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Distinctive Output through Hardware Manipulation
Adam Chau

Abstract: With ceramics-focused research, this positioning paper proposes that the role of hand-crafted tools within digital environments can lead to objects that are produced with distinct gesture and break from the conventional digital aesthetic.

Efficiency and perfect tolerances seemingly go in tandem with digital fabrication. CNC machines[1] themselves establish a highly engineered ecosystem that leaves no wasted space; hobby-level machines aside they are a true testament to form-follows-function. The anatomy of these built entities are for the most part fixed, with few areas to be tampered with after various parameters are met to do a serviceable job. The area that can be altered for different tasks or upkeep is the direct point of contact between itself and the object: the hardware[2]. No matter the type of production, CNC machines all utilize specific tools to produce objects. The conventional way to systematically produce particular results is to control the type of hardware being used in parallel with the code that the machine is directed to perform. These pieces are fabricated to an exact dimension[3] to keep in confinement to the program's calculations of movement versus addition/reduction/etc. The focus here is to understand the tool as a crafted object and how injecting traditional craft paradigms would change the understanding of digital production and the resulting aesthetics, scale, and usability of commercial goods that derive from it.

Intense manipulation of input-CAD-CAM to generate more variables, and thus a more unregulated object, can only go so far to accommodate a fabricated piece to look "non-digital" or "unpredictable". This commonly derived approach to individualize production is a red herring due to the repeatability of said manipulation even when input is organic by nature (say, if one were to 3d scan an apple a 3d printer would produce the same nuanced form over and over again). Output in the form of crafted hardware, however, can create a genuinely individual and unique response within a digital environment.

Hand-based crafts already use specific and tailored tools that are distinctive between each individual even within the same discipline. Different potters will prefer different ribs of select size, stiffness, and contour to achieve the same or divergent result. This is due to a number of prepossessions of the maker, whether it is training, hand-size, or any other temperament of the current period. The use of these curated toolsets augment the individual's gesture. To go further, a handmade tool will exacerbate the notion of an individual's intent within creation.

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[1] Machines using Computer Numeric Control including additive, subtractive, and manipulative processes.
[2] For this specific paper, "hardware" is defined as an interchangeable component to be added to a fixed mechanism for fabrication and is synonymous with "tool".
[3] Standard deviation is within 0.02mm from the manufacturer's dimensions

The handmade tool is never seen as industrially perfect; on the contrary it is an object that can be admired for its faults and flaws, creating marks that only it (and ultimately the owner) is capable of. A notable hand-crafted tool that is superior to its machined counterpart is the French rasp; with hand-stitched teeth an irregular pattern is created, which will take off more material than a perfect arrangement. Objects with atypical attributes will perform chaotically – when this is controlled correctly with refined technique it can yield remarkable results.

Within the digi-modern age the term 'hand-crafted' has been used by large corporations to market commercial goods that are singular in characteristics. This is a signifier of public perception that standardization of commodities has reached its limit. Hierarchy places handmade or custom on the top shelf; being the case there is still a distinguished appreciation between the handmade that looks standard and the goods that are perceptively one-of-a-kind. In a global context this is a conundrum as a mass-consumable object naturally refuses to be hand tailored, yet it is what the individual consumer desires.

A machining bit for a CNC milling machine is constructed with precision in mind. The deviation of tolerance can lead to gaps or overhangs onto the part it is removing material from. What if this unwanted situation was desired? What if a tool could accentuate a machined object due to its inconsistent nature? For non-electronic products, the idea that tolerance should be monitored within digital environments is one that can be shifted into a more holistic approach to incorporate the individual. The dynamic between human and machine can be more flexible with a procedure that is reactive and fluid.

Hardware in digital manufacturing is a perfect opportunity to develop a craft mindset. In combination with materials that are malleable for impression, i.e. clay, the possibility for specialized tooling can become the new practice and develop a new aesthetic. Ceramics offers an intriguing outlet to the digital because of its ability to change and move without fear of damaging a machine (or itself) if things go awry. Ironically, compared to other natural materials clay has seemed to be the least applicable material compared to its rigid counterparts[4]. This, albeit, could be due to the number of variables that clay has as its properties rapidly change with humidity, water content, and type of clay - although going full circle this is what craft excels in. The nuances of a specific material gives more opportunity for individual character to the final product.

Two visual projects have been researched that utilize CNC technology with various handcrafted tools for the creation of ceramic objects. Titled *Digital Hardware* and

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[4] CNC milling curriculums within the US do not use clay within their material library. The current method to utilize ceramics is to CNC mill plaster and slipcast into digitally produced molds. Other technologies such as laser cutting/engraving and 3d printing seem underdeveloped comparatively with plastics and metals.

Digital Calligraphy, the experimental series converts a 3-axis CNC milling machine into a system that manipulates and enhances rather than subtracting material[5]. Both projects share the same methodology of holding the hardware accountable for a spontaneous result; yet tackle different conceptual issues of surfacing in either 3d or 2d.

Digital Hardware was initiated by hand crafting metal bits in the likeness of traditional milling bits (long, cylindrical shafts with a blunt or rounded edge), which produced expectedly different results when dragged through a slab of clay at a standard stepover rate[6]. These tools were generic in shape and offered a first glance into how accentuating and exploiting the tool could define the finished. The second iteration of this was the refinement of form as well as an exploration of material properties. Silicone, wood, plastics, et cetera in different forms were examined and tested for surface results when dragged at variable depths over slabs of clay[7]; as hypothesized, a range of results came forth when the programmed toolpath stayed as the constant in the procedure. The clay itself was not removed from the stock material, but displaced and manipulated (conceptually the same as a potter does on a throwing wheel). Although the textures being composed were noticeably contrasted from each other with a standard stepover the need for such parameters dissolved when the toolbit ends became erratic and not confined to the shaft's diameter. Since the individual mark from each custom bit was pronounced the stepover was changed to 150% to showcase the distinctness of the mark (and sequentially produce it on the same object). Later forms of the design experiment graduated into circular slabs to reference ceramic plates – considering the limitations to a 3-axis machine the scope of exploration is constrained to shallow/flat starting points. The need to illustrate the project into the realm of functional ceramic ware was to add to the case of craft production and parallel the 'usefulness' of a handcrafted tool. This idea of symbiotic relationship between tool and object was strengthened when the hardware itself became ceramic. First exhibited in 2013 in Chicago, *Digital Hardware* was presented as research of designed ceramic hardware to be presented alongside sculptural ceramic plates. The role of the tool became the focal point as the object, while the plate became the archive of the performance it had gone through.

Digital Calligraphy explores the two dimensional possibilities with CNC technology. While *Digital Hardware* refined a paradigm of crafting tools, the recorded object was high in profile texture and unusable for domestic function. An aspect that was lacking was graphic illustration, color, or line fluidity; by transferring this crafted technique into a flat space there was more room to utilize common ware to analyze

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[5] This is to clarify the basic foundation of the machine to differentiate it from the basic architecture of a 3d printer or lasercutter.

[6] The hardware's movement from one linear path to another (or level for a 3d printer) should not exceed 50% of the tools diameter.

[7] The spindle head motor was turned off so that the hardware could freely rotate depending on how the clay reacted to it.

outcomes. The role of graphic illustration/decoration has a large role to play in the development and understanding of historic craft objects and was acknowledged through a process which resulted in a two dimensional mark. Hand fabricated brushes made of animal hair were fixed onto a 3d printed ferrule that served as an adapter to the spindle head of the CNC. As with the former tests there were various sizes, types, and lengths of brushes with a fixed toolpath as the constant. Animal hair carries a range of properties depending on the type of animal – some hairs might be fine, pliable, and quick to dry while others are course and retain moisture. The exercise was done on pre-formed ceramic plates not yet glazed. Cobalt carbonate was used to highlight minute discrepancies between the brushstrokes as the carbonate is highly sensitive to deposition thickness. The resulting process of tool crafting to programming was alongside *Digital Hardware*, however it provided a functional recorded object that is marketable within the commercial goods industry.

Currently, *Digital Calligraphy* is still being examined for possibilities to record text. As the constant/variable research has reached its conceptual limit there is still unexplored territory onto *what* the CNC technology is generating. Text, particularly those of pictogram heritage such as Chinese, allows a historical reference to contrast against. Gestural markmaking within text is valued at a level not commonly seen in day-to-day activity in the West. As the results of *Digital Calligraphy* show a tremendous display of graphic impressions it would be worthwhile to explore the reaction to this way of working with text in regards to legibility and evocation from such gestural marks.

Other research in the field of digital craft offers insight into manipulation of software to achieve uncommon results. The use of software is a large component of digital fabrication and necessary to master to understand the capabilities and extent of any particular output process. Trained designers that do not have immediate on-site access to these machines must rely on a full skillset in modeling (and hopefully CAM processing) to hold a stake within the industry. If one were to have access, though, in-depth training of the machine would lead to more developed actions when designing through software. Intimate knowledge of the construction and limits of CNC architecture only reinforces the way a maker would design or craft an object. It would be alongside the idea of how a potter would know how to stack a wood-fueled kiln to achieve particular results from woodash flow while the kiln was firing. The workings of hardware influence the development and process of software.

Additive and subtractive technologies have been developed to a point where hobbyists can understand the fundamental functions of each and respond accordingly, but a process where manipulative technology is required needs to be advanced in order to make appropriate design choices. Grouped with hardware manipulation it is hard to say how the public would understand this practice. Potential opportunities for growth in the goods industry look positive in the mid-scale production range as the hybridized course of action takes from both industrial design and studio craft.

The twenty-first century craftsman needs to understand digital fabrication practices, but not necessarily radicalize their practice. With hardware manipulation there is inherent nuances in the process that is congruent with traditional craft theory. Those who do not value efficiency or precision can still engage with the conversation at large. Industrial craft practices have developed the technology, however the capacity for artistic and creative growth is still in an embryotic stage. As with all new technologies (not necessarily digital) it will take innovation and patience to mature the practice and understand it as a craft. The hardware/tool itself plays an integral role in this and is the bridge between the nexus of art, design, and craft.