in a digitally-controlled kiln. Once we had achieved full-melt temperature fluid glass was able to flow and fill the patterned void of the mould (Figure 14).

The workflow of generating complex geometries in VR to a cast glass object presents many new opportunities for novel forms and surfaces that have previously been difficult or impossible using traditional glass casting and blow-moulding methods. Oussoren's workflow of shifting from the VR interface to the production of a glass object is worth consideration. This precedent exposes opportunities for generating novel forms and surfaces previously difficult or impossible to construct within the implicit constraints present in traditional glass casting and blow-moulding processes. Digital's explicit promise is to deliver these 'otherwise unattainable' forms that exemplify a practice integrating what Harrod (2007, p.236) calls an 'important ingredient of the ideal new media-applied artwork'; that what is made is only possible using digital fabrication methods. The use of 3D printed moulds for casting glass and ceramics reduces time and waste, as there is no need to make an original positive form as required in the traditional casting method.

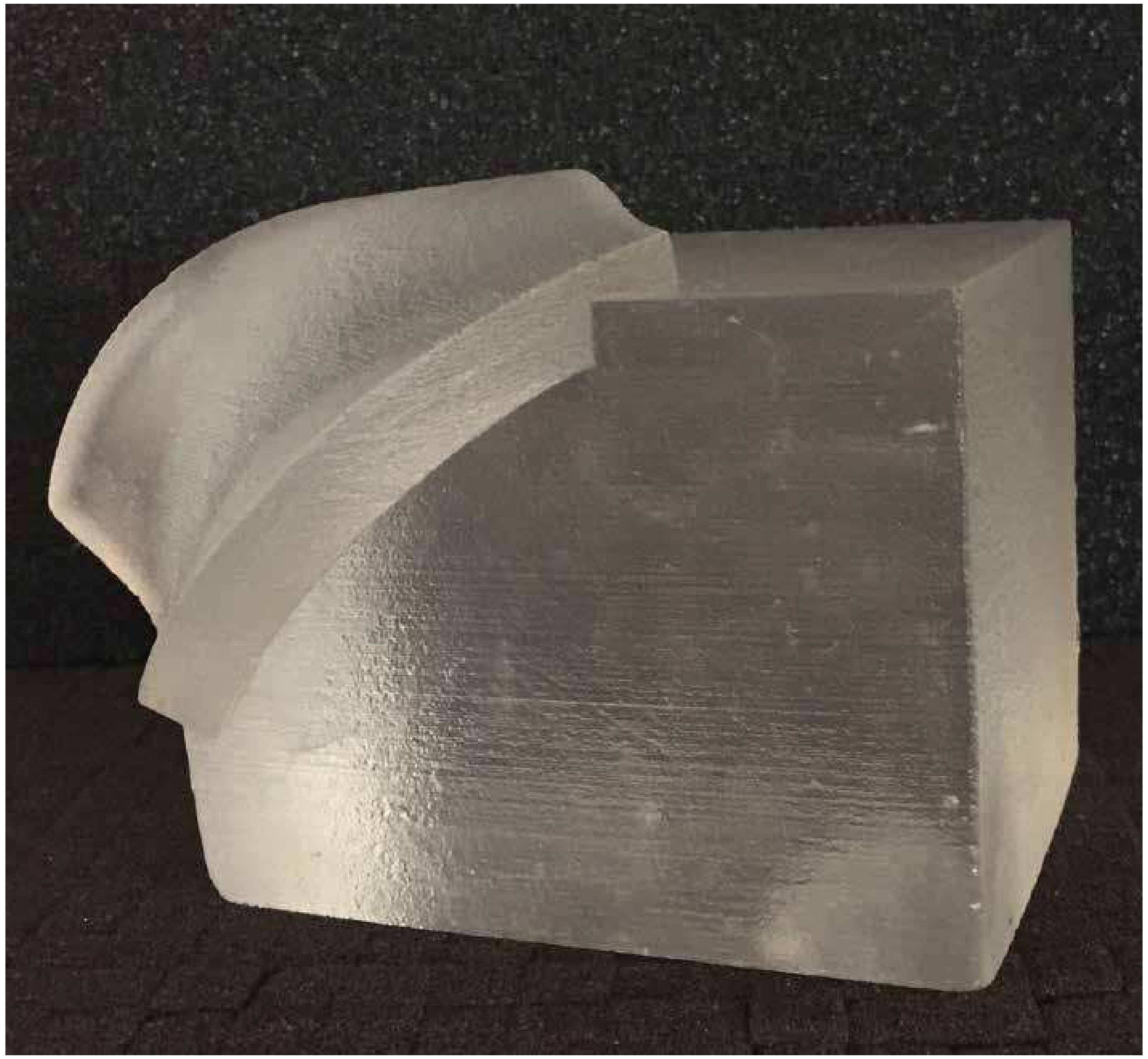


Figure 14. Cast glass from 3D printed mould, based on VR form.

Discussion: Knowing and Meaning Making in Collaborative Research Through Design Practice

How do our associations with knowledge and the creation of meaning shift as we begin to work creatively using machines that allow for infinitely replicable, yet easily customisable objects? Working with technologies that afford this type of production appears 'to expand the meanings connected to the things that are produced' (Nimkulrat et al. 2018). Meaning is grounded in one's experience of the world and is created by tacit knowing through indwelling sets of clues and integrating them into coherent wholes (Polanyi and Prosch 1975, p.36). 'We dwell in meaning through our embodiment, and meaning is continually enacted ... through bodily experience, gesture, or language' (Johnson 2006, p.9). In this section we consider 1) the role of tacit knowledge and embodied actions for makers, 2) perspectives on knowledge exchange that occur in the process of making, and 3) the creation of meaning in/of/through objects, in the context of digital manufacturing and hybrid practices.

Acts of hybridisation require translation. Translation is a process whereby textual material in one language is replaced by 'equivalent textual material in another language' (Catford 1965, p.20). In this case study, examples of the flow between the analogue language to the digital language are returned to frequently (Figure 15). Tightly connected to different gestural acts, the new workflows used by Nimkulrat and Oussoren attest to this replacing or shifting from one textual language to another. Translation (of material, surface, form) through analogue and digital languages provides new opportunities and understandings by way of gestural maneuvers and recently acquired tacit knowledge. This act of translation from one medium to another, in and in between analogue and digital boundaries, allows for an expansive understanding of the potential expressions and meanings afforded through the emergent material practice. A creative endeavour rooted in material practice simultaneously considers fabrication limitations and opportunities, the history of the material, its specific origins, the references that are inferred by its surface and form. An embodied understanding of these meanings is gained by being close to the material as it changes from one state to another. Here, meaning, as we understand it is not 'the product of representation but the product of a "conceptual integration" between material conceptual domains' (Malafouris 2013, p.90). Use of new tools affords new outcomes and new material meanings.

In this collaborative practice, meaning is created not only through the maker's interaction with materials and tools in space but also through interactions with them over time. Tacit knowledge was acquired through a 'discussion grounded in a context of practical activity' (Ingold 2013, p.9). Procedural gaps in capacity to work material into form are worth considering in relation to tacit embodied knowledge. When creating loose knots on flat peripheral devices, the implicit meaning of the material and Nimkulrat's connection(s) to it were lost. Unable to interact and give form through direct material manipulation and gesture, Nimkulrat could not pull on her deep tacit knowledge. According to Polanyi (1962, pp.71-72; 1966, pp.24-25) an act of knowing can never be fully explicit and the meaning of an act of knowing depends on constituents tacitly known by the knower. In this case, Nimkulrat's act of knowing depends on her direct interaction with the material she tacitly knew but became inaccessible due to the nature of the flat digital interface.

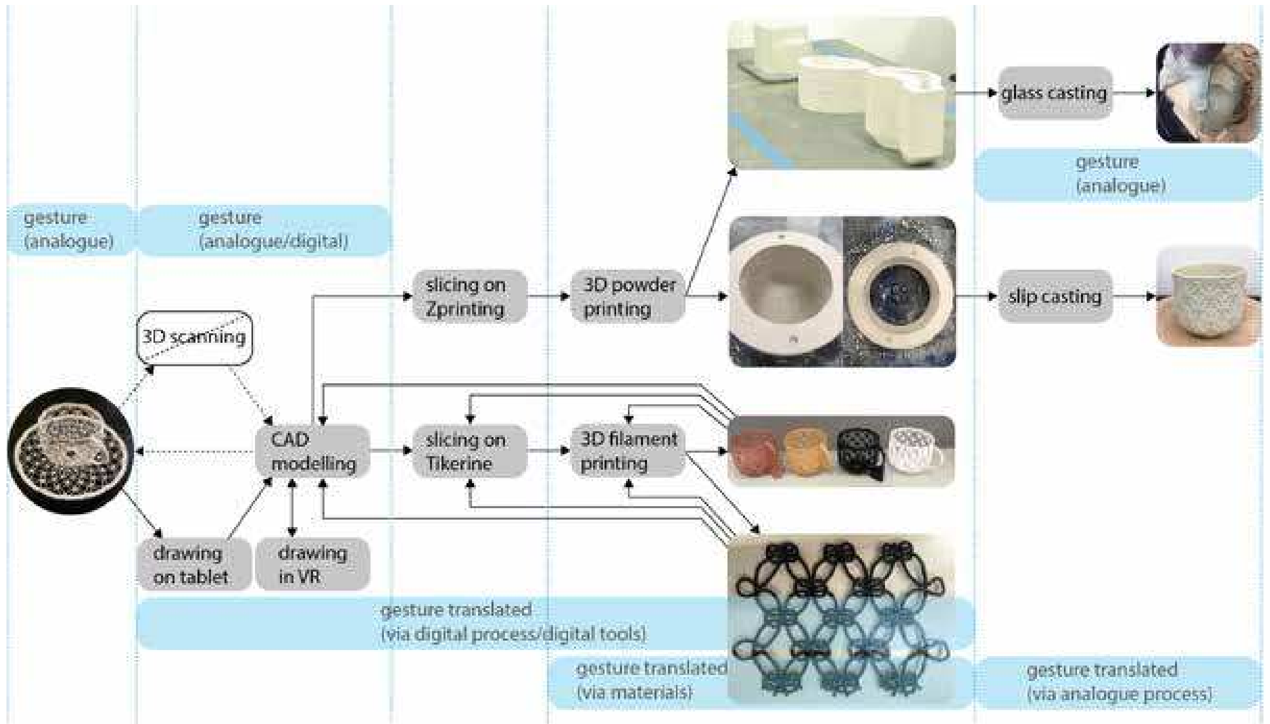


Figure 15. The flow between the analogue language to the digital language.

Shifting to a more immersive interface (VR) as a new form-giving tool, Nimkulrat was able to regain her embodied experience. While the physical material was not present in the VR space, she was able to pull on her tacit knowledge and long-standing creative practice of knotting string to create vector-line structures in three dimensions. This embodied knowing in material practice translated directly to Nimkulrat's facility for making knots virtually. Merleau-Ponty (1962, p.166) describes embodied knowledge as 'knowledge in the hands, which is forthcoming only when bodily effort is made, and cannot be formulated in detachment from that effort'. As Malafouris (2013) notes, '[e]mbodied cognitive science has made a strong case for the fundamental role of bodily sensorimotor experiences in the structure of our thinking' (p.67) and 'the material sign does not primarily embody a communicative or representational logic but an enactive one' (p. 18). Embodied knowledge is sensory and grounded in bodily experience, situating 'intellectual and theoretical insights within the realm of the material world' (Ellingson 2008, pp.244-245). It is a way of knowing where the mind is inseparable from the body (Lakoff and Johnson 1999).

The proximity of tools also plays a role. Due to the site of the lab they were working in and the tools available to them, Nimkulrat and Oussoren were able to easily move from one means of making to another as desired. Proximity also allowed these two skilled craftspersons to embark on means of making unfamiliar to them. In this case, proximity of differences lends certain permissions and a 'naive expertise' to the novice user (Wakkary et al. 2016). This 'naive expertise' mitigates expectations of the digital in the translation to analogue form. Collaborative research through design practice acts and actions were integral to form development whilst inherent differences in material practice and expertise afforded reflection-on-action (Schön 1983). Both craft practitioners shared distinct knowledge sets and understanding relevant to their original practices no matter how foreign a setting the Gravity Sketch VR 3D modelling interface presented. Moreover, both virtual and material artefacts produced by Nimkulrat and Oussoren and the process of making them played a significant role in knowledge creation, transfer and sharing. Outcomes produced with Nimkulrat provoked Oussoren to make meaning in new ways relative to his own long-standing craft practice. Oussoren began to consider parallel workflows and engagement with materials and tools. This recalls Sennett's sentiment that for craft practitioners, meaning is made through the process of making material artefacts and also in the act of observation (Sennett 2008).

The practice presented in this paper is an example of how craft practitioner-researchers attempt to discover ways of translating handcrafted artefact into a new form of craft that is digitally fabricated. The outcomes show how knowledge is gained and shared through the experience of working together. Knowing extends beyond the individual in order to accommodate broader cognitive events that include interactions among people, artefacts, space and time (Malafouris 2013, p.67). Arguably, this work is an example of the extended mind at play. Through collaboration and combined iterative efforts their particular artefacts came to be. Working alone the outcomes detailed above would not have been created. Through shared acts of knowing each practitioner-researcher's understanding of the crossing-over from analogue to the digital practice was expanded.

Research through design that is collaborative in nature is supported by interactions between people, artefacts, space and time. All of these aspects inform emerging material practice and outcomes. The artefacts produced are a demonstration of new structures and forms (Nimkulrat and Matthews 2017). These new structures and forms expand the capacities for traditional materials adding to the lexicon of material expression. Handwork and our own tacit knowledge continues to blur the line between the analogue and digital, exemplifying the opportunities for emergent collaborative, post-digital fabrication.

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