Upcycling as Interaction

A Research Agenda to Enable Inventive Repair

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Upcycling offers a making process for addressing the material waste that is being produced as a byproduct of disruptive innovation's adoption model. Interaction designers have seized on this opportunity to incorporate existing materials into the making process, but have largely neglected the socio-technical ecosystem that is implicated. This material myopia overlooks how transition to circular making processes must also attend to creative communities and their norms. This paper revisits arguments for upcycling as an unmaking approach to digital fabrication to clarify the role of creative communities in the process and to call for greater attention to the process of upcycling as essentially one of interaction design, albeit one that attends to its material implications.

CCS Concepts: • **Human-centered computing** → **Interaction design theory, concepts and paradigms**; *Mixed / augmented reality*; Collaborative interaction.

Additional Key Words and Phrases: Upcycling, Unmaking, Sustainability, End User Programming

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1 INTRODUCTION

Upcycling is the process of transforming an object into something of greater value or quality. It can often be contrasted with downcycling in which a material becomes degraded with reuse and recycling due to the destructive process of transforming the raw material [27]. Interaction designers have seized on upcycling as an opportunity to creatively reuse and recycle material during the process of making interactive systems [11, 13, 16, 21, 23, 25, 26, 35, 47]. In doing so, they have begun to unmake digital fabrication through inventive repair [5]. Specifically, their upcycling process disrupts the use of embedded sensing to invisibly automate daily culture and craft by asserting a right to repair black box systems as an expressive and creative process [3, 4, 45, 47].

However, an upcycled approach confronts several open research questions that are essential to the process of transformation that are not present with new systems. Specifically, upcycling intervenes in the product supply chain by creating a route from a product's end-of-life to supplying a second life as part of a circular economy. To do so, several questions arise. First, existing possessions and their related life-cycles carry layers of social meaning [2, 17, 20]. In other words, they are polyvalent [37]. As a result, they may be discarded or destroyed for reasons beyond their material condition, but to sever the relationships they are a part of [1]. Thus, how can material recapture processes be shaped to enable disposal at an owner's discretion [14]? A second, related challenge, emerges from responsibly transferring ownership once an artifact is discarded. Owners have authority and responsibility for an artifact's transformation [47], and if it has been discarded, are charged with care that they manage it responsibly [14]. This can cause serious harm if

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materials are not managed appropriately owing to the potential introduction of hazardous materials to the environment and their risks to human health [14]. How can ownership transfer of discarded materials occur responsibly? Finally, upcycling unmakes linear material flows and reconstitutes relationships in a way that must be designed for [46, 47]. In doing so, how are the existing roles and relationships of current material flows renegotiated and re-envisioned?

This paper reflects on The IoT Codex—a project to enable an upcycling approach to developing the domestic Internet of Things (IoT)—both its contributions and related work's contributions to the above open questions, and outlines remaining open problems. In doing so, this paper synthesizes the state of research on upcycling within human-computer interaction (HCI) to characterize ways that the HCI community could make progress on developing upcycling as a viable approach to incorporating computing into a circular economy.

2 HOUSEHOLD DISCARD

The world's most popular waste management system is informal and depends on small businesses. Waste management systems that are centralized, formalized, and support curbside pick-up are recent phenomena in the course of human history that enable household disposal in many western countries [48]. Challenges for western countries concentrate on enabling household recycling and sustainable business models for diverting materials away from landfill. However, much of the rest of the world heavily relies on the informal waste management sector to handle household disposal [48]. The informal sector is typically comprised of small businesses and entrepreneurs operating at the neighborhood level and using door to door techniques to collect waste [28].

Household discard offers a point of intervention for upcycling. To understand discard, ethno-archaeological methods enable researchers to examine a household's material culture by focusing on the presence/lack of artifacts and the use of space [7, 33]. Linking patterns of objects distributed throughout a site with the human activities that are responsible for their accrual and decay allows unobserved behaviors to be inferred [7]. For example, the Garbage Project used ethno-archaeological methods to analyze living persons' decisions to advance an object forward in its life-cycle or to discard it [33, 38]. These methods compliment other research methods informing upcycling such as experience design using design probes [39], design space explorations [12], surveys and studies of online communities [22], material analysis [16], and systems based approaches [23].

Garbology methods revealed that home-based and informal upcycling present longtail design challenges. Formative work for the IoT Codex employed ethno-archaeological methods from the Garbage Project to understand household discard [46, 47]. Using garbology methods—the use of ethnoarchaeological methods to study discard—to study IoT adoption in the home revealed many idiosyncratic use cases household upcycling quickly becomes entangled with [46, 47]. Although customization to unpredictable material geometries continues to have an important role in research on upcycling for idiosyncratic context (see [11, 12] verses [23, 26]), personal attachment to existing possessions and challenges with idea generation continue to pose persistent barriers to upcycling [22, 47]. Researchers note that part of the challenge with generating upcycling ideas is that design skills especially with respect to existing objects require substantial expertise [9, 41].

3 CUSTOMIZATION

Fabrication based approaches and physical prototyping are uncovering creative avenues for using maker techniques for DIY customization. Faced with the insurmountable challenges with recycling plastic [16], interaction designers are uncovering ways to upcycle plastic materials [13, 15]. Others are identifying ways that DIY fabrication approaches can eschew plastic altogether and trying to create material flows from waste [10, 35]. These approaches contribute toolkits

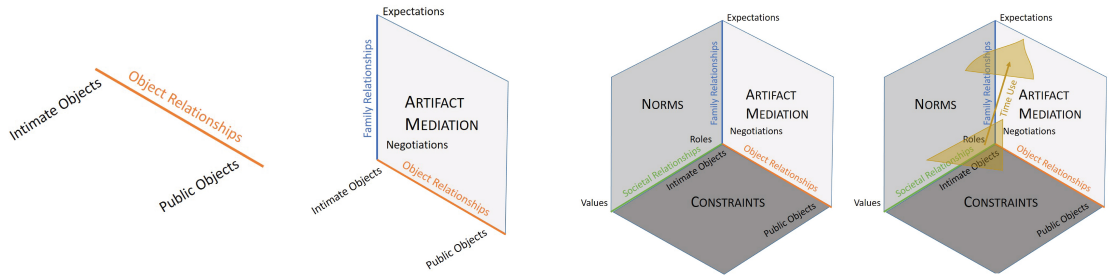

Fig. 1. The diagram shows the four axes of the Lightweight Modification Framework. As each axis is introduced, the range of concepts that axis captures are labeled and the attendant interactions are captured by the span of those axes with the exception of Time Use. The way the home's relationships evolve is conveyed as the change of the family's model of the home at two different stages.

to support end users with generating and ideating ways to incorporate upcycling into their fabrication workflows using the normative ground embodied in their user interfaces [24].

Yet, how personal fabrication techniques for household upcycling contend with small group norms remains an open question. Much of the work in this area focuses on existing institutional norms within known organizational settings. For example, electronics recapture and upcycling [25, 26] focus on design labs and maker spaces that operate in engineering education settings or NGOs created to approximate industry design settings [16, 44]. Relatedly, upcycling adaptive mechanisms appropriate for medical making assume point of care contexts that are present in western clinical contexts [19, 40]. However, in the idiosyncratic contexts of informal upcycling, imaginative authority is negotiated, collaboratively constructed and constrained among group members [34, 46]. Upcycling proposals must secure group buy in and feedback [46]. Informal upcycling is fundamentally collaborative [34, 46]. How upcycling approaches can support collaborative customization remains an outstanding challenge.

Work on the IoT Codex contributed a framework for enabling a collaborative upcycling process and developed a system to show how this might be realized in a system supportive of upcycling. The Lightweight Modification Framework makes the work households do to learn, adapt, and personalize objects within the home an explicit part of the upcycling process (see Figure 1). The Framework for Lightweight Modification centers four axes of the household's process:

- Object Relationships
- Family Relationships
- Societal Relationships
- Time Use for Evolving Relationships

Each axis of the framework illustrates a tension with the others. For example, generating ideas for upcycling an object can be constrained by the family's shared model of home as when feasibility and societal norms upheld by the family curtail ideas before they are ever seriously considered.

The IoT Codex was created as a system for at home upcycling of existing possessions into IoT devices. It constructs the creative and expressive process of upcycling as interaction design for end user programming [45]. The design space exploration is directly informed by empirical findings on family member processes of modifying the home's everyday objects. Validation of the design space is accomplished through both means of traditional validation, by building sample applications, and through a design workshop using the dialogue labs method. The workshop found that the tangible

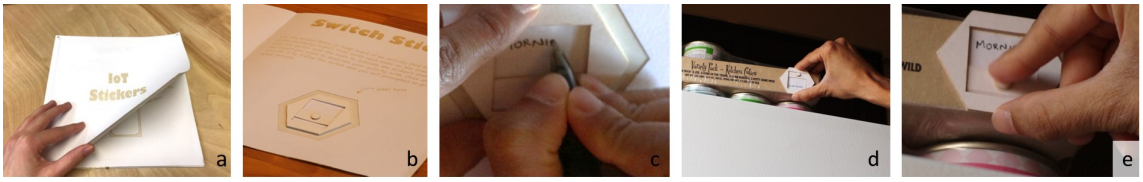

Fig. 2. The IoT Codex is a book of inexpensive, battery-free sensors and interaction patterns to support linking everyday objects to software and web services using stickers. To use, a sticker is selected, customized, peeled from the page, attached to an object, and then invoked using its kinetic mechanism.

user interface supported the group with making deictic reference to indefinite context as suitable for unarticulated assumptions implicit in small group norms. Further, The Codex supported collaborating on upcycling ideas as needed for negotiated destruction and dispossession of existing possessions [31, 32, 46, 47].

4 UNMAKING DIGITAL FABRICATION FOR INVENTIVE REPAIR

New interactions enabled by adopting IoT bring displaced processes, requirements to upgrade or reconstruct past practices, and the work of configuring the new technology to the household [47]. This displacement offers an opportunity to redefine home relationships to craft new relationships and ideals. Destruction can be employed as a deliberate design move to realize agonizing design approaches that critique portrayal of democratic discourse as a deliberative process building towards consensus, and instead, posit that disagreement and conflict are productive and healthy aspects of democratic dialogue [31, 36]. This destruction follows in the unmaking design tradition. In the home, experience design for digital fabrication revealed that household members wanted critical making tools for their home's everyday object to adapt, reappropriate, modify, and otherwise extend their possessions [39]. Interviews with families on how to modify the home with IoT uncovered the disagreement between family members when modifying shared objects in shared spaces like the kitchen and livingroom [46]. While recognizing the importance of disagreement for healthy relationships as unmaking posits, upcycling differs from agonism by designing for the coordination process that is essential for building trust in the household's IoT system [46].

An upcycled IoT recognizes how IoT's costs have become an ever growing socio-material problem. Through its preference for newness, the modern American household's excessive material consumption is having negative side-effects. These include increasing stress, deteriorating health, growing landfills, short life-cycles for non-renewable on non-biodegradable materials, and enlarged energy demands [7, 8, 29, 33, 42, 43]. Redesign for these costs needs to consider how artifacts can change relationships people ve to them and to each other [17, 20].Family members may resist an IoT artifact being domesticated to the home if trust and coordination have not been adequately established [18]. Domestic objects socialize others, and as part of this, their life-cycle carries layers of symbolic meaning that can indicate family rifts and rejected socio-material relations [1, 43, 46].

However, family members do not always have equivalent availability to do the work of integrating IoT into the home. This creates asymmetries in the ability of any given family member to lead the process of ideating, planning, and implementing an IoT modification [47]. These asymmetries can be further exacerbated by a member's technical skill which can shut down family involvement, ideas, and modifications as families defer to this member's technical expertise [46]. This asymmetry continues to be an outstanding research problem for domestic IoT, and researchers have found that it can contribute to substantial costs.

Fig. 3. Study participants collaboratively built off and modified each other's IoT proposals.

Upcycling as supported through the IoT Codex contributes an unmaking approach to digital fabrication through inventive repair. Specifically, the Codex's five sticker types and design patterns scaffolded idea generation to lower the barrier to brainstorming, involvement, and ownership over ideas to modify the home with IoT [45]. This process of imagining something new was found to be important for family members growing attached to a modification idea [46]. This attachment is important for successfully integrating a modification in the home and prolonging an artifact's lifecycle [6, 30]. The IoT Codex's embodiment of programming abstractions enabled collaborative programming composition [45]. This collaborative dynamic was found critical to family members empathizing with one another to envision proposed changes to the home [46]. This family empathy forms the basis for household reconfiguration to support redefining family member roles, routines, and obligations [46, 47]. The IoT Codex is designed to support such collaborative disagreement to nurture brainstorming and defamiliarization of problematic domestic relationships as sustained by the homes material relations as realized in its possessions (an associated object relationships). To repair such relationships, The IoT Codex draws on tangible end user programming to enable families to initiate and explicitly specify alternative socio-material arrangements for their home [45].

5 CONCLUSION

This paper reflected on outstanding challenges for upcycling and progress made by the IoT Codex. In doing so, the paper set out an agenda for interaction design of end user programming to address the idiosyncratic and creative processes needed for upcycling to become a viable approach for transforming existing objects into interactive devices. The IoT Codex contributes tangible and collaborative end user programming for reconfiguring domestic socio-material relations in a way that is responsive to domestic discard. However, the project stops short of deploying The IoT Codex in domestic settings. Further work is needed on 1) identifying and detecting moments of domestic discard for upcycling intervention, and 2) situating this disposal within economic exchange. More work is needed in this direction to enable an inventive repair process.

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