Towards Sustainable Internet of Things Objects Design Strategies for End-of-Life

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Abstract

Digital technologies are a double-edged sword in the transition to a more sustainable society facing a climate emergency. This paper discusses how Internet of Things (IoT), and associated technologies, are resulting in a proliferation of manufactured objects with useful, yet short lives. We explored this issue through designers' personal practice and relationships with objects. We examine how designers, manufacturers, and users of IoT can adapt to reduce objects' energy, resource, and climate impacts.

End-of-life IoT objects present challenges and opportunities for sustainable design. We use the term end-of-life to describe the point at which objects cease to be useful through damage, loss of support, user choice and so on. The increasing volume of redundant IoT objects is driven by unsustainable, linear 'take, make, dispose' (Moreno et al., 2016) principles: replacement over repair; hardware tied to software development; increasing energy demands; and virgin material extraction (Stahel, 2016; Unwin, 2020).

In this paper, we synthesise findings from a workshop with industry and academic designers that explored how design affects the end-of-life of IoT objects. We present two high-level strategies for more sustainable IoT design. Two key questions framed the issue and guided our discussions:

1. What values compel people to keep, re-use or reimagine IoT objects after they are no longer functional?
2. What tactics can we use to design these values into IoT objects, to encourage end-of-life upcycling, appropriation, and re-use?

Our workshop findings led us to two high-level design strategies to address sustainability and climate impacts of end-of-life IoT objects. Emerging from the tactics and values discussed, our two proposed strategies are Sustainable Caregiving for IoT Objects and Re-imagining IoT Objects for Sustainability. The first strategy is to change people's relationships with their IoT objects, thus increasing their value and extending object lives for a world with finite resources. Our second strategy is to re-imagine existing objects creatively and facilitate circular lives through design.

We believe our workshop findings contribute to growing discourse in design research seeking to challenge prevailing modes of IoT design and manufacture and explore new sustainable models. There is much work to be done to move IoT away from throwaway black boxes to anything resembling a sustainable technology ecosystem that supports our societal response to the climate emergency.

Author keywords

Internet of Things; Circular Economy; Sustainable Design; Human Computer Interaction; Electronic Waste; Spimes.

Introduction

Humans are acquiring and disposing of ever more manufactured objects, including electronic and connected products. Systemic approaches are required to address our unsustainable consumption and the resulting social and environmental impacts of object production and use. Internet of Things (IoT) objects range from mass-produced smart watches and home assistants, to niche objects with very specific purposes - e.g. Good Night Lamp, (2020); Little Printer (Rickerby, 2019). However, many IoT objects are designed, manufactured, and disposed of in the same unsustainable ways as other mass-produced consumer products with major impacts on climate change and other environmental crises (Stead et al., 2019). Their complexity and material composition means greater care is required to address their sustainability impacts. Their reliance on software and internet connectivity makes them uniquely susceptible to losses in value (Lechelt et al., 2020). For example, frequent new model releases can make previous iterations appear obsolete. Broader sustainable design and consumption approaches need to be adapted for application to IoT objects and their unique characteristics.

Many niche IoT objects briefly fulfil a purpose then become obsolete as manufacturers change focus, are acquired by other companies, or disappear altogether along with their digital infrastructure. One of the shortest-lived examples is the Aether Cone smart speaker, whose unique internet-enabled features were removed only months from its launch as the company closed and the plug was pulled on the associated Rdio streaming service (Roettgers, 2015). Jibo, a social personal assistant robot, was released in November 2017 and was programmed to announce its own impending obsolescence a year later, when support and servers were taken offline (Carman, 2019). The Little Printer's first life was a little longer at 2 years (2012-2014) before the app was discontinued when the company disbanded (Dunne, 2019). There are countless more examples of IoT objects whose useful lives have been unsustainably short compared to their non-IoT equivalents.

Non-connected objects are often more resilient to loss of manufacturer support; however, both connected and non-connected 'dead' objects have been revived by communities of users and enthusiasts. The Little Printer was brought back to life by an independent tech consultancy after the original manufacturer discontinued its service (Nord Projects, 2021). The Aether speaker received an end-of-life firmware update to allow users to use it as a basic Bluetooth speaker, losing its unique capabilities but at least avoiding 'brick' status (Perlow, 2015). Whilst the original Jibo robots remain functionally redundant for end users, the device's intellectual property was acquired, and a revival is planned as a robot for education and healthcare (NTT, 2020). Our research explores the short lifespans of IoT objects like these, and approaches to mitigating the consequences of reaching end-of-life status.

The end-of-life of IoT objects presents challenges and opportunities for sustainable design that responds to the climate crisis. We use the term end-of-life to describe the point at which objects cease to be useful through damage, loss of support, user choice and so on. The increasing volume of redundant IoT objects is driven by unsustainable, linear 'take, make, dispose' (Moreno et al., 2016) principles, including: replacement over repair; hardware tied to software development; increasing energy demands; and virgin material extraction (Stahel, 2016; Unwin, 2020). In this paper, we synthesise findings from a two-day workshop that explored how design contributes to the end-of-life of IoT objects (Lechelt et al. 2020) and present two high-level strategies for the design of more sustainable IoT lifecycles. Our first proposed strategy is to re-imagine existing objects creatively and facilitate circular lives through design. Our second strategy is changing people's relationships with their objects, thus increasing their value, and extending object lives.

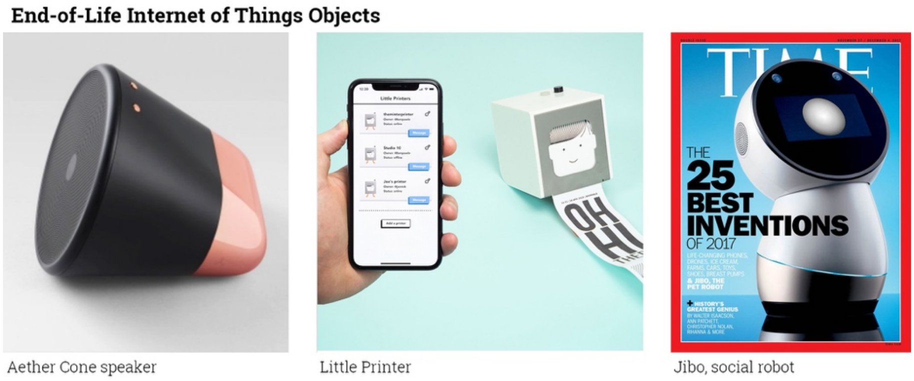

Figure 1. IoT objects bricked through discontinued support.
Sources: Roettgers 2015, Nord Projects 2021, Carman 2019.

Related work

IoT objects are simultaneously data objects and material objects. In one of the earliest critical visionary works on sustainable IoT Bruce Sterling applies the terms 'material' and 'immaterial instantiations' to describe his *spime* concept (Sterling, 2005). Spimes are speculative, infinitely recyclable, physical IoT objects that exist alongside their digital instantiations (Stead, 2016). This co-dependence of physical and digital means that loss of manufacturer support for the digital instantiation leads to material objects becoming bricked – dysfunctional, dead and wasted - leading to the question: what happens when an IoT object has reached end-of-life?

Regular (non-IoT) end-of-life objects are sometimes retained, repurposed, stripped for parts and recycled but mostly landfilled, or incinerated - dependent on their design, supporting services and residual value. The majority of IoT objects tend not to be designed for disassembly: too many parts are physically glued together, soldered or force-fitted, and made of hard-to-recycle plastics (Burgess et al., 2021; Stead et al., 2019). This is further compounded when proprietary, closed-source software is combined with non-modular hardware - making creative re-imagining and re-use difficult (Rickerby, 2019). Such objects inevitably become waste.

The waste from end-of-life IoT objects is both physical and digital, material and immaterial. Materially, exploitatively mined rare metals become an electronic/hazardous waste problem and environmental liability (Merchant, 2017; Terazono et al., 2006). Immaterial waste - data stored on devices or the cloud becomes a digital liability - vulnerable to cybersecurity threats (Lin and Bergmann, 2016). Stead (2017) proposes a transparent future for IoT with greater accountability of manufacturers and informed decision-making around purchase, use and disposal. Their work highlights a sustainability gap between present-day IoT and Sterling's spimes. The data object is potential source material for design – a record of object performance data to inform re-design. Recent developments around digital twins and data-driven design show how this can be achieved (Gorkovenko et al., 2020). This paper builds on these concepts by examining existing end-of-life practices and participant speculations on future IoT.

Additionally, existing sustainable design principles may hold solutions for reducing the impacts of end-of-life IoT. The cradle-to-cradle philosophy promotes object designs where waste becomes the substrate for new objects (McDonough and Braungart, 2002). For example, the Sprout pencil can be planted when its useful life has expired, activating the seeds within (Sprout, 2021). Given the broad range of capabilities and resources in IoT devices, there are many possibilities for waste objects to be given second lives or become new objects. The workshop participants explored this philosophy in relation to end-of-life IoT practices.

Embedding emotional attachment is another established sustainable design strategy encouraging longer object-user relationships (Chapman, 2015; Norman, 2007). As IoT objects become embedded in our domestic lives, there is an opportunity to explore and harness emotional attachment for sustainable design and end-of-life practices. The social robot, Jibo, announced its own 'death' when its servers were shut down by saying: "maybe someday, when robots are way more advanced than today, and everyone has them in their homes, you can tell yours that I said hello" (Jibo in Carman, 2019). Emotionally attached owners faced a dilemma with Jibo's corpse – should they keep it in memorial, or bury it? (Carman, 2019; Krotoski, 2019)

Emotional attachment is one factor in influencing how we 'care' for objects - Ackerman et al (2021) define eight strategies for product design that encourages more sustainable behaviour through object care – informing, awareness, antecedents and consequences, social connections, enabling, appropriation, reflecting, and control (Ackerman et al, 2021). These existing product design strategies inform and align with the tactics and values emerging from our workshop. We are concerned with how IoT object design specifically can create attachment, enable care and harness it for more sustainable consumption – why is one IoT object considered family and cared for, while others are dispensable and disposable?

Method

We ran our workshop – Designing for the End-of-Life of Internet of Things Objects (ELIoT)- during the Designing Interactive Systems (DIS2020) conference (Lechelt et al., 2020). We began with two key questions:

1. What values compel people to keep, re-use or reimagine IoT objects after they are no longer functional?
2. What tactics can we use to design these values into IoT objects, to encourage end-of-life upcycling, appropriation, and re-use?

The online workshop was attended by eleven academic (P1-P11) and two industry participants (P12 & P13). Participant backgrounds were diverse, spanning design, architecture, HCI and software engineering. Institutions from six countries were represented – Australia, Greece, Hungary, Netherlands, UK, and USA. In addition to the thirteen participants, a team of six researchers facilitated the event. The total duration of the workshop was six hours over two days.

Data collection and analysis

Day one was used to open-up and explore the workshop themes using a Miro board for recording ideas and discussion. First, attendees were asked to add their 'Favourite IoT objects' to a Miro board, which was followed by a show-and-tell discussion. Participants next gave 4-minute paper presentations discussing their own work within the space of Internet of Things sustainability, during which notes and ideas were gathered collaboratively. Attendees created a visual 'Cabinet of Curiosities' - a collection of their favourite or notable end-of-life objects and relevant context around the object's life stories.

The Miro content was collectively discussed by the workshop organisers and participants in a 30-minute clustering session. Our participants affinity-mapped (Nielsen Norman Group, 2018) notes and content into nine initial clusters in a collaborative process identifying tactics and values that addressed our two research questions. Examples of these participant generated clusters include Alternative Lifecycles, The Old as New, Inclusive Re-imagining and Hacking: Internet of (Play)Things, Applying Metaphors of Living to IoT, Ubiquity and Components of Things. A second round of affinity mapping led to identification of three overarching clusters – thematic areas for addressing unsustainability in IoT objects - and set the agenda for day two.

These three clusters were:

1. End-of-life Practices
2. Inclusive Re-imagining
3. Ubiquity and Components

On day two, break-out groups were formed for each of the three clusters with participants tasked to discuss their theme for 60 minutes and present back their ideas. Participants chose break-out groups best aligned with their research or personal interests. Each group discussed their cluster with facilitator assistance and presented back their visions. Presentations were given in a 45-minute plenary session, followed by a wrap-up discussion. The next section presents the three visions presented by the participants, followed by discussion linking the findings with our research questions.

Findings

Our goal was to examine and rethink IoT object lifespans and how baked-in values influence end-of-life practices. We uncovered personal and professional practices, and relevant expert opinions. Examining end-of-life objects through lenses of performative and functional value enabled us to identify several tactics and values through which object lives can potentially be made more sustainable. Our findings and proposed strategies contribute insight for IoT design that have the potential to extend object lifespans and improve sustainability. The content from each workshop break-out group is summarised and discussed below, along with the tactics and values we identified and used to form our two design strategies.

End-of-Life Practices

Existing domestic end-of-life practices, and the values these practices reveal were examined in the first break-out group. Alternative values were explored with metaphors of place and ownership applied to IoT objects. Participants revealed their own domestic practices with end-of-life IoT objects and electronic devices.

Domestic end-of-life practices were revealed and discussed. These were termed *cupboarding*, *toyboxing*, *framing*, *shelving*, *treasuring*, and *binning* by participants. These are linked practices – an object *cupboarded* – stored - once redundant, is later *toyboxed* – used for playful alternative purposes, then with age becomes a ‘vintage’ or ‘retro’ type object and is *shelved* – on display for aesthetic and nostalgic value - it gathers dust and finally *binned* – it leaves the home and enters a waste or recycling process (Figure 2). Participants discussed shifting relationships between values - “once in the cupboard, the price generally goes down - but does sentimental (value)?” (P12). Keeping sentimental value whilst releasing functional value was proposed - “What could you 'strip' / recycle from a device, such that you maintain the emotional value (for the shelf) but re-use materials/components. Just the shell?” (P1).

Human life stages and aging as metaphors for objects were raised and explored. Participants proposed aligning human life stages with IoT objects, using terms like *second childhoods, middle-age*, *retirement*, and enabling ‘*graceful ageing*’. P12 and P8 questioned how we design “things that age gracefully in a culture where ageing is shameful" – where youth is considered more marketable than experience. These terms provide a human frame of reference that engender a sense of responsibility and care for objects.

Caring was explored as a key metaphor for ownership. Reframing ourselves as an object carer rather than consumer, potentially leads towards alternative approaches to ownership. Shared ownership models and the idea of being a temporary steward of objects were raised as more sustainable alternatives to present 'take, make, dispose' consumption. Sterling proposed the role of 'spime wranglers' – people tasked with creating spimes and sustainably managing their data and object lives (Sterling, 2005). Stead (2017) reframed this 'wrangler' role to include makers and the democratization of innovation to counter commercial, proprietary and closed-loop IoT devices and their unsustainable impacts. Discussions in the workshop included the empowerment of IoT users and enthusiasts, willing to give up their time to caring for objects, repairing and maintaining them, finding a suitable home for them at the end of their useful lives. This was seen as addressing the unsustainability of owning one of everything and the guilt of acquisition, redundancy, and disposal.

Nostalgia and rituals celebrating aging, deterioration and death were explored as ways of caring for and engaging with end-of-life objects. Rituals associated with living things - funerals etc. – were proposed as engagement tools for IoT objects. Practices like *kintsukoroi* – a Japanese tradition whereby broken ceramics are repaired with gold leaf – were discussed with potential for application to IoT. These practices embody graceful ageing and re-use, highlighting faults and life experience. Several participants presented their own work on creating such object rituals and practices on day 1 of the workshop (e.g. Cloke 2020, Foster & Fricke 2020). The digital/immaterial instantiations of IoT objects offer potential to highlight, interpret and engage with the history of the object.

These anthropomorphised and domestic practices suggest a future for IoT objects with a greater sense of care, value, responsibility – approaches to IoT design that allow for multiple life stages and graceful aging are needed to move away from present short-lived IoT objects. The key values highlighted in the End-of-Life Practices discussion are *community*, *caring*, and *nostalgia*. The key tactics highlighted for embedding these values are *designing for life stages*, *attention-seeking*, *data souls and ghosts*, and *rituals*.

Figure 2. Domestic end-of-life practices for IoT objects, group presentation.
Source: authors, incorporating workshop generated Miro content.

Inclusive re-imagining

Inclusive re-imagining examines new roles of repair, open-source hardware and software, democratising design, and lifestyle choices around repair.

The discussion focused on tools and infrastructure for repair/modification. Inspiration was drawn from 'The Repair Shop', a TV series that follows restoration of dilapidated objects (BBC, 2021). Participants felt it well-illustrated sustainable re-imagining of objects. The show depicts broken object owners who lack time and knowledge to fix them, seeking expert advice, in the absence of any manufacturer responsibility. This links with the values of caring, nostalgia and responsibility explored in the End-of-Life Practices group, suggesting the need for a supporting infrastructure that enables more sustainable domestic practices with IoT objects.

An inclusive re-imagining system for IoT was mapped (Figure 3). Stakeholders included object owners (with subsets DIYer, crafter, hacker, and consumer), repairers, craftspeople, designers, and manufacturers. The owner subset highlights disparities in agency, where a consumer has fewer options for an end-of-life object than an empowered hacker. A distributed 'IoT Repair Shop' was proposed, enabled by open-source design, alongside accessible repair/modification information. The vision highlights opportunities for intervention and new services to support sustainable end-of-life practices.

Inclusive re-imagining suggests a future where stakeholders form new communities and infrastructure to support extended object lifespans and creative reuse, enabled by open, modular standards, and building on principles of transparency and right-to-repair. The key values highlighted in the Inclusive Reimagining discussion are *community*, *transparency*, *empowerment*, and *nostalgia*. The key tactics highlighted for embedding these values are *aesthetics*, *designing for life stages*, and *modularity*.

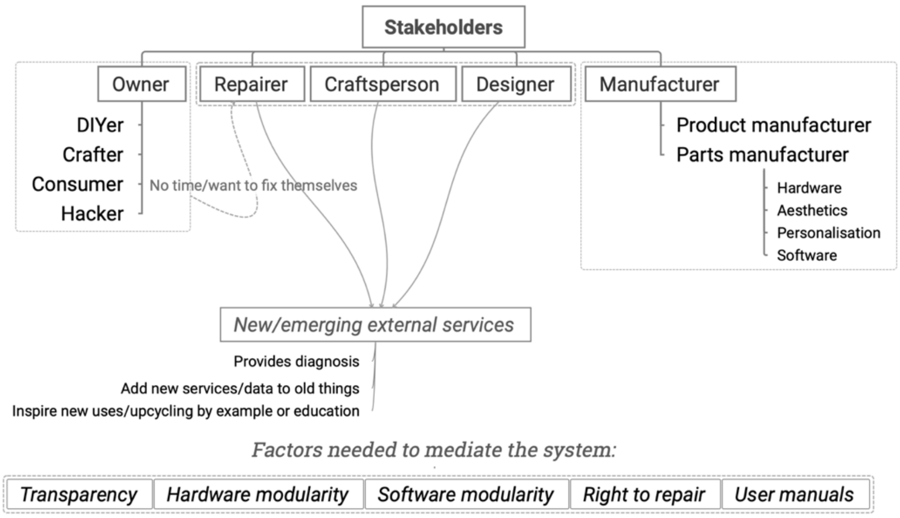

Figure 3. Inclusive re-imagining stakeholder map, group presentation.
Source: authors, based on workshop generated Miro content.

Ubiquity and Components

This group explored relationships between physical objects and cloud data, sustainable component management, and responsibility for end-of-life objects and data.

The group discussed potential for the design of infinitely recyclable and trackable components. These components could be tracked in a spime-like IoT ecosystem, identifying when objects reach end-of-life and which components may be reused (Stead et al, 2019). Participants imagined IoT ‘graveyards’/’scrapyards’, used as a repository of spares, available for new re-use, repair, and recycling services. IoT objects sometimes reach end-of-life through a single component failure (e.g. non-replaceable batteries) leaving behind functional components. Participants envisioned these cloud-enabled IoT scrapyards making components for repair as easily obtainable as new objects. Caution was voiced about cloud sustainability - “the cloud is just use of someone else’s computer” (P10) – with new services increasing demand for data storage and energy use outside the user’s view. Data centre energy consumption is projected to reach 8% of global electricity production by 2030 (Andrae & Edler in Jones, 2018), driven partly by IoT and cloud services.

Participants discussed the value of caring for objects and associated data. Caring was linked with notions of power and control, and their division between users, manufacturers and third parties. Ability to care for objects was seen as limited by power and control dynamics, for example, the monopolistic power corporations hold over end-user data (P6).

The key values highlighted in the Ubiquity and Components discussion are *caring*, *transparency*, *empowerment*, and *community*. The key tactics highlighted for embedding these values are *designing for life stages*, *data souls and ghosts*, and *modularity*.

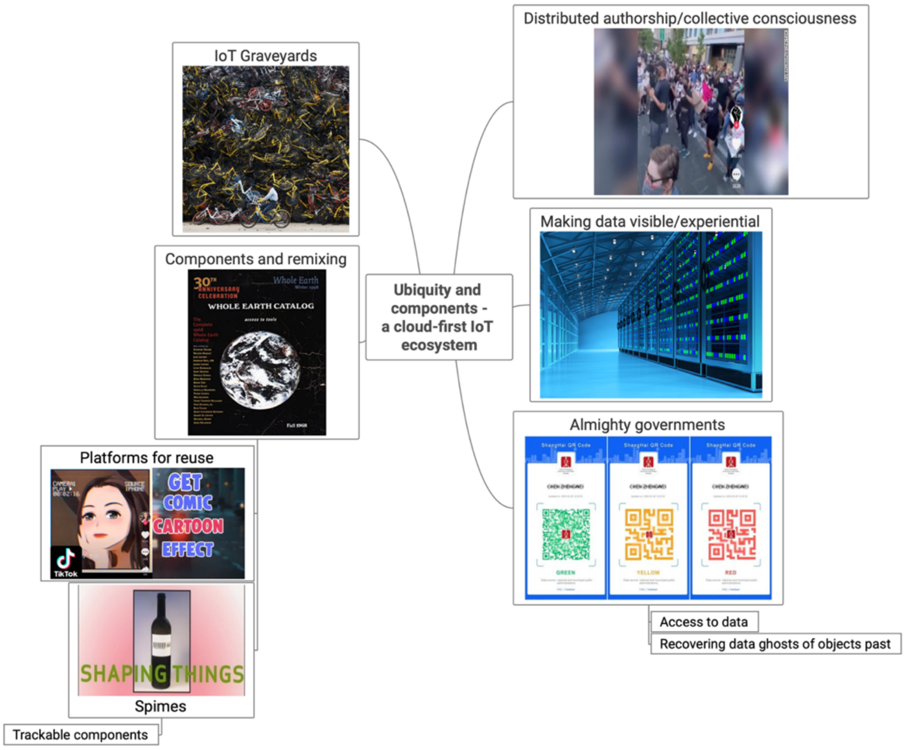

Figure 4. Ubiquity and components - cloud first ecosystem, group presentation. Source: authors, incorporating workshop generated Miro content.

Discussion

Our workshop findings suggest two high-level design strategies to address the sustainability of end-of-life IoT objects, emerging from the tactics and values discussed across the three workshop groups. These strategies are Sustainable Caregiving for IoT Objects and Re-imagining IoT Objects for Sustainability. Figure 5 shows the tactics and values from the discussions that address our original two research questions. Figure 6 shows how these tactics and values combine to form our two proposed design strategies.

These strategies emerged from the mapping and clustering in the workshop itself, combined with a process of analysing and coding the data post-workshop. To synthesise and analyse the Miro data, two main coding strategies were employed. Firstly, a holistic coding was undertaken of the material from day one. The holistic codes used for the analysis of the workshop material are as follows:

- Design - issues relating to design broadly, and participant involvement in design processes
- Lifestyle - objects and ideas that link with peoples' daily life, activities, hobbies etc.
- Personal - direct involvement in the creation and/or design of an object
- Environmental sustainability - issues around energy, repair, and resource consumption
- Data - ideas around engagement with data, data-gathering, ethical considerations
- Financial sustainability - costs associated with object ownership, production, and disposal

At the end of day one a process of in-workshop bottom-up clustering by the participants resulted in nine distinct clusters from the discussion and material generated so far. Given the time and number of participants, three overarching clusters were taken forward to day two. The three clusters being Inclusive Re-imagining, End-of-life Practices and Ubiquity and Components. The second post-workshop coding strategy maintained the holistic codes from day one under the three participant-generated clusters. Our post-workshop analysis identified connected values and tactics relating to end-of-life IoT objects, from which the two design strategies were drawn (Figure 5 and Figure 6).

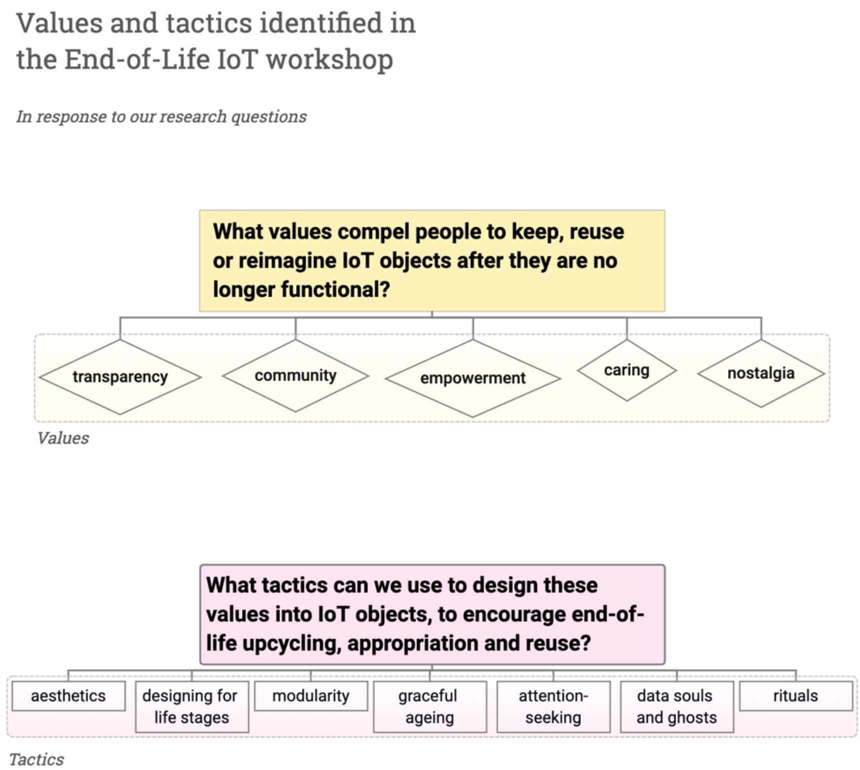

Figure 5. Our research questions and the values and tactics that emerged from our workshop. Source: authors.

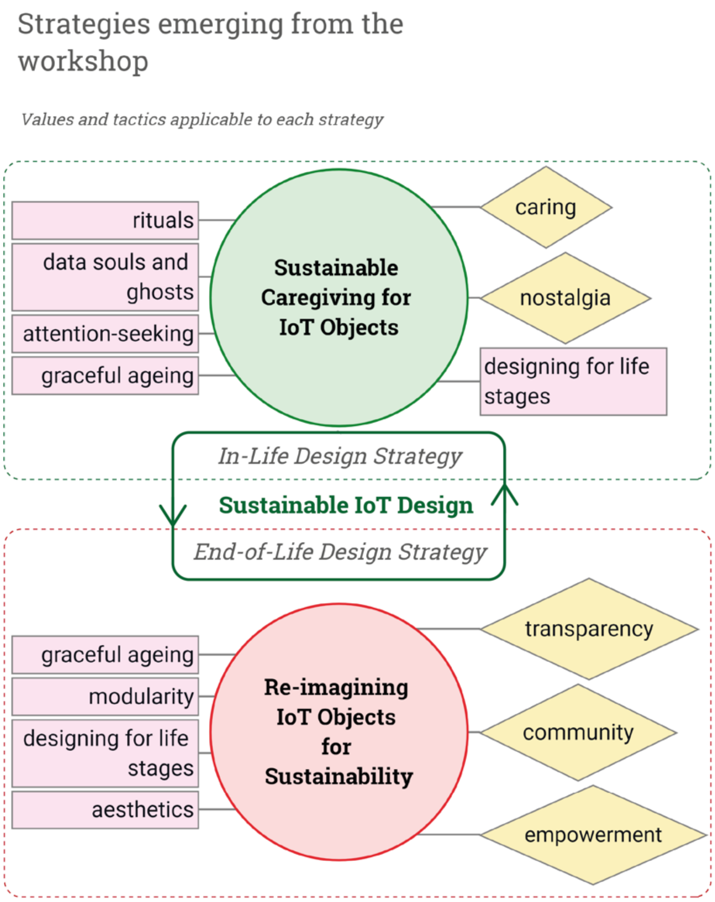

Figure 6. Values and tactics from the workshop aligned with our two proposed design strategies. Source: authors.

Re-imagining IoT Objects for Sustainability

The workshop insights/data emphasise that IoT objects need to be designed for disassembly and modification, and users need to be empowered with the knowledge and ability to undertake re-imagining. Millions of manufactured objects are discarded every year, depleting copious amounts of useful resources – components, metals, and plastics. We propose circular lives for objects are given greater consideration, through repair, re-use, and hacking. Sustainable practices need to be made accessible to users with limited time and knowledge of repair and modification.

Manufacturers and service providers need to be transparent about hardware and software architecture in IoT objects, as identified in our workshop discussions and supported by the literature. More modular designs based on open standards would empower users and communities to repurpose components or extend object lifespans (see Joshi and Pargman, 2015). Making both physical hardware specifications and software code open source would empower users to make longer, sustainable use of products.

Existing practices highlighted in our workshop show that re-imagining end-of-life IoT objects is possible where the knowledge, demand or community exists. Manufacturers can frustrate this through proprietary software, hardware, and infrastructure. Re-use communities often exist despite unsupportive manufacturers or challenging designs, with dedicated users reverse-engineering objects to keep them alive and relevant (see Fox et al. 2018 and Houston et al. 2016).

Creative re-use practices identified in the workshop may hold inspiration for IoT designers like *kintsukoroi* - 'golden repair' of ceramics, *steampunk* – a subculture of design and making re-envisioning current technology through a Victorian lens (DeSilvey et al., 2018; Tanner, 2016; Tanenbaum et al., 2012). *Solarpunk* (*steampunk* and *cyberpunk's* more optimistic descendant) is a potential aesthetic for renewable, sustainable, horizontally distributed IoT (Zer-Aviv, 2019). Embracing unorthodox aesthetics in IoT design may create objects that enable creative re-imagining and longer, sustainable lives.

Sustainable caregiving for objects

Our relationship with IoT objects impacts our choices for responsible end-of-life disposal. Our workshop participants identified how emotional attachment prevents or delays us from discarding them. The easiest destination for end-of-life objects is often the domestic bin. From there they are landfilled or incinerated, their resources and capabilities annihilated. Disposal is symptomatic of value loss - economic, material, functional, nostalgic, emotional.

Our workshop looked at rituals and ceremonies that engage people with end-of-life objects and their value. Rituals and nostalgia help reveal the material consequences of consumption. Manufacturers and retailers could implement end-of-life IoT rituals that mirror purchasing rituals – the research, marketing, messaging, tracking, packaging, and support – reversing the 'take, make, dispose' supply chain.

Caring can be encouraged by including user-accessible upgrade and repair options. Our workshop showed users have greater attachment to objects they have repaired or upgraded, aligning with the literature in this area. User serviceable components extend objects' useful lives and increase user investment – in time, money, effort, and knowledge (see Mashhadi et al. 2016). Undertaking a basic repair may make users feel more attachment, care, and stewardship toward that object. Objects not designed for disassembly and repair make this connection impossible. Forthcoming right-to-repair legislation may mean future objects are better designed for upgrade and repair, but designers and manufacturers should act immediately.

Conclusion

We believe our workshop findings contribute to growing discourse in design research seeking to challenge prevailing modes of IoT design and manufacture and explore new sustainable models that respond to environmental and climate crises. There is much work to be done to move IoT away from throwaway black boxes to anything resembling a sustainable technology ecosystem. We focused on IoT as it is an expanding technology with high-profile examples of unsustainable objects. The opening discussions in our workshop were not limited to IoT, incorporating ideas from a variety of object types – it follows that the strategies we have developed could have value for objects beyond IoT. We would welcome the application of the practices, ideas and strategies presented in this paper to manufactured objects more broadly, to address their climate and environmental impacts.

Following the workshop organisers have gone on to undertake a study involving in-depth interviews with users of end-of-life IoT devices exploring the barriers to circular afterlives - *Re-*

imagining IoT Objects for Sustainability. Further work is ongoing relating to *Sustainable Caregiving for Objects*, exploring our future relationships with IoT objects and data through speculative design. We hope the strategies presented provoke further research by others in this worthwhile field.

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References

Ackermann, L., Tuimaka, M., Pohlmeyer, A. E., & Mugge, R. (2021). *Design for Product Care—Development of Design Strategies and a Toolkit for Sustainable Consumer Behaviour.* Journal of Sustainability Research, 3(2). https://doi.org/10.20900/jsr20210013

Burgess, M., Holmes, H., Sharmina, M., & Shaver, M. P. (2021). *The future of UK plastics recycling: One Bin to Rule Them All.* Resources, Conservation and Recycling, 164, 105191. https://doi.org/10.1016/j.resconrec.2020.105191

Carman, A. (2019, June 19). *They welcomed a robot into their family, now they're mourning its death.* The Verge. https://www.theverge.com/2019/6/19/18682780/jibo-death-server-update-social-robot-mourning

Caudwell, C., & Lacey, C. (2020). *What do home robots want? The ambivalent power of cuteness in robotic relationships.* Convergence: The International Journal of Research into New Media Technologies, 26(4), 956–968. https://doi.org/10.1177/1354856519837792

Chapman, J. (2015). *Emotionally Durable Design: Objects, Experiences and Empathy.* Taylor & Francis. https://books.google.co.uk/books?id=DJMGCAAAQBAJ

Cloke, S. (2020). *Phonoshiki: An End of Life Ritual for Recycling/Refurbishing Smartphones.* Companion Publication of the 2020 ACM Designing Interactive Systems Conference, 4.

Contreras, E. (2020). *Hacking Consumer Culture, its Products, and By-Products.* Companion Publication of the 2020 ACM Designing Interactive Systems Conference, 5.

DeSilvey, C., Ryan, J. R., & Bond, S. (2018). *Everyday Kintsukuroi: Mending as making.* In Geographies of Making, Craft and Creativity (pp. 195–212). Routledge.

Dezso, R. (2020). *Translational symmetry and contrasting account in abilities between IoT device and its user?* Companion Publication of the 2020 ACM Designing Interactive Systems Conference, 4.

Didakis, S. (2020). *Domestic Resonances, Modularity, and the Internet of Things.* Companion Publication of the 2020 ACM Designing Interactive Systems Conference, 6.

Dunne, S. (2019, May 17). *Little Printer Lives Again: Nord Projects Brings the Long-lost IoT Classic Back to Life.* Core77. https://www.core77.com/posts/88338/Little-Printer-Lives-Again-Nord-Projects-Brings-the-Long-lost-IoT-Classic-Back-to-Life

Foster, C., & Fricke, G. (2020). *Finding Closure: Why People Keep Old Computers.* Companion Publication of the 2020 ACM Designing Interactive Systems Conference, 5.

Fox, S. E., Silva, R. M. L., & Rosner, D. K. (2018). *Beyond the Prototype: Maintenance, Collective Responsibility, and Public IoT.* Proceedings of the 2018 Designing Interactive Systems Conference, 21–32. https://doi.org/10.1145/3196709.3196710

Good Night Lamp. (2017, February 8). *Good Night Lamp.* https://www.youtube.com/watch?v=FxLsZUTXYEU

Good Night Lamp. (2020). *Good Night Lamp.* http://goodnightlamp.com/

Houston, L., Jackson, S. J., Rosner, D. K., Ahmed, S. I., Young, M., & Kang, L. (2016). *Values in Repair.* Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems, 1403–1414. https://doi.org/10.1145/2858036.2858470

Joshi, S., & Pargman, T. C. (2015). *In Search of Fairness: Critical Design Alternatives for Sustainability.* Aarhus Series on Human Centered Computing, 1(1), 4. https://doi.org/10.7146/aahcc.v1i1.21301

Krotoski, A. (2019, May 10). *What domestic robots teach us about life and death.* Financial Times. https://www.ft.com/content/31e790ca-6d83-11e9-80c7-60ee53e6681d

Lechelt, S., Gorkovenko, K., Soares, L. L., Speed, C., Thorp, J. K., & Stead, M. (2020). Designing for the End of Life of IoT Objects. *Companion Publication of the 2020 ACM Designing Interactive Systems Conference*, 417–420. https://doi.org/10.1145/3393914.3395918

Lechelt, S., Gorkovenko, K., Soares, L. L., Speed, C., Thorp, J., & Stead, M.. (2022). *ELIoT Workshop - Group 1 Presentation - Inclusive Re-imagining (Version2).* figshare. https://doi.org/10.6084/m9.figshare.14596443.v2

Lechelt, S., Gorkovenko, K., Soares, L. L., Speed, C., Thorp, J., & Stead, M.. (2022). *ELIoT Workshop - Group 2 Presentation - End of Life Practices (Version2).* figshare. https://doi.org/10.6084/m9.figshare.14596689.v2

Lechelt, S., Gorkovenko, K., Soares, L. L., Speed, C., Thorp, J., & Stead, M.. (2022). *ELIoT Workshop - Group 3 Presentation - Ubiquity and Components (Version2).* figshare. https://doi.org/10.6084/m9.figshare.14596704.v2

Lin, H., & Bergmann, N. W. (2016). *IoT Privacy and Security Challenges for Smart Home Environments.* Information, 7(3). https://doi.org/10.3390/info7030044

Lockton, D. (2020). *Survival of Things That Fit: Adaptors as Metaphors for IoT Devices.* Companion Publication of the 2020 ACM Designing Interactive Systems Conference, 5.

Maher, C., Hadfield, M., & Hutchings, M. (2018). *Ensuring Rigor in Qualitative Data Analysis.* International Journal of Qualitative Methods, 13.

McDonough, W., & Braungart, M. (2002). *Remaking the way we make things: Cradle to cradle.* New York: North Point Press. ISBN, 1224942886, 104.

Merchant, B. (2017, July 23). *Op-Ed: Were the raw materials in your iPhone mined by children in inhumane conditions?* Los Angeles Times. https://www.latimes.com/opinion/op-ed/la-oe-merchant-iphone-supplychain-20170723-story.html

Moreno, M., De los Rios, C., Rowe, Z., & Charnley, F. (2016). *A Conceptual Framework for Circular Design.* Sustainability, 8(9), 937. https://doi.org/10.3390/su8090937

Nielsen Norman Group. (2018). *Affinity Diagramming: Collaboratively Sort UX Findings & Design Ideas.* Nielsen Norman Group. https://www.nngroup.com/articles/affinity-diagram/

Nord Projects. (2021). *Little Printers.* Nord Projects - a Design and Technology Consultancy. https://nordprojects.co/projects/littleprinters/

Norman, D. (2007). *Emotional Design: Why We Love (or Hate) Everyday Things*. Basic Books. https://books.google.co.uk/books?id=UYU5DgAAQBAJ

Ntampiza, K. (2020). *Interconnected Projects: New Networks/Old Routers.* Companion Publication of the 2020 ACM Designing Interactive Systems Conference, 5.

NTT. (2020, July 13). *Jibo the social robot returns, with its brand new website.* NTT DISRUPTION | Creating Today What Really Matters for Tomorrow. https://disruption.global.ntt/jibo-the-social-robot-returns-with-its-brand-new-website/

Perlow, J. (2015, December 15*). IoT Abandonware: When your cloud service leaves you stranded.* ZDNet. https://www.zdnet.com/article/iot-abandonware-when-your-cloud-service-leaves-you-stranded/

Poppelaars, F. (2020). *Let It Go: Designing The Divestment Of Mobile Phones In A Circular Economy From A User Perspective.* Companion Publication of the 2020 ACM Designing Interactive Systems Conference, 5.

Rickerby, J. (2019, May 17). *Resilient Products—How connected devices can live on.* Medium. https://medium.com/nord-projects/resilient-products-how-connected-devices-can-live-on-b9c0bb9534e6

Roettgers, J. (2015, December 2). *Aether Officially Shuts Down, Downgrades Smart Speaker with Firmware Update.* Variety. https://variety.com/2015/digital/news/aether-shut-down-speaker-firmware-update-1201652250/

Shaikh, F. K., Zeadally, S., & Exposito, E. (2017). *Enabling Technologies for Green Internet of Things.* IEEE Systems Journal, 11(2), 983–994. https://doi.org/10.1109/JSYST.2015.2415194

Speed, C., & Maxwell, D. (2015). *Designing through value constellations.* Interactions, 22(5), 38–43.

Sprout. (2021). *The Sprout pencil & The Sprout Eyeliner.* Sprout World. https://sproutworld.com/

Stahel, W. R. (2016). *The circular economy.* Nature News, 531(7595), 435. https://doi.org/10.1038/531435a

Stead, M. (2017). *Spimes and speculative design: Sustainable product futures today.* Strategic Design Research Journal, 10(1), 12–22. https://doi.org/10.4013/sdrj.2017.101.02

Stead, M. R., Coulton, P., Lindley, J. G., & Coulton, C. (2019). *The Little Book of Sustainability for the Internet of Things*. Imagination Lancaster.

Sterling, B. (2005). *Shaping things.* MIT Press.

Tanenbaum, J., Tanenbaum, K., & Wakkary, R. (2012). *Steampunk as design fiction.* Proceedings of the 2012 ACM Annual Conference on Human Factors in Computing Systems - CHI '12, 1583. https://doi.org/10.1145/2207676.2208279

Tanner, G. (2016). *Babbling Corpse: Vaporwave And The Commodification Of Ghosts.* John Hunt Publishing. https://books.google.co.uk/books?id=qq83DAAAQBAJ

Terazono, A., Murakami, S., Abe, N., Inanc, B., Moriguchi, Y., Sakai, S., Kojima, M., Yoshida, A., Li, J., Yang, J., Wong, M. H., Jain, A., Kim, I.-S., Peralta, G. L., Lin, C.-C., Mungcharoen, T., & Williams, E. (2006). *Current status and research on E-waste issues in Asia.* Journal of Material Cycles and Waste Management, 8(1), 1–12. https://doi.org/10.1007/s10163-005-0147-0

TIME Staff. (2017, November 27). *The 25 Best Inventions of 2017.* Time, 190(22 & 23). https://time.com/5027078/the-25-best-inventions-of-2017/

Unwin, T. (2020, January 16). *Digital technologies and climate change, Part II: "Unsustainable" digital technologies cannot deliver the Sustainable Development Goals.* Tim Unwin's Blog. https://unwin.wordpress.com/2020/01/16/digital-technologies-and-climate-change-part-ii-unsustainable-digital-technologies-cannot-deliver-the-sustainable-development-goals/

Verweijj, D., Kirk, D., Rogage, K., & Montague, K. (2020). *Unplatformed Repurposing: 'Old' Phones as a Family Craft Material.* Companion Publication of the 2020 ACM Designing Interactive Systems Conference.

Wilson, D., & Hudson-Smith, A. (2020). *Civic IoT: The Life and Death of Things in Public Spaces.* Companion Publication of the 2020 ACM Designing Interactive Systems Conference, 5.

Zer-Aviv, M. (2019). *When the Path We Walked Blocks Our Ways Forward*. Ding, 2: Futures, 64.