Decomposable Interactive Systems

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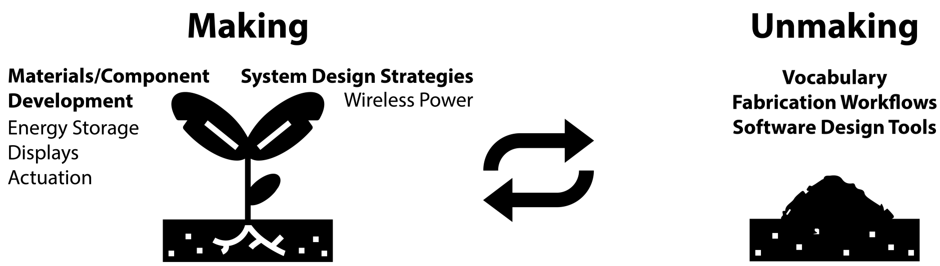

Figure 1: Overview of this work's approaches to creating a landscape of decomposable interactive systems.

ABSTRACT

As sustainability becomes an increasingly pressing concern across disciplines, the design and fabrication communities within HCI are rapidly discovering and sharing a wealth of novel materials, tools, and workflows, allowing us to make physical artifacts that are more eco-friendly than ever before. Still, sustainability and functionality are often at odds with one another when it comes to the design of interactive systems, with most systems still relying on conventional electronic components that must be extracted and individually handled at end of life. My work offers approaches for designing decomposable interactive systems that are made with materials that are widely available, safe, and even edible, empowering the "everyday designer" to make sustainable systems for applications that do not demand long operation times or high power. Enabled by the growing ecosystem of decomposable materials and systems, I also propose new opportunities for designing for unmaking, a counterpart to making that opens the opaque, industrial processes of recycling and composting as rich design spaces to encourage further engagement and critical reflection around themes of sustainability, materiality, and consumption.

CCS CONCEPTS

• **Human-centered computing → Interaction techniques**; **Interaction paradigms**; **Interaction devices**.

KEYWORDS

sustainability, decomposable systems, edible electronics, wearable technology, DIY, unmaking

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1 INTRODUCTION

Amidst the looming threats of climate change and ecological crises, sustainability has become a prominent priority across research disciplines. HCI researchers and practitioners have embraced many approaches to sustainability; in the fabrication and design communities in particular, one prominent method of making more sustainable tangible systems is to develop and prioritize the use of materials with a carbon footprint as small as possible [2]. Many of these materials, such as mycelium, have been widely adopted, both in research and commercial applications [1, 8–10]. Still, when it comes to making systems that are *interactive* and responsive, functionality and sustainable material selection are often conflicting desires, with most "eco-friendly" materials being suitable only for enclosures and other passive components. Additionally, many materials labeled as "biodegradable" and "compostable," such as poly-lactic acid, require specialized industrial conditions to degrade and still end up as landfill at end of life.

My dissertation work centers on developing **decomposable interactive systems** – that is, systems that are interactive and functional but, at the same time, readily degradable under "backyard," non-industrial conditions once they are no longer needed. I take two complementary approaches to creating decomposable systems. The first is a materials-centric approach to design electrical components – for example, energy storage, displays, and mechanical actuators – for stand-alone interactive systems that are decomposable in their entirety. My second approach augments the prioritization of decomposable material selection with system design strategies to find solutions for applications that demand higher levels of power or longer operation times than stand-alone decomposable systems can currently provide. In this paper, I present past and ongoing projects that exemplify these approaches and also present a case for unmaking, a counterpart to making enabled by the prioritization of decomposable materials.

First, however, it is worth noting that decomposable interactive systems admittedly may not be suitable for all applications. For one, designing within the limitations of "safe" workflows and degradable materials comes with inherent performance trade-offs that make it difficult to imagine high-power or high-speed systems that are fully decomposable. Furthermore, some systems are in fact intended to be used for virtually forever, and it would be more sensible (and sustainable) to design such systems to be as durable as possible instead of focusing on their decomposability. Nonetheless, as this paper will elaborate upon, there are plenty of naturally low-power and temporary interactions for which the conventional approach of creating durable electronics is both overkill in terms of performance and wasteful in terms of materials resources; these are the domains that I argue would benefit from decomposable interactive systems.

2 MAKING: DECOMPOSABLE COMPONENTS

The materials-centric approach of my work is dedicated to the development of individual electrical components as building blocks for stand-alone decomposable interactive systems. I envision these systems as ones that are self-powered and made with an array of components – energy harvesters, energy storage, sensors, displays, actuators, interconnects, etc. – that are all fully decomposable, allowing entire systems to be conveniently disposed of in a garden, for example, for easy degradation and perhaps even soil enhancement. While much work remains to be done to develop complex systems, I subsequently describe two projects that take this approach and discuss how the two can even be combined to create a 100% decomposable interactive wearable.

2.1 Vims: Energy Storage

Energy storage is fundamental to the operation of virtually all electronic interactive systems, but it poses one of the most serious challenges in making these systems sustainable. Batteries, the most common solution for energy storage, rely on toxic metals, such as cadmium, lead, or lithium, that are extracted through resource-intensive processes, and they must be carefully recycled or contained at end of life. Waste handling is particularly problematic for not only individual designers but also electric car manufacturers and consumer electronics companies. Lithium ion batteries that are improperly disposed of in regular landfills can cause fires, endangering nearby communities.

Vims, illustrated in Figure 2, are Do-It-Yourself-friendly energy storage elements that can be made using hand tools with graphite, activated charcoal, food-grade binders, and salt, among many other widely available materials [7]. Vims are highly customizable and mechanically flexible. As they are supercapacitors, they may be charged quickly – to 2V in a few minutes under a constant-voltage charging scheme and a few seconds under a constant-current charging scheme – and are capable of delivering current on the order of milliamps. They may simultaneously serve as both power sources and decorative elements in a design, making them more desirable from an aesthetic and design point of view than batteries, which come in rigid, pre-determined sizes. By joining 4-5 Vims together in series, we can power low-power applications for >24 hours.

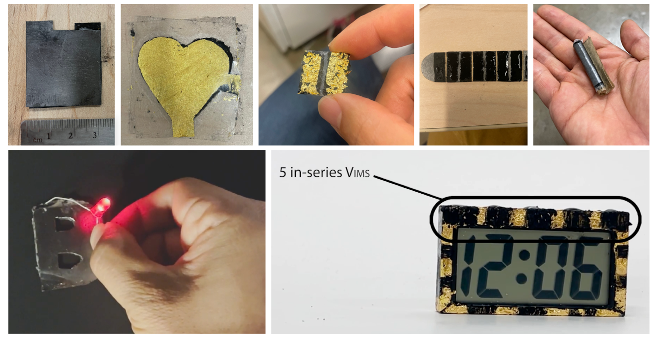

Figure 2: Top: Vims are energy storage elements that can be made using hand tools in a variety of shapes, colors, sizes, and geometries to best suit various applications. Bottom: they may power LEDs and small electronics, doubling as decorative elements.

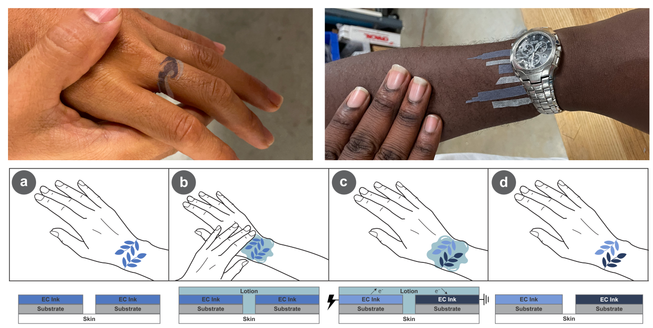

Figure 3: Top: *Vims* are energy storage elements that can be made using hand tools in a variety of shapes, colors, sizes, and geometries to best suit various applications. Bottom: they may power LEDs and small electronics, doubling as decorative elements.

Vims may be stored in ambient conditions, and charged and recharged virtually endlessly for multiple months. When no longer needed, they may be simply buried in a garden, where, as they fully degrade in a few months, they become soil conditioners.

2.2 Lotio: Wearable Electrochromic Display

Fashion is one domain for which decomposable interactive systems are ideal. Despite efforts to counter "fast fashion," pressures to continuously refresh wardrobes persist. Some accessories are only appropriate to don in certain occasional situations, and often only once; fads inevitably fall out of style. Thus, when it comes to smart wearables for accessorizing and personalizing a look, we ought to offer technology that is targeted for only a few hours' worth of wear and can then be disposed of in an environmentally responsible way.

We developed **Lotio**, a decomposable, electrochromic on-skin display that is responsive to the application of lotion [4]. The act of applying lotion is familiar, often habitual, and laden with cultural meaning. Leveraging lotion as a mediator between the wearer and

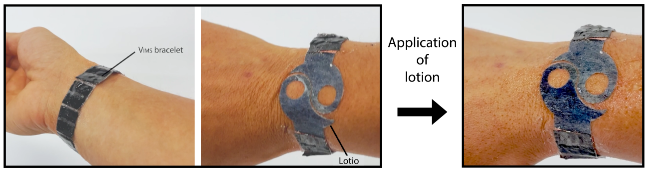

Figure 4: Vims and Lotio may be combined to form a decomposable wearable bracelet whose color changes in response to Lotio.

skin-based technologies can enable new forms of embodied interaction, augmenting the perhaps mundane act of applying lotion, imbuing it with additional meaning or playful opportunities. Figure 3 shows Lotio overlays on various skin tones as well as a schematic that illustrates the envisioned interaction. Lotio is a 2-state electrochromic display that comprises a single layer of electrochromic ink – which serve as color-changing electrodes – on a paper surgical tape substrate. The electrochromic ink we use is based on PEDOT:PSS, a polymer that readily degrades in hydrogen peroxide. Lotion serves as an electrolyte, and when applied over Lotio, it completes the circuit for the electrochromic display. As a result of the color-changing redox reactions that occur at the electrodes, parts of the Lotio design turn darker, while adjacent parts turn lighter. As lotion evaporates, Lotio returns to its original state.

Lotio is extremely low power, consuming <350µW of power when switching states and no power when not switching. By combining Lotio and Vims, we can create standalone wearables that are interactive, aesthetic, functional for more than a day on a single charge, and fully degradable in backyard soil in a few months. As seen in Figure 4, Vims can be strung in series as a bracelet and connected to a Lotio overlay, which changes color in response to lotion application, on one side of the wrist. Such a system can provide positive feedback to the user when lotion is applied through the form of playful aesthetic experiences, reinforcing healthy skin routines.

3 MAKING: WIRELESSLY POWERED DECOMPOSABLE SYSTEMS

There are several other applications for which decomposable interactive systems would be highly desirable, but the current state of decomposable materials development makes it difficult for completely standalone decomposable systems to meet ideal performance requirements. For these, I augment my decomposable materials-minded approach with a systems-level design approach to create decomposable systems that are physically separated from but can be wirelessly activated by a durable (non-decomposable) electromagnetic transmitter. The former has the benefit of being able to be disposed of in an environmentally responsible manner, and the latter ideally is either already ubiquitous or can easily be integrated into existing electronics. I describe one past and one ongoing project below.

3.1 Leaf-Based Large-Area Heaters

Packaging for food and other goods is another domain well suited for decomposable interactive systems. There is an increasing demand to integrate "smart" functionality, such as heating, freshness sensing, and tamper monitoring into packaging. An eco-conscious consumer likely wishes for packaging to be reusable, but packaging inevitably becomes too soiled or inconvenient to carry, and at that point, the packaging should be able to be disposed of responsibly.

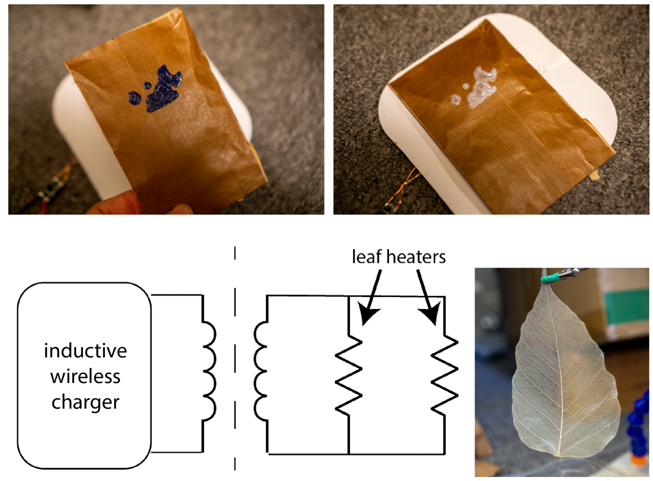

Figure 5: Top: a 100% decomposable paper packaging envelope that we developed heats its contents when placed on a standard wireless charger. Bottom: electrical schematic for our system. Silver nanowire-coated, chitosan-stabilized leaf skeletons are connected in parallel to a receiving coil with water-soluble silver ink.

Illustrated in Figure 5, we developed a fully decomposable paper packaging envelope that leverages silver nanowire-coated, chitosan-stabilized leaf skeletons as large-area Joule heaters [5]. With silver traces printed in a coil shape, the packaging couples to standard inductive chargers – available around the world in offices, airports, and other public spaces – to heat its contents up to 70°C. Finally, when no longer desirable or functional, the entire packaging envelope may be simply tossed into garden soil, where it degrades within months. Easily meeting the requirements for milk pasteurization, for instance, our leaf heaters can be easily adapted for enhanced food safety in environments and locales where specialized equipment is unavailable, among many possible expanded applications.

3.2 Edible Interactions

In-mouth and edible interactions present yet additional opportunities for decomposable systems. Edible materials are by definition easily degradable, generally possessing far lower carbon footprints than plastic alternatives or conventional electronics. Similarly, eating experiences are ephemeral by nature. One ongoing project leverages the abilities of ultrasound energy to be transmitted wirelessly and to mechanically excite structures through the skin. We combine innovations in focused ultrasound (FUS) along with techniques from molecular gastronomy and culinary science to create taste experiences with real, edible, and potentially nutritious ingredients that are not illusory or synthetic. Our system comprises a completely edible pouch, enclosing multiple different flavor capsules, that unobtrusively rests inside the mouth against the cheek.

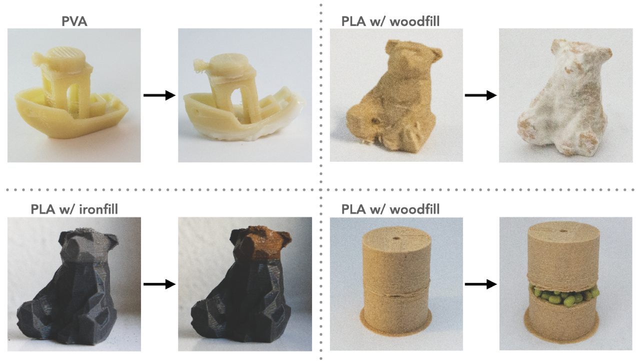

Figure 6: Examples of physical artifacts being "unmade" in accordance with the designer's intent.

The capsules are fabricated so that they may be individually and selectively burst open to release their inner flavors upon being excited by a small wireless high-intensity focused ultrasound transmitter. This transmitter, existing outside the face, can be integrated into cell phones, audio headsets, and head-mounted displays, allowing dynamic experiences to be computationally triggered and choreographed in real-time in response to stimuli such as music, gaming events, or bio-signals.

4 UNMAKING

Aside from offering new sustainable ways of making interactive systems, decomposability enables new opportunities for unmaking, a counterpart to making. With roots in movements such as Auto-Destructive Art, unmaking is a design approach that imbues destruction and decay – natural parts of the lifecycle for decomposable materials and systems – with additional emotional and potentially sociopolitical value. While not a moniker for sustainability, unmaking is an ally to sustainability, elevating the otherwise opaque processes of recycling, composting, and reuse into design spaces ripe for exploration.

My research develops vocabularies; fabrication strategies and workflows, compatible with digital fabrication tools such as 3D printers; and software design tools that enable designers to architect and plan for unmaking in the initial design process when working with decomposable materials [3, 6]. Examples of unmaking effects that may be achieved with different materials and making strategies is shown in Figure 6.

5 FUTURE WORK: DEMOCRATIZING DECOMPOSABLE INTERACTIVE SYSTEMS

I intend to continue to pursue materials and techniques for creating decomposable energy harvesting, mechanical actuators, and other more advanced components to enable a richer landscape of decomposable systems. In addition, my remaining PhD work will also develop software tools that democratize and facilitate the design of sustainable systems. I am particularly interested in prioritizing the accessibility of decomposable interactive systems to the "layperson" – one with limited access to specialized tools and materials and one with potentially limited knowledge of electronics. The landscape of decomposable interactive systems is still in its infancy, and widespread community involvement and participatory design will be critical in exploring new and perhaps unexpected applications, helping researchers interested in decomposable system design shape future technological directions, and also generally promoting new ways around thinking about sustainability, making, and consumption in society. As a first step, I seek to understand how artists, hobbyists, and novice makers with little electronics expertise think about and interact with decomposable materials and technologies so that we may develop design tools that help these users the most. I am planning a community workshop that will invite such makers to prototype electronics with Vims and a preliminary software design tool to better understand the points of confusion, the appropriate level of abstraction, and the most salient design handles to incorporate into future software tools that I plan to develop.

6 DISSERTATION STATUS

I plan to defend my dissertation in the summer of 2024. From the doctoral symposium, I seek feedback to help me frame and develop themes for my past and ongoing work. Furthermore, I am looking for critical perspectives to guide my future work in such a way that it builds on my past work and personal interests while also being relevant and interesting to the UIST and CHI communities.

7 CONCLUSION

My research aims to contribute a landscape of decomposable interactive systems that can be made and unmade by the everyday designer with widely available and sustainable tools and materials. In this paper, I have described projects that span two complementary directions: (1) a materials-centric approach that focuses on the development of electronic components – both individually and in conjunction with one another – for completely stand-alone systems that are interactive and also fully decomposable, and (2) a systems-minded approach that prioritizes a fully decomposable module while also leveraging the power of wireless transmitters that can be seamlessly integrated, if they are not already, into existing electronics and infrastructure. I aim to develop decomposable interactive systems not only as sustainable alternatives to conventional electronics where they are suitable but also as accessible technologies that more generally transform sustainability from being a mere design constraint or obligation into a new kind of opportunity for creativity and invention.

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