Practices in the Creative Reuse of e-Waste

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ABSTRACT
E-waste is a generic term embracing various forms of electric and electronic equipment that is loosely discarded, surplus, obsolete, or broken [27]. When e-waste is improperly discarded as trash, there are predictable negative impacts on the environment and human health. Existing e-waste solutions range from designing for reuse to fabricating with eco-friendly decomposable materials to more radical critiques of current practices surrounding capitalism and consumerism. Complementary to theses efforts, this paper presents an accessible reuse framework that encourages creativity while maintaining personal ownership of e-waste. Through a series of online surveys of existing personal e-waste stockpiling behaviors combined with observational studies of existing reuse practices, we developed a *design reuse vocabulary: materials, shapes, and operations* to enable wide ranging and creative reuse of obsolete electronics by everyday people. We operationalized this vocabulary and evaluated its legibility and usefulness. As a result, we derived a novel *reuse composition framework: reuse as-is, remake, and remanufacture* designed to be accessible and to have broader impact in encouraging creative reuse across a wide range of e-waste types beyond those specifically used in our study. We believe these frameworks will be a catalyst for the creative reuse of e-waste.

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Sustainability, e-Waste, DIY, reuse, creativity

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

General Terms
Human Factors

INTRODUCTION
Seventy-seven percent of the 1.5 million Apple's iPhone 4 sales on the first day of launch in June 2010 were upgrades purchased by existing iPhone owners [22]. Economically speaking, Apple has been successful in building a recurring revenue stream from a growing base of loyal customers. Environmentally speaking, on the other hand, the launch of iPhone 4 accelerated the creation of e-waste. In just a single day, most of those fully functioning and relatively state-of-the-art mobile phones suddenly became of little to no use: migrating into desk drawers, storage bins, and garages. While we have heard this story before [14], the sheer volume and acceleration of e-waste beyond mobile phones are staggering. More importantly, these e-waste practices significantly exacerbate environmental pollution leaving behind environmentally hazardous byproducts [26].

Electronic equipment is a ubiquitous part of modern living across the US and other developed countries. We cohabitate with electronics in a comfortable symbiosis; we watch television in our homes, listen to music on the go, and work and play on laptop computers. Americans own approximately 24 electronic products per household [5], and Europeans and Oceanians are similar: owning 26 and 22 items respectively [2,5]. Meanwhile, our relationship with electronic products is short lived; Americans replace their mobile phones every 17.5 months [13], and laptop computers every 3 years [11] on average. Such rapid change in technology resulted in a fast-growing surplus of e-waste. Approximately 30 million computers in the US and 100 million phones in Europe become obsolete or outdated each year turning into e-waste [31].

While purchasing trends follow the *replace and discard* pattern [6] by rapidly replacing old products with new ones, electronics itself does not follow this same behavior. Rather than immediately throwing things away, people often hold onto obsolete electronics [10]. For example, three-quarters of all computers ever purchased in the US remain stockpiled in storerooms, garages or basements of homes, and up to 75 percent of obsolete cell phones are stockpiled in drawers [19,30]. We posit four primary factors contributing towards this e-waste behavior:

1. **Lack of information:** information on how to properly recycle obsolete electronics is often unavailable.
2. **Burden in action:** time and location challenges for transporting e-waste are a significant barrier to proper discarding and recycling action for many consumers.
3. **Attachment or emotions**: non-technical barriers such as attachment theory [29] often play an important role in preventing individuals from relinquishing ownership of

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the objects even if the product's life span approaches a natural end [3].

4. **Restrained ideas**: while many individuals may indeed desire to reuse obsolete electronics in new ways, there is no accessible mechanism to easily discover, use, and invent intuitive and realistic ideas for reusing electronic objects to creative ideas beyond disposal and recycling.

These four factors emerged out of our own early internal research brainstorming sessions about e-waste. The first two factors were derived based on existing practices by governments and organizations, which try to build an infrastructure to reduce e-waste. The third factor came from the classical framings of attachment theory. The last factor was derived from our experiences with attachment theory, second hand cultures, and DIY communities. This fourth factor forms the basis of our research hypothesis and design opportunity.

The first two challenges above are currently being addressed by governments, manufacturers, retailers and non-profit organizations who have put significant effort into making information available and facilities accessible in order to encourage recycling e-waste. In this paper, we focus on the second two reasons for stockpiling e-waste: attachment or emotion, and lack of ideas, or access to ideas if any, about what to do with e-waste besides discarding. Particularly, our work attempts to make a contribution through two mechanisms: (1) the development of *a design reuse vocabulary* to characterize e-waste reusing patterns, and (2) a more generalizable *reuse composition framework* to inspire everyday designers to creatively reuse e-waste.

In the next section, we explain our goals in this work. Then, we provide a review of previous works in issues related to sustainability in the HCI community. Next, we describe the design of a series of field studies and key findings from data analyses. Then, we propose a subsequently evaluated reuse design vocabulary. We present a generalizable reuse composition framework for enabling and inspiring creative reuse of e-waste. Finally, we conclude by discussing the key implications of this work.

GOALS

The overarching long-term goal of this work is to find ways to facilitate latent resources such as e-waste, and to prolong the longevity of use in electronic products by its creative reuse. To tackle this problem as HCI researchers, we have three practical goals in this paper. First, we want to acquire baseline understanding of e-waste stockpiling behaviors, especially to answer why people keep end-of-life electronics instead of discarding them. Secondly, we aim to understand the existing creative reuse practices of e-waste within environmental activists and Do-It-Yourself (DIY) communities. Lastly, from these understandings regarding e-waste stockpiling and reusing cultures, we aim to develop a simple design strategy that can inspire everyday people to reuse domestic e-waste creatively and actively. We plan to derive high-level scaffolding patterns for the general e-waste reuse patterns from low-level properties regarding reuse practice patterns.

RELATED WORKS

Over the past several years, the HCI community has started to discourse the role of interaction design in sustainability. Blevis introduced the term Sustainable Interaction Design, proposing a rubric for understanding the material effects of particular interaction design cases in terms of forms of use, reuse, and disposal [3]. Since then HCI practitioners have begun investigating environmental sustainability within HCI from a variety of perspectives: exploring the material and behavioral challenges of sustainability in relation to interaction design [18]; taking account of sustainability as part of the material design of products [17]; helping elevate individuals to have a powerful voice in society, act as citizen scientists; and learn and lobby for change worldwide [21]. Our approach is to help promoting users to actively reappropriate domestic e-waste for creative reuse.

Wakkary *et al*. broadened the role of users and their identity from a mere consumer to a creative everyday designer by introducing the concept of design-in-use [24]. In their work, they claimed that people appropriate and adapt artifacts in the creative and sustainable ways in their everyday experience, which generates a set of design principles that can prompt sustainable interaction design. Our work is similar to their concept of design-in-use in that we also regard a user as an entity to elongate the useful lifespan of an artifice by creative reuse and reappropriation. While *design-in-use* took an ethnographic approach to understand everyday experience in the homes, we drew similar inspiration from Wooduff *et al*. research into informing everyday design practices through an exploration of existing green activists [28]. However, unlike their work, we focused specifically on the reuse of e-waste.

Huh *et al*. researched the adoption practices of used personal digital assistants (PDAs) with eBay users who bought used PDAs to explore reuse of outdated computing products [15]. In a similar vein, there are many programs and organizations to collect obsolete electronics to reuse creatively or to give away refurbished electronics to disadvantaged people all over the world [1,23]. While recycling is a prevalent method to dispose e-waste properly, its practice is actually in direct conflict with the known cultural practices of ownership and attachment theory [29]. The challenge was to develop complementary strategies for appropriate e-waste reuse for individuals who have desires to retain their ownership of e-waste regardless of its usefulness and functionalities. An important part of our approach is to focus on the existing practices of the creative reuse of e-waste in everyday life. The key insight is that such existing reuse practices provide for continued ownership of e-waste – one of our primary goals.

Factors besides the physical form and design of the object play another vital role in e-waste practices. Huang and Truong found out the importance of context in how people

replace and dispose of their mobile phones through a field study of mobile phone ownership, replacement and disposal practices [13]. Further, Dourish argues for a broader rhetoric surrounding environmental HCI research and scoping that takes into account significant political and cultural contexts of environmental practices [8]. While we agree that context is a crucial factor that determines the lifespan of our relationship with various consumer electronics, the focus of this paper is on the everyday design of e-waste. [25].

METHODS

We performed three different studies in this work: a Mechanical-Turk based survey, an online community observation, and a customized online survey. First, to understand the variety and personal perceptions of e-waste found in homes, we conducted an online survey using Amazon's Mechanical Turk (AMT)[1]. AMT is an online labor market where people are paid small amount of money to complete small tasks called Human Intelligence Tasks (HITs). Online AMT "workers" previewed our HIT, completed the survey voluntarily, and got paid 25 cents for each successfully completed HIT. Second, we conducted an observational study across three Do-It-Yourself online communities to understand the current practices surrounding the creative reuse of e-waste. We studied publicly available online DIY communities where we reviewed and collected items posted on the community websites and blogs in the US such as Instructables[2], Craftster[3], and Etsy[4]. From the first two studies we developed a candidate reuse design vocabulary. Lastly, we evaluated this vocabulary within individuals in various online communities such as DIY communities, environmental activists and mothers groups. The following sections further detail our methods, studies, and findings.

UNDERSTANDING E-WASTE IN HOMES

A fundamental component towards our understandings of patterns and practices regarding accumulation and reuse of e-waste is the study of domestic e-waste life and co-habitation. In this section, we describe two separate studies that were conducted to understand patterns of e-waste stockpiling behaviors and practices of e-waste reuse.

AMT Online Survey: Accumulation of e-Waste

This survey was designed to collect data on e-waste that individuals currently live with in their homes. The purpose of this survey was to acquire a baseline understanding of the types of unused electronics stored in homes and insights into the rational and personal attachment towards their e-waste. We were particularly interested in why some electronics that had reached the end of their usable lives were stockpiled in homes rather than discarded or recycled. By understanding both the types of collected e-waste and the reasoning behind keeping it, we expected to gain a baseline understanding of e-waste stockpiling behaviors.

The survey participants were asked to complete a simple task of photographing unused electronic objects in their home in its surroundings, uploading it to AMT, and answering a series of questions about the object including:

- A title/label for the photo
- What is this? (Inviting them to tell a personal story or provide a description of a pictured object)
- How long have you kept it without using it?
- Why don't you use it anymore?
- Why do you still keep it even if you don't use it anymore?
- Is this waste? (With a four point scale of acceptable answers: Yes, definitely waste; likely waste; likely not waste; definitely not waste)

In order to prevent influencing participants' perspective on obsolete electronics in their homes, we did not use the term *e-waste* or *waste* except in the last question in this survey. Our survey was not presented or framed as a study of electronic waste or waste in general.

In total, we received 179 responses over 14 days from AMT users in the United States with 41 responses filtered out for image duplicity or quality issues – plagiarized or unrecognizable images, or those with unrelated text. In the end, we analyzed 138 answers from 61 unique users (4.4 responses per user on average) with a 58% Male / 42% Female gender breakdown. The age range was 20 - 59 years old with 32 years being the average (11.6 SD).

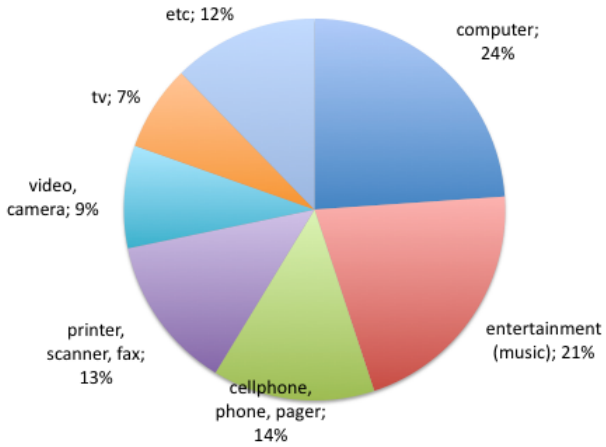

Figure 1. Proportions of e-waste by the types of electronics

The types of obsolete electronics kept in homes are analogous across households. Nearly three-fourths (71%) of all reported e-waste fell into one of only four electronics categories: computer and computer accessories (24%, *e.g.*, modems, mice, and routers); entertainment electronics

[1] Amazon Mechanical Turk, http://www.mturk.com

[2] Instructables, http://www.instructables.org

[3] Craftster, http://www.craftster.org

[4] Etsy, http://www.etsy.com

(21%, *e.g.,* video game consoles, CD players, and cassette tape players); phones (14%, *e.g.,* landline phones and cell phones); and printer/fax products (13%). (See Figure 1)

Not surprisingly, changes in technological media (e.g., CDs to mp3 players or desktops to laptops) and significant drops in retail prices (39% and 22.2% respectively) were two main reasons for why our survey participants stopped using an old but fully working products and purchased new ones. Meanwhile, only 25% of participants answered that they replaced existing electronics with new products because of broken or non-functioning issues:

> *"Buying a replacement ink cartridge was more expensive than buying a new printer. So we bought a new printer instead of refilling my old one. That still prints in pink so we might need to print lots of pink things sometime."*

Most participants had high expectations or anticipations that they would want or need to use the obsolete electronics in the future. Almost half (48%) of the participants answered "possibility for future use" as a main reason for keeping unused electronics instead of throwing them away:

> *"It [the CD player] is still in good working condition and I may have use for it in the future since I still own CDs."*

> *"I always think that I will start playing this game again. But eventually the day never came."*

However, as we evidenced in the previous quote, many participants also showed their contradicted thoughts between their expectation and anticipation of future use:

> *"I would like to use it later. But I know it would never happen. But I still hope to use it."*

11% of obsolete electronics are kept due to sentimental reasons, and 7% are kept because of a lack of knowledge or available resources to properly dispose of the electronics:

> *"There are special, environmentally friendly disposal procedures for computers and we've been too lazy to research them. We don't want to toss it the wrong way."*

One significant finding from this survey is that answers to the "Is this waste?" question were almost evenly distributed across alternatives (definitely yes: 34%; likely yes: 28%; likely not: 19%; definitely not: 19%). This wide distribution of individual values people place onto unused electronics opens up design opportunities for these objects to be reused or re-purposed since the owners express hope for reuse:

> *"Why am I keeping it? Just in case we ever get beans that aren't already ground!"*

These findings could be biased and these results are not generalizable because of the small size of user pools who are registrants on a particular website (AMT). In spite of the small sample size and possibly biased set of participants, the results still revealed some interesting insights about the characteristics of e-waste stockpiled in homes and residual values on e-waste. First, e-waste is considered different from generic waste; in fact, most obsolete electronics are not regarded as "waste". Second, much e-waste is still functioning or has either material or emotional value. Lastly, people showed a contradiction between their expectations or desires and the anticipation of e-waste for the future use of their e-waste. This sheds light onto the desire to utilize e-waste, and, at the same time, the lack of knowledge or methods for the reuse of e-waste.

Figure 2. Pictures of e-waste uploaded: desktop computers, printers, and electronics junk drawers from top to bottom

Online Community Observation: Reuse of e-Waste

Next, we collected the photos of redesigned e-waste posted to online communities. The purpose of this observation was to understand the current practices of how environmental activists and Do-It-Yourself (DIY) enthusiasts have reused obsolete electronics in creative ways. Throughout the observation of these current practices of redesigning e-waste, we developed our initial *design reuse vocabulary*. This vocabulary was derived in part from extracting various patterns of material use, e-waste forms, and reuse operations that were prevalent across these communities. We reviewed over 400 hundred unique photos with accompanying instructions for reusing various objects within three major DIY community websites hosted in the United States such as Instructables, Craftster, and Etsy. We selected 58 of these that were derived directly from electronic products.

DESIGN REUSE VOCABULARY

The combination of insights and data collected from our online survey and observation framed the choices for *design reuse vocabulary*. After examining the photos and instructions collected from our online observations, we defined three primary properties of e-waste redesign patterns based on the original properties of the object [4]: materials, shapes, and operations. To be clear, our vocabulary is not exhaustive but rather presents a novel reframing of the problem of how to inspire, enable, and encourage personal, novel reuse of e-waste.

We developed the reuse vocabulary from the previous two studies we conducted. In the first study, we examined the collected photos to extract an initial set of the vocabulary. Then, we iteratively refined the vocabulary within the

colleagues in our research group. In the second study, participants were asked to provide extra keywords if the vocabulary we provided was not sufficient. Finally, we consolidated all the keywords into the reuse vocabulary.

Material Properties

Material properties refer to the physical characteristics of the primary construction material of e-waste. We derived 20 keywords to capture a range of material properties we observed in our studies.

- Transparent/transmissive
- Opaque
- Porous
- Impermeable
- Smooth
- Rough
- Fragile
- Stiff/rigid
- Reflective
- Absorbing
- Thin
- Thick
- Heavy
- Light
- Soft/malleable
- Hard
- Sharp
- Dull
- Duplicable
- Decomposable

Shape Properties

Shape properties refer to the quality of a distinct object or body in having an external surface or outline of specific form or figure. From our observations, we derived 7 keywords to describe shape properties.

- Block/rectangular
- Hollow
- Complex
- Spherical/circular/round
- Concave
- Symmetric
- Curved

Operation properties

Operation properties are the methods or means that people apply to the artifact for reappropriation. From our studies and observations, we derived 21 keywords to describe operation properties to be applicable to e-waste reuse.

- Attach
- Bend
- Break
- Burn
- Cut
- Engrave
- Fill
- Fold
- Fuse
- Glue
- Hollow
- Lean
- Melt
- Paste
- Paint
- Sand
- Screw/unscrew
- Scratch/scrape
- Smash
- Solder
- Stack

EVALUATING THE DESIGN REUSE VOCABULARY

We conducted another survey collecting personal experiences of e-waste reuse. The purpose of this survey was to verify the design reuse vocabulary presented previously. The evaluation was conducted by asking individuals to apply the vocabulary to their own experiences of e-waste reuse. In this survey, participants were asked to complete a task of photographing the object in their home, uploading it to our customized survey, and answering a series of questions about the photographed object including:

- A title/label for this photo
- What is this? (Inviting them to tell a personal story or provide a description of this piece)
- What was it originally?
- Why did you remake this object?
- How did you remake this object?
- Apply three sets of vocabulary to this object.

For the last question, we provided sets of vocabulary in three categories; material properties of the object, shapes of the object, and techniques applied for reuse. Participants were asked to select relevant keywords from a given set of vocabulary about the photographed object. If there was no relevant keyword in a given set, they were asked to add their own keywords to describe their experience.

In total, we received 55 responses over 14 days with 13 responses filtering out for duplicity and quality issues such as images plagiarized or unrecognizable. In the end, we analyzed 42 answers from 40 unique users with 99.5% Male/ 0.5% Female gender breakdown. The age range was 18 - 63 years old with 27 years being the average (9.02 SD). We received relatively small number of responses (55 in total before filtering out) in spite of the large number of media we posted our survey on (3 DIY community websites, 8 distribution mailing lists, and 2 hackers' community websites). This directly reflects the current trend of rare e-waste reappropriation or the lack of knowledge about how to reuse it. Lastly, participants were asked to add extra keywords if they found anything missing from our design reuse vocabulary.

We found a great gender bias among the participants of this survey; only two participants (0.5%) were females while the rest (95.5%) were males. There could be two possible reasons of such an enormous gender bias; registrants in the community websites or mailing lists where we distributed our survey may be male dominant. Or, practices of remaking or redesigning electronics may be prevalent for males. We claim that the gender bias might be due to high inclination that males are more responsible for and much interested in disassembling, hacking, and playing with electronic than females. The conventional wisdom is that electronics are thought to require special skills or techniques while non-digital artifacts do not except dexterity, which is not always true. Moreover, since the survey has distributed to female-dominant communities as well such as mailing lists for moms and housewives, the chances that the gender bias might be due to the gender characteristics in communities are low.

Findings

We evidenced that participants easily and actively applied the operational design vocabulary we created to their redesigned objects. In total, 456 keywords were applied to 42 objects (11.4 keywords per object on average).

Material Properties

It was not surprising that keywords that could represent hardware's material properties such as *stiff, hard, heavy, thick, impermeable and decomposable* were used frequently with electronic objects. However, we were surprised to also find frequent usage of properties more closely associated with glass such *smooth, transparent, fragile, light, reflective* and *opaque*. An obvious explanation for this is the common integration of glass into the screens of electronics. Besides 20 keywords provided, 3 keywords were additionally proposed for material properties by participants such as *light-emitting, luminescent* and *brittle,* but nothing was significant except the fact that all keywords represent additional properties for glass properties.

Shape Properties

The most commonly used shape properties were *hollow* and *curved*. With cases and enclosures being an integral part of consumer electronics, the choice of *Hollow* is not surprising. Similarly, the industrial design trend of curved surfaces for enclosures is a likely contributor the common use of *Curved*. *Symmetric* represents one of the electronics' characteristics; electronics have accessories or components that are symmetric in shape such as floppy disks or keyboard keys. Beside 7 keywords provided, 1 keyword was additionally proposed for shape properties, *retro.*

Operation properties

Various keywords were applied to the objects frequently that could represent various simple operational property which do not require special skills such as *attach, screw, glue, cut, bend, paint, fill, fold* and *stack*. One keyword that represents a complicated operation, *solder,* was also frequently used but not as often as simple operation properties. Besides 21 keywords provided, 13 keywords were additionally proposed by participants for operation properties, which include wide range of operations from simple keywords such as *tape, stitch* and *polish* to complicated ones such as *drill, hack, melt, program, saw* and *silicon.* Especially, complicated operations were commonly proposed across different participants; *drill* was applied 8 times and *hack, melt and programming* were applied *3 times per each.*

REUSE COMPOSITION FRAMEWORK

While we were able to gain insight and value from the development and evaluation of the design reuse vocabulary, a more important goal of our work was to develop a generalizable mechanism for encouraging and enabling everyday designers to reuse e-waste creatively. We focused specifically on the *operation properties* from our studies to develop a higher-level abstraction of e-waste reuse patterns from the lower-level reuse design vocabulary. We use the term *reuse composition framework* to describe this higher-level abstraction. We classified the type of e-waste reuse into three categories from reuse design vocabulary: *Reuse As-Is, Re-make*, and *Remanufacture*. This new higher-level abstraction is the basis of our reuse composition framework which we detail further by demonstrating its usage when various reuse techniques are combined with other properties derived from our reuse design vocabulary. This framework could be a good measure to probe the reusability of e-waste before recycling or discarding it. We hope this framework will become a catalyst for everyday designers to reuse stockpiled e-waste creatively and actively.

First, we define *Reuse As-Is* as the use of e-waste for other purposes then originally designed by simple operations such as removing off or adding some parts without any expertise in manipulating electrical parts. Second, we define *Re-make* as changing the functions or features of e-waste with medium level of expertise in either crafting or manipulating electrical parts. Lastly, we define *Remanufacture* as complete reconstruction of e-waste with high level of expertise in both crafting and manipulating electrical parts. In what follows, we present a series of everyday design operations intended to help facilitate and promote the overall potential for E-waste reuse and product lifespan while still maintaining personal ownership of the E-waste. The goal is that such everyday design operations can be generalized and readily applied to a wide range of e-waste beyond those specifically used in our study.

Reuse As-Is: Aesthetics

When its appearance is aesthetically pleasing, electronics were often used as-is for other purposes than originally designed without much restructuring. In some cases, the electric parts are removed from the piece to hollow so that it can be used as a case or a holder:

"The Apple g4 Cube is a joy to service/take apart, you click down on the handle, and pull the whole computer assembly right out of the case. Put that aside you can still use the computer, without the shell."

Figure 3. First row: a USB drive, pushpins, a necklace, and a key chain made of keyboard. Second row: a walk-man soap dish, electric Halloween pumpkins, and VHS notebook covers. Third

row: an iPod shuffle Altoids case, a Mac tissue holder, and an Apple G4 tissue box.

Characters or patterns printed on the surface of artifices were also good pieces for reuse (*e.g.*, characters on a keyboard). One interesting thing is that the majority of redesigned e-waste classified in this category is Apple products like an iPod shuffle, iMac, or Apple G4, which contain a high degree of industrial design form elements. One result is that the these aesthetics in design play a role not only in prompting the original desire for the object but also serves as valuable components in its reuse. 17% of photos uploaded from the second online surveys, and 23% from online observations were classified in this category:

> *"It is small, slim, slick. Perfect for Altoid or TicTac case. Isn't it cute?" (See the bottom left photo in Figure 3)*

Reuse As-Is: Transparent & Hollow

A *transparent - hollow* pair is one of the most frequently selected keyword pairs for material and shape properties. *Transparency* is selected when the body of the electronics consisted of glass or transparent plastic materials in part or on the whole. *Hollow* was selected when the electric parts can be dismantled from the body to utilize only the body part. Light bulbs were the most popular artifices that people easily remake for creative reuse such as a plant pot, a vase, snowballs, and an ornamental piece (see the photos at the top in figure 3). Computer monitors are another type of electronics in this category that people often reused with creativity; we received two photos of fish tanks made out of old CRT monitors. 17% of photos uploaded from the second online survey, and 20% from online observations were classified in this category:

> *"I took the case of a G4 Cube, removed the computer (a simple step) and added a plexiglass bottom. Silicon and a few small brads later I had an aquarium." (See the bottom right photo in Figure 4)*

Figure 4. Light bulbs redesigned for various purposes above, and iMac speaker lights and monitor fish tanks from left to right below

We also evidenced that people are often inspired by the ideas of others when developing their own ideas for e-waste reuse.

> *"Someone posted his light bulb vase on a blog. It looked simple and pretty." (See the top photos in Figure 4)*

> *"I had seen others on the Internet make a fish tank out of an old monitor and thought it was really neat. It is geek chic." (See the last two photos at the bottom in Figure 4)*

Reuse As-Is: Block & Attach

When the shape of electronics is *symmetric* or *rectangular*, *assembly* was often applied to reuse for other purposes than originally designed. Most electronics are made of plastics or similar stiff materials in a rectangular shape making it is rigid and easy to *stack*, *attach*, or *assemble*. Depending on the size of the electronics and the number of pieces used, different forms and functions are made from the same piece. For example, ringing 2 floppy disks become a notepad, stitching 5 floppy disks becomes a pencil holder, and tying multiple floppy disks becomes a bag. These practices did not require any expertise either. 12% of photos uploaded from the second online surveys, and 15% from online observations were classified in this category:

> *"I drilled holes in the floppy disks so that they could be knotted together with twine or zip ties. These were then glued to a canvas backing and the whole thing was stitched together." (See the second photo in Figure 5)*

> *"Overall, I thought it a waste to spend money to buy something that I could make a substitute with stuff I am going to get rid of. I thought of assembling old computer components that I am too much of a packrat to get rid of." (See the right-most photo in Figure 5)*

Figure 5. A floppy disk penholder bag notepad, and a laptop desk made of keyboards and a scanner from left to right

Re-Make: Circular - Cut

The unique metallic color and shape of flat circular parts in electronics such as a hard drive and CDs were often inspiration for the creation of art or ornamental pieces. In some cases, the metallic flat surfaces were used for the base of an object. The basic operation properties applied to the circular electronic parts were *attach*, same as the one in *Reuse As-Is: Block & Attach*. Circular objects differ from rectangular ones in that additional advanced operation properties were applied altogether with *attach* such as *solder*, *screw*, and *etch*. 16% of photos uploaded from the second online surveys, and 13% from online observations were classified in this category:

> *"I had old hard drives lying around wanting to get rid of. I dissembled it and glued parts together to use as a candleholder."(See the second photo in Figure 6)*

> *"I found this platter at a flea market. Not knowing what to do with it, I bought it for $20 anyways because it was such a cool piece. After sitting in my basement for a*

while, it became apparent that the best use would be to make a coffee table." (See the third photo in Figure 6)

Figure 6. An artificial flower, a candleholder, a coffee table, and disk clocks from left to right

Re-Make: Complex & Attach

PDAs, laptops, and other similar electronics are what people tend to retain the ownerships the most due to the original monetary values [20]. At first glance, people might think it very difficult, if not impossible, to repurpose obsolete PDAs or laptops. However, we got a few obsolete PDAs and laptops repurposed as digital picture frames. Plastic parts (or casings) were dismantled, and then the monitor was attached on a picture frame. While not requiring much expertise in manipulating electronic parts, it needs elaborate crafting skills to dismantle and assemble parts to reappropriate electronics in this category. In some cases, a basic level programming skill is applied too. For example, one participant reprogrammed the digital picture frame as a clock to show time in words (see the right-most photo in Figure 7). 12% of photos uploaded from the second online surveys, and 15% from online observations were classified in this category:

"It was an old PDA and I thought I should use it for something rather than just let it sit around unused. I removed some unnecessary parts, and mounted the PDA on the back of the frame."

"I made a very simple wood frame to accommodate the dimensions of my old laptop, and reconnected the video and power cable. I use a simple slide viewer or the screen saver to run the pictures in the frame."

"It was originally a digital photo frame, but unfortunately of very poor quality that was basically unsuitable for displaying images. Rather than throw it away, I decided to re-purpose it in a way that it could be of some use."

(See the photos in Figure 7)

Figure 7. Digital photo frames made of an old PDA and a laptop, and a word clock from left to right

Remanufacture: Reform

Form factors are good clues for creative reappropriation. For example, shape and thickness of a CD case might be suitable for a portable speaker, and the size of an empty inkjet cartridge might be appropriate for a handheld flashlight to utilize the form factor. 7% of photos uploaded from the second online surveys, and 12% from online observations were classified in this category:

"I made a portable speaker in a CD case for my iPod without spending even a penny. Now I can carry this portable speaker anywhere you like. I can even put my iPod inside the CD case when it is not in use."

Figure 8. A palm pilot display for Roomba, an inkjet cartridge flashlight, a videotape USB hub, and a portable speaker in a CD case from left to right

Remanufacture: Hacking

There were some serious expert hacking and programming works among the data we collected. These works typically required some level of expertise in manipulating electronics and/or mechanic parts. Obsolete electronics were totally dissembled, parts from different pieces were reassembled, and a piece with total new functionality was created as a final product. Many pieces in this category were more for hobbies or fun by experts rather than for practical uses by everyday users. 15% of photos uploaded from the second online surveys, and 9% from online observations were classified in this category:

"I replaced the horizontal sync with an audio input instead of a video input and left the vertical sync with video input. This is a fully functional oscilloscope with a positive and negative input. It works like a commercial oscilloscope and didn't cost me penny! " (See the first photo in Figure 9)

"The body was an Apple Airport wireless access point. The wheels/motors came from an early-series Roomba vacuum cleaner. The undercarriage is a set of wheel-mounts made from ShapeLock[5] thermoplastic screwed into the wall-mounting bracket that came with the Airport." (See the third photo in Figure9)

Figure 9. A monitor oscilloscope, a can phone, a self-moving robot, and speakers for an MP3 player from left to right

DISCUSSION

We believe that this work has several implications. Primarily, it provides insights, mechanisms, and framings for enabling people to more easily find creative reuse ideas for their obsolete e-waste. We discuss other insights from our work below.

[5] *ShapeLock* is an ultra-high molecular weight low temperature thermoplastic. http://www.shapelock.com

The Role of Aesthetics Plays in Reuse As-Is

The physical appearance of a product has a profound effect upon the way in which it is perceived [7]. Therefore, aesthetics is often used to differentiate products from the competition and stimulate consumption. Particularly in mature market segments, where products are often indistinguishable from each other on a technical basis, investing in product form may increase market share and profitability. In this work, we evidenced the important role of aesthetics along the entire lifetime of the product, from purchase to reuse. When the life span of the original functionality is over, products with higher quality design seem to be better suited as candidates for reuse. This insight should serve as motivation for industrial product designers and interaction designers of electronic objects.

Sharing Experiences Can Encourage Reuse of e-Waste

Sharing is an effective mechanism to trigger positive behaviors [9]. We evidenced the power of sharing in this work as well where we observed individuals inspired by the creative reuse of others. For example, a CRT monitor fish tank, keyboard artifacts, and light bulb casings are widely known reappropriation practices spread via sharing ideas, all of which are practical in use and pleasing in appearance. However, with limited resources outside of hackers' and DIY communities to publicize and discover these ideas, there is almost certainly a significant design opportunity to further sharing creative e-waste reuse ideas. One challenge is how to make such information widely sharable, publicly available, and easily accessible. While online forums and websites exist to share experiences and instructions in reuse, the majority of those communities focus on crafting non-digital artifacts. These communities also focus specifically on electronics for hacking and building experiences. None of these communities are solely focused on the design of e-waste for reuse. Beyond sharing, we will need further work to understand the needs of browsing, searching, using and contributing to community collected reuse ideas. Such online resources will also need to be diligent in their focus on e-waste.

Appropriate Disposal & Recycle Mechanism is Still Needed.

It is not always safe to handle electronic products. In many cases, dismantling electronics require extra safety precautions (*e.g.,* high voltage circuits and unstable batteries technologies). Thus, special steps are required when dismantling electronics for e-waste reuse. We evidenced that the majority of e-waste reuse focuses solely on the exterior properties of e-waste. This is encouraging since it may mean that a significant amount of e-waste reuse can occur while avoiding a range of hazardous dismantling procedures. This also means that e-waste reuse would not require advanced electronics skills and knowledge – avoiding even basic operations such as soldering. Our reuse composition framework is designed primarily to inspire creative reuse of everyday e-waste. As such it serves more to extend product lifetime rather than focus specifically on product redesign to avoid toxins and hazardous chemicals. It also does not serve directly to improve the recyclability of products. However, we argue that it provides an extremely valuable secondary contribution – that of e-waste awareness. By inviting broader participation by others into the creative reuse of e-waste, our approach consequently has the effect of promoting awareness of e-waste, its use, mis-use, and reuse. It a sense our approach is positioned to celebrate e-waste in ways that have the potential to elevate e-waste to a more participatory, active, and useful role in the everyday lives of individuals. The strategy is to leverage everyday design and grassroots efforts as mechanisms to motivate a new cultural awareness of e-waste and potentially a new appreciation and awareness of the importance and role of e-waste in environmental health.

CONCLUSION

The overarching long-term goal of this work is to find ways to facilitate latent resources such as e-waste, and to prolong the longevity of use in electronic products by its creative reuse. As a practical goal for this paper, we aimed to develop a simple design strategy that can inspire everyday people to participate in the creative reuse of e-waste. To that end, we acquired a baseline understanding about domestic e-waste stockpiling behaviors and e-waste recreation practices from a series of surveys and observational studies. Through a baseline understanding of current e-waste culture, we developed *a design reuse vocabulary* that consists of three primary properties: materials, shapes, and operations. The design reuse vocabulary captures a range of low-level properties that can be readily integrated into e-waste reuse practices. We evaluated and validated this design reuse vocabulary through another series of survey studies. Drawing for the results of those studies, we developed *a reuse composition framework,* which consists of three degrees of manipulation: reuse as-is, remake, and remanufacture. The reuse composition framework generalizes the practices of e-waste reuse, and provides a scaffolding mechanism for non-experts to reuse e-waste. We believe these frameworks could be a catalyst for everyday people to reuse the vast quantities of e-waste creatively and in meaningful ways – namely by allowing continued product attachment. Furthermore, we claim that the active engagement in doing and experiencing such e-waste reappropriation can lead to greater awareness of the problems and solutions regarding e-waste.

Our work has contribution to the field of HCI research for environment and sustainability in three ways. First, we identified a range of issues surrounding the secret life of our cohabitation with e-waste. Second, we developed a design reuse vocabulary that could easily be applied to e-waste by non-experts to promote product reuse and extend product lifetimes. We view this as an interim goal of solving the more general wicked problem [12] of e-waste in our culture and environment. Lastly, we came up with a simple design strategy to be accessible and to have broader impact in encouraging creative reuse across a wide range of e-waste

types beyond those specifically used in our study. We are hopeful that our work can motivate future research in HCI regarding the importance of e-waste.

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