Chapter 15
Towards Digital Craft

Paul Loh

Introduction

With rapid developments in computational software and increased accessibility of computer numerical control (CNC) tools such as the CNC router, 3D-printer, laser cutter and robotic manipulator arm, the making process is increasingly aided by digital technology, often referred to as digital fabrication. When digital fabrication comes to be in the mix with architecture, design and craft, scholars and practitioners describe the artefact that is created as a form of digital craft (Kolarevic, 2008; Marble, 2010; Self & Walker, 2011; Ponce de Leon, 2011; Harris, 2012). But what defines the craft in computational design and digital fabrication? The term 'digital craft' implies a relationship between craft and digital fabrication. It also indicates an intimate connection between the material and its production, as well as the tooling and making techniques. Several authors claim these to be the critical ingredients in contemporary design processes (Marble, 2010; Kolarevic, 2008; Kolarevic, 2003).

In this chapter, I shall anchor my discussion on digital craft around two theoretical frameworks. The first is David Pye's notion of workmanship, and the second is Lambros Malafouris's theory of material engagement. Here, craft is explored as a form of tacit knowledge that is practised. An essential component of the knowledge used in the making process is often categorised as tacit (rather than explicit) knowledge, which can be difficult to capture (Frayling, 2011; McCullough, 1997; Sennett, 2009). Glenn Adamson (2007) describes craft as only existing in motion and emerging. When it comes to the 'digital', however, the information as explicit knowledge is often declared at the start. Daintith and Wright (2008) define digital as 'operating by, responding to, or otherwise concerned with the use of digits (as discrete units) to represent arithmetic numbers'. While design information in architecture,

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design and craft can be discretised and expressed as numeric data, the physical matter remains in the realm of the continua. As Peter Downton (2003) suggests, 'the domain of the analogue is continua; the digital is the area of the discrete'. Here, I highlight the contradiction in the term 'digital craft'. Namely, 'digital' refers to the discretisation of information, and craft (of the material artefact) refers to the continuum of action. In order for craft to be discussed as digital craft, the hypothesis here is that both tacit and explicit knowledge must co-exist during the making process, and there are specific dialogues and negotiations that happen between these pieces of knowledge.

I propose two strategies for negotiating the digital and the tacit, each accompanied by a case study: a robotically carved table, and a CNC-milled reception desk. The case studies reveal how the marking of the tool and the integration of tacit knowledge in a digital workflow enables the makers to embed the digital in the making process. However, these layering and superimposition techniques are only the beginning of digital craft. Through a third project titled 'Mapping the Stack: self-portrait of the internet', I shall discuss how, in the future, machine learning can begin to emulate particular craft techniques to create new and unique artefacts. Here, we are confronted by the uncomfortable scenario where automation begins to challenge the authenticity of craft (Kettley, 2016; Fuchs et al., 2015). Here, the authenticity of craft refers to the authorship of making (Loh et al., 2016b, pp. 201–202). Malcolm McCullough (1997) suggests that the authenticity of an object lies in the process of the making activity, which includes the intellectual property surrounding the object. Kettley (2016, p. 168) suggests that authenticity in craft lies in the thinking and 'the maker as a skilled connoisseur of technique, a master of material'.

This chapter concludes by reflecting on how these strategies set up a framework in which digital technologies can cast a more critical lens on the nature of making in contemporary craft practice.

Theoretical Background

McCullough (1997, p. 24) first identified the term 'digital craft', drawing a parallel between the practice of using a computer and traditional craftsmanship. McCullough uses the term to describe the tacit skill in using the hand and mind to manipulate digital data and information on the computer. He also draws a similarity between computation design and craftsmanship, comparing the use of prototypes and grammars in computational design to pattern books used by traditional artisans. He asks, 'if the tightening loop between design and fabrication does indeed give people a renewed sense of workable material, responsive process, and mastery over form-giving enterprise, then is that a renewed form of craft?'(McCullough, 1997, p. 189).

Unfortunately, the reading of digital craft in architecture is often limited because the word 'craft' is used as an analogy to draw parallels between craft production and digital fabrication techniques. As numerous authors have pointed out, the debate around the level and nature of technology harnessed in craft production is not new

(Adamson, 2007, 2013; Fuchs et al., 2015; McCullough, 1997; Sennett, 2009). However, there remains a gap in the knowledge of what contemporary craft practice can bring to digital fabrication as a discourse or, more precisely, the mechanism that allows digital fabrication projects to be understood as a form of craft.

To extend McCullough's argument of digital craft, we must consider two other theoretical positions of making. The first is David Pye's concept of 'the workmanship of risk', which is used extensively in current architectural and design discourse to qualify digital fabrication as craft production (Kolarevic, 2008; Marble, 2010; McCullough, 1997; Self & Walker, 2011). In his seminal book, *The Nature and Art of Workmanship*, Pye suggests that high risk in the *making* can yield positive design opportunities. In other words, through taking risks in working with the material, tools and techniques, the craft can be pushed to its limit, and new knowledge can be generated (Charny, 2012, pp. 36–37). One can argue that the contradiction in making with CNC tools is precisely that almost all outcomes are predefined in the digital model, and therefore, the act of making is inherently low risk. How can making with digital techniques negotiate this contradiction?

The second theoretical position to consider is Lambros Malafouris's (2016) theory of material engagement, which is useful in analysing the causality and effect of making. Based on actor-network theory and in the field of archaeology, Malafouris positions making as an active knowledge-seeking activity. Here, he proposes that both the materials, the tools and the makers have agency in the production of the artefacts. Malafouris's theoretical framework considers the tools (both digital and manual) as part of the agency of making and is useful for our discussion on digital craft.

Pye's Notion of Workmanship

I have previously re-examined Pye's concept of workmanship in my other writing (Loh, 2019; Loh et al., 2016a, 2016b, 2016c). Here, I will highlight a few critical arguments that are useful for our discussion. The fundamental reason for many authors to align digital fabrication with Pye's writing is because he was a craft practitioner. Unlike other authors who had written on the topic of craft in the twentieth century, Pye's writings reflect his practice. Hence, the semantics of craft was absent from his writing. Instead, he chose to focus on understanding the making process and its relation to design intention.

Pye (1995) proposed the idea that craft is about workmanship and technique. Within workmanship (be it good, bad, rough or precise) lies an intimate relationship between the design intention of the designer and the execution of the work. To make an accurate judgement of workmanship is to understand how closely the design is aligned with the executed object. Here, Pye described a 'sliding scale' relationship; for example, good workmanship is where the physical object is aligned with the design, and bad workmanship is where the executed object is far removed from the design intention (Loh et al., 2016a, 2016b, 2016c). This sliding scale model is relevant, as it allows us to evaluate workmanship in relation to design intention.

Pye is known for his articulation of the terms ‘workmanship of risk’ and ‘workmanship of certainty’. While they are set up as a dichotomy, Pye’s writing suggests that it is intended as another sliding scale model. In his critique of mass production, he emphasises the lack of risk in workmanship. Similarly, he recognises that at various stages of work, there are different levels of risk. For example, in a mass production scenario (from a product design point of view), there are high levels of risk at the preparatory stage in terms of tooling, e.g. preparation of tools mould. Once the procedure is refined through an appropriate tooling process and establishment of control over the material (using mould or jig), the level of risk is typically reduced. This coincides with the economic requirements of mass-produced artefacts: lower cost, repeatability and controllable production. According to Pye, most craft practice leans towards the risky end of the spectrum with a certain level of control and dexterity in the process.

Material Engagement

Lambros Malafouris provides another reading of making as a knowledge-generating activity. He approaches making from an archaeologist’s point of view, and his argument is primarily based on observation of artefacts; in other words, working backwards to understand the nature of what it means to engage with the physical material. I have highlighted two critical arguments below that are relevant to our discussion.

First, Malafouris (2016, p. 118) points out that ‘material signs do not represent; they enact. They do not stand for reality; they bring forth reality’. For example, a speed bump on the road is not just a sign for cars to slow down. The very physical reality—that is, the height and shape of the speed bump—conditions the deceleration of any moving vehicle. Any driver ignoring the material sign will feel the impact of the consequence. The intention behind the speed bump is outlined in its shape, material and location; that is, the material form speaks of its design intention.

Secondly, Malafouris argues that as the material form has intent, it also has agency; a quality that is not only limited to human activity but can be satisfied by a material in-so-far as the material (tools and technology included) can become an extension of the person. He highlights the role of the material agent through the making of an axe head, using the knapping technique on flint. The act of knapping, he argues, is an exercise of multiple agents at work; for example, the hand of the maker, the knapping stone, and the stone being knapped. Each subsequent strike of the flint determines the angle of the next strike. He suggests the making of the axe head is not the traditional notion of a preconceived image of the axe head within the flint, but rather an iterative negotiation of materials. He states, ‘There are no fixed agentive roles in this process; instead there is a constant struggle towards a “maximum grip”’ (Malafouris, 2016, p. 176).

The words 'agent' and 'agentive' should be differentiated to make the argument more precise. An agent is defined as 'any element which … makes other elements dependent upon itself and translates their will into a language of its own' (Malafouris, 2016, p. 286). Agency or agentive capacity is the capacity of an agent to act or to deliver information and knowledge. As Nafus and Beckwith (2016) observe, 'knowledge comes not just in the planning, but in the doing'. Referring back to knapping an axe head, the agents include the hand and mind of the maker, as well as the knapped stone and the stone being knapped. The agency is the know-how of the activity action through the knapping technique. The various agents deliver specific pieces of knowledge or information that facilitates the process.

As the maker actively engages with the material to produce the form through the act of making, the process of making is an enacted embodied engagement. Malafouris suggests the form of an intended object is not external but learned and sustained as an idea and developed through the making process as an explicit 'sense of agency' of the maker. That is, the making process contains the intentionality of the maker expressed through the agency of tools, and material is shaped in the process of the activity. He posits, 'intention no longer comes before action, but it is in the action'(Malafouris, 2016, p. 140).

Digital Craft: Case Study Projects

Both theoretical frameworks discussed above propose dialogue within the making activities, from the interaction of tools to the sensorimotor of the maker's body. The interaction or exchange of agency is critical. Here, I suggest that the digital can intervene and formulate a new relationship as digital craft.

From my design practice experience and over 10 years of teaching on digital fabrication in architecture school, I observe several strategies that one can deploy to enhance the exchange of agency between the digital and the tacit. I will explore two of these strategies in detail through case study projects; both developed through my design practice LLDS/Power to Make.

Lily Table: Re-Imaging Tooling

The Lily table utilised machine tooling as drivers for the design. The table, composed of 39 layers of plywood laminated together, is CNC-milled with a robotic arm (see Fig. 15.1). The conventional method is to digitally model the surface and use the CNC software to achieve the smooth surface as a representation of the digital model. In this project, we want to challenge this convention and explore the potential of the tooling, in particular, the cutting shape and how it may affect the outcome.

We experimented with several router bits with differently shaped profiles. Each profile delivered different effect, and some tooling was not appropriate to use as it

Fig. 15.1 Robotic milling of the Lily table using the Core Box tool bit. *Credit* Photography by LLDS

either gouged the surface (a local over cutting of material) or could not reach the full depth of the complex surface. For the Lily table, we used the Core Box tool bit as it produces a fluted pattern across the surface. To CNC-mill the table, the complex shape of the table is divided into a series of lines using a parametric software that allows us to manipulate and determine the path of the tool, commonly known as toolpath. The toolpaths converge in areas where the surface has extreme curvature, resulting in areas of smoothness towards the base of the table and a more pronounced fluted profile when the toolpaths fan outward (see Fig. 15.2).

Strategy: Tooling and the Digital

Pye discusses how the markings of the tools in an artefact can demonstrate a level of craftmanship in making. In his writing, he relates the marking of tools on an artefact as a demonstration of 'free and rough' workmanship. He attributes this effect as 'the workmanship of risk' (Pye, 1995, pp. 42–44). Other authors following Pye's observation have proposed that the higher the level of risk, the closer the object is to being craft (Kolarevic, 2008; Marble, 2010). Tool markings left on a material's surface are often seen to authenticate the craft of an object.

When we consider the Lily table against Pye's notion of craft, one could argue that the Lily table conforms to the authentic nature of craft. The intricacy of the surface texture produced by the robotic milling process is highly varied with hardly any repetition. It resembles the work of a skilled craftsperson carving timber with a chisel over several weeks, and yet in reality, the outcome is the result of 16 h of robotic milling (see Figs. 15.3 and 15.4).

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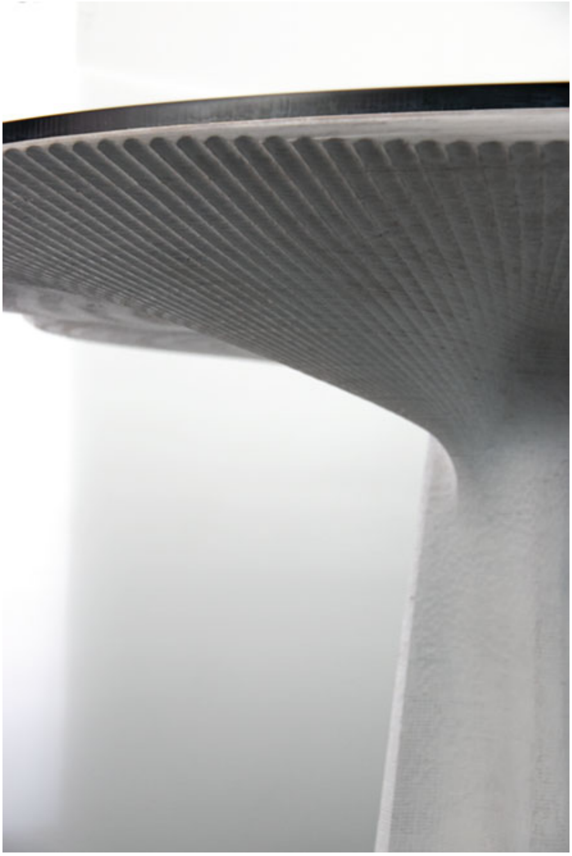

Fig. 15.2 Lily table showing variation of texture across the surface. *Credit* Photography by LLDS

When we analyse the computational strategy of using the tooling to create the artefacts, the integration of tacit knowledge of the tool and the digital information of the design as a set of toolpaths demonstrates a renewed understanding of making. Here, I suggest that risk of workmanship that Pye stipulated is inherent in the strategy in-so-far as the material outcome is not a predetermined surface but a predictable set of aesthetics with intentionality.

While the Lily table is a custom object, technically, we can reproduce it on demand. How do we consider the one-off or limited nature of craft objects against the reproducible nature of a piece of digital craft? The Lily table is associated with a parametric model, in which the width, height and several other parameters can be adjusted. With each iteration, the outcome in both the final geometry and surface patternation is different. Here, I suggest that digital craft provides another means of evaluating craft as limited edition or one-off artefacts. Instead, digital craft objects should be seen as a continuous set of material production within the repertoire of the maker (Loh, 2019; Loh et al., 2016a, 2016b, 2016c). This mode of working can also be observed in contemporary craft practice such as the ceramic work of Gwyn Hanssen Pigott,

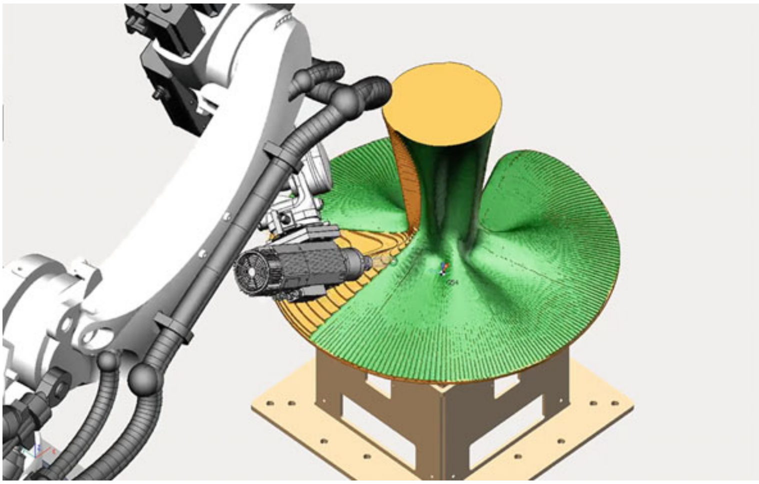

Fig. 15.3 Simulation of robotic milling demonstrating a predictable set of aesthetics with intentionality. *Credit* Image by LLDS

Fig. 15.4 The Lily table. *Credit* Image by LLDS

which is a significant example (Loh, 2019, p. 307). The computational model that structured the Lily table could be argued to be a piece of physical evidence that captured such a repertoire.

GPT Concierge Desk: Procedural Approach to Making

The GPT concierge desk is an architectural scale piece of furniture developed in collaboration with BVN Architects. The design is composed of 1,600 unique pieces of CNC-milled 18 mm thick plywood to form a seamless undulated surface that in part becomes seating and, in some areas, raised to form a desk and ceiling (see Fig. 15.5). The project developed what we called a smart-assembly procedure which was successfully applied to several projects by LLDS/Power to Make (Loh et al., 2016c). The procedure overlays the fabrication and assembly process as part of the digital fabrication process (refer to the workflow diagram in Fig. 15.6). In other words, it tries to systematically translate complicated tacit procedure of the assembly process into a defined rule set or algorithms. On a practical level, the integrated workflow makes the assembly of what is otherwise a complicated task feasible and reasonably easy to build. More importantly, the workflow imparts a methodology for the integration of tacit knowledge into the digital medium.

The complexity of the concierge desk lies in the assembly sequence of the parts. The structure is further complicated by the fact that the entire form is hung from

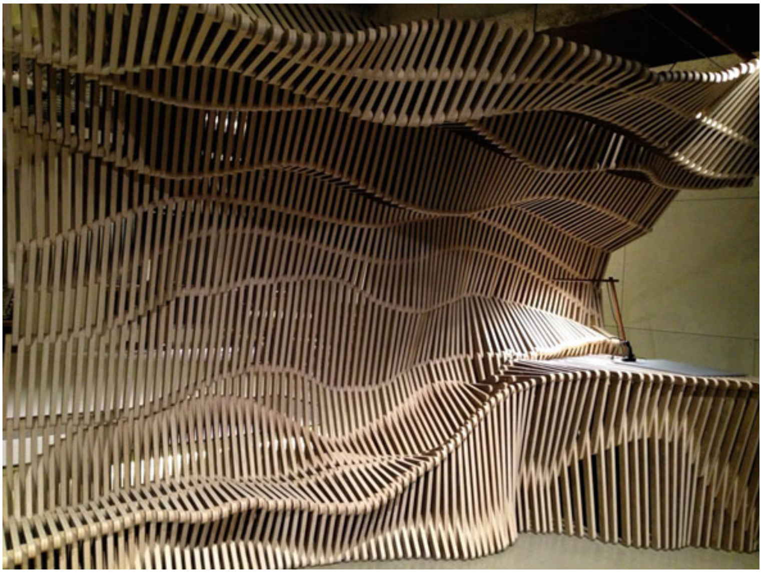

Fig. 15.5 Concierge desk for GPT group. *Credit* Photography by LLDS

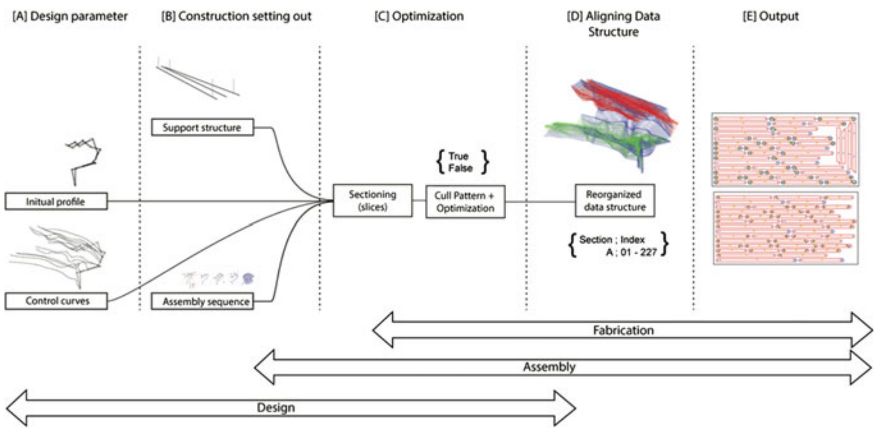

Fig. 15.6 Digital workflow for the Concierge desk from design to fabrication. *Credit* Image by LLDS

the ceiling with two metal struts, and alternating parts are omitted to create a visual pattern across the surface. The assembly needs to be robust, and each component is fixed at a minimum of two positions to triangulate the structure. The entire structure is sectioned vertically; 228 section in total (see Fig. 15.7). The assembly procedure in Fig. 15.8 demonstrates the complexity in the hit-and-miss sequence to achieve the visual pattern across the surface. To avoid misalignment of parts, each horizontal segment of the structure is also indexed (see Fig. 15.9). The indexing of the sections allows the assembly team to ensure that all the components that belong to the section

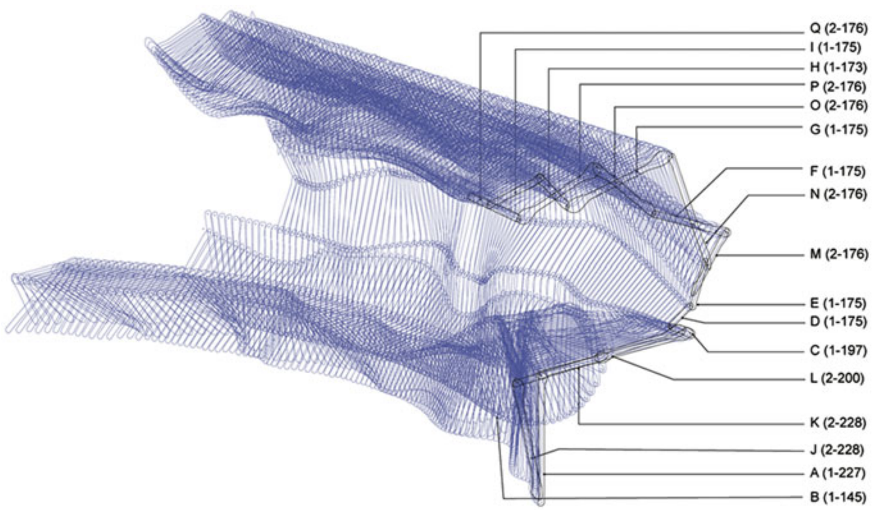

Fig. 15.7 Indexing of Concierge desk for assembly. *Credit* Image by LLDS

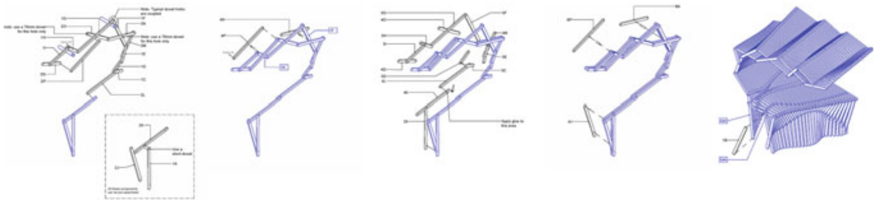

Fig. 15.8 Assembly procedure of Concierge desk. *Credit* Image by LLDS

Fig. 15.9 Joinery detail of Concierge desk. *Credit* Image by LLDS

is grouped together and assembled from ground to the ceiling following the alphabet order of the horizontal segment (from A to Q, in Fig. 15.7). The above strategy is developed through several prototypes. Lessons learned from the prototypes are used to inform the strategy and shaped the digital workflow.

Strategy: Assembly and Workflow

Malafouris suggests the form of an intended object is not external but learned as an idea. The design developed through the making process is a clear sense of agency of the maker. How can the shaping of a digital workflow (Fig. 15.6) constitute such a learned process?

In the concierge desk project, I suggest that the incremental learning and translation of tacit knowledge from the various prototypes to the digital workflow begin to describe the learning process of the maker. While the form of the design is driven by a set of freeform curves in space, which allows the design team to manipulate at will, the geometry is constrained by the assembly logic described in Sect. 3.2. The explicit sense of agency of LLDS is evident in the setting up of computational script and the digital workflow from design to fabrication and assembly. While the feedback from tool to the sensorimotor of the maker in craft is far more immediate (Malafouris, 2016) than in the digital fabrication procedure discussed in this project, the level of material engagement remains consistent in both processes of making. The latter merely translates and synthesises the tacit information into a digital workflow.

Discussion

The two strategies described above attempt to establish how tacit knowledge can construct a dialogue with digital information. Through designing with tooling and translating making procedure into digital workflow, we begin to understand how craft can be digital.

The implementation of digital technology and tools on the material does not necessarily imply the formation of digital craft. We often witness the wilful manipulation of material using CNC technology. Of course, any geometry is possible given an abundance of resources, but one must ask, has the maker or designer understood the material? Has the digital technique and (most importantly) the digital making process considered the various aspect of workmanship? Lastly, how can this knowledge inform and drive the physical outcome through the computational method? All these questions suggest a feedback process from the making to the design that creates a sense of agency (of the maker) that is bestowed onto the artefact to warrant it as a piece of digital craft—a sense of authenticity.

Challenges of Craft in the Post-Digital Age

In the previous case studies, we observe how the traditional concept of craft is challenged by technology on three levels: the issues of one-off and limited production, the markings of tools as a representation of authenticity, and lastly, the learned and sustained process of making. I have argued that digital process can negotiate these challenges to formulate new territories as digital craft. With recent advancements in technology and the emergence of AI, craft could be further challenged in the future.

What Happens to My Painting?

We recently investigated the use of AI in design. *Mapping the Stack: self-portrait of the internet* was investigated through a design studio at the University of Melbourne coordinated by the author in collaboration with the Architectural Association Visiting School, directed by Mond Qu. Led by Andrea Savard with six Undergraduate and Master-level students from the Melbourne School of Design, the project set out to explore the use of AI to map the vast internet megastructure. The project was conducted over the course of 2 weeks, and was intended as a demonstration of an early phase exploration using AI in design. Frank Burridge, a Master-level student lead the team in coding and setting out the AI workflow. The outcome is a series of digital 'self-portraits' of an internet search auto-generated using an AI script (Fig. 15.10).

The AI script first searched for metadata in the form of 'tags' or keywords associated with images via the Google™ Images search engine. Tapping into Google™ Vision AI, the software identified objects in approximately 2,000 downloaded image samples, which were used to generate a new image based on the machine learning process. The team used DeepAI.org's text2img application program interface (API), to create new images based on the knowledge the software has acquired. The outcome is a set of auto-generated 'paintings' that considers the bias inherent in the search engine and VisionAI. For example, as Burridge observed, when training the software to recognise the objects in an image there is a bias towards human figures, as VisionAI is better at identifying humans than it is with other objects. Hence, the image tends to have a human-like impression, akin to Francis Bacon's paintings (see Fig. 15.11). There are several limitations in this project developed from the constraints of the software API; for example, the image generated cannot be read back to its original search terms. Nevertheless, the project demonstrates the ability and potential to use AI in creating new content; in this case, painting-like images.

Discussion: AI and Digital Craft

I open this chapter boldly with the question: what is the future of craft (concerning technology)? In this section, I would like to reflect on how emerging technology such as AI can begin to disrupt our understanding of craft, and what it means for digital craft in the future. The AI project sets out an uncomfortable precedent. If AI can search and reconstitute new and unique images based on sampling techniques and machine learning process, then can it be applied (in the near future) to craft techniques, such as wheel throwing in ceramics? If this is possible, then what are the implications for craft?

In the Lily table, we observed that multi-axis robotic milling could produce craftsmanship on both the aesthetic and technical level. If craft is a form of learned and

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Item no.: 1Franks-MacBook-Pro:~ frank$ googleimagesdownload -k "accidental megastructure"

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all we got for this search filter!

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Fig. 15.10 AI code for *Mapping the Stack: self-portrait of the internet*. *Credit* Image by Frank Burridge

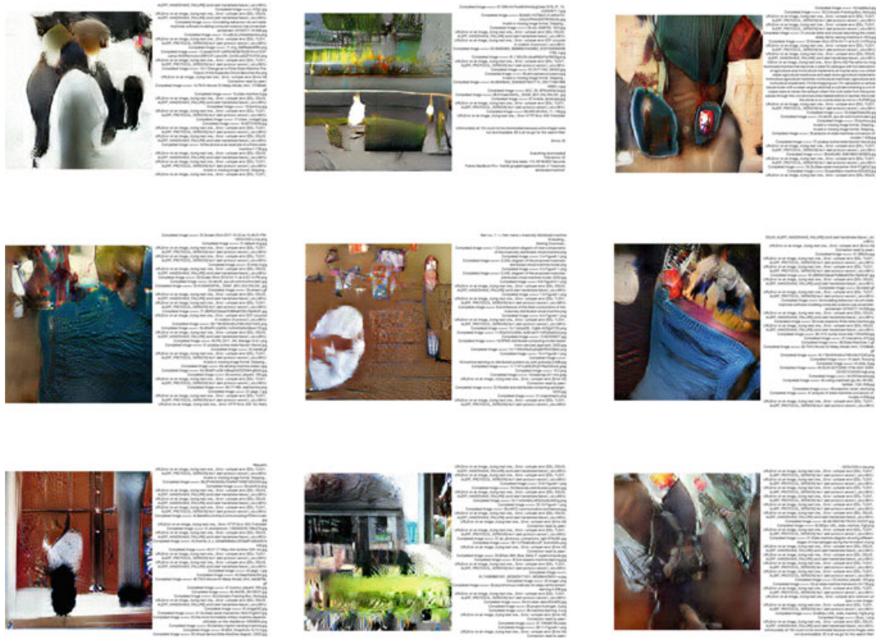

Fig. 15.11 A series of digital 'self-portraits' of an internet search auto-generated using an AI script. *Credit* Images by Frank Burridge, Sophie Gearon, Jiatong Li, Jinru Lyu, Cristina Napoleone and James Oberin

sustained practice, then can such learning also be sustained through AI? This reading fundamentally challenges the authenticity of craft on two levels.

First, the AI project implies the replacement of the cognitive capacity of the maker and (in digital craft) the designer, by machine learning. Once AI can associate techniques with outcomes (whether as images or movement), then the AI can potentially be trained to build on the technique through circular logic (Adamson, 2007, pp. 70–78) and what Adamson (2007, p. 72) called the mental skill or know-how. If one aspect of the authenticity of craft is the learned process of making, then AI has directly challenged the authorship of the maker, and more precisely, his or her workmanship; the application of the technique to making as defined by Pye (1995, p. 51).

Second, the AI project already demonstrated the ability and potential to make new artefacts or self-configure parts, in this case, the organisation of similar pixels that form contents based on the associated metadata of the sample images. While the ability to make tools and useful objects is typically associated with the Homo Faber, the AI project points towards a future of self-organisation through artificial intelligence where machines can make decisions based on learning of a particular pattern or behaviour. Machine making could one day be coupled with machine learning to create novel objects. So, does this mark the end of craft?

Not quite, in my opinion (though future research may prove me wrong), there is one aspect of craft that remains a difficult line for technology and AI to cross; namely, the intent of the maker and designer. Both Pye and Malafouris emphasise the importance of intent during the making process; an essential governing factor in design even if the outcome is emerging. While a machine can learn habits and behaviour patterns to make judgements, it is much harder to learn or establish intentionality through codes without resorting to copying or mimicry. While intent can be studied (Pacherie, 2006), there is complex feedback in the design decision-making process we sometimes call intuition, which often drives the creative process leading to an emerging working method, techniques and sometime re-working based on aesthetics (Loh, 2019; Malafouris, 2016)—a territory that warrants further research.

Conclusion

In this chapter, we examine how we can construct a dialogue between craft and digital technology to create a meaningful relationship that qualifies as digital craft. Two strategies are put forward as a means to translate tacit knowledge into digital codes or algorithm. The first utilised tooling to drive the digital design, and in the process, refined aesthetics emerge from the tooling process. The second aligned assembly knowledge into the digital workflow. It can produce complexity, as observed in traditional craft objects. More importantly, it creates feedback that is learned by the maker to improve his or her craft. The feedback process creates a sense of agency of the maker over the digital procedure. Through case studies, I demonstrated that digital craft could begin to challenge the authenticity of craft in its various form, from the one-off and limited edition to the marking of the tool on a craft object, and lastly, the learned and sustained process of making as a knowledge-generating activity.

Artificial intelligence further challenged the renewed relationship between craft and the digital. Through an AI project, we begin to question the authenticity of contemporary craft, and several uncomfortable questions are raised on the future of craft. I proposed a more radical rethink of where future craft lies with the relentless technological advancement of our society. With the emergence of AI and cognitive-driven technology, it is now more vital than ever that we, as academics and practitioners of craft, begin to reconsider the craft theories of the twentieth century in relation to technology. I call for a renewed understanding of craft as digital craft in the twenty-first century.

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