Digital Entanglements: Craft, Computation and Collaboration in Fine Art Furniture Production

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ABSTRACT
This paper joins a growing body of CSCW and HCI work exploring questions of creativity and collaboration at the intersection of digital and material practices of craft. Drawing on studio visits and interviews with fine art furniture maker Wendell Castle and his team, we investigate one studio's experience with integrating digital fabrication tools into their studio practice, and its implications for the collective organization of work and creativity. We explore how the introduction of new computational and industrial machine objects (here, Computer Numerical Controllers) remediates traditional relations of craft and the forms of human-object value, care, and creativity built around them. We also chart new forms of creative practice and material flow that emerge from this encounter, and show how remediations of craft in the Castle studio may pose questions and opportunities for wider CSCW concerns around craft, creativity, and design.

Author Keywords
Craft; fine art; studio; digital fabrication; post-digital; computer-aided design; handwork

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INTRODUCTION
…in the Machine lies the only future of art and craft - as I believe, a glorious future; that the machine is, in fact, the metamorphosis of ancient art and craft; that we are at last face to face with the machine - the modern Sphinx-whose riddle the artist must solve if he would that art live…. Frank Lloyd Wright, 1901

The pace of technological creation and its incorporation into everyday life alters the power, shape, and meaning of human practice. Relationships between people, social and natural environments, work and leisure, and how we conceptualize and interact with the material world are being (re)mixed as a result of this encounter. Artists, as sophisticated makers, are often at the forefront of this process. They act as creative and critical users of tools – both computational and otherwise – whose practice has the potential to reveal new insights and understandings about the world in which we live, while also generating new theoretical frameworks that may apply to other contexts of human-computer interaction [3]. Digital fabrication tools such as 3D scanning and printing and Computer Numerical Controlled (CNC) robotics can expand the practice of artists by enlarging artistic repertoires and opening up design to new physical possibilities. New computational tools may also enter into and remix sites of ideation and imagination themselves, (re)imagining concepts and outcomes and redistributing collaborative practices and relations within complex work environments. These processes may at the same time challenge and restructure relationships and values at the interface of technology, design, and creative production.

In this paper we explore the studio practice of American fine art furniture maker Wendell Castle, who for more than forty years has kept his studio precariously balanced on the edges of contemporary technological practice and traditional woodworking techniques. Referred to as "post-digital" [28] by contemporary craft scholars, Castle is internationally regarded as both an innovator and master craftsman whose work bridges the fields of industrial design, fine art furniture production, and sculpture. Castle's studio couples highly complex computational tools (including Computer Numerical Controllers) with traditional woodworking practices in innovative, playful and interdisciplinary ways.

From a CSCW perspective, Castle's studio presents an intriguing case study around the adoption of complex computational tools in collaborative and creative work environments. It brings to the fore larger questions and concerns around the nature of creativity and innovation, and what it means to design, create, and make in an increasingly computational world.

The paper that follows analyzes Castle's evolving studio practice in light of theories of craft, creativity, and materiality drawn from CSCW, HCI, and the social sciences. It seeks answers to three basic questions. How has the integration of complex computational design tools and manufacturing robotics maintained or expanded Castle's

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conceptual and imaginative practices? How have collaborations in the studio been remixed as a result of these new tools (and what does it mean to do craft under such conditions)? And what can this experience teach us about relations of creativity, craft, and collaboration under the shifting conditions of digital production?

BACKGROUND AND LITERATURE REVIEW

The incorporation of mechanical tools meant to replace, augment, or assist human labor and skill have long played a central and contested role in the evolution and meaning of art, craft, and handwork processes. From the English silk weavers of the 1800's who destroyed Jacquard's loom to the birth of artistic genres such as the Arts and Crafts movement, controversies around the use of machines as crafters of artifacts recur throughout history. Englishman William Morris, founder of the Arts and Crafts movement, advocated for a return to the simple beauty of handcrafted, utilitarian objects as a way of staying true to materials and labor. Morris and others of similar mind saw artists transitioning into servants of the machine, and they sought to free both artisan and artifact from the dehumanizing effects of mass-produced, machine made goods [17]. Other artists and craftsmen of the era however welcomed the revolutionary power of the machine as aid and extension to the craft process. In a 1901 speech, architect and designer Frank Lloyd Wright explicitly rejected Morris' concerns, arguing that the machine, once it could be freed from its role as solider of industry, represented the very future of art and craft making. Artists were in the best position to realize this ambition. According to Wright artists, as well as craftspeople, were graced with a type of creativity and openness well suited to *embrace* the machine, not as contested outsider or interlocutor, but as "best friend" and ally to the art making process [26].

The same rough opposition continues to inform values surrounding machines and craft processes today, as new computational tools and infrastructures enter into "traditional" processes of artistic and craft-based production. This question has been taken up by a small but growing body of HCI and CSCW work exploring the dynamics and tensions surrounding the integration of new technological systems and practices into craft and creative design environments. Some of this work has looked towards expanded and "active" concepts of materiality as a mode of analysis for gaining deeper insights into the interplay between objects and humans at the heart of the creative process. The work of Tholander et al [25] for example has sought to reconceptualize materials as agents with unique properties and abilities to constrain or enable design outcomes. Material agency is witnessed and enacted through dialogues that unfold between human and material elements within complex sociomaterial practices. In this way, the agency of materials and objects is seen as *becoming* through human/object negotiation and sociomaterial interaction [25]. In a similar light, Rosner et al [22] find that materials, information, techniques, and human relationships are bound and rebound in a "cross-bred" (or interdisciplinary) network, which blurs and reconciles the ontological "gap" between digital and physical environments. In separate work, Rosner [21] explores the ways in which the active property of materials "unfold through collaborations with people, workspaces, and even each other" – fixing and transforming all parties to the encounter. Jackson and Barbrow [12] find that the introduction of new computational tools into existing partnerships remediates (read: challenges, disrupts, expands, remixes) the complex relationships between human agents, objects, and the wider infrastructures to which they are intimately joined. Dourish and Mazmanian [7] point to similar instances of remediation, arguing that materiality carries both symbolic weight and human value – and that transitions from one material to another can therefore shift experiences of identity at both the individual and community levels.

Recent work has connected these interests in turn to more specific questions of materiality and collaboration in creative work processes. Countering individualistic and human-centered notions of creativity, Jackson and Kang [13] argue instead for an *entangled* notion of creativity and design, built on recognition of how creativity may be embedded, constituted and completed within a world of things. Through such processes, materials (with all their affordances and limitations) and people (with their complex value systems) are intertwined in and through the creative process. It is precisely these forms of entanglement that generate the push and pull that moves creativity forward. Such a view shifts ontological understandings away from those that privilege human actants toward ones that recognize materials as integral to the way we live, act, and create in the world. In sum, "we think and imagine in concert with things, not just through them or about them. Creativity is something we do *in* and *with* the world, not just to it."

These arguments build in turn on a broader body of work around materiality and social life growing in the organizational and social sciences. Orlikowski [18] finds that materiality is integral to organizational life and that developing new ways of dealing with material is critical if one is to understand the multiple, emergent, shifting and interdependent technologies at the heart of contemporary practice. Orlikowski sees humans and technology as bound through acts of 'recursive intertwining' or 'constitutive entanglement' that eschew pre-ordered hierarchies or dualisms. Rather, human actors and technological practices are enmeshed and co-constituted, emerging *together* from entangled networks that are always shifting and co-emerging in time.

Drawing on the design notebooks of painter Paul Klee, social anthropologist Tim Ingold [10, 11] argues that the essence of matter lies in form-taking activity, movements

and variations "swept up in the generative currents of the world" [10:95] that collectively constitute time, history, and forward trajectory. In such a world, the role of the artist is not to make (in its ex nihilo sense), but to follow and to bend, to "…join with and follow the forces and flows of material that bring the form of the work into being" [10:97]. In this way, "artists – as also artisans – are itinerant wayfarers… bringing forth their work as they press on with their own lives" [10:97].

As the materials, tools and practices of creative wayfarers move into abstracted spaces, tensions can surface. Matthew Crawford [6: 24] finds that integrating the computer into craft-based workflows may shift making into a type of algorithmic "rule following" that requires a different sort of cognitive disposition than the embodied manipulations of analog tools. For this reason, hybrid practices that intertwine computation and handwork without an embodied, sensual knowledge can be "technologically correct" but otherwise "disastrous", occupying a contested landscape that challenges the aura of rusticity and traditionalism sometimes attached to craft in the modern imagination [23]. However Malcolm McCullough [16] takes another path. He sees computational tools as 'extending' tools that allow forms and ideas to be materialized in new and concrete ways. [16:81]. Richard Sennet [23] seconds this position, tracing craft's theoretical, material, and social development from ancient weavers to Linux programmers, arguing that 'good craft' can be found in any human undertaking – from carpentry to parenting to software engineering – wherever material engagements are deep and commitments to quality for its own sake are high.

Parallels to these lines of HCI and social science work around materiality and craft – and the anxieties and shifting values that digital production may occasion – can be found in recent scholarship in art theory and history. Craft and design historian Ron Labaco, curator at the Museum of Arts and Design in New York, has mapped areas where fine arts and design intersect with digital tools and processes. In a series of upcoming exhibitions (which includes the work of Wendell Castle described further below), he explores the developing genre within digital art practice referred to as the 'post-digital' [9]. Being post-digital (a term that "sucks but is useful" according to art theorist Florian Cramer [5]) differs from the "digital art" that preceded it. The post-digital emerges from a blended digital practice that does *not* pay undue attention (positive or negative) to the technological means by which it was produced. It marks a period in time when our unquenchable fascination with computational systems and gadgets has become historical [1:1]. For artists and theorists such as Mel Axenburg [1] post-digital art is a humanizing one, restoring balance and the possibility of a more constructive and even-handed aesthetic relationship between creative handwork and digital work. In a post-digital studio, technological tools and methods are just one of the toolsets artists use (or might), without any particular fascination or anxiety either way. It is the digital made ordinary, even boring – until enlivened by the flow and possibilities of a vibrant aesthetic process.

The literatures reviewed above raise important questions and possibilities around the shifting relations between craft, computation and collaboration in the fine arts furniture environment (and other spaces of collaborative creative endeavor). Tholander [25], Rosner [21,22], and Jackson and Kang [13] all point to the formative agencies of materials, and how these may be brought out and revealed through human-object interaction and use. Dourish and Mazmanian [7] and Jackson and Barbrow [12] point to the crucial effects of remediation, and the important ways in which tools and material choices may shift human values and practices, including those central to individual and collective experiences of collaboration. Crawford [6] and McCullough [16], like Morris and Frank Lloyd Wright before them, point to the somewhat ambivalent remediations of craft that new digital tools may produce, with contradictory effects on the nature and understanding of craft itself. Orlikowski [18], Ingold [10,11] and post-digital concepts from the arts [1] suggest a more measured and ontologically neutral account of the forces and changes at play here: recognizing the real and formative effects of digital tools and other material changes on collaborative creative process, without overweighting their contributions.

The sections that follow test and develop these claims against the experience of digital tool adoption in the Wendell Castle studio, a fine arts furniture studio in upstate New York, long at the forefront of the American art furniture movement. Drawing on a series of studio visits, observations, and interviews with Castle and his collaborative team conducted during spring and summer of 2014, we follow the processes by which a new computational intermediary – a Computer-Numerical Controller sourced from the U.S. Postal Service and referred to as "the robot" – was integrated into the collaborative work practices and material flows that collectively constitute the processes of imagination and production that define the Castle studio and its unique creative process and vision. Here we seek answers to three basic questions. How has the integration of complex computational tools such as 'the Robot' maintained or expanded Castle's conceptual and imaginative practices? How has collaborative studio work been remixed as a result of this addition? And what lessons might this story bring to the field of CSCW regarding the nature of creativity, craft, and collaboration under the shifting conditions of digital production?

ACCESSING PRACTICE: FINE ART FURNITURE MAKER WENDELL CASTLE

Our case study of the Castle workshop unfolded during studio visits which were designed to facilitate observation, structured and unstructured interviews (about 8 hours of interviews were recorded, transcribed, and analyzed), and the collection of photographic materials illustrating evolving fine art furniture design as well as tools and methods. We interviewed 4 full time studio employees who gave us permission to use their first names. Due to the public nature of Castle's work we did not attempt to anonymize the research – a fact made clear to our informants prior to and during the research process. Our interviews included conversations with Wendell Castle, who's original design concepts the studio collaboratively executes, Marvin, or Marv, Castle's longtime associate who now acts as the studio's manager and computational programmer and technician, Terry, one of two studio carvers/woodworkers, and Bryon, who with his apprentice, finishes each piece by preparing it's final surface.

Figure 1. Original *Long Night* chair by Wendell Castle

We focused our fieldwork on one area of the studio's ongoing practice, progressing towards completion during our visits. Our line of questioning circulated around the studio's first attempt to fulfill Castle's Paris gallery's request for an edition of 8 identical chairs (which were part of a larger order for 25 pieces). The chair to be multiplied, *Long Night* (*see figure 1*) originated with Castle's 2013 "Leap of Faith" series. This is the first instance in the studio's history where an edition of nearly identical wood furniture pieces has been possible to complete. "*There's no way we could have done that before [the robot)*" says Castle. "*We'd never be able to get the chairs to match*". Our research looks back to tell the story of one studio's history with technological integration over five years' time, and shares how they see that integration affecting their creative and collaborative work. Through observation, we witnessed the collaborative mastery of form, process and material flow grow from early concept drawings, evolving into finished work. Key moments from this process are described further below.

Formal Analysis of Castle's Work

Castle, who is considered the founding father of fine art furniture design, crafts large, playful and intriguing sculptures one is meant to interact with as furniture pieces. They are said to invoke grace, beauty, humor and comfort while unifying form and function, aesthetics and utility. "From the mechanic to the organic, his forms often reference natural or biomorphic shapes that almost seem to grow directly from the gallery floor" [27:1]. The work is said to be both "practical and transcendent" [8]. The literature shows that since the early 1960's, Castle's aim as a maker and creative thinker has not been tied to the materiality, expression or beauty of wood. Instead he is motivated by a desire to "...free wood forms from structural convention…" [2:8].

The data we gathered from conversations with the studio craftsmen as well as the literature surrounding Castle's career, reveal him as a fine art furniture maker whose work neutralizes categorical boundaries between fine art, the decorative arts, industrial design, and craft [24]. His latest series of one-off pieces are darker, more dreamlike and mysterious than earlier pieces, and some work, such as his large-scale installation *A New Environment,* from 2013, incorporate private nooks that the viewer can curl up or escape into. This new work stems in part from Castle's playful and conceptual interest in defying gravity. Pieces from *A New Environment* have been finished in an inky dark stain, simultaneously both severe and entrancing. One feels the invitation to run a hand slowly over the piece's organic contours, and because this work is meant for bodies to interact with, one *is* permitted touch, or even to rest, in the seat. Its easy to imagine spending moments sinking into these dark and edgy yet nurturing pieces, losing one's self in their onyx wishing-well depths. Pieces with nest-like seats are comfortable – and comforting. "*They sit okay*", says Castle, "*I think that's important - so we find a way to make them sit pretty well*" [4].

Introduction to Studio Process

"*In some ways*," Castle says regarding his practice, "*things here are not vastly different from the way they were in the 1960s*" [4]. And, in many ways, Castle's process has remained relatively stable over the decades. Pieces start with a drawing. A form evolves and is sculpted into a small-scale model. Castle commits to the design. Slabs of wood are then cut into cross sections, stacked, clamped, and glued together. The stack is carved with a variety of tools, from chainsaw to grinder, revealing a final form. The surface of the piece is refined and finished and the work is then numbered, signed, and delivered to the collector or gallery.

Yet in 2009, the process that had been relatively stable for nearly 50 years began to evolve as Castle began introducing digital fabrication technologies into the workflow. According to Castle [4], the implementation of

these tools created a disruption to the artisanal woodcraft process not seen since the Industrial Revolution. This technological integration was driven by necessity. Says Castle, "*We absolutely needed to work in a different way. We needed to get an accurate model of these cross sections. If we glued up the pieces accurately, it would greatly reduce carving*" [4]. Today, five years after the first integration of digital design tools, the studio's workflow is tight, complex, and technologically innovative. It is a process continuously reflected upon and redesigned by Castle and studio collaborators. "*Wendell is always interested in and encouraging us to tweak the process, or shape the workflow in the name of efficiency or precision,"* says Bryon, who is responsible for finishing the work. He notes that Castle is not as keen to allow others to influence design however: *"He'll listen to ideas regarding concept, but not too warmly"* [14].

Castle juxtaposes his use of digital fabrication tools with artists such as Joris Laarman, whom Castle believes allows technology to drive his design. For Castle, the work is all about form. "*I don't want this to be about how the work is made, or even what it's made of. I'm not even that interested in wood as a material. I want the work to be about form – and if the technology used to make the object is too apparent, the form starts to get lost…I'm very interested in technology but I just want it to help*."

General Methods and Evolution of Process: 1960-2014

Today's process as reported by Castle, Marv, Terry, and Bryon, and as we witnessed it, generally unfolds as explained below; though there is evidence that the workflow is flexible and varies from piece to piece. Factors such as artist's intent, material constraints, unforeseen limitations, or collaborative suggestions from studio workers all contribute to the modification of the process.

Castle, who draws daily with paper and pencil, conceptualizes form by creating a number of uncomplicated 2D sketches. These sketches are numerous, and can be seen hanging on walls and covering work surfaces throughout the studio. These drawings guide his production of small, but accurately scaled, foam models informing the larger wood piece to come. These hand-sized models are carved from thin planks of urethane foam glued together (a process that mirrors the large-scale wood lamination stage which we discuss further below). The small foam laminates are sent off-site to a woodworker unaffiliated with the Castle workshop who utilizes 3D scanning tools to digitize the model, creating a CAD drawing of the piece. The offsite scanning facility also adds line work to the image, marking the future wood laminate layers. This image is then sent to Marv, who manages the studio's computational practices.

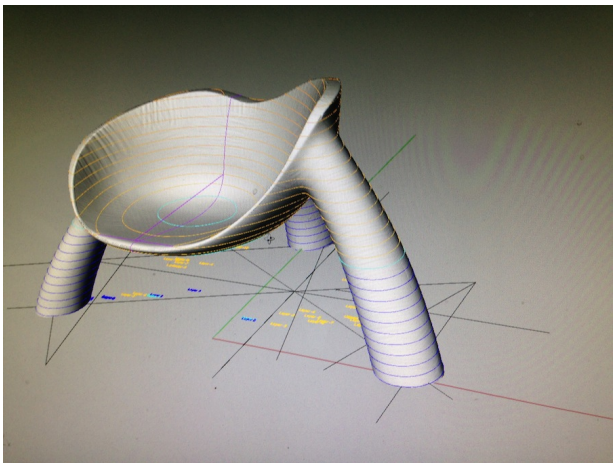

Figure 2. Digital Long Night

We sit with Marv as he reviews the digital file of the chair *(see figure 2)*. He points to the 1 ¼" thick "stacks" or hairlines, shown on the digital image. These cross sections will be individually printed out on paper using the studio's plotter, resulting in large patterns meant to inform both the shape of the wood planks to come, as well as their order within the developing laminate block. The layers that make up the laminate block will be cut from Ash, a hard and scratch-resistant wood. Ash is an appropriate if not extravagant choice for furniture. It is inexpensive, yet often overlooked and, says Castle, "*super common*".

Evolution of Laminates and 3D Scanning: 2009-2014

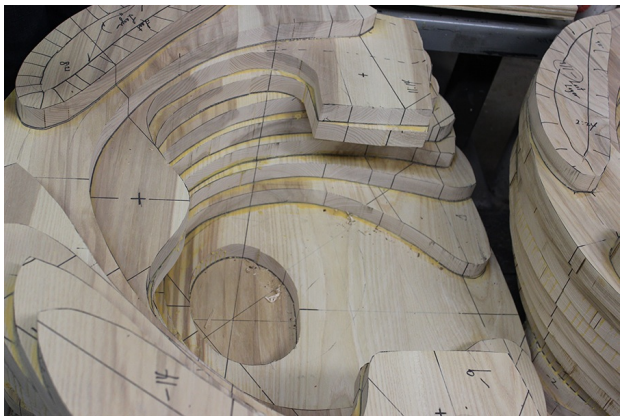

Figure 3. *Long Night* showing laminate layers

Castle references 1960's sculptor Leonard Baskin as the force responsible for introducing him to the stack lamination process. Castle explains, "anybody who ever glued two pieces of wood together, laminated. But what I brought to the table was the idea of large pieces with the cross sections pre-planned, so that you bandsaw out each layer to roughly its right size before you glue it on. That means you can only glue one layer at a time, but then you can see the form developing and you can actually make some small changes. And you can make really big things. You just keep throwing the wood on" *(see figure 3)* [15].

In the days before 3D scanning was the studio norm, sketches of Castle's forms were placed upon an opaque projector and beamed onto the wall. These projections were meant to aid the carver's estimation of stacks. Additional large drawings would also hang for the carver's reference. This process, however innovative in the larger practice of furniture making, was not accurate enough for Castle's needs. Cross sections were informally imagined rather than precisely mapped, and the result was a high potential for error, combined with the probable and costly loss of time and material.

"*What I would do before was just imagine a cross section in a piece, and begin at a point where it was the easiest to imagine, and start there…you can't get terribly complex...it becomes so much work it just gets ridiculous*" says Castle. "*We absolutely needed to get an accurate cross section".*

The 2009 implementation of 3D scanning combined with accurately printed paper patterns "*…improved things",* says Bryon "*…because the large scale mockups…translated Wendell's instructions more clearly. That clear translation allowed him to get much more complex in the design*". In Castle's words, the technology "freed up" the design, while greatly increasing accuracy. Fewer errors were made and less materials, time and energy were lost.

The new digital process came with an unanticipated benefit. Within the digital environment maintained by Marv, Castle is afforded the ability to consider the furniture object in 3D virtual space before large-scale physical shaping begins. He can make slight adjustments (IE raising or lowering a seat while instantly exploring the digital result) by tweaking the files with Marv's help.

Once decided upon, the patterns and laminates are accurately cut, stacked, glued and clamped into place. A chainsaw wielded by carvers Castle, Terry, or Peter becomes the first physical tool used to reveal the final form.

Finding the form – Carver's Technique

A carver's ability to 'find the form' within the rough laminates is a high-level skill often mentioned to us during our interviews. Castle, Marv and Bryon all speak of an innate difference in skill between woodworker and carver. "*Carvers know how to be reductive to reveal the final form, and then know when to stop. They somehow see "it" in their mind*" [4] says Castle. Traditionally trained woodworkers, while familiar with wood's physical opportunities and constraints, may not necessarily 'see' positive and negative space as a sculptor/carver does. They may not have the embodied knowledge needed to understand the delicate boundary between taking away or leaving too much material. While the patterns greatly improve accuracy, the next step of the work demands the skill of a master carver versed in the material properties of wood. (This need for skill, finesse and accuracy has challenged Castle to experiment with non-traditional crafting processes and tools, and as we discuss further below, was a motivation for the implementation of the CNC router).

Finishing the Work

Once the initial carving of the laminate block is completed, it is taken through a series of sanders and grinders that continue to refine and reveal the final form. When this shaping is finished the work is sent to Bryon, who sands or perhaps wire brushes the piece, depending on the predetermined surface. Not including this finishing time, the shaping, carving and refinement of the piece takes the studio 4 or 5 days to complete.

Says Bryon regarding the finish of each piece, "*In our art here at the studio, it's a normal thing to strive for balance. Subtlety is always what we are after. Wendell is really all about the form, the design, not really about the wood. So we don't want to draw too much attention to the wood with the style of finish. But, we still need to leave the evidence of wood. We could make these look like giant plastic works, but we don't*".

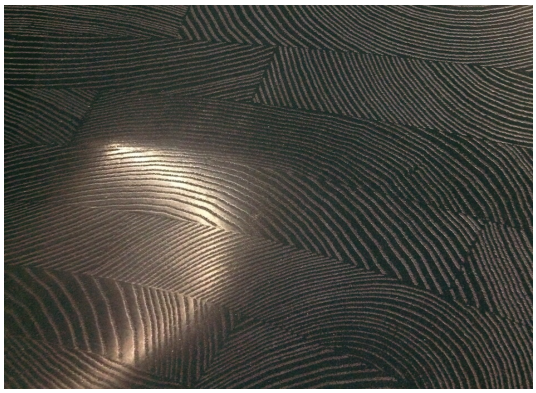

Figure 4. *Long Night* finished surface

According to Bryon, the 8 commissioned chairs we followed went through a "*complex and labor intensive finishing process".* Due to the gallery's request for clearly revealed and deep grain patterns (referred to as the "open" finish - a style popular in the European market) each seat required hand finishing with a wire brush meant to reveal the grain while also opening the wood's pores. After wire brushing, Bryon sanded the surface with a number of paper grains. He applied alternating coats of black lacquer and an oil filler capable of reaching deep into the grain. Finally, he applied layers of an abrasive polish in a satin finish, treating the surface until it achieved its dark, deep, and lustrous aura *(see figure 4)*. The process is especially regimented for these pieces, as there can be no deviation among the edition. Once cured, the finished chairs are signed and stamped and then moved into the studio's waiting area until it is time to package and ship.

The tightly knit teamwork responsible for crafting a Castle piece took another technological leap in 2013 with the integration of the CNC machine, as discussed below.

Implementing the Robotic Carving Arm: 2013

"How the technology comes into this is something I'm very interested in…but I don't think of this as a 'crafting' technology. I think the end product is more important, and if any of these things stand out– like the technology – then it's too much. You may not even think we are using any technology, even though we are. It won't be obvious, the work that the Robot does… in the end no one will know that the robot will do anything"[4] – Wendell Castle.

It was a sense of need, play and adventure (as well as a hunch that it might help with some of the work) that led to Castle's purchase of the studio's latest digital fabrication tool, a computer numerical control (CNC) machine. The industrial orange machine, who's name is evolving through use (The Robot/Mr. Chips) was repurposed by the studio from its pick-and-place past in service of the US mail system. The machine was hacked (or released from it's proprietary purposes) by Marv, who transformed it into a 6-axis carving arm. The robot's new mission in pursuit of art is to mill several feet of laminated wood stack quickly and accurately, using the X and Y reference points that Marv identifies and enters into its RAPID code. Marv, who is tasked with the building, programing, care, and execution of the CNC's process, speaks of this new aspect of his work as "*exciting*" while also expressing other initial emotions such as uneasiness or apprehension.

Figure 5. CNC with Long Night

In 2013 Castle hired Marv, his long-time associate who was at the time working with another studio running its 3-axis CNC machine, to come back and devise a system for running a yet to be purchased 6-axis CNC. As a professional woodworker and carver, Marv understands the properties of wood, and as a mechanical engineer he understands the constraints and possibilities of software designed primarily to be used by the aerospace and automobile industries (where most CNC robots are utilized). His intrinsic knowledge of wood and woodcarving gives him an access point into the process. Marv states that he has the ability to "*…tailor the software driving the CNC to fit the shop's specific needs. Differentials such as feed speeds and types of cutters are all issues here.*" [19].

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MoveL [[-176.961,-171.635,616.684],[0,0,1,0],
MoveL [[-178.541,-168.842,616.788],[0,0,1,0],
MoveL [[-180.554,-165.286,616.674],[0,0,1,0],
MoveL [[-182.567,-161.73,616.386],[0,0,1,0],[
MoveL [[-184.579,-158.174,616.36],[0,0,1,0],[
MoveL [[-186.592,-154.618,616.175],[0,0,1,0],
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MoveL [[-190.91,-146.988,615.88],[0,0,1,0],[-
MoveL [[-192.629,-143.95,615.686],[0,0,1,0],[
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MoveL [[-198.667,-133.282,615.155],[0,0,1,0],
MoveL [[-200.679,-129.726,614.957],[0,0,1,0],
MoveL [[-202.692,-126.17,614.726],[0,0,1,0],[
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Figure 6. *Long Night* in RAPID code

It took Marv over a year to assemble all the CNC add-on parts and locate the translation software that redirected the robot into becoming a milling machine. He describes the current CNC workflow: it begins with a CAD (mac) file delivered to him by the outsourced 3D scanning studio. The file must be translated into a set of CAM (Computer Aided Manufacturing) (windows) M and G codes using Rhinocam. These codes are then translated into RAPID code *(see figure 6)*, the proprietary software language used by the *ABB Robotics* CNC machine. In Marv's estimate, the amount of RAPID code needed to drive the movements of the CNC machine (which is fit with routers of varying size depending on the stage of the carving process), is in the realm of hundreds of thousands of lines. These lines of RAPID code are broken into sections, which are lined up to be run at carving time.

Once the RAPID codes are ready, the laminate block must be placed properly in the "blank" space that surrounds the carving reach of the machine. "*We don't start with an industrial material, and we don't start with an industrial form such as a rectangle or a cylinder. The first thing the RAPID program asks you is, 'What is the blank size?' well, if I just glued up a big cube of wood the machine would know where your blank is, just X, and Y and Z…we don't do that. It would take days for it to cut down to that form and waste an awful lot of wood as well…so the difference between a piece that goes to the robot and a piece that goes to a human carver is that the robot doesn't care…it has no thought. It goes through the motions and does what you tell it to do. To work around this I make a judgment call and make the laminate bigger – maybe an inch here, an inch and a half over here, so that I know it will fall within a range where we need it. The other thing I did was place a laser on the robot and have a program written that allows it to trace the grid work lines we put in the 3D drawing. While the program is running it's just tracing those lines. I then pick those lines on the work piece itself and I move the work piece around on the bed until the X and Y lines of the virtual space and the lines of the actual piece match up. Its an act of faith. You hit that go button and you hold your*

breath and you hope you haven't made a mistake somewhere. I copy and paste the software code and run it again, bringing the carving tool closer and closer to the final form until its maybe 1/32 of an inch away from it… and that is going to give us a surface you can start sanding on.

The CNC in action is "*mesmerizing"* for both he and Castle to watch. But according to Marv, integrating the machine into the studio practice also came with a sense of hesitation and caution. "*This machine can move 2 meters a second. Safety is a huge issue. When I told my brother, who used to work in the automobile industry about the robot, he had real safety concerns for us".*

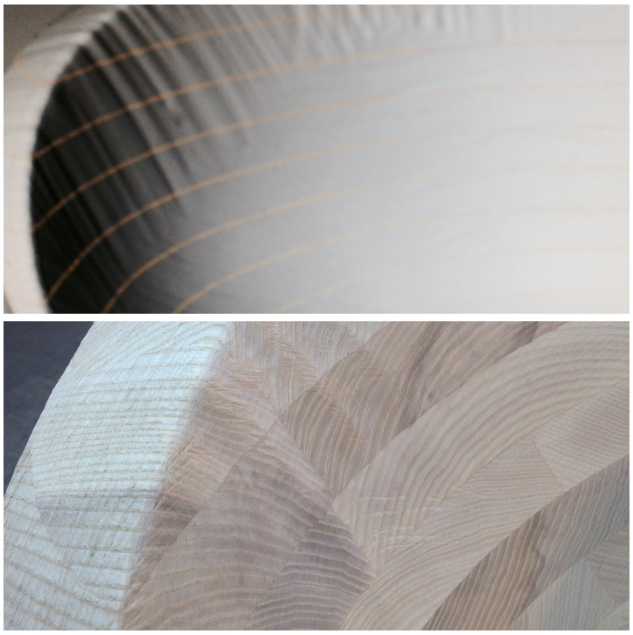

Figure 7. Scanning anomalies replicated in wood

As we completed our initial site visits, the studio had pulled 8 identical chairs off of the machine. Marv was still working with perfecting his process. He shared his current challenge of removing anomalies from the scanning process that were rendered as wavelike artifacts carved into the surface of the wood *(see figure 7)*. Marv points to the virtual image and says, "*See these waves on the surface right here? Well, The Robot carves exactly what you tell it to, and these waves are carved out perfectly*." Marv attributes the waves to the outdated scanning technology used by the offsite firm, but doesn't want to resolve the issue by changing technicians. "*We have a long relationship with them. They are woodworkers too, so we can speak the same language. They know what I mean when I ask them for something, so because of that we'll work around the anomalies".*

After a year of non-recurring manufacturing on the part of Marv - building, hacking, tweaking, writing code, purchasing random parts on ebay, devising a complete workflow and then finally, running the machine to pull off the chairs, Marv remains mostly unromantic about the machine. *"All the robot is doing is executing functions that could otherwise be performed by hand. But there is a degree of repeatability here, that could never be achieved manually*". It was this degree of repeatability that enabled the studio to produce their first edition of wood furniture pieces.

Robot Reorganizes, and Saves the Studio from (some) Grunt Work

All of the workers we spoke with saw the robot as a machine capable of sharing the carver's workload. In fact it seemed to have taken over some of the more tedious parts of the carving job. Says Castle, "*The robot worked for four hours without a break and never got bored! That really helps our carver out a lot"*. Terry, to whom Castle was referring, traditionally spends most of his workday rough carving and then refining the laminate shape. He mirrors Castle's statement. *"The robot helps. When Wendell said he was getting a robot, I expected it to do more complex work. Instead, it does the rough cuts, but very fast. So it saves me a step. It saves me a lot of time actually. It can carve the seat of a chair in a day, and that would have taken me 2 or 3 days. It can do a whole edition at the same time. If I were to do an edition at the same time, that would be boring and, well, I'm not sure I would know the best way to manage that."* [20].

Says Marv, "*It allows us to better use our human labor where most needed. If it were up to Wendell, every piece would be pulled off the carver. But to be cost effective, multiple pieces need to be pulled to make the initial time investment worth it economically. It takes …a bit… of planning…and it's sometimes a challenge to explain that to the boss."*

Bryon estimates that the CNC machine has removed 30 percent of the work from Terry's process. This frees him up to work more efficiently on the refinement of the finished pieces, where his skill and expertise as a carver makes him most suited to be placed. "*It removes the grunt work from Terry and speeds up the process, saving probably weeks of work for the entire series by the end"* Says Bryon.

While the machine can mill the laminates in much less time, it can never address the sensitivities of an organic material the way a human carver can. Marv: "*If you see the wood, a good woodworker can tell you what areas of the wood had a knot. The grain will deviate around that knot. A guy who has a tool can say, 'I have a problem here, I can go this way or this way'… but the machine never can. Natural materials will always represent constraints with the CNC, as it was designed for industrial materials - for steel, or plastic."* Wood must therefore be carefully preselected for the CNC machine. If the CNC were to meet a knot, the laminate could potentially crack or split.

"*At the end of the day, it's the physical properties of the material that drives our process*", says Marv as he describes the way the wood grain of a Castle piece can be read to determine the orientation of the tree's growth within the forest. *I always say, this tree is now dead, but its wood is not - and it's important to know that going into this.*" Bryon understands this in a similar way, "*There's a lot of tension in wood. When you start cutting it up, that tension is released, free to do as it will. And form changes. Things crack, they bend, and warp*" [16].

Bryon reports that his work has not drastically changed since the robot has been implemented as a carver, except that there is now more work to be finished. He isn't quick to attribute this to the robot, finding the increased finishing work more representative to an influx in gallery sales. "*To avoid getting backed up we're training Matt now."*

The Robot and its Conversation with Castle: Expanding Design Vocabulary

As described below, the robot expands design in three important ways: by extending reach, allowing for more complex joinery, and creating hollows in solid form. Besides sharing the workload of the carvers by assuming the rough, boring, strenuous cuts, the carving arm of the CNC machine can reach underneath, around and within the wood block to shape a sculpture in ways a human arm could not due to the limited reach of arm and chainsaw. This expanded reach frees Castle's design from some of the historical constraints of the material. As Castle explains, the CNC robot has allowed him to remediate or "free up the vocabulary" of his design. Castle plans to combine this extended reach with the robot's ability to hollow laminates to go bigger with the work than ever before.

"*We were never able to do anything as complex as this before. Things can be made so much larger now because we can hollow out the form and we can break it down due to the new cuts and joints we can make…and the idea is to get gigantic. We're making a floor lamp for a Paris exhibition that's 9 feet tall…like a big tree."*

Additionally, the mechanical arm allows for seamless, previously impossible joinery to be realized. "*No one will ever know how these pieces are attached*." Says Castle. The improved seam potential allows Castle to conceptualize form in new ways, facilitating his current explorations into crafting sculptural forms that seem to defy gravity.

Despite the opportunities created through Mr. Chip's introduction into the studio, not all of the attention generated has been without caution. While the Paris gallery's request for an edition of *The Long Night* shows its comfort with wood editions of previous one-off collector objects, one unnamed dealer was still deciding how to address the implementation of the robot to the larger craft audience and community of buyers. "*They're not yet completely comfortable discussing the robot*," says Castle. "*They weren't sure if it should be more secretive than not*." Castle is quick to assure that the robot could never overstep its bounds and assume too much of the crafting. He says frankly, "*I don't think it can cross over into my space...but besides, I just want it to be a helper. I don't want it to lead me*."

Five years of technological implementation has shifted the nature and location of collaboration, creativity and craft within the studio. The process, growth trajectory and eventual implications of adopting computational tools and systems are still very much in the process of being worked out, both by the collaborative team in the Castle studio and the wider worlds of art and craft they touch. Under the wrong circumstances, this could challenge and undermine the core values of craft, collaboration, and creativity the studio has long depended on. But where such changes unfold against the backdrop of a tightly knit workplace experienced with the techniques and expressions of balance, finesse, and beauty and where human ties to collaborative process are strongly forged, forms of innovation that extend and sustain core strengths and values may result.

DISCUSSION

Through the implementation of 3D scanning technology, the studio realized improved speed, precision and accuracy within certain crafting processes. Additionally, the studio began interfacing with its designs in digital form, a step that gave Castle another entry point to the evolving work via Marv's 3D software.

In a more powerful way, Mr. Chips can be seen as a collaborator capable of remediating Castle's relationship with creative wood design forms. While extending the reach of a human carver, the robot entered the process in such a way that Castle's pursuit to "free wood from its conventional form" took an evolutionary leap. Form could be conceptualized in a larger, more complex way not possible before the CNC entered the process.

In this way, the role and significance of Mr. Chips within the design and craft process help us expand Jackson and Kang's argument that creativity is emergent and performative, happening in and with the world of things. In the Castle studio, creativity can be found emerging within and through the use of a remediating tool, meeting the artist and his medium and sparking a creative capacity not possible before such computational and robotic intervention. Mr. Chips collaborates with the design work of Castle in a way no other studio member does. And in doing so, it reduces the ontological gap some see between the human/object relationship.

In this light we begin to see Orlikowski's notion of the constitutive entanglement in action. Suddenly, not only are materials understood as performative and unfolding through collaborative actions, they are also understood as entangled within sociomaterial "flows" comprised of all the various entities of the work process - studio members, wood, Mr. Chips, RAPID, collectors of art, glue, 3D scanners, wood

clamps, galleries, patterns, etc. Together, these actors create an object through a full orchestra of players uniquely different from any that could otherwise be formed. Though it was not Castle's intent for the tool to '…cross over into [his] space', it has surely met him there and offered a way to collaboratively evolve design together.

The piece-by-piece building, hacking and appropriation of the CNC machine relies on the creative repurposing, and in some way reimagining, of the tool from its expected or proprietary roots. It's working the tool against its grain, exploiting its material form and propensities in ways that can be bent to the intentions of the work. In this way it's not so different than the chainsaw must have looked and felt when it showed up in Castle's practice several decades ago.

Perhaps less romantically, Mr. Chips collaborates with and reorganizes labor within the studio by assuming some of the more specialized and repetitive grunt work, which frees other studio employees to focus on work best suited for crafting capabilities and human skill. Marv, as the studio worker who must deal with the precise work requirements necessary to translate the non-native languages into RAPID code, understands that it is not yet practical for the CNC to work each studio piece. As a result, he must choose projects most suited to the machine. He is cognizant that although the robot can carve quickly and accurately without tiring, amplifying technicalities of repeatability, diligence, precision and efficiency, it cannot respond to the materiality of wood in the same way a human carver can. As a tool built for industrial labor, the CNC is not devised to know the properties of organic crafting material like wood. It does not know how much force it can absorb or which way it will bend under pressure. It cannot analyze growth patterns to read how to approach a cut, nor bring out the Ash grain using a wire brush. It does not "see" form, but precisely executes a set of commands fed to it linearly. In this regard, it is unlikely that the machine will soon replace the handwork of the artisans working within the studio and as we saw, even those pieces tweaked in the computer and roughly-carved by the machine begin and end with the hand.

At the same time, because of the machine's ability to store libraries, The Robot enables the studio to reimagine wood pieces as reproducible parts of a larger edition, where they were once relegated and honored as completely unique pieces. This development affords new market opportunities, as shown by the gallery's request for the *Long Night* series. One of the more interesting contributions of digital fabrication tools may in fact be to provoke new questions around authenticity and authorship that challenge the very assumptions behind such terms. Now that new forms of technology make editions of fine art furniture a possibility, might we one day value such work much like the way the larger lexicon of artmaking has long valued the printmaker's editions? Yet for what reason did Castle's dealer show hesitation when discussing the robot with larger audiences? Amidst the opportunity of doubles or multiples may come the talk of protecting Castle's market value and preserving the more sacred qualities of each unique studio object. The importance of one-off designs for both financial and deeper, more human value must be honored.

Other questions center on the challenge of defining a reasonable stopping point in identifying tools that support without somehow damaging or violating the artisanal expectations of craft. Should the CNC's programmable nature or its past as a soldier of industry leave it outside of accepted "crafting" tools? If so, why might a chainsaw be an acceptable tool for wood craftspeople and a CNC mechanical arm (that essentially carries out a similar process as requested by its user) a potentially devalued one? How much space these developing tools are granted when it comes to evaluating and honoring craft and handwork may remain to be seen.

Castle may intuit some of the above-mentioned risk when he remarks that it is not his intention to allow the robot to *lead* him, but to merely *help* with some of the work. Such an attitude is illustrative perhaps of one of the foundations of the term *post-digital*. Such a term exposes trends in contemporary art and making that have implications for grounding the role of digital technologies as one aspect of creative work and work in general. Labaco's analysis aligns with Ingold's vision of the artist's practice as one positioned to "…join with and follow the forces and flows of material that bring the form of the work into being" [11:97]. Rather than suggesting that technology is serving the needs of the artist, we can argue that artists and their digital fabrication tools are engaged in creative entanglements where technology and human making expand and inform one another.

As the above literature shows, the space that exists between humans and the world of things is an active and productive one, giving rise to new forms of value and agency. As digital technologies remix these relationships, deeper insights about how we engage with the world of things as makers, collaborators and users of new tools emerge. Locations where traditional artistic activity is remixing with digital tools offers a rich landscape for delving deeper into such lines of inquiry.

Castle, who launched his career during the era of the "lone creative genius" working alone in the studio with his carving tools and materials, offers us a new way of looking at creative practice. His expanded creative workflow now includes processes and methods more aligned with contemporary digital art practices (or indeed, industrial manufacturing) while still honoring the material properties of organic forms and materials and human craft. This represents in some ways a break with the past, but in others a further cementing of Castle's considerable reputation as both craftsman and innovator. That Castle's emerging practice can support both evaluations simultaneously speaks to the complexity of craft transitions in a post-digital era.

CONCLUSION

As the above story makes clear, the introduction of new computational tools into longstanding and craft-based forms of creative work carry deep implications: both for the experience and organization of work and the values that surround it. It can reorganize the nature and sites of creativity, and the forms of collaborative work that give rise to it. It can call into question the basic tenets of craft, and the values assigned to these. It can point to new forms of connection and attachment between creative producers and the materials with which they engage. And it can point to new possibilities for creative work and imagination beyond these points of change.

If this analysis suggests findings relevant to the nature and organization of creative work, it also speaks to core CSCW interests in materiality and collaboration more generally. In this as in other contexts of collaborative practice, tools can rarely be isolated or reduced to their immediately functional dimensions, but are instead embedded in historically layered networks of value and meaning that can shape the nature and form of their adoption. Similarly, the built forms of tools and the material flows they engage are central to the constitution and meaning of collaborative activities, and not mere passive background to human defined and dominated fields of action. In these and other ways, places like the Castle studio and other sites of distributed creative practice may help cast important new light on core problematics of CSCW work.

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