Lessons from the Woodshop: Cultivating Design with Living Materials

Kristin N. Dew
Dept. of Human Centered
Design & Engineering
University of Washington
Seattle, WA
kndew@uw.edu

Daniela K. Rosner
Dept. of Human Centered
Design & Engineering
University of Washington
Seattle, WA
dkrosner@uw.edu

ABSTRACT

This paper describes an eighteen-month ethnography of timber framing at a tiny house construction program in Port Townsend, Washington. This case exposes the intricate, ongoing processes that define a project where people learn to imagine, create, and ultimately maintain living materials. This case sheds light on the nature and scope of interaction design with living materials, an area of growing significance to HCI scholarship on new materials, sustainable design, and digital fabrication. Drawing from this project, we distill five lessons for design with living, finite materials. We end by discussing three emerging areas for HCI: designing for material recuperation, collaborating with more-than-human actors, and approaching material properties as prototyping sites.

Author Keywords

Apprenticeship; making; sustainable design; DIY; everyday design; materials; digital fabrication.

ACM Classification Keywords

H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

INTRODUCTION

Over the last two decades, HCI scholars have begun to examine the role of materials that grow, learn, change, or regenerate, extending and reworking the very nature of technological systems. From robot swarms to self-healing screens, biologically-informed materials have set the stage for the celebration of novel interactions for fabrication, home life, and sustainability. Although the possibilities mount, designers face key limitations around their means of dealing with materials that change form, seeking out new tools, procedures, and pedagogies for working with living materials. For example, 3D printers typically rely on passive models of material production wherein a designer delegates a fixed form and properties to the material. However, as this paper argues, recognizing the living qualities of materials requires recognizing the entangled contributions of technology development cultures, forces of decay and resurgence, and the material itself, with the material's characteristics emerging well before the designer arrives. Materials, in this sense, are neither discrete nor passive things to be worked on.

Beyond HCI's typical sites of production lie other worlds of practice that take this performative view of material qualities as a starting point. This paper describes one such site and its lessons for the design of technologies with living, active materials. Specifically, we draw from an 18-month ethnographic study of timber framing tiny houses at a woodworking trade school in Port Townsend, Washington State. Timber framing is a craft building construction method using large wood timbers linked together with joinery*,* the handwork of shaping and assembling wood pieces into a structural whole. Over the course of the study, we learned how to find, prepare, construct, and maintain material properties of new and old growth timber while building three tiny homes. Drawing on this case, we shed light on processes of envisioning, designing, building, and sustaining living materials. By contextualizing this case in light of HCI developments in living materials, we offer new insights into the design of technologies for fabrication and long-term inhabitance.

This paper builds on prior work exploring how people contend with and actively design for expectations of decline: code rot, hardware decay, device obsolescence, and general technological degradation [9]. A range of work in HCI and technology studies by Blevis [6], DiSalvo [14], Maestri [37], and Tsaknaki [54], among others has evidenced the importance of attending to temporal qualities of material in the context of interaction design. From patinas and antiquarian materials, this work has shown how processes of aging, degradation and attrition serve as material resources. Our ethnographic inquiry into practices of timber framing exemplifies a process of design wherein the designers learn to work with the diachronic properties of their materials, attending to the development of the materials' living and temporal potentials.

CHI 2018, April 21–26, 2018, Montreal, QC, Canada

ACM ISBN 978-1-4503-5620-6/18/04…$15.00
https://doi.org/10.1145/3173574.3174159

Learning the process of timber framing thus provides an unusual and especially compelling case for examining emerging concerns for new materials, sustainable design practices and digital fabrication. In particular, we ask: *What does the interplay between living materials' properties and the environment from which they came tell us about new materials? What lessons might the processes of timber framing have for the sites, practices and pedagogies of sustainable design? And how might living forms such as wood extend digital craft materials?*

In addressing these questions, we make two core contributions to the human-computer interaction (HCI) literature. First, we outline five lessons from working with living material that specify the shifting interplay between changing material properties and designers' engagements well beyond their sites of assembly. Second, we reflect on three methodological orientations deriving from these lessons: designing for material recuperation, collaborating with more-than-human actors, and approaching material properties as prototyping sites.

BACKGROUND

Before we introduce our case of timber framing and how it may shift understandings of living materials in HCI, we turn to the traditions of design practice and inquiry on which our work builds. The sections that follow survey HCI's ongoing conversation about material agency and its implications for design practice.

Living Materials

Interaction design increasingly entails working with living materials. We define living materials as design resources that actively change over time, bringing their own histories to the design encounter. Among these are computational composites that blend familiar characteristics and unexpected computational forms [5, 56-57], "smart" and transitive materials [8] that change, and organic materials like bacteria and algae [33]. Linking this intersection of making, computing, and material to the surrounding environment has been described as a key design problem best addressed by borrowing from natural principles [40]. For instance, recent advances in 3D printing allow for new materials to be manipulated and compiled at the volumetric pixel, or "voxel" level, including color, elasticity, and texture, among other characteristics. This approach assumes designers can adequately know material properties through specifications and apply those properties through digital means, meaning designers must create and apply new materials in ways that lie outside of their direct perception and understanding [5].

However, several interaction design scholars have shown that this disembodied view of material engagement may not account for materials as active participants in the design process. Scholars have demonstrated that materials act as communicative resources [28] and performative objects [52], suggesting possibilities and constraints as they become active during design work. Beyond the design process, materials go on to shape aesthetic experiences and daily practice [19, 32, 11].

While most of this work concerns traditional design materials, other work has recently taken up its underlying materialist view by seeking to collapse long-standing distinctions between digital and physical form to better account for the emerging range of interactive "computational composites" available to design [43, 56-57]. To build a greater understanding of these new materials and their roles in interaction design, design scholars have highlighted the gap in methods for exploring and communicating the properties, possibilities, and applications of computational composites [17, 56, 30, 59, 15]. Research and design methods such as the material probe [29], DIY [11], and materials experience frameworks [19, 59] have begun to address this gap, giving designers useful resources for envisaging how material properties might give rise to future activities, practices, and aesthetic experiences [5, 19, 32, 15].

This understanding of materials as active has also called into question HCI's tendency to privilege early design and production processes, opening the possibility of conceiving surrounding objects as participants in more sustainable futures [26, 55]. As scholars in collapse informatics have pointed out, a future of growth and abundance is no longer a given [53]. "Broken world thinking" offers a productive frame moving forward, one that recognizes the limits of our natural resources and societies and posits breakdown, repair, and maintenance work as central concerns for design along with development and innovation. Here the designer's work lies in apprehending the emergent landscape of human-technology relationships and the idiosyncrasies of found, worn, and discarded things in order to reconfigure them in novel and meaningful ways [27]. In the pages that follow, living materials in the form of wood, natural forces, and their ongoing entanglements with human processes of resource extraction join the fray.

Expanding Material Properties

Within the early decades of HCI and design research, discussions of material properties focused primarily on the idea that interactions depend on discrete material attributes, and that such attributes lie within things. Drawing from the work of environmental psychologist James Gibson [20], Don Norman introduced a concept of "affordance" to design and HCI, emphasizing the perception of properties as a core aspect of interaction [39]. The language of affordance connects theories of agency that seek to take either the thing or human as the progenitor of activity. Rather than view interactions (or interaction potentials) as determined by a thing or human alone, design affordances (handles, door knobs, buttons, etc.), and the interactions they enable derive from the confluence of the two actors (thing and human). According to this view, material properties do less to determine human-machine interactions than to enable their occurrence. Across the 1990s and early

2000s, design researchers deployed such relational views to explore a broad range of artifacts and systems, from text documents to interface windows, and from teapots to bush pumps [10]. Others expanded the “properties” discourse to examine the “scripts” or scenarios resulting from designers’ intentions for material form [2]. While not “properties” in the traditional sense, these capacities for action emphasize the negotiated nature of material agency.

If the relationalists saw properties and their possibilities for interaction as inscribed into things, the new materialists took this emphasis a step further: painting properties as lively enactments of matter produced by the confluence of social and material forces; for example, clay could act “dusty” when a miner first digs it out of the ground, “plastic” when mixed with water, and “rigid” when exposed to high heat in a kiln. HCI research of the last two decades draws on this literature to reframe its objects of study: re-reading interactions as “intra-actions” (per Karen Barad [3]) and reframing agency through “proclivities” [25] and “propensities” [27] – using the language of dynamism to allow properties a stronger “say” in ongoing activity (reflecting Schön’s [50] famous notion of materials talking back). Here properties become less embedded in materials than emerging with and through a vast array of human-machine relationships.

Design scholars have begun to address the gap in theory and methods for exploring and communicating the properties and possibilities that arise in intra-actions with active materials [38, 17, 56, 30, 59], and for attending to materials as non-human participants in design [12, 13, 40]. Worlds of traditional craft such as weaving have been important sources of insight, bringing links between making, materials, and values into greater focus. In examining a 140-year-old Jacquard loom, Fernaeus et al. [16] found lessons for creating durable interactions in the loom’s natural material construction with recyclable, repairable, and upgradable components, and in the way it employed whole-body interaction to operate. They attributed the loom’s longevity in form and quality interaction to these characteristics. In the book binding workshop, Rosner and Taylor found aging and wear to be emergent qualities of a designed object, in this case books, with book binders producing age in a skillful ongoing negotiation amongst tools, materials, and debated notions of provenance, value and authenticity in their restoration work [48-49].

The work presented below adds nuance and detail to how exactly material propensities emerge in a situated design practice that takes the limits of natural resources seriously, picking up on the call for documenting how designers bring material qualities into relation with design’s complex arrangements of collective work [43]. Drawing together these strands of literature, the case of timber framing animates the relationships between changing material properties and engagements well beyond the materials at hand. In doing so, it highlights frictions and opens questions for HCI scholarship on new materials, sustainability, and digital fabrication that expands possibilities for the liveliness of finite materials and practices for working with them.

METHOD

We structured our study of traditional joinery through apprenticeship-led fieldwork, a tradition of critical ethnographic practice [34] that embraces manual work, the flux of people and materials, and the lived experiences of developing embodied knowledge that can best be described by doing oneself. This involved participation in three intensive workshops, two practicing DIY tiny house timber framing and one practicing fine joinery alone, at a woodworking school in Port Townsend, a small Victorian port town in Washington State known for its active crafts community. During spring and summer 2016, Dew worked alongside students and master builders to learn how to build a tiny house using techniques that have been in use for centuries. The timber framing and joinery instructors, Stan, James, and Mike, have worked for decades in the building trades, making custom houses, boats, wood caravans or “vardos”, fine furniture, and cabinetry. The instructors said they chose timber framing construction methods in part because they can use less material and form a structure that lasts longer than it took the component trees to grow, making sustainability practices central to this site. Dew worked full time for a month with six fellow participants in the first course to build two 200-square-foot houses on skids, commonly termed “tiny houses” [31] in spring and early summer 2016. She returned as participant-observer and “sponsor” for six days of the second DIY tiny house class in spring 2017; sponsorship meant funding the woodworking school’s materials and overhead for the workshop in exchange for the built structure, which now lives on the University of Washington campus.

In addition to participating in the construction of three tiny houses, Dew collected hundreds of videos, photos, and sketches, conducted informal conversations with over twenty builders around Port Townsend, and recorded around ten hours of in-depth interviews with eight

Figure 1. Completed tiny house frames being moved to their (semi)permanent sites

interlocutors who were identified as key informants for their experiences in woodworking and DIY building. Her questions examined their experiences designing and building tiny homes and other DIY projects. Interviews included a fellow student (Ralph) from the workshop and his partner (Anne), who have recently moved into one of the tiny houses while finishing it out themselves.

Analysis of fieldwork materials comprised iterative rounds of annotation, memoing, and discussion among the research team to develop themes and their relationships. We also conducted close readings of literature on fabrication technologies from these materials in the extended case method tradition [7]. By following fabrication processes through the lens of timber framing presented below, we find long-standing strategies for engaging in design activities with materials that have lives of their own.

CHARACTERISTICS OF LIVING MATERIALS

The characteristics of living materials that we outline below emerged while moving through the process of timber framing. While creating strong, modular structures of timber pieces, we learned techniques for interlocking wooden members despite changes in the material — and sometimes because of them. Drawing on our ethnographic accounts, we later crystalized these material qualities into thematic orientations that offered insights into working with living materials, starting with the examples that we supposed would be familiar to people who have never worked with wood.

Although our claim to distill "characteristics" of living material may seem to imply that fixed properties indeed exist, we use the term characteristic to refer rather to the momentary stabilization of such material qualities. Represented here as discrete qualities, we would like to emphasize the inseparability of each characteristic from the others. We came to see these characteristics as products of working with the wood as much as engaging the surrounding work environment and its history through the woodworking practices at hand. In this sense, the qualities of living material we describe below illustrate the interplay between the changing material properties and engagements well beyond the woodworking school.

Figure 2. Helen finds a knot when carving this tenon for a wall stud. The knot's placement meant the tenon would not be strong enough, so this piece was reused for another purpose.

Lessons from Knots: Defensive Traces

In the woodshop we began to learn how the material's life prior to the design encounter provided clues to its past, and how to account for and navigate past damage in finite resources. We describe this characteristic as *defensive traces*, marks of past hardships evidenced by irregularities in the wood's grain that expand and remake the wood in the present: shaping the wood's current strength and flexibility and offering clues to how that piece will behave in the future.

A knot in a piece of wood, for example, evidences grain growing around a past disruption in the wood's growth, like a branch that broke off or an infection. In these vulnerable spots the tree grows new grain, filling them in — often more tightly or loosely than before, or in new directions. This transformation of wood grain then produces new material qualities. In the woodshop, the instructors pointed out that a small knot — identified as a dark, round, hard spot — will probably stay how it is when fixed tightly to the surrounding grain. But as the grain fills in loosely or changes in direction, the wood is more likely to work its way out of the timber and split the grain after many years of expansion and contraction. When a fellow student, Helen, began cutting a piece of timber for a wall joint, she noticed the grain suddenly curving and saw a hard, unruly spot. The knot's placement directly in the tenon suggested the joint would not be strong enough to carry weight. Rather than throwing those timbers away the instructors urged us to place knots in visible areas that were not load-bearing so that future inhabitants could watch them continue to change without damaging the house. Helen returned her timber to the pile to be reused as corner braces instead.

Here we see that knots not only provide a glimpse of adversities — the ways the tree grew around damage — but they also help builders draw from hardships to create generative changes from otherwise problematic traces: shaping how the resulting grain may act over many years and inviting alternative forms and configurations. Such attention suggests opportunities for adjusting to idiosyncrasies of living material by inviting technologists to use a material's traces of difficulties and resistances as a means of refiguring and growth.

Lessons from Wood Grain: Legible Textures

By learning to continually identify changes in wood we found living materials produce *legible textures*, physical patterns that reveal something about the material's past as well as its future to be redeployed by the attentive builder. Within the woodshop, this characteristic most often stemmed from the meeting point of wood grain and experienced maker. Wood grain is the marking produced by the tree's growth, formed into annual rings. In our woodshop, we learned to pay close, ongoing attention to the grain as a record of how the tree grew and how it might continue to change when worked into a different form,

Figure 3. Roofing joinery takes the grain's movement into account, while the small splines in the uppermost joints make for visually interesting wear as the wood moves and ages.

working through each piece's history and the still-emergent implications of that history each time tool met wood.

For example, for a builder to find the wood acceptable for the work ahead, instructor James explained that each milled piece should have very straight and tight grain to be strong over the long term. He said tight grain was an indication of the tree's slow and healthy growth, and is increasingly rare as industrial forestry practices have depleted old-growth stands in favor fast-growing trees. Even after wood is cut, the grain continues to shift with moisture, temperature, and pressure changes. As a result, the master builders urged us to orient the wood to account for the moving grain. When we began framing the roof, instructor Stan explained the joinery options that best take into account the grain's movement in structural support and aesthetic qualities over extended periods of time: "As long as the grain is continuous, you can spline them," a design we used (see Figure 3) because it brings two pieces of wood together at an angle with a third strip joining them to hold them more stable as the grain changes. It might seem that the roof would be stronger with just two supporting pieces joined together, but in this case removing some of the wood from the supporting pieces and replacing it with a softer bridging spline made the roof more durable by giving the grain room to move and helps make more visible how the structure is reacting to forces of wear and decay (see final lesson on Performative Scarcity).

Wood grain, in this sense, becomes an intentional designer itself — holding lessons for HCI designers as they consider the structural quality of technological artifacts, tools, and systems within the life cycles of those things and long after their initial design and construction. Attending to wood grain suggests bringing a constant, deliberate attention to the shifting behavior and appearance of living materials in relation to their local placement.

Lessons from Weeping Sap: Reparative Expressions

The tree's ongoing response to damage in the form of running sap exposed *reparative expressions* as a key characteristic of living material. Restoring the wood could involve more than simply ensuring its nourishment, but also using its reparations as forms of creative expression.

In the woodshop, Stan drew our attention to wood's self-healing processes and how they form traces of past encounters that damaged the tree. He described the implications of using commercially available kiln-dried wood like the fir. The sticky sap (also known as "pitch") carried nutrients while alive. Later that sap congealed in knots and other damaged places, much like a scab. In this sense, learning to identify parts of the wood producing sap became integral to ensuring the eventual habitability of the timber structure.

While sorting the delivered wood, the instructors pointed out how the kiln drying process seemed to have crystallized the fir's sap. But once we began cutting it for the house's joinery, it started to ooze again, forming little sticky beads on the wood's surface. Stan drew a contrast between kiln-dried and air-dried lumber, saying air-dried wood is more pleasant to work with but the sap can keep running for years after a cut. Ralph, a more experienced fellow student, fondly recalled a stool he had built that was still running (or "weeping," as he said) from its legs years later. Stan enthused that the porch he built on his own house still weeps sap in seasonal flows, freezing in winter and oozing again when the wood thaws. Running sap could be a problem for the novice, but for the skilled builders in the workshop it served as a material of self-care, embraced and even creatively deployed. As long as the sap did not run in a spot that would stick to the house's inhabitants or their belongings, it became another connection to the life history of the structure, a feature to be embraced and made visible.

Much like the grain and knots, weeping sap drew us into the wood's life story through reparative encounters that existed long before we arrived and lasted long after we turned the wood into another form. Sorting the delivered fir, its crystallized sap became an opening for reading past meetings between human and wood, rendering visible how the fir healed itself before being cut down and how kiln drying deadens the sap to make it more predictable and workable. Cutting into a timber we disturbed the wood again, causing the kiln drying process to lose its hold over the material and encouraging the sap to resume seeping. In this woodshop, the sap is an intimate connection to the tree's life and its efforts to recover from human encounters to be re-activated and deployed in reparative expressions rather than controlled and hidden away.

Lessons from a Tusk Tenon: Vital Decay

Vital decay refers to the complex non-human influences that builders work with while connecting timber members, such as the influential forces of gravity, weather and aging that shift and degrade the components in wooden joinery over time [9, 4].

In the woodshop we learned that a tight, well-executed joint can act as a durable structural component for many decades. The process involves bringing the surfaces of each timber member into full, snug contact so the joint can withstand the local forces of wear and decay. Instructor Mike introduced a tusk tenon, a style of joint he says is often used on tables, beds, and other pieces of furniture that had to withstand daily repeat forces. With a tusk tenon two pieces of the same wood interlock at a 90-degree angle, but the horizontal piece has an additional hole for a third piece of wood, a wedge that has more weight on top (see Figure 4 below). As the wood grains expand and shrink over time, gravity draws the wedge down and keeps the tusk tenon from wobbling or breaking apart. According to Mike, the wedge should be made of a harder piece of wood so that if gravity does not keep the joint tight enough you can take a hammer to the top to tap it down.

Classmate Ralph described this kind of speculation with time and future wear as materials as "*four-dimensional thinking*." He elaborated, "*I think builders, craftsmen, especially the more experienced they become there is like a way of thinking that, you know, you have to think about this two-dimensional drawing in a four-dimensional world and then add weather, add time, add extra materials […] and the more experienced you are the better you are at thinking 'OK, what are the potentials? Where could this go wrong…?'*"

Strategies for dealing with such questions of decay included selecting the right joint for the materials at hand such as the tusk tenon. The forces of gravity or weather that lead to decay become co-designers. Developing as a designer in this tradition meant learning from experience what you cannot control, drawing attention to the unruly materials in response (see "announcing the joint" in the next section), and accepting that the house will still be imperfect and wear in unknown ways — living in the balance between skillful anticipation and letting go.

Lessons from a Scarf Joint: Performative Scarcity

The characteristic of *performative scarcity* exposes how working with damaged material recognizes resource scarcity as a vital feature of the material at hand. Even joints by the most skilled builders can eventually wear out from friction, rot, or any number of accidents. Building in joined members allows for individual members to be removed and replaced without damaging the overall structure.

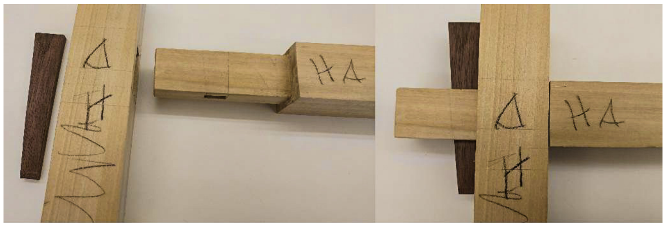

Figure 4: A tusk tenon taken apart (L) and together (R). The markings denote orientation so gravity can help keep the joint secure despite daily racking forces.

We practiced dealing with finite resources by learning to create scarf joints, making long pieces of lumber out of shorter ones by attaching their tapered ends. The process becomes useful for doing repairs to long horizontal beams that would otherwise be impossible to replace due to their scarcity or placement within the structure. Instructors Stan, James, and Mike described learning scarf joints as a critical skill because the joints can be used to piece together continuous lengths of timber out of shorter lengths that are more widely available and less expensive.

The second week in the woodshop, we set out to build the top and bottom plates of the houses, long horizontal timbers that hold the walls together. Because we did not have the nearly 20' boards we needed for the length of the house due to the scarcity and expense of large timbers, scarf joints became central to the construction scheme. We measured and drew out the joint for each pair of timbers we matched, cutting one side then carrying the lines from the cut piece to its mate and painstakingly shaping them to each other. On our first attempt, Helen and Dew worked on leveling out a scarf joint for nearly two hours: checking for pits and crowns in the pieces over and over again, looking for light between a straight edge and the board to indicate where to plane and imagining how forces and loads will work on the grains and knots over time until they locked together. It was not entirely snug so they sawed, planed, chiseled and checked the contact between the pieces dozens of times before they were satisfactory.

Later, during a visit to instructor Stan's workshop, we found the scarf joint again, this time for repairing long timbers on a wooden wagon or *vardo*. For people with the appropriate skills, Stan explains, wood artifacts assembled with joinery are "easier to repair than sheet goods." Sheet goods referred to wood products like plywood and particleboard that come in standard dimensions and are used in most contemporary building projects in the U.S. Rather than replace finite resources, Stan suggests cutting away the damaged wood.

Cutting and replacing the damaged wood using a scarf joint meant not only coping with scarce resources but embracing opportunities for performativity: making the fir's emergent changes and irregularities more apparent to the future inhabitant. Consider, for example, when instructor James advised rounding the edges of visible joints to draw attention to their handmade nature and to blur the visual lines:

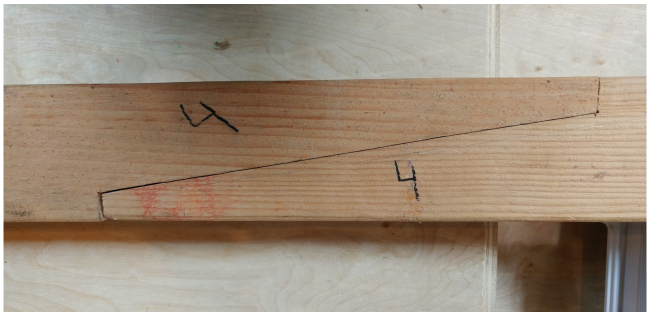

Figure 5. A well fitted scarf joint helps make a longer timber out of shorter pieces or repair damage

James: *"Hollow the outside of the joint slightly so that when it shrinks – which will occur – it doesn't look like it doesn't fit. You basically create a more visible line and 'announce' the joint from the get go."*

Ralph: *"Yeah, so if you're doing this by hand, you might as well make it interesting, which might even be harder to do than just making it straight. There's room for error, but if you know there's going to be error you can make it interesting."*

Trina: *"Do it intentionally."*

Stan: *"But know after it's been there a year, it will be different."*

As we see in the exchange above, resource scarcity did not necessarily represent something to fix or avoid. At this site, mistakes and instabilities undergird a performance of "announcing the joint." Announcing the joint involved making the work "interesting," helping distinguish craft building techniques from those of mass production by highlighting their modest partnership with living materials. Here we begin to see the scarf joint as a technique for accounting for the contemporary scarcity of long timbers while celebrating their aesthetic form. Through recognizing this scarcity, builders construct a strong material fit from the start and develop the skills needed to care for the material fit as it wears out over time.

DISCUSSION

The five lessons discussed above highlight important aspects of living material under-examined in HCI research to date, whether around digital fabrication or sustainable design. As more nuanced understandings of agency have entered the HCI literature, researchers confront a decentered designer and the challenges of taking up new theoretical understandings of designer-material relationships. Although readers familiar with woodworking tools and practice may find the insights knots, wood grain, etc. bring to design materials obvious, we argue that as HCI contends with a growing range of living materials and fabrication techniques in contexts of natural resource scarcity, designers must reconsider their engagement with traces of provenance, legibility, reparation and decay. It is these modes of entanglement with histories of encounter and wider ecologies that our lessons highlight for design. Working with legible textures, defensive traces, and reparative expressions draws our attention to the vibrant agencies that flow through materials and can be engaged as design resources; in the woodshop, the fir is an active co-designer with a rich life of its own to be understood and grappled with, instead of a latent, passive resource awaiting encounter with a human designer or machine.

Furthermore, we saw non-human materials appreciated as active collaborators with life cycles bound up with our own. This entangled relationship stemmed from processes of damage and response: ecological engagements central to both the design process and the finished structure but that began long before the tree was cut into wood, its sap crystallized in the kiln. The timber framing practices we cultivated contrast with contemporary currents in biodesign and digital fabrication that rely on deadening the materials at hand by rendering them steady and predictable, with clearly bound and operationalized properties to be controlled at a discrete and all-important design moment.

The lessons from the woodshop thus offer designers another way of working with properties and natural processes, particularly in biodesign, sustainable design, and digital fabrication. Instead of treating Nature as "out there" [51], waiting to be mined for raw materials or models of biological processes, we see tactics that seek to temper such extractive sensibilities and instead grapple directly the contentious meeting points of ecological and fabrication processes. Making scarcity and resource limits a central design engagement draws attention to the rhythms of ecological growth and decay in which HCI participates. The reparative expressions, vital decay, and performative scarcity we found while working with wood invite approaches to sustainable technology development that recognize Nature and technology as mutually constituted, each responsible for the dynamics of those constitutive relationships. This kind of design work requires a view of the complex, intersecting temporalities and scales of design activity, along with tactics for navigating them, which we outline below.

We now turn to a discussion of such design practices with living materials, exploring the above lessons from timber framing to help answer our first research question: *What does the interplay between the properties of living materials and their environment from which they came reveal about new materials?* Through practicing alongside master builders and fellow students, we learned that with experience a carpenter can read her material's life history, recognize certain types of wear and damage are inevitable, and use her knowledge of the wood's specifics and its predicted life ahead to engage in design activity that centers and engages the living qualities of the material – the histories and propensities of the grain and knots, weeping sap, and encounters with forces of wear and decay.

So far we have focused on the materials themselves, but we have also moved across a process of design: from the material's arrival on site to its usage and repair. In learning from a site where design with living materials has been a long-standing practice, we now outline possible strategies for engaging these qualities in HCI design work in addressing our remaining research questions: *What lessons might timber framing processes have for the sites, practices and pedagogies of sustainable design? And how might living forms such as wood extend digital craft materials?* A core commitment of each of these strategies involves identifying the multiple temporalities design work with non-human actors orders and inhabits. Ralph called this "four-dimensional thinking", looking at the living material now for hints as to how it will act over time in a given arrangement.

Designing for material recuperation

HCI has long attended to how computational tools, systems and infrastructures comprise components sourced from a variety of sites and regions. In the woodshop we saw sourcing in action in the frictions between the liveliness of young, kiln dried fir timbers and building methods that work best with old-growth timber that is increasingly scarce due to excess resource extraction. Emphasizing the need to work in alignment with the wood's past and future revealed timber framing as a method of attending to the scarcity of the materials at hand, coordinating with the life cycles of forestry growth and human extraction processes. Timber framing methods provided pathways for countering excessive resource extraction, making resource stewardship a central engagement emerging from the tiny house building process. How might HCI take up similar stewardship commitments to not use more materials than what the earth can regenerate?

In addition to paying attention to supply chains [42], HCI needs ways of examining and situating design activities in terms of the finite resources that sustain them, particularly the rates and rhythms at which those materials are generated and used. While on the surface the materials common to technology development may not appear to be living in the way wood is living (i.e. organically), we can trace every material we use back to extractive processes somewhere; even digital materials have an extraction cost, not least in the energy sources that keep code alive and devices powered. As researchers continue to explore self-assembling [35] and self-healing materials, promising opportunities for other surfaces like damaged mobile phone screens[1], our work points in a different direction towards rehabilitative design processes that take into account the scale, open-endedness, and diversity of actors involved in "healing" materials.

Design work exploring material recuperation processes involves locating opportunities for offsetting or repairing such extractive relationships, a process that Haraway calls "making-with" [22, 36]. Just as we saw in building a house that should last longer than it took the component trees to grow, designers can orient technology development around the generative tensions between the collaborative survival needs of humans and the other species on which our lives and livelihoods as HCI designers depend. For example, the practice of acknowledging the scarcity of large timbers and avoiding wasting wood by designing modularly out of smaller pieces of douglas fir offers an important contrast to the material use practices of digital fabrication like CNC milling, printed circuit board production, and electronic component use. While the latter processes often rely on making forms out of larger blocks of material manufactured for those purposes, thus producing substantial waste in the form of removed material, temporary supports, and discarded misprints, our work suggests turning to alternative tools and processes for fabrication using less material. Beyond such reductions, researchers could also explore ways of broadening fabrication practice to include salvage materials (e.g. fabrication scraps) and engage with their circulation infrastructures (e.g. e-waste non-profits). Digital craft work like Zoran's hybrid re-assemblages [60], Jackson and Kang's broken objects [27], and Rosner et al.'s designing with traces [46] provide important starting points for such explorations.

In addition to making contemporary digital fabrication techniques less wasteful, creating more durable and repairable artifacts, offsetting the carbon footprint of computational work, and exploring self-healing materials, we see openings for multispecies collaborations for material recuperation. Applications like Forest[2] (which partners with a non-governmental organization to plant trees on behalf of users who stop using their phones for specific periods of time each day) are a step in this direction, but there is room to explore the ways of more thoroughly integrating extractive technology products and processes into ecosystems of preservation and regrowth.

Collaborating with more-than-human actors & timescales

Where we saw tensile and compression strength, hardness, and rot resistance as important qualities of durability in woodworking, we may care more for the ability of materials to conduct heat or electricity (e.g. the fan on a computer) in computational systems design. Similarly, forces of wear and decay may look different at the scale of devices at which HCI has operated for decades, and that of interactive environments and buildings. Paying attention to how forces of wear and decay are treated at the level of a building

---

[1] http://www.independent.co.uk/life-style/gadgets-and-tech/news/self-healing-technology-one-step-closer-after-scientists-produce-aircraft-wings-which-fix-themselves-10302249.html

[2] https://www.forestapp.cc/en/

versus device or algorithm reveals important assumptions about where the scope of design work ends – when the artifact or interaction breaks, is overwritten by a new version, or otherwise rendered obsolete from the designer's perspective.

This project prompts HCI designers to look beyond the immediate screen, system, or users to the wider environmental, biological, and ecological actors that shape and radically rework the operative timescales of design activity before the human designer enters the scene. Work like Devendorf's postanthropocentric making [13] and generative design frameworks such as Oxman's material ecology provide an important step in bringing materials' and tools' agencies into clearer view in digital fabrication practice; however, material ecology still embraces a particular notion of "biology as technology" [40], divorcing non-human actors from their native environments and livelihoods to be put to use by the human designer at a paramount fabrication moment. The ethnographic project presented here indicates an opportunity to decenter the human designer further, recognizing the historical and ecological locatedness of more-than-human encounters. Such decentering begins with noticing, reading and appreciating the material's life history prior to and extending beyond the design moment without framing it solely in terms of its value to humans. As we saw in the woodshop, this ongoing process of discovery and interpretation happens through making traces of the fir's past encounters visible and legible in the embodied practice of cutting joinery, noticing moment to moment what the wood is telling of its past and how that history might continue to play out as time brings forces of wear and decay as co-designers. The particular histories of the human actors matter just as much – noticing and working with the wood's longer biography in the process of building requires skills and muscle memory written to the body over months in this case and decades in the master builders'.

We emphasize that working with material histories is not the same as just knowing *about* them; such skills cannot be neatly operationalized and plugged into the modelling activities that currently dominate digital fabrication, e.g. solved with a machine vision function. Instead this view insists on working through material histories and recognizing the human designer's intervention as a temporary and modest collaboration (with potentially immodest repercussions) situated in a longer biography. This shifts our view of the designer's task to that of negotiating meeting points between different material histories and forces of dissolution, wrangling appropriate wear out of intersecting encounters.

This "four-dimensional thinking" as classmate Ralph called it, provides a different avenue for engaging the material changes entailed by 4D printing through situating the designed artifact and material in a broader scheme of more-than-human encounters. Like announcing the joint that is eventually going to move out of alignment, designers and fabrication researchers might re-examine the possibilities for computational composites and new property-changing materials to turn the glitches and flickers of electronic decay into meaningful glimpses of a broader ebb and flow of computational materials and their life cycles.

Approaching material properties as prototyping sites

In HCI, properties are often treated as fixed attributes of the material to be manipulated. Contemporary 3D printing technology, for example, relies on comparably inflexible computational models of material properties and programmable parameters for assembling them. Many biomimesis and biodesign approaches still treat material as passive – extracting natural processes like cell duplication from their settings to drive novel design and fabrication processes. By continually measuring, analyzing and recombining different properties such as tensile strength or conductivity, designers forge new materials with desired and predictable results [e.g. 58]. In the woodshop, however, we saw that properties were not always predictable and changed in conversation with the tools and task at hand: knotty fir can be desirable or not depending on how it's used, and intentionally worn wood is a testament to the builder's skill and foresight as much as a problem to be controlled. We saw the properties of the wood emerge moment to moment when chisel meets grain, being revealed in the tree's history, the woodworker's skill and tools, and non-human forces.

Taking a lesson from the woodshop, we see material properties as temporary, as sites for momentarily holding together a relationship between a material and its meaning in a situated fabrication practice. In doing so we gain opportunities to read properties as prototypes of these relationships, open to reworking. We use "prototyping" here to denote the tenuous and temporary alignments between material and meaning, explorations into what the properties might be *for now* and in *this* assemblage. Attending to properties as situated prototypes of what might be instead of universal, permanent, and impressed upon, the material opens new pathways to explore and rework taken-for-granted material behaviors like "conductivity", "self-healing", or "flexibility".

This points towards the value of design tools and techniques for speculative materials prototyping, for defamiliarizing taken-for-granted material properties anew. Instead of a reflexive conversation [50] about how a material might function within a solution, a designer might look to more speculative conversations, intra-actions with tools, living beings, and artifacts that make materials strange to reveal their overlooked or surprising qualities outside a specified problem-solution frame. How can we make familiar materials with settled properties strange again? How can we better see their potentialities as open-ended? One approach complementary to that of deconstruction [38] might be taking common materials –

aluminum, glass, plastic, conductive wire – and building a series of speculative artifacts that seek to deploy less obvious characteristics of the material.

In parallel, researchers working to develop novel digital fabrication materials and techniques might pursue alternatives to programmable physical materials with predictable and consistent properties. As we have demonstrated, in designing with living materials properties may change in response to being worked with, and which properties are considered desirable and applicable can shift in the hands of experienced practitioners. Technical infrastructure like fabrication machinery, software, post-processing techniques, and documentation could better support such transformations if developed around more flexible and situated notions of properties. Researchers could also explore means of incorporating shifting properties across the lifetimes of printed objects by locating additional avenues for human and more-than-human interventions beyond the fabrication moment.

CONCLUSION

HCI’s interest in living, changing materials both in theory and in application has brought new challenges for designers. Using timber framing as a lens, we have shown how centering the living qualities of materials — grappling with materials as non-human design collaborators — decenters designers and situates them in longer material histories that extend from traces of past encounters into future forms. In the woodshop we learned how design activity takes place alongside and *through* forces of decay and resurgence where new fabrication and resource scarcity meet, highlighting five characteristics of living materials that interrogate contemporary design practice: legible textures, defensive traces, reparative expressions, vital decay, and performative scarcity.

We also learned that cultivating a design practice with these living material characteristics requires multiple methodological reorientations. The first is a move away from treating materials as passively awaiting designer intervention in order to see agency in action; looking more closely we find materials have their own lives that extend before and after the design encounter. In this approach, materials and non-human forces become active collaborators in design, and the human designer’s touch is just one of many important meeting points from the material’s historically grounded perspective. Second is a move away from treating Nature as somehow separate from HCI practices or as a boundless source of raw materials and fabrication models; instead it suggests turning toward mutually constituted technology development pursuits that inhabit the messy intersections of ecological and industrial processes. When viewed as alive alongside humans, materials enact resource scarcity and limitations as central design engagements requiring recognition of the rhythms of ecological growth and decay for which HCI practices are partially responsible.

Lastly, our work expands a program of work on computational composites and digital material within HCI by exploring properties as temporary alignments between material proclivities, tools, and meanings rather than fixed attributes of the material to be manipulated. The designer’s task, we argued, is to work alongside living materials, exploring their possibilities and crafting more sustainable relationships in partnership with non-human collaborators.

ACKNOWLEDGMENTS

We thank our interlocutors in the woodworking community in Port Townsend, including the instructors, classmates, and douglas fir we worked with. We also thank Audrey Desjardins, Sarah Fox, and other colleagues who have provided feedback on this project along the way. We lastly thank our generous reviewers, whose input and encouragement improved this paper.

This work was made possible by financial support from the National Science Foundation grants 1453329, 1423074, and 1523579.

REFERENCES

1. Abowd, G. D., Atkeson, C. G., Bobick, A. F., Essa, I. A., MacIntyre, B., Mynatt, E. D., & Starner, T. E. (2000, April). Living laboratories: the future computing environments group at the Georgia Institute of Technology. In CHI'00 Extended Abstracts on Human Factors in Computing Systems (pp. 215-216). ACM.
2. Akrich, M. "The De-Scription of Technical Objects in Bijker and Law (eds.) Shaping Technology/Building Society: Studies in Sociotechnical Change." (1992).
3. Barad, K. (2003). Posthumanist performativity: Toward an understanding of how matter comes to matter. *Signs: Journal of women in culture and society*, *28*(3), 801-831.
4. Bennett, J. (2009). Vibrant matter: A political ecology of things. Duke University Press.
5. Bergström, J., Clark, B., Frigo, A., Mazé, R., Redström, J., & Vallgårda, A. (2010). Becoming materials: material forms and forms of practice. *Digital Creativity*, *21*(3), 155-172.
6. Blevis, E. (2007, April). Sustainable interaction design: invention & disposal, renewal & reuse. In *Proceedings of the SIGCHI conference on Human factors in computing systems* (pp. 503-512). ACM.
7. Burawoy, M. (1998). The extended case method. *Sociological theory*, *16*(1), 4-33.
8. Coelho, M., Poupyrev, I., Sadi, S., Vertegaal, R., Berzowska, J., Buechley, L., ... & Oxman, N. (2009, April). Programming reality: from transitive materials to organic user interfaces. In *CHI'09 Extended Abstracts on Human Factors in Computing Systems* (pp. 4759-4762). ACM.

9. Cohn, M. L. (2016, February). Convivial Decay: Entangled Lifetimes in a Geriatric Infrastructure. In *Proceedings of the 19th ACM Conference on Computer-Supported Cooperative Work & Social Computing* (pp. 1511-1523). ACM.
10. De Laet, M., & Mol, A. (2000). The Zimbabwe bush pump mechanics of a fluid technology. *Social studies of science*, *30*(2), 225-263.
11. Desjardins, A., & Wakkary, R. (2016, May). Living In A Prototype: A Reconfigured Space. In Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems (pp. 5274-5285). ACM.
12. Devendorf, L., & Ryokai, K. (2015, April). Being the Machine: Reconfiguring Agency and Control in Hybrid Fabrication. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems* (pp. 2477-2486). ACM.
13. Devendorf, L., De Kosnik, A., Mattingly, K., & Ryokai, K. (2016, June). Probing the Potential of Post-Anthropocentric 3D Printing. In *Proceedings of the 2016 ACM Conference on Designing Interactive Systems* (pp. 170-181). ACM.
14. DiSalvo, C., Sengers, P., & Brynjarsdóttir, H. (2010, April). Mapping the landscape of sustainable HCI. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (pp. 1975-1984). ACM.
15. Dourish, P. (2017). The Stuff of Bits: An Essay on the Materialities of Information. MIT Press.
16. Fernaeus, Y., Jonsson, M., & Tholander, J. (2012, May). Revisiting the jacquard loom: threads of history and current patterns in HCI. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (pp. 1593-1602). ACM.
17. Fernaeus, Y., & Sundström, P. (2012, June). The material move how materials matter in interaction design research. In *proceedings of the designing interactive systems conference* (pp. 486-495). ACM.
18. Fox, S., Ulgado, R. R., & Rosner, D. (2015, February). Hacking culture, not devices: Access and recognition in feminist hackerspaces. In Proceedings of the 18th ACM conference on Computer supported cooperative work & social computing (pp. 56-68). ACM.
19. Giaccardi, E., & Karana, E. (2015, April). Foundations of materials experience: An approach for HCI. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems* (pp. 2447-2456). ACM.
20. Gibson, J. J. (1979). The ecological approach to visual perception. Psychology Press.
21. Graham, F. D., & Ulrey, H. F. (1966). *Audels carpenters and builders guide*. T. Audel.
22. Haraway, D. J. (2016). Staying with the trouble: Making kin in the Chthulucene. Duke University Press.
23. Houston, L., Jackson, S. J., Rosner, D. K., Ahmed, S. I., Young, M., & Kang, L. (2016, May). Values in repair. In Proceedings of the 2016 CHI conference on human factors in computing systems (pp. 1403-1414). ACM.
24. Ikemiya, M., & Rosner, D. K. (2014). Broken probes: toward the design of worn media. Personal and ubiquitous computing, 18(3), 671-683.
25. Ingold, T. (2013). Making: Anthropology, archaeology, art and architecture. Routledge.
26. Jackson, S. J. (2014). Rethinking Repair. Media technologies: Essays on communication, materiality, and society, 221-39.
27. Jackson, S. J., & Kang, L. (2014, April). Breakdown, obsolescence and reuse: HCI and the art of repair. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (pp. 449-458). ACM.
28. Jacucci, G., & Wagner, I. (2007, June). Performative roles of materiality for collective creativity. In *Proceedings of the 6th ACM SIGCHI conference on Creativity & cognition* (pp. 73-82). ACM.
29. Jung, H., & Stolterman, E. (2011, January). Material probe: exploring materiality of digital artifacts. In *Proceedings of the fifth international conference on Tangible, embedded, and embodied interaction* (pp. 153-156). ACM.
30. Jung, H., & Stolterman, E. (2012, October). Digital form and materiality: propositions for a new approach to interaction design research. In *Proceedings of the 7th Nordic Conference on Human-Computer Interaction: Making Sense Through Design* (pp. 645-654). ACM.
31. Kahn, L. (2012). *Tiny Homes: Simple Shelter*. Shelter Publications.
32. Karana, E., Giaccardi, E., Stamhuis, N., & Goossensen, J. (2016, June). The Tuning of Materials: A Designer's Journey. In *Proceedings of the 2016 ACM Conference on Designing Interactive Systems* (pp. 619-631). ACM.
33. Kuznetsov, S., Taylor, A. S., Regan, T., Villar, N., & Paulos, E. (2012, June). At the seams: DIYbio and opportunities for HCI. In *Proceedings of the Designing Interactive Systems Conference* (pp. 258-267). ACM.
34. Lave, J. (2011). Apprenticeship in critical ethnographic practice. University of Chicago Press.
35. Le Goc, M., Kim, L. H., Parsaei, A., Fekete, J. D., Dragicevic, P., & Follmer, S. (2016, October). Zooids: Building blocks for swarm user interfaces. In *Proceedings of the 29th Annual Symposium on User Interface Software and Technology* (pp. 97-109). ACM.

36. Lindström, K., & Ståhl, Å. (2017). Plastic Imaginaries. *continent.*, *6*(1), 62-67.
37. Maestri, L., & Wakkary, R. (2011, November). Understanding repair as a creative process of everyday design. In *Proceedings of the 8th ACM conference on Creativity and cognition* (pp. 81-90). ACM.
38. Murer, M., Vallgårda, A., Jacobsson, M., & Tscheligi, M. (2015, January). Un-Crafting: Exploring Tangible Practices for Deconstruction in Interactive System Design. In *Proceedings of the Ninth International Conference on Tangible, Embedded, and Embodied Interaction* (pp. 469-472). ACM.
39. Norman, D. A. (1988). *The psychology of everyday things*. Basic books.
40. Oxman, N., Ortiz, C., Gramazio, F., & Kohler, M. (2015). Material ecology.
41. Pargman, D., & Raghavan, B. (2014, October). Rethinking sustainability in computing: From buzzword to non-negotiable limits. In *Proceedings of the 8th Nordic Conference on Human-Computer Interaction: Fun, Fast, Foundational*(pp. 638-647). ACM.
42. Raghavan, B., & Hasan, S. (2016, June). Macroscopically sustainable networking: on internet quines. In *Proceedings of the Second Workshop on Computing within Limits* (p. 11). ACM.
43. Robles, E., & Wiberg, M. (2010, January). Texturing the material turn in interaction design. In *Proceedings of the fourth international conference on Tangible, embedded, and embodied interaction* (pp. 137-144). ACM.
44. Rosner, D. K., & Ames, M. (2014, February). Designing for repair?: infrastructures and materialities of breakdown. In Proceedings of the 17th ACM conference on Computer supported cooperative work & social computing (pp. 319-331). ACM.
45. Rosner, D. K., & Fox, S. E. (2016). Legacies of craft and the centrality of failure in a mother-operated hackerspace. new media & society, 18(4), 558-580.
46. Rosner, D. K., Ikemiya, M., Kim, D., & Koch, K. (2013, April). Designing with traces. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (pp. 1649-1658). ACM.
47. Rosner, D. K., & Ryokai, K. (2009, October). Reflections on craft: probing the creative process of everyday knitters. In Proceedings of the seventh ACM conference on Creativity and cognition (pp. 195-204). ACM.
48. Rosner, D. K., & Taylor, A. S. (2011, May). Antiquarian answers: book restoration as a resource for design. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (pp. 2665-2668). ACM.
49. Rosner, D. K., & Taylor, A. S. (2012). Binding and aging. *Journal of Material Culture*, *17*(4), 405-424.
50. Schön, D. A. (1983). The reflective practitioner: How professionals think in action (Vol. 5126). Basic books.
51. Taylor, A. S. (2011, May). Out there. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (pp. 685-694). ACM.
52. Tholander, J., Normark, M., & Rossitto, C. (2012, May). Understanding agency in interaction design materials. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (pp. 2499-2508). ACM.
53. Tomlinson, B., Blevis, E., Nardi, B., Patterson, D. J., Silberman, M., & Pan, Y. (2013). Collapse informatics and practice: Theory, method, and design. *ACM Transactions on Computer-Human Interaction (TOCHI)*, *20*(4), 24.
54. Tsaknaki, V., & Fernaeus, Y. (2016, May). Expanding on Wabi-Sabi as a design resource in HCI. In Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems (pp. 5970-5983). ACM.
55. Tsing, A. L. (2015). The mushroom at the end of the world: On the possibility of life in capitalist ruins. Princeton University Press.
56. Vallgårda, A. (2014). Giving form to computational things: developing a practice of interaction design. *Personal and Ubiquitous Computing*, *18*(3), 577-592.
57. Vallgårda, A., & Redström, J. (2007, April). Computational composites. In Proceedings of the SIGCHI conference on Human factors in computing systems (pp. 513-522). ACM.
58. Vidimče, K., Wang, S. P., Ragan-Kelley, J., & Matusik, W. (2013). OpenFab: a programmable pipeline for multi-material fabrication. ACM Transactions on Graphics (TOG), 32(4), 136.
59. Wiberg, M. (2014). Methodology for materiality: interaction design research through a material lens. *Personal and Ubiquitous Computing*, *18*(3), 625-636.
60. Zoran, A., & Buechley, L. (2013). Hybrid reassemblage: an exploration of craft, digital fabrication and artifact uniqueness. Leonardo, 46(1), 4-10.