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High Tech | Low Tech: Teaching Augmented Fabrication in the Zoom Era

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Abstract

High Tech | Low Tech: Experiments in Spatial Computing for Design and Fabrication was an advanced elective offered in online format in Fall 2020. The class sought both to introduce computational skills and lead students in explorations and discussions around the emerging potential of design and fabrication that incorporate augmented reality (AR). While AR and the free Fologram mobile app that connects to Rhino/Grasshopper were the central focus, the course content was meant to foster critical consideration of design technologies through history. A theme that emerged through the semester was a critique of the architect's fascination with and reliance on precision and hyper-control in order to create designs and communicate them reliably for construction, as well as the lost potential to elevate skill-based labor and invite serendipity in such controlled processes.

The course revolved around a series of assignments, or "experiments" in the parlance of the class, that successively built confidence in the AR interface while relating to weekly topics—the history of design media, the tool's imprint on the designed object, labor in design and construction, material tolerances, reclaimed waste and material flows. It also touched on art and social practices, with guests speakers from the art world and local craft community.

Assignments were lighthearted and short-fused—an attempt to add levity and spark curiosity during an unexpectedly isolating and difficult semester. Students learned to anchor digital objects into physical space, control their appearance and orientation, and apply physics simulations. They spatially tracked their devices (and thus themselves) and made spatial recordings of movements. Finally, attaching trackable markers to simple tools, they created AR interfaces that explored how a traditional handcraft or building methods might be reinvigorated or reborn through augmentation. The course posited that AR techniques could democratize advanced fabrication (by greatly reducing cost and lowering bar to use) and reinvent construction labor by putting agency, and thus dignity, back into what are seen now as low-level construction jobs.

Household items and handheld tools were brought into experiments that tended to be simultaneously infuriating, as they pushed tolerances of the phone-based app, and yet invigorating, offering windows into an expanding realm of material culture and design potential. The topic was a perfect fit for a semester when remoteness was required, new technologies for communicating were necessary, and most of us only had access to the simplest and most basic tools and supplies. Digging deeper into home, humanity, culture and craft while embracing advanced technologies built hope for the future of design in uncertain times.

Keywords: Materials and Construction, Pedagogy, Fabrication, Augmented Reality, Mixed Reality, Computational Design

Introduction

In his 1996 book *Abstracting Craft*, Malcolm McCullough, looking from his vantage point prior to the last 25+ years of experimental fabrication predicated on expanded CAD/CAM availability and development, discusses the implications of digital computing processes that take on the mantle of "craft," once only ascribed to those processes in which hands and haptic interaction are involved.[1] The practice of architecture has developed along an arc that tends to remove the designer further and further from the act of constructing the thing designed, and this practice has necessitated increasing levels of precision, both in terms of representing a design prior to construction and within construction processes.

Similarly, a divide has emerged between fabrication processes that we term *manual* and those we term *digital*—the low-tech and the high-tech. While there have been some productive overlaps in these categories in the past, advances in spatial computing can offer new modes of design, design communication and fabrication that could profoundly redefine their current relationships. McCullough imagines a time when computers might be more conducive to the “flow” necessary for skillful application of craft as “greater breadth of input…relieves us of too much burden of instruction.”[1]

Spatial computing is a blend of software and hardware that allows human interaction with a computer to retain and manipulate referents to real objects and spaces. Virtual reality (VR) is perhaps the most commonly known variant of spatial computing, but unlike VR, augmented reality (AR) and mixed reality (MR) allow the user to see and manipulate digital objects as if they were anchored in their physical environments. This blend of 3D digital info with a user’s physical space, moving 3D models off of the screen and into the environment, generates new ways of engaging both design and construction.

“[Bent],” a project presented at ACADIA’s 2019 conference, provides an example of a design predicated on material manipulation and assembly involving spatial computing. Holographic guides directed the steam bending of wood and manual jig bending of steel to create a complex swirling assembly with relative ease, no printed drawings, and very simple tools. Alternatively termed “holographic handcraft-based production,” works like these offer the merger of the improvisational methods of craft and the pre-ordained and complex forms of digital design. From the paper, “This holographic augmentation—of simple and easily attainable analog tool sets—allows for the creation of extremely complex forms with high levels of precision in extremely short time frames.”[2]

High Tech | Low Tech: Experiments in Spatial Computing for Design and Fabrication was offered as an advanced elective course for architecture students at the Fay Jones School of Architecture + Design at the University of Arkansas in the fall of 2020. The course was set up to explore and question the way that advancements in spatial computing might manifest in material processes in design and construction, both elevating low-tech or manual processes, and making high-tech digital fabrication more attainable.

The nature of the semester, owing to the ongoing Covid-19 pandemic, necessitated fully remote course delivery for a course that was originally planned as an in-person fabrication-based course. The remote delivery method coupled with a desire to explore emerging potentials in mixed reality fabrication, both theoretically and through physical experimentation, fast-tracked the development of this course, running parallel to the creative scholarship of the instructor, whose work and teaching engages advanced fabrication that uses digital techniques to open the potential of manual fabrication processes.

The Fologram[3] application was developed specifically to enable spatial computing that links with some of the most common software currently used in design and digital fabrication processes, Rhino and Grasshopper. Fologram allows real time interaction with and manipulation of 3D models in Rhino that are placed and anchored into the physical environment by the user. The paid application runs on Microsoft’s Hololens headset, but there is also a free mobile phone app that works the same way, yet with somewhat reduced accuracy and stability. This free app was ideal for this course, in which students didn’t have access to the school’s labs or equipment, necessitating the sole use of tools/items common to many households. Though the reduced accuracy of the phone-based app could be a barrier for certain processes, it was perfect for an introductory remote course, allowing students to develop the computational skill required to use the software, understand the capabilities of mixed reality interfaces, test and iterate ideas for their use, and imagine applications beyond the tolerances of these limited setups.

This paper will discuss the organization of the course through its topics and assignments, show results of student work, and reflect on course outcomes and future work seeded through the exploration of these ideas.

Course Organization

The course revolved around a series of assignments, or "experiments" in the parlance of the class, that successively built confidence in using and adapting mixed reality interfaces while relating to weekly topics such as the history of design media, the tool's imprint on the designed object, labor in design and construction, material tolerances, reclaimed waste, and material flows. The course also touched on art and social practices, inviting guests to speak from the art world, the local craft community, and hosting a class overlap on activist practices.

The class met via Zoom on Tuesday and Thursday afternoons each week. The Tuesday class introduced a new weekly topic through a short slide-based lecture. The students were assigned a reading or a video to watch related to the topic, and each week's assigned experiment dovetailed with the topics of discussion. Thursday's class was generally reserved both for topical discussions, direct skill-based training, and presentation/ discussion of student work. This format provided an anchoring rhythm for the course and allowed successive skills to be built through practice using the spatial computing tools while related ideas underpinning the topic were introduced and explored simultaneously.

Weekly Topics

The topics engaged in the class are a combination of themes from previously taught seminars in digital fabrication with the addition of ideas that are specific to the potentials of mixed-reality fabrication. The range of topics was quite broad; thus each lecture provided only an introduction to concepts, thinkers and projects that students could return to as references for future work. Below is a list of the topics covered by week, revealing a progression that traces how design media and material culture have come together, particularly in the recent past, and how this relationship could be drastically altered by the technologies students were concurrently learning to control.

Week 1 – **Going Off Screen:** What is spatial computing? How can it affect design practice?

Week 2 – **The [Design] Medium is the Message:** Design media and ramifications through history.

Week 3 – **I Seeeee You:** Tracking and interaction in space and time.

Week 4 – **How Do I Look?:** Scanning types/methods and visual occlusion.

Week 5 – **After Blob Wall:** A review of digital fabrication in architecture. Aggregation strategies. The democratization of tools?

Week 6 – **Beyond Geometry:** Physics simulation, big data and other types of design computation.

Week 7 – **A New Phase for CDs?:** Overview of construction documents and designer/fabricator communication.

Week 8 – **Material Systems:** The evolution of construction systems based on place, tech, climate and culture.

Week 9 – **Material Flows:** Where are the freesources? Biological and technological nutrient streams.

Week 10 – **AR Art:** Collaboration with fellow makers and thinkers. Guest talk on projection mapping in art.

Week 11 – **AR Activism:** Spatial computing in the public realm. Could AR installations reveal social needs and deeds? Combined with other course.
Week 12 – **AR in AR:** An overview of craft and material practices specific to Arkansas and the region.
Week 13 – **Documenting and Disseminating:** What is the life of this work beyond this class?
Week 14/15 – **Production and Final Discussions**

While some topics were more directly informational, the course also posited some outcomes of integrating spatial computing techniques into design and construction—specifically the potential democratization of advanced fabrication (by greatly reducing costs of equipment, thus lowering bar to use), the remaking of design communication for construction, and the reimagining of construction labor by reinvesting agency, and thus dignity, into what are commonly seen as low-level construction jobs.

Experiments

Calling the weekly assignments "experiments" was an attempt to remove the stigma of trying unknown methods and to encourage an attitude of open exploration without inducing fear of ridicule or lowered grades. While this is generally the desired approach in many design studios and courses, students can hesitate to enter into a mode of work that embraces uncertainty. An attitude of "serious play"[4] was encouraged throughout the semester, and grading was not based on outcomes so much as serious attempts and the positioning of work in response to worthy questions.

Experiments were lighthearted, an effort to add levity and spark curiosity during an unexpectedly isolating and difficult semester, and they were short-fused, acknowledging the short attention spans and fatigue that come with a semester of screen overload.

The hope was that bringing the digital models and information off of the computer screen and into relationship with physical spaces and objects might provide relief from constant screen use. However, students were learning Grasshopper and computational design methods for the first time, and their processes were still being mediated through the mobile phone screen, so this particular promise of mixed reality wasn't fully realized. As well, documentation of the experiments, while extensively collected as screenshots and videos, is rather rough due to the nature of cellphone photography, particularly when movement is part of the process.

Several of the experiments will be described in more depth in the following section along with student work. Students learned to place digital objects into physical space, accurately anchor geometry in space, control its appearance and orientation, and apply physics simulations like gravity to models. They learned how to occlude physical objects, to track their devices (and thus themselves) and to make spatial recordings of movements. They uncovered how their phones "see" their environments through various scanning types and how real-time scanning might enable interaction in mixed reality. Finally, attaching trackable markers to simple tools, they created mixed reality interfaces that explored how a traditional or manual handcraft or building methods might be reinvigorated or reborn through augmentation.

Household items and handheld tools were brought into experiments that tended to be simultaneously infuriating, as they pushed tolerances of the phone-based app, and yet stimulating, offering windows into an expanding realm of material culture and design potential.

Student Work and Outcomes

Skill-Building Experiments

The first seven experiments were aimed at skill-building and facilitating experiences that stimulated discussions. The first experiment, "Digital Magritte", asked students to call on the painter's bizarre juxtapositions by downloading a preexisting Rhino model from the internet and placing it into their physical spaces, recording the juxtaposition with a still image and a video. In the student image shown in Figure 1, a digital model of a TV trades viewpoints with the student who might otherwise be sitting in the pictured chair to watch a real TV. The technical skill developed was basic familiarity with the Fologram interface and ability to place and scale a digital model in AR, but the assignment also seeded the first discussion on what ubiquitous mixed reality might mean for the future in many and varied forms, and it paired well with a reading on McLuhan's theories of media.[5]

Fig. 1. "Digital Magritte" experiment by Lauren Dillon.

The follow-up assignment, "Tethered," builds on previous skills by asking students to anchor newly created geometry to some recognizable aspect of their physical space. Figure 2 shows a digital addition to a window, precisely drawn to fit into its physical environment, placed via QR code. The lofted tube-like surface is controllable through several Grasshopper sliders, accessible on the phone screen, allowing the user to move and scale one end of the tube, while the other remains firmly anchored to the window. This experiment helped students to learn and practice the precise placement of geometry in Fologram, and it reveals the power to adapt the perception of architectural space and spatial edges through spatial computing.

"Do you See What I see?" used the tracking feature built into Fologram to reveal the surfaces that the application collects via the phone's camera in order to relate digital geometry to the surroundings. While the phone's sensors are less capable than those of a Hololens, these primitive scans (Figure 3) reveal the scale and patterns of inhabitation in these domestic spaces. This experiment helped students understand the flow of information back and forth between their MR-enabled device and their computers that underpins any mixed reality experience.

Fig. 2. "Tethered" experiment anchors parametrically controllable digital geometry to physical architecture.

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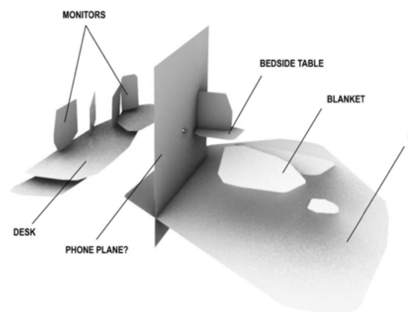

Fig. 3. "Do You See What I See?" by Hannah Gray.

"Drawing Off the Page" was an experiment that built on previous skills with tracking in Fologram, and asked students to undertake a common household movement or action while tracking their phones through the app. A ribbon-like surface was generated by recording the motion as a set of relative points in Rhino, transformed via a predefined Grasshopper definition[6] into a continuous surface in which width reveals the speed of motion.

Students first showed the group their generated surfaces in isolation, as seen in Figure 4. Other students guessed at the activity (walking upstairs in this case). Then the ribbon was revealed as an image within the context it was recorded, as seen in Figure 5, where a student tracked the motion of vegetables being chopped on a cutting board. Many of these images called to mind Eadweard Meybridge's use of photography to reveal human and animal motions—tracking the folding of laundry, sweeping a floor, a dog running to fetch a treat. They also speak to the current ability to compress a time-based motion into a captured modeled object and to spatialize it anchored in context. How such data could be used in the context of design is yet underexplored, but it was a topic of discussion during that week's class.

Fig. 4. "Drawing Off the Page" submission shows ribbon of movement walking up two flights of stairs, by Joe Green.

Fig. 5. "Drawing Off the Page" revealed motion of chopping on a cutting board, by Wenjie Zhu.

"In/Under/Around" asked students to place a digital object in a manner that it would be obscured by physical objects from some vantage points and not others. Students needed to draw the contextual physical objects with good accuracy, set them up as occlusion objects (objects that won't be cast into space using spatial computing, but will be used in the model to calculate when a mixed reality object is being obscured), and to make images and video of the setup. Occlusion happens automatically when using more sophisticated devices like the Hololens, but for the phone-based app, occlusion is set manually. Exploring occlusion with this assignment showed students more fully how visual information reveals relationships between objects or between spaces, and how these relationships might be manipulated in mixed reality settings. In one student image, a red ball changes scale in the video, passing through the shelf on which its resting as it grows. (Without occlusion, the ball would appear to float in front of the shelf.) The class discussed ways in which this technique can create the appearance of spatial depth where it does not exist. Thus, AR can both add objects into space and subtract material from existing objects. One student produced convincing infinitely-deep holes in the floor of their apartment.

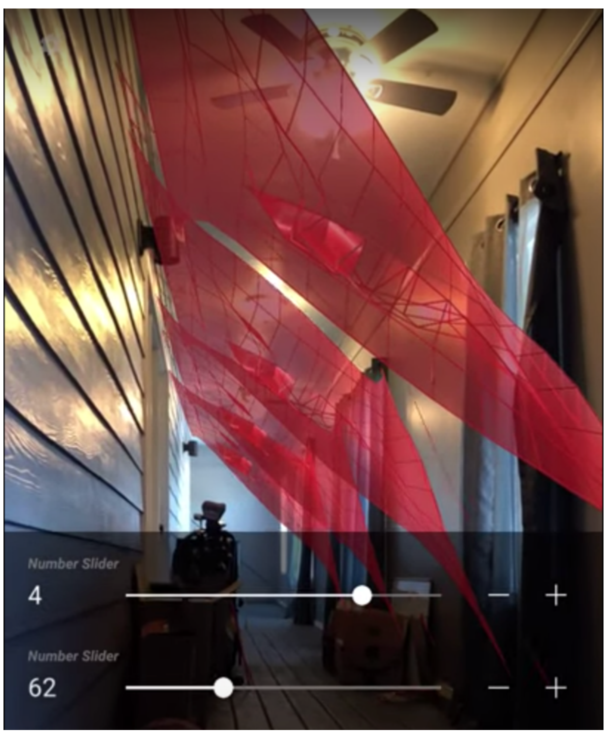

Fig. 7. "Throw In the Towel" by Matthew Scott shows Grasshopper slider integration in an installation in the student's home hallway.

The final skill-building experiment, called "Throw in the Towel," (Figure 7) used the Kangaroo plugin to for gravity simulation and acquainted students with tracking printed markers set within their physical environments as interaction device within a mixed reality environment. Assistant Professor Shelby Doyle of Iowa State University was a class guest during this week, providing a lecture on her work, as well as introducing a method to generate digital models that mimic the draping of webs of rope or yarn. Doyle has used this technique to envision the way that a woven piece will hang in architectural space[7], and this class adapted this existing Grasshopper method for use with mixed reality. The four corners of a web became points that could be placed into physical space using printed markers, allowing students to hang a digital web in their spaces and move markers to change its shape and position in their environments.

Experiments in Speculative Construction

The final two experiments in the semester use previously built mixed reality skills and ideas seeded through course lectures to creatively investigate the potential of augmented fabrication. The experiments, called "What Does a Can Want to Be?" and "Augmenting a Tool," both ask students to conceive of a mixed reality interface for first aggregating a found object, then adding trackable augmentation to a common tool or process to explore how a combined manual-digital process might alter the outcomes or open up new aesthetic or performative potentials.

"What Does a Can Want to Be?," a play on Khan's famous line about a brick, was an experiment that allowed students to consider the freely available material resources that surround them—both natural and manmade, standardized and idiosyncratic—and construct a system of non-standard aggregation. Playing off of course topics on material flows and the evolution of material systems, students were asked to conceive of an aggregation strategy that uses spatial computing as a holographic guide for fabrication, rather than needing advanced equipment like laser cutters, CNC routers, or 3D printing.

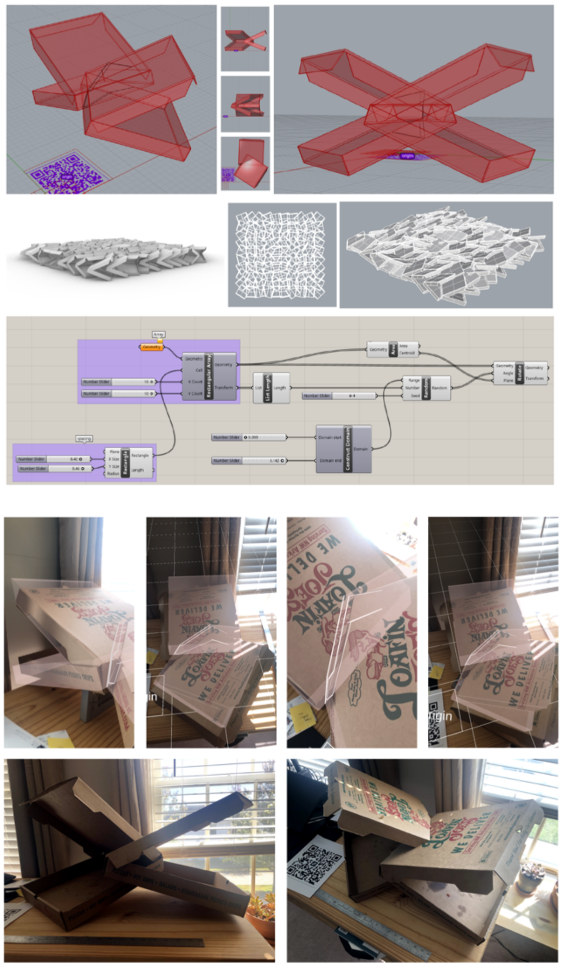

Fig. 8. "What Does a Can Want to Be?" experiment in non-standard aggregation with holographic guide. Pizza box aggregation by Matthew Scott.

Students responded by modeling the object(s) of choice and creating an aggregation digitally, then attempting the first step of joining at least two of their "bricks." This work linked directly with the previous class discussion on Greg Lynn's BlobWall, and the elevation of a pool toy into a refined aggregation system through advanced fabrication.[8] How might we reconsider the unitized pieces of matter that are used in construction? Another touchstone for this project is Brandon Clifford's Cyclopean Cannibalism, which posits ways of reusing discarded concrete and stone in compression-only structural aggregations, with beautifully rational yet idiosyncratic joint maneuvers.[9]

Student work shown in Figure 8 shows an aggregation of pizza boxes, along with the process of using a holographic guide to trace the lines of intersection of the boxes to make a physical mockup. The students were able to describe their observations when attempting to use the holographic guide, and discussed ways that these guides, essentially fabrication interfaces, might be improved through "graphic" adaptations—adding color, using occlusion. Processes were messy and imperfect, yet they worked well enough to be considered first prototype interfaces for new augmented fabrication systems. Pizza boxes aside, students could imagine larger or more substantial aggregations and the interfaces that could enable them.

For the final experiment, each student chose a tool or a material process to which they would add an augmented interface, along with some tracking ability. One student from the landscape architecture department chose to augment the planting process, creating an interface that would overlay a complex planting pattern onto the ground in situ, even depicting the hole size below the surface of the ground to aid in proper planting depth. Another student developed an augmented lath woodturning process that showed a color range as the tool approached the proper cut depth along the desired digitally produced profile. Other student work included various wood or foam carving or chiseling interfaces, a reciprocal frame aggregation of toothbrushes, a pizza cutting template with tracked cutter. The work depicted in Figure 9 is a cake decorating interface that projects lines or surfaces onto the cake form and tracks the icing dispenser, providing visual feedback with the tool tip is within a certain tolerance of the desired lines. In this case, previous skill in cake-decorated would have been preferable, which prefaces work discussed later.

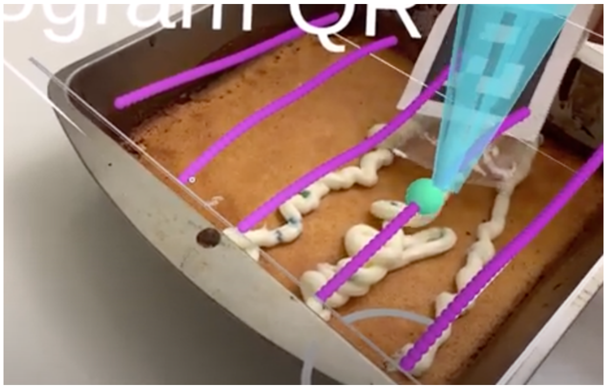

Fig. 9. "Augmenting a Tool" shows Wenjie Zhu's experiment in developing a spatial computing interface for cake decorating. The green ball shows whenever the icing tip is within tolerance.

While the course hosted a guest speaker on regional craft practices, these final experiments only anticipated more fully developed augmented interfaces that could be used to adapt fabrication methods that might ease the use of local, waste or non-standardized materials, the creation of complex forms or intersections, and the allowance for individual nuance as to how a holographic guide might be followed thus allowing for the maker's hand to have presence alongside the designer's.

Outcomes and Reflection

In *The Architecture of Error*, Francesca Hughes speaks of Gordon Matta Clark's *Unbuilding* works, in which he uses rough hand-tool processes to create massive incisions into buildings, as direct challenges to architecture not because they are violent demolitions, but because within his methods, "there is no separation between instruction and operation."[10] The two modes of envisioning and producing, designing and constructing, are simultaneous. There is improvisation and choice, and any seeming error can be redefined as part of the composition.

As Hughes' book discusses in depth, the practice of architecture has followed a path of increasing precision, in both the design and production of buildings. One of the insights that came into sharper focus through discussions in the advanced elective course was that the mixed reality fabrication interfaces that the class was exploring could similarly challenges norms of architectural practice.

The course posited that spatial computing techniques could democratize advanced fabrication (by greatly reducing cost and lowering bar to use) and reinvent construction labor by putting agency, and thus dignity, back into what are seen now as low-level construction jobs. Could AR bring the vernacular (with its site/material specificity and regional talent) more fully in line with the great potential (aesthetic, performative, environmental) of computational design? Previous marriages of the high and the low, such as Edward Durrell Stone's Fulbright Collection of furniture that engaged local artisans in its production[11], remain an inspiration for this work as it moves forward.

The topic was a perfect fit for a semester when remoteness was required, new technologies for communicating were necessary, and most of us only had access to the simplest and most basic tools and supplies. Digging deeper into home, humanity, culture and craft while embracing advanced technologies built hope for the future of design in uncertain times.

The class leaves us with a question from McCullough's book, "What will it take [in the context of digital production] for anyone to regain the sense of productive autonomy and personal impetus that we expect of a genuine craft?" In an attempt to answer, this work will be further developed over the next year into a series of creative collaborative experiments, carried out by the course instructor and student research assistants. More refined holographic interfaces will be created to engage specific hand-tool and craft practices, and both novice and master craftspeople will be engaged in assessing these tools within specific realms of use, refining them, and observing as new types of material practices for design and construction emerge.

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