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Method& Critique *Frictions and Shifts in RTD*

Resisting Plastics for Ambiguous Results

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Abstract: This paper illustrate present a constructive design research process centred around 3D printing with a wood-based material. This process was highly explorative: it involves the development of a new material and the use and hacking of a machine to materialize a design intention. Along the way, elements of craft emerge, as the designers develop skills in navigating the tensions that exist between material, machine and design intention.

We present the process of navigating this design space by unpacking the act of making, using a digital fabrication technique, through a lens of craftsmanship. We employ the notions of ambiguity and resistance, to understand the factors and forces at play that may not typically be considered to be part of a highly automated digital fabrication method, such as 3D printing.

As a result of this detailed reflection, new parts of the design space were articulated. All resistances appear as a result of the tension between and designer's skills and intention, capabilities of the machine and possibilities of the material, all materialised in the Printed Future Vase.

This publication contributes to the development of a new additive manufacturing method, and increases our awareness of what factors and forces are at play in this new additive manufacturing method, in which the development of the designer's tacit skills have been articulated more explicitly.

Keywords: Constructive Design Research; 3D Printing; Digital Fabrication Methods; Resistance; Ambiguity; Design Process; making;

Introduction

Research through Design (Frayling, 1993), or, as it has been reframed, Constructive Design Research, can be described as "research that imagines and builds new things and describes and explains these constructions" (Koskinen et al., 2011). The knowledge that is generated in this form of inquiry exists both in the dynamic understanding of a design situation, as well as in the final artefact that is created. But exactly what happens in the process of designing, is difficult to unpack. Several ways have been described what this process of designing entails. One of them, Ehn (1998), builds on Schön's Reflective Practitioner (1983) to describe what designer's do: to make decisions in dialogue with the design material in a way that is neither completely absorbed action nor completely detached theoretical reflection.

In this paper, we expose a design process centred on 3D printing with a wood-based material using an FDM (Fluid Deposition Modelling) technique, trying to unpack what designers have done in this particular case. We do this by observing the design process, with a focus on how the designer navigates the design space created between the machine, material, intention and skills of the designer. We aim to contribute to this understanding from a particular point of view. Namely, that of craftsmanship in the context of a digital fabrication method.

We offer a very practical and detailed description of a design process, to unpack the role of making in this process. This is different from a common step-by-step, functional approach used to describe and sometimes teach a process of making, where the intended outcome is predetermined. We articulate the process with the aim of increasing our understanding of what happens in the process of designing something new. We use the metaphor of the design space (Gaver & Bowers, 2012), as an infinite amount of possible designs. The designer navigates through this space of possible syntheses to arrive at a point in that space, the final artefact, often taking form as an artefact.

Throughout the process of navigating this design space, possibilities and limitations emerge, which alter the designers' intention, shape her skills and develop an understanding of the design situation (Peeters, 2017). To better understand the ephemeral act of designing, scholars have sought to define and describe the factors and forces at play.

We turn to Sennett's The Craftsman (2008) for a lense on making, to better understand the dialogue between designer, material and machine. We articulate the process from this lense since it prescribes a compelling vocabulary and a way of describing the process of making decisions, that balance the desired outcome and the obstructions or opportunities provided by the material at hand. While, at the same time, the notions leave space for intuition and the unknown as a guiding force.

Sennett describes resistances as "facts that stand in the way of the will" (2008). Resistances present themselves in two forms: found and made. Found resistances are unexpected or unforeseen obstructions. For example, unexpected knots in a piece of timber. In contrast, made resistances are obstructions created by the maker herself. For example, when a craftsmen starts over on a workpiece, unsatisfied with the shape it is taking. Ambiguity refers to engaging in an action that does not have a clear result. Often, to deal with resistances is to decide on a path forward, uncertain of the outcome. To move with or around the resistance. The outcome is not always known, and often results in new resistances.

We use the flexibility offered by the RTD template, to reflect on the presence of the notions of ambiguity and resistance in this process in great detail, in order to highlight some of the factors and forces at play in the process of designing. We show a particular, craft inspired, view on how a designer navigates the design space, up until the formation of a point in that design space: The Printed Futures Vase (Figure 18).

A Material

The materials in any design situation may be material, or immaterial. In our case, an important design material is an actual material: wood. Wood is a common and versatile natural resource, used to create buildings, furniture and paper, amongst others. In the process of turning forests into usable forms such as planks, side stream materials such as sawdust and wood flour are generated. Such sidestream materials are today often burned for energy production, while they offer other uses, for example to be used in additive manufacturing.

Materials typically used in FDM printing used are polymeric and fossil based materials, industrially produced and commercially available in pellets or filament roles. This material is thus ready made and homogenous, it acts predictably and printers are engineered to produce consistent results. An important part of the design process described here, involved the development of a material made from these sidestream materials that would be suitable for FDM printing. To become suitable in this case, the material needed to be biodegradable, wood-based, fluid enough to be printed yet able to cure or otherwise post-processed in order to achieve a stable form, and at the end of this, preferably elicit aesthetic qualities. The development and use of a new material presented the designers with resistances. For example, through its physical properties, e.g. the material paste being inconsistent in size or fluidity, the difficulties encountered in the mixing of different components, the drying process being too fast or too slow, difficulties in the consistency of extrusion, etc. The designers needed to address such resistances: work with, change or move around them. Thus, the material itself forms an important factor that shapes the design space that the designers navigate through.

A Machine

Additive Manufacturing (AM) is nowadays a well known production technique that is no longer only found in industry. AM has reached many households through small and affordable 3D printers. Fused Deposition Modeling (FDM) is one of the most common forms of AM. Many of the consumer grade desktop 3D printers on the market today utilize FDM with plastic filaments to produce prototypes, models and end use parts.

The use of these machines does not typically entail any interaction between human and machine during the printing process. There is little if any possibility of interfering with the outcome, after the start button has been pressed. It is as if these printers were designed according to the positivistic principles set in the industrial revolution: aiming to maximise efficiency and minimising resis-

Figure 2. Close-up of the finished Printed Futures Vase
Photo: Ronald Helgers

tance, which in this case, is materialised in the necessity of human interference during the process. Pye referred to this contrast as Workmanship of Certainty vs. Workmanship of Risk, in which the first is “always to be found in quantity production, and found it its pure state in full automation.” “The quality of the result is exactly predetermined before a single salable thing is made.” (Pye, 1968). In contrast, Workmanship of Risk is described as a process “in which the quality of the result is not predetermined, but depends on the judgment, dexterity and care which the maker exercises as he works. The essential idea is that the quality of the result is continually at risk during the process of making..” (Pye, 1968). This is closely related to the way designers navigate a design space: the process of attributing physical or dynamic form to abstract intions, without a predetermined outcome in mind but rather an emergent one.

The tool with which we shape material in the process we describe here is a particular 3D printer, the WASP 3MT. This printer was designed to print both with PLA pellets as well as with porcelain clay. The latter requires the installation of a “clay kit” extension. This clay kit consists of a cylinder that houses fluid material and a different printer head featuring a mechanical extrusion nozzle. A pneumatically controlled piston within the cylinder pushes the material out to the printing head where it is extruded.

This machine has its own possibilities and limitations that result in resistances encountered by the designers, forming important factors that shapes the design space. The clay kit was designed to print with porcelain clay, and although it is able to produce great results in skilled hands, the unpredictability of a natural and manually prepared material make the process more difficult than printing in synthetic materials such as PLA. Once the machine is running, there are parameters that the operator can - and needs to - check and refine. Physical interaction with both the printed object and the machine are frequently necessary. For example, to stop and restart the print, adjust the air pressure on the pneumatic piston that regulates material supply, or the flow rates of material and printing speed. The unpredictability of the machine, in addition to the material, becomes another important factor in shaping the design space.

Navigating the Design Space that emerges

As design researchers, we start this project with a desire and an aim: to us an AM technique to print a beautiful and usable artefact that is mostly made from wood without unsustainable additives. The creation of this artefact involves not only its design, but also the development of a material, the mastering of a machine and developing the skills and sensitivity of the designer to find its way through the limitations and possibilities that arise. The design process here becomes to navigate the design space that emerges in the tension between the possibilities and limitations of the material and machine, and our intentions, skills and judgment as designers.

In navigating this design space, we learn by doing what is possible and impossible: to address the resistances that emerge and find a way forward. During this process, material, machine and design intention shape one another. In this publication, we articulate what we learn by navigating in this design space. The lense through which we articulate it, are the notions of resistance and ambiguity as put forward by Sennett (2008).

The resistance and ambiguity that we engage with in this process are not stable, but dynamic. The limitations of both material and machine change and influence one another, and the development of skills influence how the designers might deal with these limitations. For example, as the designers discover new formulas to create material with improved properties that open up new ways of using the machine settings, or as they discover how to hack the machine to access otherwise inaccessible features.

The particular design process described here is part of a larger research effort around 3D printing in wood. Besides design researchers, there are other disciplines and skills involved, that in parallel to our efforts, shape the design space through material and machine respectively.
The material is co-designed by material scientists that explore the development of wood-based polymers to re-use waste products from the wood-pulp and timber industry.The machine is co-designed by the engineers that produce it, possessing and sharing incredible craft skills and knowledge while continuously improving and expanding the 3D printers’ functionality. The design intention, the material and the machine form interweaving strands that shape one another as the designers navigate through design space towards the final artefact.

The Journey

Throughout the journey, to make is to play with resistances offered by machine and material and to decide on ambiguous ways forward towards materialisation of a design intention. The design intention, the machine and the material, create different points of resistances and steer the process into certain directions as capabilities and intentions are obstructed or opened up. On the following pages, different moments within the process are highlighted to illustrate how the design space emerges and changes continuously as the designers navigate through it. We demonstrate the encountered resistances and ambiguities, and present how we addressed them.

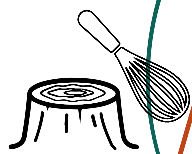


Figure 3-5. Initial Explorations of Work
Initial explorations started with saw dust, as a common waste product of the timber industry. To make the material uniform, sawdust was manually sifted. During this process, the material becomes statically charged, making it difficult to work with (Figure 3). In a series of experiments, the refined saw dust was mixed with different amounts of water, methylcellulose acting as a glue, and bentonite acting as a binder. Resistances encountered here include the large amount of manual labour involved in refining the saw dust. However, despite this, the material remains unpredictable: different sizes of fibers and contimations result in an inconsistent material. The ratio and amounts of sawdust, water, methylcellulose and bentonite, to add to the mixture were ambiguous. Some test prints were acceptable and become very strong when finished, others collapsed under their own weight while printing. Photos: Martina Bambi and Ronald Helgers

Figure 6. Preparing & Mixing Material
Material scientists involved in the project suggested a way to deal with the resistance presented by the inconsistency and laborious process of refined saw dust as a base material. A lesser known side stream material, wood flour, was suggested. It is commercially available in specific and precise particle sizes. The consistency of this material allowed for a more systematic exploration of component ratios in the mixture. Ambiguity comes into play here, as the designers developed tacit skills in material preparation: “You can already feel how the material will come out of the printer when mixing the material”. The process of creating the material mixture did not involve careful measurement or components, moist levels or density. Rather, the designers trusted their senses and previous experiences to play with the ambiguity and reach a desired consistency: “With mixing, we tried to get as much air out of the mixture as possible, since mixing it a certain way, air bubbles tend to appear during the printing”.
Photo: Ronald Helgers

Figure 7. Developing Skill in Printing
With a fairly consistent and functional material in place, the development of skills in using the 3D printer becomes necessary. Ambiguity appears as designers explore what shapes, forms and constructions the material affords in printing. For example, in trying out different types of sizes, overhangs, hollows and other form features are possible. In such explorations, new resistances start to present themselves. For example, attempts to print artefacts over 30cm high proved difficult, as the bottom layers of the material do not dry fast enough to support the weight of later layers and prints collapse. Or, difficulties in controlling the material at the moment of extrusion make it impossible to produce sharp corners.
Photo: Ronald Helgers

Figure 8. Babylonic Resistance
One particularly stubborn difficulty that emerged throughout explorations, was the amount of water necessary for a fluid mixture that could be printed. Water decreases the strength of the artefact during printing while also increasing its weight. The designers called upon material scientists to refine the material properties and in particular to reduce the amount of water necessary. An interesting resistance emerges here, based on language. Where the material scientists expected clear and concrete factual information about the material, such as rheological properties, the designers offered reflections on intuitive actions that lead to ambiguous results.

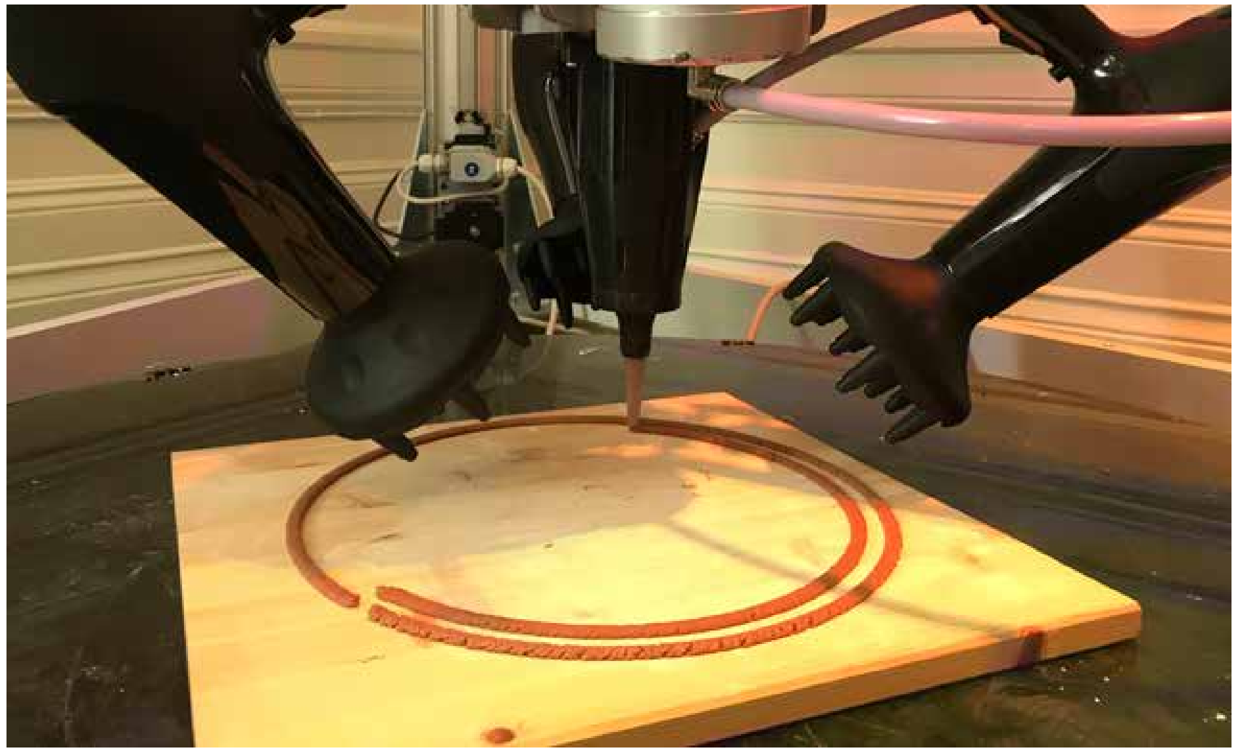
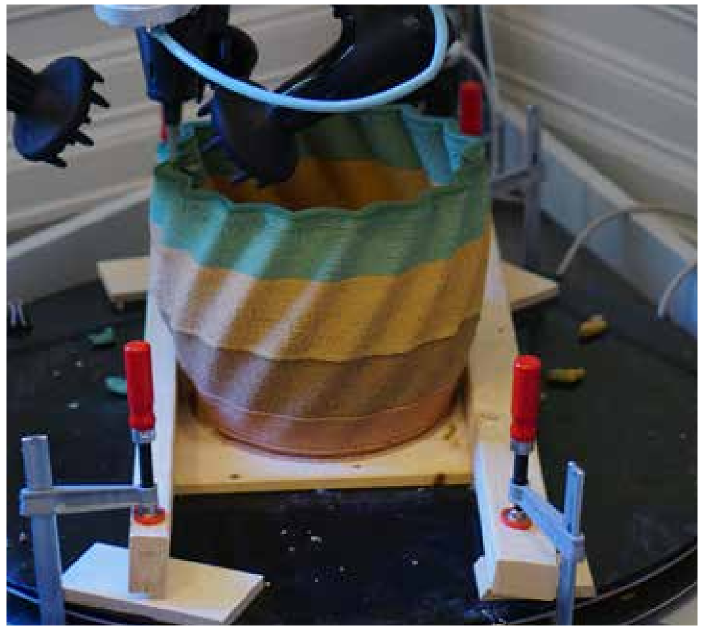
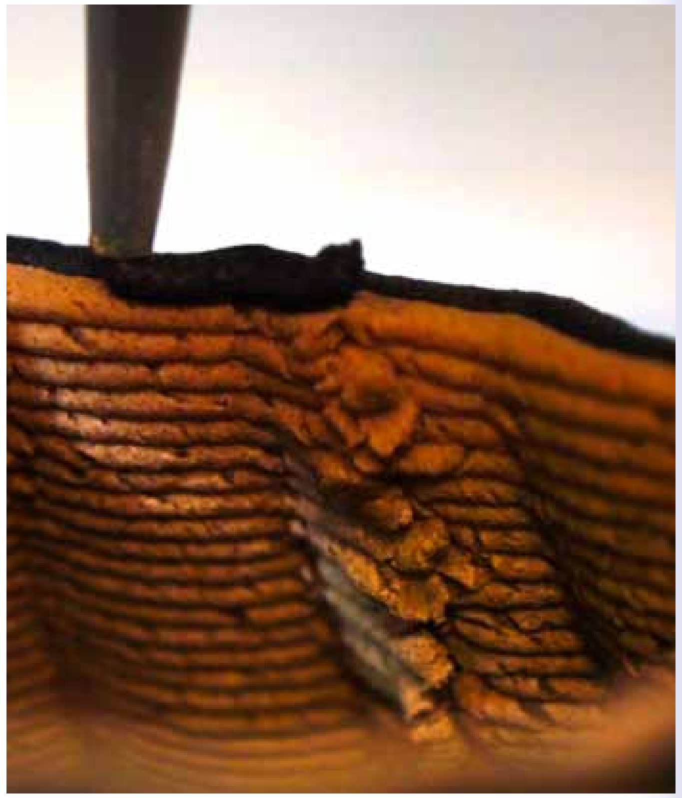


Figure 8. Babylonic Resistance
One resistance encountered as a result of the amount of water necessary, was the weakness of material before drying. Systematic experiments with different ratios were not able to produce a reliable way forward. Instead, the designers explored a way around this resistance. The addition of hair dryers to the printing head proved to facilitate drying during the printing process, as the strength of printed layers was enhanced while new ones were were added. Navigating this resistance required ambiguous actions of tuning temperature and airflow in tune with the machine’s existing printing parameters such as movement speed and material flow.
Photo: Ronald Helgers



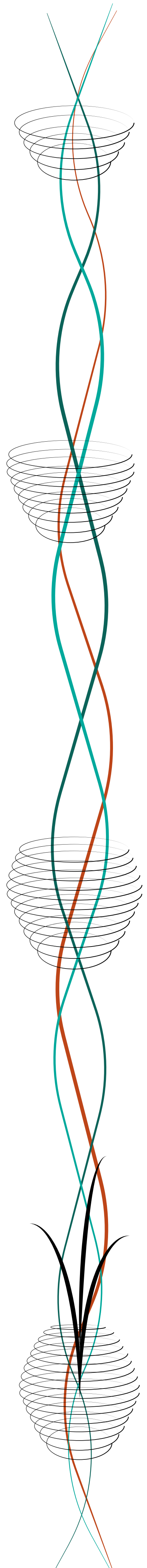
Figures 10-11. Adjustments During Printing. While printing a large scale object, different resistances emerged that required rapid reflection and action from the designers. An example of a resistance encountered here was the warping of the wooden print surface as it absorbed moisture from the print material. The artefact’s circular footprint started to become oval shaped. To overcome this resistance, the designers clamped down the base place manipulated the printed object while printing: pulling the object back into its intended shape as the printer head passed over it to deposit additional layers. Another example of a resistance encountered during large scale printing emerged in the form of increasing inconsistencies in the material. Longer printing times results in parts of the material drying out as it sits in the cylinder before being printed. The state of material within the cylinder is hidden, and thus continuous manual adjustment of pressure and flow rates were necessary to influence extrusion of decreasingly fluid material. These ambiguous actions had to be continuously and directly refined based on sensed results. These actions also created a new resistance: as a side result of increasing pressure, small amounts of material creep out of seems on the motor housing at the top of the extruder. This resulted in small amounts of material falling onto the printing surface and artefact in the making, requiring the designers to be present and remove this material to prevent it becoming solidified within the artefact.
Photos: Ronald Helgers

Figure 12. Random Layer Start and End
The printer prints separate layers on top of each other in order to create the walls of the vase. The starting and end points of each layer is the point where the nozzle of the printer moves one layer up to start a new layer. Throughout the print, a weak spot appeared due to the fact that the start and ending points were at the same spot on every layer: the material at these particular points started to fall inwards. A resistance emerged here: the designers did not have complete control over how the software determined the start and end points of the layers. “A way to overcome this in the future is to try to set the starting and end points of the layers within the software that was used to create the 3D model of the vase into a model that the printers understand: a complete interlocked shape in which the layers are not build on top of each other as separate layers, but are intertwined”.



Figures 13-15. Adding Colouring
The colours of the print were not set beforehand. The designers experimented with different pigments to understand the right concentration of pigment within the mixture to create distinguishable colours. They played with the ambiguity of ratios, while dealing with the resistance of time: each batch needed to be made and finished before the material in the machine ran out. Experimenting with the colours presented a new resistance: the way material is pushed from the cylinder out the nozzle of the printer. When inserting different layers of material with different colours into one cylinder, the designers assumed that the different colours would be extruded one by one, from bottom to top in the cylinder. However, the extruded material showed a mix of all the different colours loaded into the cylinder. From this, the designers understood that the pressure within the cylinder had an effect on not just the material closest to the nozzle, but pushed all the layers in a cone like shape out of the cylinder, further developing the skills and understanding of the designer around the machine. Photos: Ronald Helgers

Figures 16-17. Batches of Material
The large size print meant that the cylinder had to be refilled with new material seven times throughout the process, and printing could only be stopped for short periods of time. This presented a new resistance: there was no way for the designers to see how much material was left in the cylinder while printing. In response, they developed an ambiguous skill: learning to hear the amount of material left and stop a print in time, by knocking on the side of the cylinder. Before developing this skill and develop this trust in their senses, the designers indicated to be quite anxious about the process, since stopping the print too late would result in layers without enough density to provide the necessary strength. One way the designers navigated this resistance, was the discovery of a hidden functionality within the printer to manually set a start point on a specific height. “This realisation was a big step in reaching the end result. We felt more confident about the process, because wasn’t crucial that it had to go right the first time. We gained control, since we could jump to the printing of a specific layer. We were able to take more risk and we became more daring to try out new things. This made it easier to discover functionalities of the printer and improve the material outcome of the print”. Figure 14 shows how two batches of material towards the end of the print could be connected virtually seamlessly with the newly developed skill. Figure 15 shows careful adjustments of a the adherence of a new batch to the already printed artefact. Photos: Ronald Helgers



Reflections

In this paper, a design project was presented, which unpacks the making process through the lens of resistance and ambiguity. These two notions have been proposed by Sennett in the Craftsman (2008), who offers a thorough and compelling account of how such notions can support the description and understanding of a making process as well as the acquisition of a skill over time. This triggered our interested within the context of a digital fabrication operation: we found that in a process that could typically be considered to be highly automated, elements of craft started to emerge. There was a necessity of continuous physical involvement of the designer throughout the course of printing, who needed to develop material knowledge and tacit skills in order to shape the outcome in a desired way. As design researchers, we set out to do an 'exercise' and see how ambiguity and resistance took form in this particular digital fabrication process, to shed light on the qualities that emerged in this process of making.

As a result of this detailed reflection, new parts of the design space, emerging in the tension between machine, material and design intention, were articulated. All resistances appear as a result of the tension between intension and skills of the designer, capabilities of the machine and possibilities of the material. The skills of the designer appear in the ambiguous decisions in navigating and synthesising this tension, up until the formation of a point in the design space: The Printed Futures Vase.

In future work, we will continue to explore 3D printing using wood-based materials. This, with an increased awareness of what factors and forces are at play, and in which the development of tacit skills of the designers involved have been articulated more explicitly. Our aim is to contribute further artefacts that establish points in this design space of printing in wood-based materials, in order to further understand our own making processes and develop our competence in this new area of additive manufacturing.

Acknowledgements

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Figure 18. Finished Artefact: the Printed Futures Vase
The final artefact is a vase that measures roughly 65cm high with a footprint diameter of 45cm. It is 100% biodegradable and is estimated to consist of 85% wood after air curing. The vase is one of the largest objects 3D printed objects in wood.The finished artefact still presents resistances that point directions forward for further development. For example, the cured material is hydroscopic and absorbs moisture from the air around it. This causes it to change shape as it becomes heavier or lighter. As a result, some outer layers of the vase wall detached as inside layers lean down (see Figure 1). Another resistance is formed by its biodegradable character: if the material does not become dry enough, it can start to mould. The designers are currently exploring ways to navigate this resistance. This could be to seal or finish the finished prints to protect them, or to find a way to control moulding for ambiguous results.

Figure 19
The struggle with resistances and ambiguities does not end with the finished artefact. Sharing the vase at an international conference on additive manufacturing, allowed the designers to discuss resistances and the skills to navigate them with others. For example, the cracking of layers as discussed in the caption of Figure 18. This resistance also presents itself to those printing with porcelain using the same machine. Their solution has been to develop a layering pattern that interweaves and in its physical form, allows for minimum and consistent shrinkage. Such shared reflections amongst a community of designers and makers form input for future iterations.

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