Technology and Object Modifications in Upcycled Homes

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ABSTRACT
The Internet-of-Things (IoT) looks to bring computing capabilities to everyday objects by creating new, replacement versions with internet-connected advantages. Our focus was on how IoT can fit into homes through a process we called *upcycling*, where common household technologies and objects are modified with computing properties. Using inventory data collected from 10 diverse American households, we investigated the distribution of pre-existing technology and modified objects. We found that household members use their current technological objects to negotiate or claim personal space in shared rooms. Opportunities for redesigned objects with computing capabilities were found in recurring modified objects across a household or modifications that were able to influence beyond the room the object resided in. These modifications highlighted a want across households for greater control over objects, with hopes to make relevant task performances more convenient. We then underline how these findings demonstrate the user considerations and potential future trends for implementing IoT modifications on existing household objects.

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INTRODUCTION
The Internet-of-Things (IoT) seeks to extend computing capabilities to everyday objects such as curtains, beds, and couches. Rather than creating new versions of these objects, we examined how objects could be modified and retrofitted to include computing capabilities. These devices can be adapted to be internet connected while still retaining their normalcy as common household objects. By adding 'smart' computing capabilities to current household objects, homes keep their pre-existing technologies and objects while upgrading on functionality.

With the rise of IoT, we need to consider how objects can be modified and what modifications interest consumers. Some households prefer to continuously upgrade on their existing objects; however, used objects can still be purchased and reused. Older objects can be repurposed, recycled, or in this case upcycled, in order to remain useful to families. Modifying objects with technology lets owners upgrade without completely discarding an object that does not have computing capabilities. Designing for IoT upcycling, would allow for upgrades that can be retrofitted to pre-existing technology and objects. Modifications would have to be installed differently depending on the original object design constraints. These modifications would also vary based on user preferences for upcycling.

Our questions about upcycling considerations were directed at current technological objects as well as the imagined modified objects. First, how do households use objects in relation to the spatial layout of the home? Second, what opportunities are there for modifying objects with computing capabilities? To address these questions, we worked with 10 different households to examine their pre-existing technology, identify proposed modifications, and record the motivations behind object redesigns. We used ethno-archaeological methods to understand how households currently organize their objects and what computing capabilities they seek in upcycling.

We found that families use their technology and objects to negotiate boundaries or claim personal space in shared household locations. In shared bedrooms, these objects were used to denote 'sides' of the room. For other household locations, these objects were used to carve out home office space. Object modifications often recurred throughout a household, impacted a large physical area of the home, or communicated across objects. Our findings underscore how users would like to have IoT supported modifications for pre-existing objects. While modifications varied based on household needs, underlying motivations

included a want for greater control over object functionality, reduced effort due to laziness, and higher efficiency in performance. Our work contributes trends in spatial object use ajd types of modifications users gravitate towards alongside their motivation for these modifications.

Related work

The IoT brings various costs to households as objects are replaced. Upcycling could bring greater control over such costs as IoT is tailored to pre-existing objects. Researchers have looked into how households approach coming up with object modifications. They developed a framework for how families make object modifications, looked at cost trends and modification patterns, as well as considered the system burdens brought by upcycling [10]. Additionally, there is a need for object modification customization and awareness of modification impacts on displacing user skills. Researchers also found that household members use objects to negotiate relationships [9]. We contribute to these results by investigating pre-existing object trends in comparison to the later redesigned object trends. Our analysis uses the spatial layout of the house and placement of the object to define the negotiation and modification trends. We also consider the reasoning for modification decisions that lead to overarching trends.

Methods

We used ethno-archaeological methods to assess the distribution of technological and modified objects across 10 diverse households. These ethno-archaeological methods assume that material items, or a lack thereof, reflect on human behavior within households. During the home study, households were also asked to think about and enact which objects would be augmented with IoT capabilities.

Participants

We recruited 10 households for our study from a mid-size American city. We sampled participants across gender, age, race, class, disability, and household structure in line with persistent categories of concern to the HCI research community. We also chose these in part because our participant pool's demographic distribution could be approximated from public records. We excluded potential participants if, (1) working with them would require changing our protocol (e.g., translator or adapting materials for intellectual disability), (2) their household had changed over the past year (e.g. baby, divorce, or new roommate), (3) they lived alone, or (4) required by our screening tool (see below). Our criteria slightly shift our population away from a representative sample for our recruitment city. For example, our 2.9 average persons per household and entire population lived in the same home one year ago is greater than the city's averages of 2.1 per household and 77.8% in the same home. We include children < 5 yrs. and those with severe intellectual disabilities by proxy in participant interviews, but we did not directly work with these family members.

We recruited through several NGOs and public organizations using word of mouth or flyers. We screened participants using a 5-minute questionnaire that probed household structure, income, home ownership, languages spoken, work status, and disability. To ensure we had a representative sample, we used this questionnaire to exclude potential participants if we had a sufficient number of households with similar answers. We required all household members participate and commit to the entire duration of the study [9].

Procedure

We asked families to inventory the current technology in their households by drawing a blueprint of their house and labeling objects with stickers. We took technological inventory for pre-existing tech objects such as microwaves, televisions, and laundry machines, to look at the distribution of objects across the 10 households. Household members went through the rooms in their household to show where tech objects reside. They then came together to envision potential upcycling of household items which were modified objects. Object inventory consisted of modified objects that household members wanted to upcycle. Household members named the object modifications they would want to have, such as voice-activated lights, smart TVs, and refrigerator scanners. Object type was determined by if the label sticker was labeled in an individual color, multiple colors, or a dark blue color for shared objects. Room location type was determined by how many household members had access to the room based on the object types of stickers in that room.

Data and Analysis

Using the blueprints, tech inventory and object inventory was recorded from P1 to P10. The process compiling inventory across the households was to go through the tech inventory blueprints for each household, and then label the floor level, room location, and ownership of each tech inventory sticker. This same process was repeated for the object inventory. We coded the room location and the object type as *liminal* if the object was in an in-between space, *roaming* if the object traveled around with its owner(s), *global* if the modification was across the same object name multiple times. For modified objects there were additional categories of *autonomous objects* such as robots. Room location was coded as *private*, *semi-private*, and *shared* depending on access to the rooms. Object type was coded as *private*, *semi-private*, and *shared* depending ownership of the objects. Objects and the room they are placed in do not always coincide in ownership. Object ownership is determined by the sticker labels of which household members held ownership over each object. Private objects belonged only to one owner. Semi-private

objects belonged to multiple owners, but not everyone in the household. Shared objects belonged to every member of the household.

A similar method of labeling was done for each inventory sticker in Altas.ti. Coding and analytical-memoing were performed to visually examine object placement and interaction. Codes were created to identify the properties of objects such as *claiming territory*, *large-scale influence*, and *pluggable*. Memos were attached to these codes to leave a paper trail of thoughts while taking into consideration the spatial arrangement of objects and rooms.

FINDINGS

Modified objects spanned functional changes in current object design such as voice-activated lights, remote control blinds, and video game vision. The rooms these tech objects and modified objects resided in included liminal spaces, identified as in-between spaces such as doorways, windows, and stairways. Phones and electronic watches were classified as roaming objects, because they are pre-existing technology that are carried around by household members and do not reside in a stationary room. A type of modified object that changes the design of multiple recurring objects across the household is classified as global objects such as clocks. Another type of modified object type are autonomous objects which are able to move by themselves such as robots for car parking and cleaning. We highlighted the distribution of tech and modified objects based on room location type and object type.

Tech Inventory

We took tech inventory for P1 to P10, by identifying the object name, room location, floor level, and ownership type. Households reported that they owned 9 to 30 pieces of technology. Liminal space such as the front door was seen in P3 and P6, and roaming objects such as iPhones were found in P7 and P8. The majority of locations and technology were locations and objects shared by all household members. Overall, rooms such as living rooms, kitchens, and dining rooms were most commonly shared across all households.

Modified Object Inventory

The modified objects ranged from 7 to 43 objects. More liminal space use occurred in P2, P3, and P6 for object inventory compared to liminal space use for tech inventory. No roaming objects occurred. In P7, there were 4 global objects due to a desire to modify numerous analog clocks. Autonomous objects such as a robot and an insta-maid occurred in P1 and P3. Modified objects were mostly shared. Modified objects in P2, P5, P6, and P8 were all shared objects. The distribution of object ownership types demonstrates a variety in the number of modified objects across households as well as differences in modified object type within households. The variety in how many modified objects a household had tells us that households differed in the number of modifications they came up with. From the differences in modified object types, we learn what functions each household wanted in their object modifications.

For the 20 spaces with preexisting tech, 5 spaces were liminal, 9 rooms were shared, and 2 rooms were semi-private. This trend demonstrates how tech objects such as security cameras often occur in liminal spaces which could be considered a subset of shared spaces. With most objects residing in shared or semi-private spaces and none in private spaces, preexisting tech such as an office laptop, often has multiple owners or can be accessed by multiple household members. For the 16 spaces with modified objects, 6 spaces were liminal, and 5 rooms were shared, and 1 room was semi-private. This trend highlights how modified objects such as voice-activated lights in the study were designed to be in liminal as well as shared spaces so that multiple household members could use the redesigned technology.

None of the modified objects were in a private space and only 1 semi-private object was in a shared setting, possibly due to a lesser inclination to use modified objects to denote personal territory. The 1 modified object was a rolling pin in the kitchen of P9. The rolling pin was modified to have a sensor that tells how thick the dough is to make the rolling uniform.

In comparison to the rooms which fell into one or two location types, bedrooms differed from being shared to semi-private to private location types across households for tech objects. This arises as household members occupy bedrooms differently across households and place objects in bedrooms that also vary in types of access and ownership. Table 1 further details the breakdown of the bedrooms with multiple location types.

Tech Inventory	Number of Rooms

		Bathroom	Bedroom	Total
Location Type	Private Location	1	9	10
	Semi-Private Location	1	55	56
	Shared Location	0	1	1
	Total	2	65	67

Table 1: The table shows the tech inventory in bathrooms and bedrooms which fall into all 3 location types.

Tech Inventory		Number of Rooms					
		Closet	Dining Room	Kitchen	Living Room	Office	Total
Location Type	Private Location	0	0	0	0	0	0
	Semi-Private Location	2	2	2	2	5	13
	Shared Location	11	8	18	58	14	109
	Total	13	10	20	60	19	122

Table 2: The table shows the tech inventory in closets, dining rooms, kitchens, living rooms, and offices which fall into 2 location types: semi-private and shared locations.

Modified Object Inventory		Number of Rooms		
		Bedroom	Closet	Total
	Private Location	0	0	0
Location Type	Semi-Private Location	51	1	52
	Shared Location	2	4	6
	Total	53	5	58

Table 3: The table shows the modified object inventory in bedrooms and closets which fall into 2 location types: semi-private and shared locations.

Object Use in Relationship to Home's Space

We then looked at the question of how households use their objects in relation to the spatial layout of the home. To approach this, we looked at pre-existing technology that was labeled on each household's floor plans, their ownership, and placement in their respective rooms. The first code used on these objects was *boundary negotiation* which was when household members shared bedroom space and delineated boundaries using their objects. This interaction was seen in many households. We focused on cases with couples, siblings, and roommates. Often, one owner's private objects were on one side of the room with another owner's private objects on the other side. Sometimes there would be shared objects between the two sides which helped soften boundary transition. Other cases arose when items were shared by the entire household, meaning beyond the members who resided in the bedrooms. These cases occurred in a couple's bedroom where the TV was shared with their children who had their own rooms, and in a housemate's private bedroom which was the only way for other housemates to get to the shared bathroom. Boundary negotiation suggested an invisible line of who has which "side" of the bedroom. *Claiming territory* was used when household members used their personal objects to carve out private space in shared rooms. When these private objects are in use, more private space is being taken up or used in the public room. This was often seen with objects such as laptops and phones which highlight a potential to use common spaces for reasons beyond their primary use, such as a living room being used as an office.

Boundary Negotiation

Boundary negotiation occurs when objects in bedrooms belong to different household members and are used to denote boundaries in that space. We observed household members, who shared the same bedroom, organize their possessions along different sides of the room. This spatial arrangement in shared spaces, like co-owned bedrooms, created an invisible boundary between each owner's side of the room. Across the 10 households, we found that 7 families arranged their home's objects in this way. 9 bedrooms in total saw this occurrence, and 46 objects were involved in boundary negotiation. Often times these objects are private, but cases of semi-private and shared objects used for boundary negotiation occurred as well.

For cases of married couples, boundary negotiation between private objects owned by different occupants of the same bedroom was seen in P2 where the main bedroom has an iHome and iPhone belonging to one person on one side of the room, and a second iPhone belonging to another person on the other side of the room. These objects seem to be as far away from each other as possible, potentially indicating being deep in each other's side of the boundary. In P3, a cell phone belonging to one household member is alongside the wall; the back brace belonging to another household member is in the middle of the room with two more of this person's items deeper in the room. Between the cell phone and back brace is a shared TV with Firestick and DVD player that may ease the transition in the boundary negotiation. In P7's bedroom, boundary negotiation occurs as a light alarm clock and wireless charge pad belonging to one of the room's occupants is in one corner of the room; a digital alarm clock belonging to the other occupant is along the same wall towards the other corner. This case of boundary negotiation highlights the divide in sides of the room, likely due to each person's inclination to sleep on the "their" side of the bed. The duplicate of having two alarm clocks asserts individual preferences in the shared bedroom. In P9, there are two iPhones belonging to either spouse. The iPhones are in different corners of one side of the room, establishing a boundary for this space. The use of the same object to negotiate the boundary occurs to likely split the sides of the bedroom.

Cases for married couples also arose when their bedrooms had objects shared with their child or children. In P4, the Apple TV and one of the cell phones belongs to one person, a second cell phone belongs to another person, and there is a shared TV. This room has instances of boundary negotiation as the two cellphones occupy the bedroom primarily shared by two people. The Apple TV's owner has their cellphone closer to their Apple TV. The TV comes into play, being a shared object, meaning that other household members are able to come into the bedroom to use this object. Two different types of TVs have different ownership types and form part of the boundary negotiation. In P5, boundary negotiation occurs as the alarm clock and cell phone belonging to one spouse is on one side of the room while the cell phone belonging to the other spouse is in one corner. The TV here is shared by the married couple while the house phone is in the middle of the room and shared by everyone in the household which includes the couple's two children.

For cases of siblings, one edge case was seen in P5. The Go-Pro in the bedroom belongs to one sibling while the hoverboard belongs to that person but is shared with the other sibling. There are no other tech objects in this room, so it is difficult to discern if boundary negotiation occurs fully here or if this is more a matter of shared ownership.

For cases of roommates, two separate instances of boundary negotiation occurred in P10 which had 3 roommates, two of which shared a bedroom. The shared bedroom has private objects belonging to either roommate as well as shared objects. As shown by the floor plan, a laptop and roaming mobile phone occupies its owner's bed with another laptop, roaming mobile phone, and iPad occupying its respective owner's bed. Shared objects of lighting, hair dryer, and iron are in the middle of the room with the beds and their objects against the wall. The shared air conditioner is also against the wall. This indicates that if other household members who do not sleep in this room want to use the air conditioner, they would cross one of the occupant's bounded space in contrast to if they were to use the other shared objects. The modified object layer of this room shows some adherence to the boundary negotiation established by the technology object layer. The bed continues to denote its owner's boundary, but the phone is invading what was the other owner's side of the room. The added air conditioner and heat is shared and in between the two beds. Shared blinds are on the window that is next to one of the owner's boundaries. This roommate also added a smart phone more in the middle of the room's space. The second instance for these roommates is a case of boundary negotiation between private versus shared objects can be seen in P10's bedroom 2 which has many private objects belonging to one household member. However, boundary negotiation occurs here as 2 shared objects are on one side of the room. The floor plan shows that passing through this bedroom is the only way to access the shared bathroom. This could be a contributor to why there are shared objects residing in the bedroom.

While there are different types of ownership for objects in bedrooms, objects are used by their owners to create boundary negotiations in this type of semi-private location. The interaction between these objects underline the

connection of each person to the space they occupy as well as the relationships between household members. Household members use their objects in relation to the home's space by denoting boundary lines in bedrooms. These boundaries can be crossed based on the layout of the house or room, but often times show a strong division in the room or a transition from one person's private items to shared items to the other person's private items.

Claiming Territory

Claiming territory arises when private objects are used to carve out personal space within shared rooms. Households often have objects belonging to one member residing in common spaces. Across the 10 households, 7 households had claiming territory codes, 12 rooms in total saw this occurrence, and 22 objects were involved in claiming territory. Typically, these objects are private, but cases of semi-private objects used for claiming territory in households with more than 2 members occurred as well.

Claiming territory can be seen in P4's living room where a PlayStation that solely belongs to one household member is in the shared space. The PlayStation resides alongside the wall, likely claiming more space by the owner when in use as there is only one other shared object in a corner of the room. In P2's living room, a private laptop claims territory as all of the 4 other objects in the room are shared. The modified object layer shows three more shared objects being added to the room. Claiming territory with a laptop could indicate a flexibility in the function of the room and variation in what the owner uses this object for.

An edge case can be seen in the claiming territory code for the sewing machine P9 which claims the entire side of a space to the point where that side of the room is classified as the "sewing room". The other half of the room is a bedroom with one shared object, but the claiming territory label is used as the sewing machine is powerful enough to claim space as its own room as well as influencing the purpose and title of the sewing room. A second edge case occurs when a private laptop in P2's dining room is the only object in the room. This laptop was coded as claiming territory since household members have to come through this room to access other rooms like the living room and kitchen. This emphasizes the shared space type for the dining room despite the single private laptop claiming territory in the room. Another edge case is found in P3 where both objects in the office are private, making this room a private location. However, the modified objects layer shows a shared doorbell added to the border of this space, indicating claimed territory through technology.

Household members use their objects in relation to the home's space to carve out private bubbles of personal space in shared locations such as kitchens, living rooms, and dining rooms. These areas of space are created by private objects used to claim territory.

Opportunities for Modifications

Next, we considered what opportunities there are for modifying objects with computing capabilities. The *global modification* code looked at when there were duplicates of a modification within a household. Examples included recurrent modifications in objects such as windows and lights due to the object's smaller reach of space and the intended usefulness of the modification. *Large scale influence* contrasted against global modifications as they were object modifications that had a wider reach in the household. These objects could influence an entire floor or household, leading to less duplicates. Their modified functionality would go beyond the physical object, such as a thermostat adjusting the temperature throughout an entire house. *Global modifications* and *large-scale influence* emphasized what modifications were important to household members. *Object movement* coded based on how tethered the objects were. This code categorized based on the household layer and properties of the object that affected placement and movement. Codes included *autonomous*, *services*, *space plan*, *pluggable*, *networking*, and *stuff*. *Autonomous* was for self-initiating objects such as robots. *Services* were brought in from outside of the house to the inside of the house using utilities such as thermostats. *Pluggable* extended services by hooking into the service without need for professional installation. *Space plan* organized the spatial arrangement of the house such as ceilings, windows, and doors. *Networking* was for objects that primarily communicated with other objects such as wireless phones. *Stuff* was for object modifications closest to normal furniture such as beds and couches. Most modifications were made with intents such as enhancing remote control, usually through a phone application, and improving object functions to be more all-knowing about what was going on inside the household. These categories in object movement would reveal how much control an owner wanted over the object and whether they thought the modification would make tasks using that object easier.

Global Modification

Global modification occurs when a modification was made across the entire household or multiple instances of the same modification was made in a household. Across the 10 households, 9 households had global modification codes and 136 objects had global modifications. This category often affected windows, lights, and monitoring infrastructure which are common objects that occur multiple times in a household.

Modifications on windows are illuminated in 4 households: P3, P4, P5, and P10, these modifications included curtains, blinds, and smart windows. A true global modification was made in P5 where the smart blinds was labeled as a modification to be made on two different floors, making the object's influence to be floor wide and occurring multiple times. In addition to these modifications, P6 specified self-washing windows as a modification to the household. These curtains or blinds modifications on the windows would have to accommodate the preexisting windows, plus be able to retrofit and mount onto these windows. In comparison, smart windows and self-washing windows may require greater modification.

Global modifications for lights can be seen in 6 households: P2, P5, P6, P7, P9, and P10. Across all 4 floors of P9, ceiling lights was a global modification which was made for 9 instances. Other types of light modifications included bathroom lights, voice-activated lights, and app-lights, indicating a large variety in the changes that could be made for lighting preferences for different households. For monitors and sensors, P6 had refrigeration sensors and P5 had eye doors which would help household members have a better environmental awareness in their respective households. Additional global modifications occurred for items such as toilets, litter boxes, clocks, TVs, phones, and beds. These modifications had fewer instances of the same object, but still indicate a want for multiple pockets of the same modification across households.

With a wide range of global modifications, there were recurring trends in modifying windows, lights, and monitoring infrastructure. These types of objects were usually added to rooms as they have a smaller influence in reach, only over the room they reside in. This would lead to some rooms having multiple of the same modification in one space to account for the limited influence. Other types of modifications allude to the potential in modifications for common household objects. Opportunities for modifying the home with computing capabilities are demonstrated by global modifications which duplicate modifications across the household in order to meet a continued need throughout the house.

Large Scale Influence

Large scale influence from modified objects are able to control environmental settings in the household and has the ability to affect the entire household or multiple floors when in use. Across the 10 households, 7 households had large influence codes and 10 objects were identified to have a large influence. This category affects the household itself, often through functioning to influence temperature or cleanliness as the scale of the object was larger than the local space taken up by that object.

Temperature control is underlined in large scale influences through thermostats, air conditioners, and heaters. P4, P7, and P8 all modified thermostats, P3 modified an air conditioner, and P10 modified an air conditioner with heater. These objects are attached or static, but still are able to influence the temperature at a larger scale outside of its control panel. Cleanliness can be seen from modified objects such as vacuum cleaners and laundry related modifications. P7 and P9 modified vacuum cleaners, meanwhile P3 modified a laundry pipeline and subsequent washer chute. The vacuum cleaners are moveable and able to clean throughout the house; in contrast, the laundry related modifications are attached but run throughout the house.

While there are different types of ownership for modified objects with large scale influence, most of these objects fall into the category of controlling temperature or affecting house cleanliness with the exception of a jacked router in P4. Often times, only one to two modifications with large scale influence were made to households, possibly due to their ability to cover a larger area of the household leading to a decreased need to having repeated modifications as seen in global modifications. These modifications also varied in their abilities to influence one room, a floor, multiple floors, or the entire household, demonstrating the variety in opportunities for modifying the home. Opportunities for modifying the home with computing capabilities arise with large scale influence objects on the services and space plan level, which is often beyond the space taken up by the object.

Object Movement

Object movement examined how tethered modified objects were in households. *Autonomous* objects were modifications that allowed self-initiating functions for objects to perform. These occurred 8 times and included self-washing windows and robots. The creation of this type of modification could indicate that household members would like for some objects to be automatic, because they think that this would require less effort and time on their part. *Services* were objects that usually had connections to wiring and plumbing, where utilities were brought in from outside of the house to inside. These occurred 46 times and

included thermostats, ceiling lights, and air conditioners. *Pluggable* hooked into *services*. These occurred 18 times and included vacuums, televisions, and refrigerators. *Space plan* impacted the house's spatial arrangement such as ceilings, windows, and doors. These occurred 36 times and included escalator stairs, remote blinds, and pocket doors. Despite current trends that push towards wireless technology, families modified the majority of their augmented possessions to remain tethered as seen in *services*, *pluggable*, and *space plan*. Yet, these modified capabilities include functions which exist for wireless technology, such as being remote-controlled, voice-activated, and self-functioning. This could indicate an inclination towards remaining "plugged in" while having objects that can perform wireless functions. *Networking* was for objects that were usually wireless and primarily communicated with other objects. These occurred 55 times and included app-lights, smart windows, and phones. *Stuff* was for object modifications closest to normal furniture such as beds and couches. These occurred 18 times and included a rolling pin, beds, and litterboxes. The modifications for *stuff* could point to trends in modifying as household comforts for rest and leisure.

Object movement focused on the degree of how tethered objects are across the households. *Autonomous* revealed a reliance on self-function. *Services* and *space plan* revealed a want for easy control of objects integrated into the house's infrastructure. *Pluggable* and *stuff* showed a desirable trait in modifying common household appliances. *Networking* displayed the want for continued improvement of devices that are already untethered, proposing inclination towards further developing currently wireless and moving technology.

DISCUSSION AND LIMITATIONS

We found that households use objects to negotiate or claim personal space and users modify objects to benefit their routines and homes. Negotiations were bound to happen across shared bedrooms as participants divided up the space and allocated sides. Yet, one roommate pair was fine with having private and shared objects mixed around evenly in their bedroom space. Though each roommate had their individual beds labeled, many private objects would cross the typical boundary lines. This introduces questions on how these boundaries develop and how objects aid in strengthening such boundaries. *Claiming territory* saw instances where one object, a sewing machine, had the power to claim an entire room, the sewing room. Similarly, some private objects revealed how one household member can preside more over a space even if that room has multiple shared items. For object modifications, many redesigns would have a small influence in function and then be placed multiple times across a household. Since these *global modifications* were made up by the participants, we assume they believed that these designs would be useful enough to the extent of being fitted numerous times within their home. *Global modifications* which creates duplicate objects could have different design implications compared to *large-scale influence* modifications. Trends for modifications and further applications in relation to the different layers of the house could impact the degree of influence the modified object has in a household. These *large-scale influence* modifications often relate to the *services* category of object movement as well. Modifications with different movability could display why users prefer various changes. *Pluggable* and *services* modified objects would often be designed to have 'smart' capabilities. This design could indicate user preferences for wireless technology in or across tethered objects.

The data used for this study was derived from only 10 households, all from one city. While the families were diverse, a larger sample should be examined to determine object use, modification, and design trends. For the visual data analysis, *boundary negotiation* was only found in bedrooms, but these can likely be applied to other spaces such as bathrooms and closets. Fewer cases of sharing space and objects for siblings and roommates arose. For couples, there could be a relationship between *boundary negotiation* and *claiming territory* as there would be only two members negotiating the entire household. Further exploration could be done for how object movement throughout the house affects claimed territory, how the interaction of multiple claiming objects in the same space works, and how strong claims are based on the object functions. Participants worked on object modifications together, so most of the modified objects were labeled as completely shared. *Global modifications* not seen in this dataset could also be considered. With a contrast in *global modifications* versus *large-scale influence*, we could look into their relationship or the general influence size of modified objects. For object movement, useful information includes the kinds of modifications being made, what these modifications are capable of, what designs are currently available, and what these modifications can move towards in the far future. Object movement also had few *autonomous* objects compared to its other categories. Additional modifications not seen in this dataset could potentially change the labeled trends and motivations for redesign choices.

CONCLUSION

In summary, we used household data on 10 diverse homes to examine object use and potential for IoT upcycling. We looked at how household members use their objects in relationship to the home's space by characterizing *boundary negotiation* and *claiming territory*. These trends both targeted the use of objects to establish ownership of space. Next, we considered the potential opportunities for modifying the home and its objects with computing

capabilities. *Global modifications* demonstrated the want to modify objects which had smaller bursts of influence within the household but performed functions that required multiple instances of the same modification. In comparison, *large-scale influence* highlighted modifications which would affect a larger portion of the household with just one instance of the modified object. Object movement displayed the variety in how tethered modified objects were, leading to a greater understanding of how movability of the object coincides with user wants in object functionality. These trends take into considerations how objects, space, and user motivations can affect object use, placement, and design. These findings look to expand on the current uses of household objects and spaces, while exploring the potential of modifying objects with computing capabilities.

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