The Pragmatics of Sustainable Unmaking: Informing Technology Design through e-Waste Folk Strategies

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ABSTRACT
Technology is becoming increasingly embedded within our material worlds, resulting in an exponential rise in the production and consumption of consumer electronics. Rapid innovations in technological systems reduce technology lifecycles, deprecating digital systems, rendering devices obsolete or incompatible with supporting infrastructure, resulting in the generation of electronic waste (e-waste). Sustainable unmaking practices are a promising avenue for harnessing and repurposing resources used in technology production, enabling us to move closer towards sustainable technology design. This paper presents an applied study investigating the pragmatics of sustainable unmaking, reporting on 12 semi-structured interviews conducted with domain experts engaged in unmaking with e-waste across diverse contexts in the consumer technology lifecycle. We present folk strategies — from rich first-hand accounts, revealing real, vivid, and current perspectives, as well as motivations, passions, and frustrations, of engaging with unmaking e-waste. These strategies inform five declarations as actionable provocations for unmaking in the HCI and design communities.

CCS CONCEPTS
• **Human-centred computing** → Human computer interaction (HCI); Empirical studies in HCI.

KEYWORDS
Unmaking, Sustainable Interaction Design, e-Waste, Folk Strategies

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1 INTRODUCTION
As digital technology becomes increasingly embedded within our material world, we have seen an exponential rise in the production and consumption of consumer electronics and technologies. According to the *Sustainable Development Goals Report 2021* [87], electronic and electrical equipment waste (e-waste) has globally generated 53.6 metric tons in 2019 (20% more than 2014); projected to further grow another 40% by 2030. Currently this translates to 7.3 kg of e-waste generated per capita, with only 1.7 kg managed in an environmentally sustainable way [87]. Improper disposal of e-waste can adversely impact the environment — releasing hazardous chemicals into soil and water, as well as cause significant loss of scarce and valuable materials (e.g., gold, cobalt, platinum, and rare Earth minerals) [87]. Rapid technological innovations, result in shorter device lifecycles, perpetuating obsolescence, incompatibility with current infrastructure, and fewer service and repair options — forcing users to shift to newer devices, resulting in more stress on resource consumption [88]. The current global semiconductor crisis clearly illustrates this, by foreshadowing the consequences of material shortages, causing massive production delays and price increases of consumer technologies such as laptops, smartphones, gaming consoles, and automobile electronics, all of which have been severely impacted [6].

With over 3 billion people (38% of the world's population[1]) still without access to the internet and digital devices [94], and concerted efforts to reduce the digital divide through proliferation of accessible digital consumer technology and infrastructure — the demand for digital technology production and strain on resources will only increase. The United Nations [86] identified *'sustainable production and consumption'* as a Sustainable Development Goal (SDG 12); however, we have seen a 70% increase of the world's material footprint between 2007 and 2017 alone [87]. Australia (where our study is situated) is one of the largest consumers of technology globally, and the fifth largest producer of e-waste (21.7 kg per capita) [33,54]. Given both the need, and demand to grow the global digital infrastructure, designers, researchers, and practitioners need to ensure there is both responsible production and consumption of resources in technology design. This dilemma is characteristic of a genuinely *wicked problem* [71], where both understanding the contours of the problem and its context, as well as devising an orientation towards a solution, must occur simultaneously.

The extant discourse about making and maker culture within HCI highlights *unmaking* as a largely under explored, and promising avenue that addresses important technology design concerns, such as: reuse, repair, and socio-ecological impact [75]. This paper focuses specifically on the pragmatics of '*sustainable unmaking*'

[1] 2022 population: 7.76 billion — Source: World Bank Population Calculator

[80] with e-waste i.e., understanding the practical, on-ground realities of how people engage in unmaking praxis; and how accounts of these folk strategies and practices for unmaking relate back to the discourse prevalent in extant literature on unmaking. We take a bottom-up approach to investigate how across the e-waste lifecycle, different domain experts engage with unmaking practices to disassemble, repair, repurpose or extend the life of e-waste. The diversity of participants and contexts of use, uncovers the richness and complexity of the context, reducing asymmetry of knowledge [70] and fostering argumentation [70] — which is arguably the *"key and perhaps the only method of taming wicked problems"* [69]. This paper hence fills a gap in HCI literature, of applied studies on unmaking [75], offering findings from multiple domains and participant viewpoints.

This study is situated in the context of Australia — the fifth-largest producer of e-waste globally [33, 54]; having doubled the rate of e-waste generated per capita over the past decade [19], with e-waste production, projected to exponentially grow, given the concurrent increase in both the population and material living standards [12]. Modelling estimates suggest that only 54% of e-waste produced in Australia is actually collected, of which 80% is processed through low-efficiency recycling, with little data available about repair, reuse, and resale activities — that might help us better understand the overall e-waste landscape, and how electronic products are kept in the economy, before becoming e-waste [12]. There is continued interest from regulatory bodies and government ministries to ensure better practices and policies are in place for e-waste management e.g., regulatory frameworks and legislation such as the Australian *Recycling and Waste Reduction Act 2020* [17]; calls for consultation inputs on e-waste stewardship [18]; official inquiries into the right to repair [67]; as well as the practical enforcement of legislation, guidance, and standards for e-waste management e.g., the Victorian State Government banned e-waste from being placed into landfill in 2019 [27]; programs such as the National Television and Computer Recycling Scheme (NTCRS), provide Australian households and small businesses free access to e-waste collection and recycling services [20], and support the creation of various council and private retailer-owned e-waste collection points [14, 83]. Additionally, there are also grassroots-level, community driven activities [60], and awareness and advocacy initiatives (e.g., see: [29]) for creating more sustainable practices with e-waste. Hence, Australia as a context of inquiry, is of particular interest, given the scale at which e-waste production is growing within the country; as well as both the legislative (top-down) and community (bottom-up) driven interests and initiatives towards curtailing challenges associated with this growth, that together aim to foster more sustainable technology production and consumption practices. To our knowledge, this is the first HCI and design-oriented work related to studying applied unmaking practices with e-waste within an Australian context.

The central contribution of this work is the presentation of rich illustrative, first-hand accounts of people engaged in unmaking with e-waste, across diverse contexts and application domains. These accounts are presented as *folk strategies* — practices that develop and emerge through lived experiences and prior interactions of unmaking with e-waste materials. These reveal real, vivid, and current perspectives and motivations, passions, and frustrations related to unmaking; providing supporting evidence to ground theoretical research concepts about unmaking through real-world accounts. Lessons from these accounts form the basis of declarations about unmaking (D1-D5) which are canvassed later in the findings and discussion. These declarations distil the findings into actionable provocations to guide future work on unmaking in HCI and design.

2 RELATED RESEARCH

2.1 Sustainable Interaction Design

Over 16 years ago, Blevis introduced *Sustainable Interaction Design* (SID) [11], a perspective that argues that sustainability *"can and should be a central focus of interaction design"* — where Blevis defines design as *"an act of choosing among or informing choices of future ways of being"*. Although not cited as a direct inspiration, this definition also resonates with Simon's more widely acknowledged definition, where to design is to *"devise courses of action aimed at changing existing situations into preferred ones"* [78], which too describes design as a means to shape and change the future ways of being, by making specific informed decisions about the actions we take in the present. Blevis [11] argues that sustainability should be the anchor that guides these decisions, by focusing on design values, methods, and reasoning. This perspective is guided by a rubric for understanding material effects of design cases, in terms of forms of use, reuse, and disposal. This rubric focuses on *disposal, salvage, recycling, remanufacturing for reuse, reuse as is, achieving longevity of use, sharing for maximal use, achieving heirloom status, finding wholesome alternatives to use,* and *active repair of misuse*. Additionally there are principles which Blevis [11] presents as goals for this orientation: (1) linking invention and disposal, i.e., *"the idea that any design of new objects or systems with embedded materials of information technologies is incomplete without a corresponding account of what will become of the objects or systems that are displaced or obsoleted by such inventions"*; and (2) promoting renewal and reuse i.e., *"the idea that the design of objects or systems with embedded materials of information technologies implies the need to first and foremost consider the possibilities for renewal & reuse of existing objects or systems from the perspective of sustainability."* These goals form the basis of *'sustainable "unmaking"'* [80] which is canvassed later.

This focus on sustainability must not be limited to the point of production. Lazaro Vasquez et al. [51] highlight the importance of taking a holistic approach to the technological lifecycle, by adapting the life cycle analysis approach — a *'cradle to grave'* evaluation of the environmental impact of materials e.g., products, processes and services [5] — for assessing impact across every phase of digital fabrication during prototyping. This same perspective can also be extended towards applying the sustainability rubric [11] towards evaluating consumer technology production and consumption, and the resultant e-waste that is generated. It is important to acknowledge that there are multiple possible trajectories for e-waste e.g., repair, disassembly, destruction etc. The inherent diversity and complexity of these trajectories, reinforces why sustainable production and consumption of technology cannot be treated as a *tame* problem [71] i.e., as all the variables and constraints of the problem are not known, and hence there is no single-solution or use context. Argumentation of different perspectives is central to better understand and address this kind of wicked problem [69, 70]. Therefore, understanding the competing perspectives, and multiple viewpoints of those engaged with e-waste becomes central to appreciating the nuances of the overlaps in strategies, values, and methods, whilst acknowledging, and learning from the differences in their contexts of use. This paper is informed by our prior work related to the role of e-waste within maker culture [89, 90], as well as the work of Dew and Rosner, on how e-waste can elicit insights on the design practices on which they were found [21]. Investigating what happens when technologies become old and obsolete, Grzeslo et al. [39] concluded that there are insufficient, systematic e-waste disposal mechanisms; lack of ownership of technology lifecycles; and that technology researchers and scholars have a very limited role in the lifecycle management of technologies i.e., they have limited influence on both technology policy and consumer use, once technology products enter the real world. Grzeslo et al. [39] argue that the only influence and control ostensibly possible, is over *how* the initial design of technology can influence the transformation of products into e-waste i.e., they can be designed to support conditions that enable more successful disposal or reuse trajectories once transformed into e-waste.

2.2 Unmaking and HCI

Unmaking is a growing area of interest in HCI [57, 65, 73–75, 79, 80, 95]. Unmaking can refer to *"the disassembly of an object or structure, or to the dissolution of values, ranks, habits, beliefs, affiliations, and/or knowledge"* [75]. The two major bodies of scholarship on unmaking in HCI are concerned with (1) sustainability, and (2) technology disassembly and repair. On sustainability and unmaking, Song and Paulos [80] argue that *'sustainable "unmaking"'* has a critical role in addressing Blevis's [11] call for both *"promoting renewal and reuse"*, as well as what they characterise as the more elusive, *"linking invention and disposal"*. Embedding unmaking pathways and possibilities into the design and fabrication of objects can counter *"the conventional concepts of disposal and waste themselves, turning the process of disposal into one of continual invention"* [80]. This creates a symbiotic relationship between invention and disposal for sustainability where *"invention should not be made without a detailed plan for the disposal of materials that will result—and that renewal and reuse be prioritised"* [80]. Motivated by similar concerns, *"elimination for good"* is a design lens that advocates critical and pragmatic approaches for determining if products, objects, and technologies are worth the environmental harm they cause [35, 84]. Pierce extends this notion by presenting undesigning as *"the intentional and explicit negation of technology"* attained through strategies such as inhibiting the use of technology in certain contexts, replacing a technology with another, and erasing certain technologies altogether [65]. Most relevant to our work is the exploration of Lindström and Ståhl on participatory engagement with the *"aftermath"* of design, for example through composting plastic [57]. Their work reveals the complexities of unmaking, including issues around safe disposal, reuse vs. destruction, and the *"conflicting speculations"* on how to unmake plastic altogether [57]. This sentiment is further echoed by scholars across various fields, calling on us to pay attention — and in turn unmake — our consumerist behaviours [91], individualist innovation modalities [58], human-centric design approaches [9], and the unsustainable pace of production, e.g., by attuning to other *"timeframes"* of being, such as soil regeneration [7] and situated and culturally informed hacking and making practices [55].

In the context of technology disassembly and repair, scholars have studied the nuances of when technological projects collapse [50], phones and batteries break [43], machines die in the workspace [61], and technological infrastructures approach their 'death' [16]. Designers have also leveraged moments of disassembly and repair as creative opportunities that start from the broken and ephemeral rather than the new and novel [23, 45, 59, 85, 96]. In this space, designers and researchers have further noted that unmaking *"cannot be based on a nice, neat checklist"* [34] since, as Jackson et al. argue, *"all functioning systems are alike; all broken systems are broken in their own way"* [46].

Unmaking as a praxis has a wide range of possible trajectories (e.g., repair, elimination, disassembly, destruction etc.), depending on the motivations, and desired outcomes of those engaged in unmaking. However, there is a lack of shared ontological understanding and vocabulary for unmaking in HCI and design, given the concept's emerging and broad nature, and a need for more pragmatic studies on unmaking that explore tools, methods, values, and participation [75]. Despite the increasing attention to unmaking, it remains largely under investigated [75]. A recent systematic review [40] of Sustainable HCI (SHCI) developments over the last decade, highlights sustainability work related to repair, making, DIY — but no studies related to unmaking were covered. A gap exists in HCI literature on applied studies on unmaking, that may help strengthen the conceptual themes identified in previous work and offer supporting evidence to ground theoretical concepts in real-world accounts and data. This present paper hence extends the foundational related work, by presenting an in-depth qualitative study of the current perspectives of people engaging in real-world unmaking practices across a multitude of contexts, where these rich portrayals fill the gap in HCI literature, of applied studies on unmaking. These first-hand accounts comprise of rich anecdotes illustrating the motivations, strategies, passion, and frustrations that participants engaging with unmaking encounter. They further help us identify challenges and opportunities that persist in moving towards designing more sustainable technologies, that are purposefully built to support unmaking.

3 METHOD

We conducted 12 one-to-one semi-structured interviews with domain experts who worked with e-waste in various capacities, across diverse contexts (See: Table 1). Purposive judgment sampling was used for participant selection, where the criteria applied focused on recruiting participants who had (1) prior experience of unmaking with different consumer electronic and electrical equipment; (2) directly engaged with and used unmaking practices with e-waste in their specific domains; and (3) represented a unique domain of expertise to the study (e.g., industrial design, technology research, technical repair, commercial e-waste disassembly etc.), to add a multiplicity of viewpoints, to better understand the problem space. This multi-stakeholder expert approach enabled us to develop a better understanding of the complexity of the wicked problem, by

Table 1: Participant domain expertise

#	Domain Role	Focus
P1	Maker/Sustainable Living Expert	Salvage fabrication for DIY smart home and gardening integrations
P2	Development Sector Specialist/Researcher	Maker culture for empowerment of marginalised communities
P3	Design Educator/Practitioner	Pedagogical practices for designing tangible computing interfaces
P4	Machinist/Technician	Maker space management, tooling, training, and facilitation
P5	DIY Hobbyist/Tradesperson	Repair and making services for social housing community residents
P6	Technology Commercialisation/Producer	Creative hacking of technology for commercialisation and performance art
P7	Repair Technician	Medical equipment maintenance and repair; DIY maker
P8	Industrial Designer/Researcher	Pedagogical value of digital technology as a creative material
P9	Music Technician/Instrument Luthier	Musical instrument and equipment design, production and repair
P10	Creative Technology Entrepreneur	Developing education technology toolkits for novice makers
P11	Commercial e-Waste Recycling Expert	B2B/B2C industrial e-waste processing commercial business operation
P12	Social e-Waste Recycling Expert	Social enterprise for community building through e-waste processing

reducing the asymmetry of knowledge [70] i.e., the notion that expertise about a problem is distributed, hence taking onboard multiple stakeholder viewpoints is important; which allowed us to draw upon rich accounts of unmaking with e-waste by practitioners with competing perspectives, agenda, values, strategies and reasoning. This orientation is also in line with the *lifecycle analysis* [51] approach, for evaluating environmental impact of different stakeholders across various stages of technology use and consumption, locating opportunities for sustainable technology design across a diverse e-waste unmaking landscape.

Given the pace at which e-waste is being generated, coupled with the multiple trajectories of unmaking with e-waste, it is impractical (and perhaps to some degree, irresponsible) for us to attempt to approach this research space with the aim of creating universally generalisable knowledge. Instead, we adopt an alternative perspective towards creating designerly knowledge, that treats the findings as what Stolterman [81] refers to as *ultimate particular*s i.e., where each individual interview is self-contained within the instance of the particular context. This enables us to not only locate valuable lessons from within the self-contained instances, but also identify patterns that might be emerge across multiple instantiations — which might generate more intermediate-level knowledge [41]; preserving the diversity of sub-cultures and localized cases that exist within the larger constellation of the problem space, but also generating some knowledge that might be applicable across multiple contexts.

The semi-structured interviews were conducted *in situ* at the respective participants' contexts of work. This approach was inspired by *contextual interviews* [8], particularly to allow participants to leverage their environments to jog their memory or bring in props to supplement their responses. We opted to do interviews, instead of observing participants engage directly in unmaking activities due to participant availability and project constraints. All sessions were conducted in person, barring P2 and P10, where participants requested to be interviewed remotely through video teleconferencing via Zoom from their workplace. The sessions comprised of a guided walkthrough by the participants of their workplace, coupled with a semi-structured discussion, featuring topics including *opportunities and challenges associated with the unmaking e-waste; impact of evolution of technology on unmaking for reuse; skills and tools needed to disassemble e-waste; values that governed their unmaking practices; strategies adopted when engaging with unfamiliar materials; and their overall process of unmaking e-waste.* Participants led the direction of the conversation and brought in artefacts and materials from their environment to supplement the discussion. The session duration on average was 60–90 minutes. Data was collected in the form of audio and video recordings, photographs, and observation notes.

Post the interview sessions, findings were discussed between the first and third author to identify key highlights. Over 17 hours of the audio and video data from across the sessions was transcribed. The data excerpts (transcripts, notes, and photographs) were then thematically analysed [13]. Researchers first reviewed the data, familiarising themselves with the content, developing open-ended codes. These codes were further analysed to identify common patterns resulting in development of aggregated higher-level themes. These themes were discussed and shared with the second author, who added additional comments and recommendations about their reorganisation. The finalised themes are presented in this paper, supported by rich illustrative accounts.

4 FINDINGS

Through the analysis of the data, we have generated themes that provide lessons for understanding the context, and pragmatic considerations, and challenges associated with engaging in sustainable unmaking with e-waste. These thematically organised findings highlight folk strategies, practices, and motivations for unmaking. The themes include: *visual assessment of materiality; commercialization of technology; dismantling strategies and constructive components; facilitating or supporting engagement with unmaking; and motivations for unmaking.* The themes are accompanied by provocations, in the form of five declarations (D1-D5). We developed the declarative statements as distilled lessons on how the findings can inform unmaking research in HCI. The findings are presented as data excerpts, predominantly in raw form, annotated by necessary explications in the sections that follow. This presentation strategy is perhaps unorthodox but has been adopted to preserve

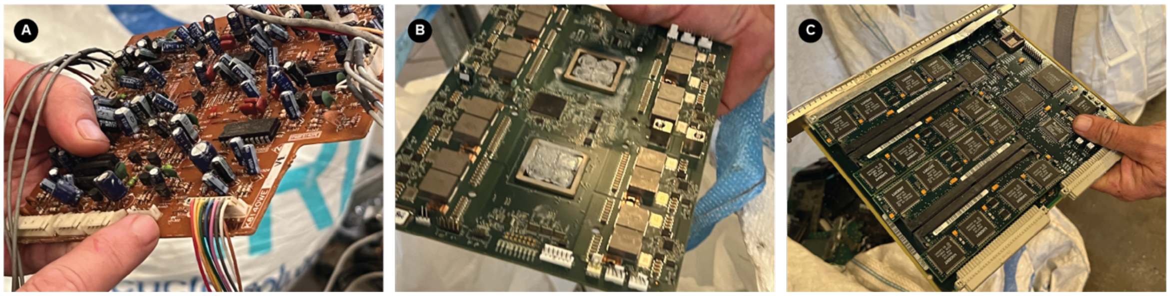

Figure 1: P11 holding different value boards (A) low-value — brown circuit board, with a lot of capacitors and larger components; (B) medium-value — green circuit board, with relatively large components, but not as heavy as higher-value boards; and (C) high-value — green circuit board, with sleek, modern, compact components, and heavy in weight.

the richness of the conversations and ideas raised during the interviews. Every point in the findings either culminates with a new declaration (Dn) or is an iteration (Dn^{i}), that extends a previously defined declaration — where each declaration is presented in the format Dn, where 'n' is the corresponding declaration number, and each declaration iteration is marked with roman numerals e.g., Dn^{i} Dn^{ii} Dn^{iii} represent three different iterations of the Dn declaration. Hence, all the declarations are empirically derived, and iteratively developed into their final versions which are later presented and unpacked in the discussion.

4.1 Visual Assessment of Materiality

The assessment of economic value of e-waste was predominantly dependent on materiality, visual cues, aesthetic properties, and prior conceptions of functionality. Participants highlighted how a *folk understanding* [1] (i.e., an understanding developed through prior interactions and lived experiences with the materials) was developed within the context, that directly impacted unmaking trajectories, to filter valuable materials and identifying capacity for recycling. P3 and P4 comment on how the hands are our first tool — indicating that before any other form of assessment can be done, exploring e-waste with your hands gives you an understanding of how it is configured — this same notion is extended to value judgement i.e., how valuable the components being taken apart might be.

The *materiality* (i.e., appearance, colour, weight, aesthetic, attachments, materials) of the e-waste, was critical to judging economic value. P11, who manages a commercial e-waste processing facility illustrated this by using the example of printed circuit boards, highlighting three dominant tiers of value — high, mid, and low. These tiers were determined by the aesthetic properties of the boards including colour, volume of components, style of components and weight. Holding up a CRT board (See: Figure 1) P11 says — *"These are your low value board. This board is brown. You can see it's not [high value], the actual boards are [not] copper based either! I think once you see it from that [brown board] and then you go to (looks for high value board, holds it up) to that [green board], that's high value! That's gone from 50 cents a kilo trade, to 10 dollars! . . .you can tell each of these chips, gold content, silver, bronze. . . you can feel the weight of that compared to the other [brown] one. . . .medium value would be more (points to other, less busy green board) [thinner], less components on it... So, the boys [floor workers] sort of know, I don't have to tell them what's a high or low value [component]."* A similar practice exists in the social enterprise for recycling e-waste as well, where P12 shares how they too have categorised bins for circuit boards based on their colour; a practice that emerged initially not because of economic value, but one that was introduced to them by someone who had requested the facility's services to disassemble certain e-waste items. They had requested the disassembled components be organised by circuit board type (predominantly organised by circuit board colour and shape).

Like most of the consumer product sector, the e-waste industry also operates on tonnage i.e., the more *weight* of e-waste commodities, the higher the value it attracts. P11 comparing circuit board value between old CRT monitors and computers and servers, states *". . .the CRT [television] circuit board is, it's very plain, very low value! More copper content in it, there's not so much gold. But with the computers and servers and phone system boards, that's where they got the chips. . . so the more chips on the board, the higher the value is! . . .usually like RAM or CPU has a lot of gold [metal] in that. . . but you need a lot [of volume] to make [any money] . . . because they are so light!"* This complexity of components is seen to not just add to the weight, but directly relates to *perceived functionality* i.e., the utility of components as originally intended (e.g., devices with higher processing power, were seen to comprise of high-value components) — P11 continues *"[boards] in a vacuum cleaner or any other sort [of product] that doesn't need processing power. . .it's pretty low value! But when you got something that needs processing power, that's when the high value comes into the boards."* The assumption is therefore that processor components will automatically have more complex componentry, and hence is seen to be more valuable.

The actual pragmatics of developing this assessment are largely linked to *tacit knowledge* — the developed acumen for making value assertations, which is reliant on exposure to, and familiarity with different types of products — especially when considering how technology is evolving. Hence the social understanding of the materiality of the components becomes an important feature. *"[Smart TV] hard drives are like a little circuit board. Boys [the floor workers] probably don't even realize that [it's a hard drive], it's just a high value circuit board — it's not like it's actual physical hard drive that we're used to. but look, the boys have trained up enough to know what sort of a circuit board it is. If it's low value, it's high value, it's*

Figure 2: e-Waste recycling social enterprise bins, for people to place components into after disassembling devices, based on the value of their components. (A) motherboards + gold chips; (B) green circuit board; and (C) brown circuit board

medium value. They know, they can see it straightaway — how many chips there are on it." — P11. This also speaks to the nature of the context, whereby efficiency is valued as floor workers are employed to dismantle materials and the faster they process the materials, the more revenue they generate. These priorities and strategies lead to the initial version of the first declaration:

> $D1^{i}$. Technology design should facilitate identifying, locating, and understanding value when unmaking

Using e-waste properties such as colour, weight, and attachment ports was critical for our participants and their floor workers to judge their economic value efficiently. The use of visuals as a way of creating a shared social understanding of unmaking and where materials should be processed after dismantling is therefore seen as very important to where unmaking happens. The social enterprise P12 manages, uses bins for disassembled components that have both names and pictures (See: Figure 2) of the components on the face of the bin — as a means of making sure there are multimodal indicators within the space for people with *all* abilities to engage. Another cue they use is the colour of the bins as a shared focal point of where to place certain items e.g., grey bin for dirty metals. P10 highlights that they have been exploring how when taking materials apart and putting them back together, visual imagery can make the process more inviting and reduce the barrier for engagement. They share going to a circuit board expo in China and asking a manufacturer to produce bespoke circuit boards with additional colours, to be more inviting for children to engage with — *"[I asked (via a translator)] 'can you do colours? circuit boards?' 'question mark?' and they would come back and be like, 'Why do you want to do that? [the] circuit board [is] for function! Not aesthetic! What are you doing? Circuit board goes in [the] box! You know, like, no one looks at circuit board. You fool!'"* — This shows the missed opportunity for making more meaningful use of the board faces themselves (as already highlighted in the value assessment section). The role board design can play in supporting unmaking literacies inspired us to extend $D1^{i}$ as follows:

> $D1^{ii}$. Technology design and materiality should facilitate unmaking literacies, including identifying, locating, and understanding component value

Beyond complexity, there are also inbuilt visual cues that directly relate to the *manufacturing process* and how materials are processed and treated during production, which has downstream implications when it comes to unmaking. P12 highlights how they use visual indicators on materials to determine the value of plastic — *"There's plastic, but it's not just one type of plastic... we've noticed that a few of these plastics have an 'FR code'; which means fire retardant... and so... we've learned they cannot be recycled! ...because they can't be reused or repurposed, because they've got that chemical in it. But we've found out that ABS plastic, in its true form without any fire retardant, and especially if it's the same colour, is quite... can be quite valuable"* — P12. This highlights how potentially valuable materials that can be repurposed and are quite durable, are rendered unusable because of how the production process is designed for the material. Fire retardants of course are meant to be applied as safety measures, and possibly mandated by policy and legal requirements — this highlights how considerations about the material decisions (both selection and processing of the material) made at the time of production, have a direct consequence on unmaking possibilities of the technology. This results in the creation of the second declaration:

> $D2^{i}$. Material decisions have consequences on sustainable unmaking possibilities and trajectories

Innovations in making, have a symbiotic relationship to, and can often be inspired by unmaking — and create value. P6 sharing details about a work project, states *"I'm gonna try to get this [button] to connect to [smart glasses]"* — they are trying to improve the photo taking interaction with smart glasses, by repurposing old technology. They say *"…you don't necessarily need to make a new thing, you can find an old thing — like this [Bluetooth button] I've had for years and I never threw it away. It's just a shitty little Bluetooth like button… but the problem we are finding with these Ray Ban [smart] glasses, is that you have to say [the command] 'Facebook, take a picture!', and by the time you've said that and it's taken a picture, it's five seconds later! So, I need to find out if I can just connect this [button] to the [glasses]. …that's just an example — this is a shitty piece of old tech, y'know, that is useless, but maybe it'll be really useful with, this like super new piece of tech which is actually a pain in the arse to use at the moment."* On the other hand, there are limitations too, especially when it comes to compatibility. P6 also details *"[this is] the first iPod, which I'm still trying to hook up actually, but again legacy systems, (points to port) [what] the fuck's going to go into that? that's FireWire 800, no 400 — that's FireWire 400!"* — P6, commenting on the inability to find appropriate cables and peripherals to access legacy devices. So, finding a middle ground for how technology of the old and the new can come together through unmaking is a very real opportunity that can be harnessed, to create value. This extends the second declaration $D2^{i}$, which we finalise as:

> $D2^{ii}$. Material decisions and compatibility options have consequences on sustainable unmaking possibilities and trajectories

4.2 Commercialization of Technology

Participants commented on how technology is predominantly designed today to further commercial interests and business agenda, rather than provide robust, sustainable value to end users. Participants brought up ownership, their right to repair, unnecessary complexity within systems, and forced obsolescence — all of which foster a throwaway culture. P4 states *"things like mobile phones frustrate me, because they are just glued together! because then you gotta get a heat gun, you've actively got to destroy something that you have to replace with things like this now… the fact is that companies are making it harder to repair things, that they are denying people the right to repair, or tinker or play with things — It's frustrating!"* P4 therefore highlights how there is an inherent irony in how the act of repair requires destruction. This frustration is also echoed by P6, who comments on unnecessary complexity becoming a product of the consumer culture, *"you got bean-counter [accountants/bureaucrats], penny-pushers [people unwilling to spend money] around, they make shit complicated! Or they encourage designers to make shit complicated! Or during the designer's training period they're encouraged to make shit complicated! And so, they actually end up with that mindset of having to change everything. Make everything proprietary. Y'know, otherwise maybe you design yourself out of a job! What's the whole thing — It's like 'design the perfect mousetrap and then you're fucked', aren't you?"* They further add *"It's capitalism, baby! It boils down to that, it's capitalism and consumption. And that's the reason that… we're faced with compounding, divergent, complexity, and often its complexity, which is unnecessary complexity."*

This collective commercial mindset also perpetuates a throwaway culture — P5 highlights *"the reason [designers make it difficult to disassemble things] is, you have to throw that away and buy a new one! It's become a throwaway society! Everything's made to throw out! It's all made of plastic. If it stops working, 'go out and get another one'. They don't expect you to pull it apart and fix it. I do pull it apart, I don't want to waste that machine…"* P4 also adds that legal safeguards such as warranties help facilitate both the manufacturer and consumer of technology to not have to deal with responsibly managing resources — *"this is the worst part about this consumeristic process. I mean, we're so hard driven to try and think about the environment… until it comes to our consumer products.! Just 'oh, we'll replace [it], its in warranty', or 'it's out of warranty, you chuck that one in the bin, and we'll sell you a new one!'"* — P4. Similar sentiments are shared by P5, who adds that commercial repairs are also viewed as resource intensive endeavours, hence organisations prefer replacement over repair *"because [if] it's too hard, [even] if they're doing it for a job, it's not worth it!"* This in turn led to the creation of the third declaration:

> $D3^{i}$. Unmaking has a fractious relationship with capitalism as the right-to-unmake subverts the throwaway culture

Beyond the physical construction, participants also commented on closed technological ecosystems. P3 states *"we've got companies that lock everything down so much that you can't fix it! Because they want you to buy (whispers) 'planned obsolescence', right? they want you to buy 'the next greatest thing!', and I think that's a really sad thing!"* P6 argues the reason for *"designing systems that are not easy to understand, is because [they are] building forced obsolescence into systems… doesn't make great sense economically, but it makes sense for business."* P7 highlights the mismatch between how technology is designed and where and how it is used, using the much-publicized legal case of John Deere tractors who have globally faced backlash on their proprietary software and intellectually property protections — *"[John Deere are] trying to say, 'No, if it breaks down in the paddock in Australia, you have to accept that the machine is broken! There is nothing you can do, nothing anyone else can do until our authorized repairman [comes]!'"* Adding how contextually myopic this view is, given *"in Australia… you can be 4000 km away or more from an authorized repairman. [This] kind of overly assertive protective attitude by manufacturers or suppliers of certain pieces of equipment isn't very helpful."* This sentiment not only highlights that the orientation towards 'authorised' servicing infrastructure is impractical for relatively developed contexts like Australia, but also opens the discussion about how this matter is magnified further in settings where servicing centres might not exist at all. It further extends $D3^{i}$, into its final form:

> $D3^{ii}$. Unmaking has a fractious relationship with capitalism, but technology must be designed to be both commercially viable and unmaking-friendly

Our findings reveal that there are contexts where electronics are not repurposed or recycled for legal reasons, even though they *can* be, and hence those materials must be destroyed. P11 shared that their commercial e-waste recycling centre had a lot of business-to-business (B2B) clients, and so they were bound by client requirements. They often had to not only erase data, but also destroy the physical devices as part of their agreements; in some cases, if the client permitted, the e-waste would be turned to commodities (i.e., shredded, sorted, and sent further downstream for processing), however in other cases it was mandated that the equipment be destroyed and put into landfill. P11 recalled a recent instance where a local video game retail store had been inundated by flood water *"The shop went under [in the flood]. They brought in a big whole 30 [cubic meter] bin of Xboxes, toys, [game] controllers — it was all wet. Had to go through that. Had to throw that to general waste. That's not too many times, we do that, but if they want it destroyed, product destruction and destroyed and landfilled we gotta follow that [instruction]."* — P11. They later added that they had to destroy everything, even though some of the materials were salvageable, while others were completely untouched by the water. Yet destruction was mandated to protect the legal interests and avoid warranty related claims that the manufacturer and retailer could have been liable for in the event end users ended up using possibly damaged products with faulty electronics. Although an isolated incident, when one looks at this instance in light of the current global chip crisis, where it is becoming virtually impossible to purchase next-gen consoles such as the *PlayStation® 5*, this highlights how most industries are designed to operate, i.e., not recycling or repurposing possibly faulty materials, because it might be more convenient and optimal to destroy them and view them as consumables. This is not to say there is no precedence of other industries salvaging resources from old products, for instance manufacturers *Apple* and *Samsung* have trade-in facilities (See: [2, 76]), where the companies aim to recycle electronics for consumers. P11 also shared that they actually store certain e-waste products and materials due to their value, this includes old Apple iMacs and Commodore 64's being kept in storage and treated with extra care because the first generation of electronics and computers are expected to increase in value over time, versus the more commodity-like recently produced electronics. This led to the creation of the fourth declaration:

> D4^{i}. Unsustainable unmaking trajectories reveal systemic shortcomings around accountability and responsibility in technology design

4.3 Dismantling Strategies and Constructive Components

There are varied strategies for how people engage in unmaking — especially in the case for repair and fault finding. This includes working systematically step by step from the point of taking apart the outer shell, and ensuring all components work till one reaches the fault (P5); or taking off any of the outer shells to be able to reach the actual area of concern (P6). Some participants describe systematically drawing out block diagrams of sub-assemblies (P7), whereas others visually assess materials — *"I look for inherent weaknesses. . . ways that it [device] might have been assembled."* (P4). Engaging with unmaking also requires at times a *"disregard for warranties"* (P10) and having a mindset to *"give it a red hot go!"* (P3). However, it is imperative to understand how materials are constructed and how configurations of assemblies come together. Participants shed light on some of these complexities and their strategies to address challenges they encountered. For instance, participants highlight hidden components such as screws are an impediment to unmaking, whereby only people who have prior experience of taking apart electronics, would know to look for these types of connections. P4 and P12 recount their strategies and approaches to understanding how to locate these hidden connection points. P4 states — *"Often time there's clues, like especially when you're looking for screws. . . the screw that they always like to hide under the label. I'll always rub a label to see where that one is — if there is one there. Because sometimes you pull that tamper proof label off, and that's the final screw you have to undo!"* Similarly, P12 highlights how when disassembling a *". . .computer keyboard, you think you found all the screws, but no, they're hiding under! Like they [designers], whoever make them, do it on purpose, so that I guess they can't be pulled apart very easily! So, a lot of the things we get in, you have to kind of problem solve and try to identify and find where the screw is, for example, that you need to remove the plastic or the cover."* Additionally, there is also a learning curve in understanding how certain components fit together, which can only be learned by repeated practice. P4 talks about plastic tabs that clip into place for certain electronics — "*working out how those little plastic tabs work, and just the correct way to do it"* — is an important skill to build. Given what folk strategies are revealing about technology design trends and how to design technology for more sustainable unmaking, we augment D4^{i}, into the final declaration as follows:

> D4^{ii}. Folk strategies developed through repeated unmaking highlight unsustainable unmaking trajectories in current technology design and suggest ways for how to design better for sustainability

P4 questions modern construction decisions and suggests alternative techniques, reiterating how one cannot disassemble components in most modern electronics without actively destroying them, because of how they are connected (e.g., glued components in mobile phones) — *"I mean, but really, couldn't you just have that touchscreen separate from the [glass] screen? So that there is two separate components? Does it really need to be glued together? Couldn't they have like y'know, half a millimetre of gap between those two surfaces? Are they really worried about dust getting in somehow? And if they made it serviceable, maybe you could open it up and get that dust out and then put it back together? Why not have two beautiful piano hinges on the side of the phone that you can just automatically clean your screen? Slide that touch panel out that's gonna get broken. . .anyway".* P5 also highlights their approach towards larger glued electronics, recalling an instance where they took apart an electric fan which had components assembled in a way that had no clear starting points for disassembly — *"I've come across stuff that's been closed up and you have [no] chance of opening it with a tool. . . they don't have screws in 'em anymore, or anything like that. So what I do is, I get out my angle grinder, put a 1mm cutting disc on it, and I cut right around the outside, and then I pull it apart. That way, I can glue it back with a good glue. So things that are sealed off! You can always get around it by doing that. You might spot glue say in ten places, and there could be a little bit of a gap, so you just fill it up with a bit of gap filler".*

A recurrent pain point that emerged across the participant interviews was how manufacturers use non-standardized screws in their products (P1, P4, P5, P6, P7, P11, P12), resulting in many participants procuring specialised tools as well as maintaining an assortment of salvaged screws (See: Figure 3). P5, a very seasoned machinist and technician who also manages a maker space, shares an account of

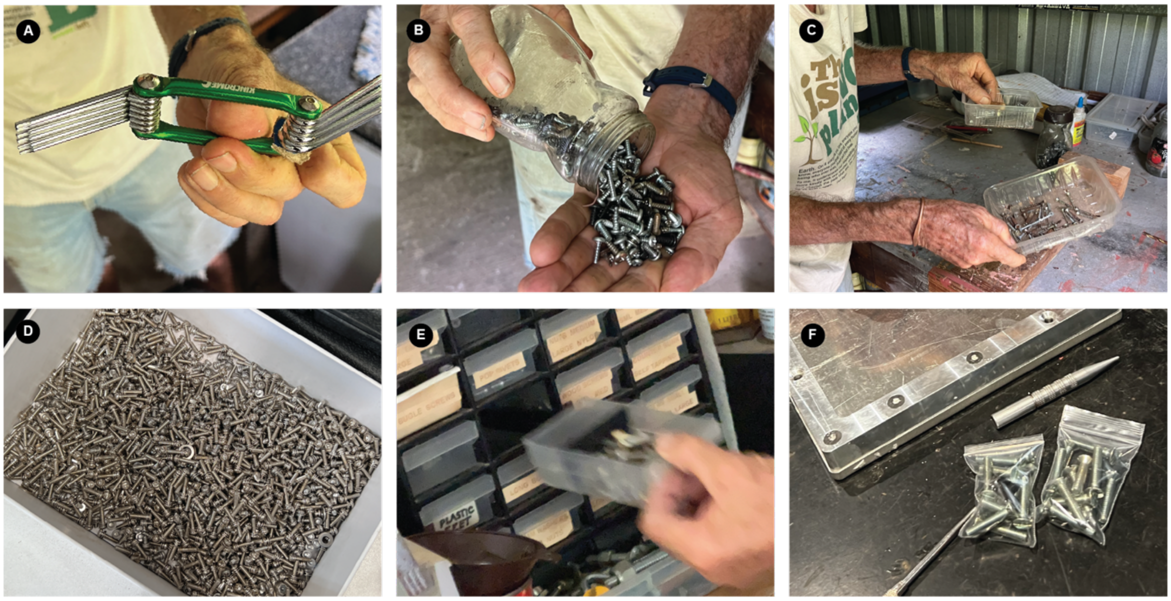

Figure 3: Mosaic of different storage units for salvaged connectors organized by participants from e-waste unmaking (A) P1 shows special tools to disassemble uncommon connectors; (B,C) P1 shows their assortment of screws; (D) P12 shows large bin of connectors from disassembly of industrial broadband equipment; (E) P7 stored and organised their connector collection into labelled storage compartments; (F) P4 shows bagged connectors in their makerspace to organise specific parts of the assembly

repairing two game controllers. They talk about a smartphone game controller that took them three days to fix — *"I've got a Razer Kishi, it's like an Xbox remote for my Android phone. I dropped it, and one of the control joysticks dislodged and locked in a certain position. So, I had to pull it apart."* They characterised what follows as the *"most annoying"* part of this disassembly, which was helped by an earlier instance with their son involving uncommon screws. They state: *"By pure luck, my son had a similar situation with one of the paddle buttons on his Nintendo Switch controller… I looked at it initially, I was like, 'Oh, yeah, that's easy enough! I've got some precision screwdrivers, I'll just pull it apart!' and then I realized they're these weird tamper proof Tri-wings — they're not Phillips head [screws], they're Tri-wing! And I'm like, 'Oh! well, well I didn't expect that!' So, then I got on to Jeff Bezos [Amazon] and they hooked me up with a nice set of tamper proof precision screwdrivers! Thank you, Jeffrey Bezos! and so now I've got a set of them, so that slowed me down but then I fixed his! — but my eight-year-old was so disappointed that 'dad couldn't fix it!' and it was my fault for not having the correct screwdrivers! So, I'm glad that Uncle Jeffrey can help me out there, but then I got to use those again from my own [controller]."* This instance highlights how this participant, who has forty-years of experience working with various tools and machines, did not have the tools in their assortment to be able to disassemble the components initially. The compounding aspect of this is the social implication of the son's disappointment who felt that their dad who was so clearly tech savvy, *should* have had the tools just adds to the negative experience for the participant. They then returned to describe the challenge they faced with the repair of their phone's controller, adding *"I noticed again that they [Razer Kishi] use the tri-wing proprietary 'FU screws' as I call them on the outside — but on the inside they're just regular precision Phillips head screws. And again, what was stopping me… one of the screws was a different length! and that stopped me being able to reassemble it correctly. Just one that just set up that little bit higher because it was the wrong length. And I missed it the first two days, so it took me the third go, and then I figured it out. But I've got it working again"*. So, it is not just the head of the screw that was problematic, but also that of the seemingly similar assortment of screws, having one screw off by a visibly negligible length, led to two days of extra work.

These non-standardized and incompatible connectors trace back to unnecessary complexity in P6's view, who argues *"It's capitalism, baby! It boils down to that, it's capitalism and consumption. And that's the reason that… we're faced with compounding, divergent, complexity, and often its complexity, which is unnecessary complexity. Totally how come we've got bayonets and screw globes? I mean, that's like that. That goes, that's fucking Edison and Tesla man! goes back to them — stupidity, still around! Like that's insane, that it's still around. Like, why do I have a box full of cables downstairs of varying sizes and shapes and descriptions? Madness! if designers were in charge, I believe they would offer simplicity… but that's just a stupid belief."* Interestingly, P6 does not attribute this incompatibility here to designers, but to the environment that they design in. This leads to the question of who is responsible and should be held accountable for designing technology that could be easier to use and unmake? This further, speaks to the very first declaration D1$^{\text{ii}}$ about incorporating unmaking literacies into the design process itself, which results in the final iteration of this declaration:

> D1$^{\text{iii}}$. Best practices around technology design, materiality, and interconnectivity are necessary to facilitate unmaking literacies and value judgment

4.4 Facilitating or Supporting Engagement with Unmaking

Breaking down e-waste at an industrial scale can be resource intensive, and not rewarding (i.e., low value return for effort). However, there are alternative, creative social avenues that can be explored to make this process more enjoyable. P12, who manages a social enterprise that focuses on community building through e-waste recycling talks about a creative and novel opportunity for *'crowd-sourcing'* unmaking (or as it is characterised here — smashing). P12 details an arrangement their organisation has with a local business that creatively helps facilitate the breaking down of certain e-waste into scrap-ready components. The business has "*a place you go to, pay money, and release your anger and stress by smashing stuff! . . . we were collecting all their 'dirty metal', so, all the items that are getting smashed! And we would give them items, they'd smash 'em and we'd pick it up. So, they were showing their sustainability, they were helping the environment, and in return we would just get free smash sessions, because you know, we loved to do it"* — P12. This indicates that unmaking can not only have cathartic value in terms of releasing stress, but that there is also an underlying social opportunity, to develop a communal culture for unmaking. There was further a certain degree of preparation required for breaking down e-waste in this manner. P12 narrates *"we'd take the inks out and then give them the printer. . . glass and all that stuff. . . we can't recycle that, but we would pick up their dirty metal, which are the carcasses of the items. . . and then take them to the scrapyard. So, anything really, that was not [dangerous], the glass is fine. No batteries! We'd always take, nothing with batteries."*

Outside of the commercial spaces where this form of unmaking can occur, there is also an opportunity of playfulness that can be embedded into communal e-waste recycling spaces. P12 comments on the social etiquette for unmaking in this way — *"we have a school come in every Wednesday or Thursday, and one of the girls loves to just release her anger by smashing something. She'll ask me politely, 'can I please smash this?' [I respond] 'absolutely, let's go outside!' but remember I gave her a broom and say, 'if you're going to smash it, you got to clean it up!' she's got. . . goggles and gloves on, closed in shoes, so she's all secure, and then she just smashes and goes to town!"* This highlights how even an activity as seemingly destructive and messy as smashing e-waste, can be structured in a way that is organised and safe, while still being playful and fun.

This more visceral approach also helps reduce some of the barriers or inhibitions people might face when it comes to engaging with technology — and develop a more balanced appreciation for just how e-waste is processed. P12 adds *"I know [smashing is] good for some people. . . some people are so delicate with the stuff and that's great, but. . . to the point where they don't think they can break it. [that] they're not allowed to! And I'll say 'no, no, this is all gonna get shredded, this is gonna get scrapped! So, if you want to be delicate with it and be nice, that's absolutely up to you, but don't worry about breaking it! watch this, 'crack' (makes breaking sound)' and they're like, 'wow, you can do that?' so, you can break in as much as you want, but yeah there's a line that you've got to go, hang on this person's disrespecting everything and throwing stuff — you've got to watch that!"* This again highlights how there is both pedagogical value in understanding what happens during the lifecycle of e-waste, a specific etiquette, but also socially engineered acceptability for unmaking with e-waste in this manner through demonstrations — or as we phrase it in a new, fifth declaration:

> D5[i]. Social practices and community engagement should be leveraged to foster an unmaking culture

4.5 Motivations for Unmaking

The underlying motivations for people engaging in unmaking practices varied across the board, where some participants were getting commercial value out of it, whilst others wanted to be more sustainable and responsible in how they consumed technology. There were however instances where the immediate social consequences of unmaking were material factors in why participants chose to engage in unmaking (especially for repair) and when they opted not to, as detailed in the cases that follow. P7, a seasoned repair technician lives by the virtue *"with sufficient information, technicians can repair anything."* They recall an instance about repairing an air conditioning unit in their house that was 20 years old. They looked up the repair process and realised the call out fee was quite high. They say "*I was able to find the service manual online, which included a troubleshooting guide, which greatly assisted me in narrowing it [the fault] down to a small board in the outside box of the air conditioner."* They continue — *"When I opened that box up and pulled it out, and just sat down and looked at this electronic board, not with any meters or testing. Sure enough, there was a component that had cracked, a soldering joint you could see it, just the vibration of the unit over the years had gradually fatigued this metal joint. As soon as I saw that, I went and put on my soldering iron. I soldered it up, I put the board back in, put the connectors on and switched it on. And the thing's gone for another six years."* Although the previous encounter with unmaking that led to repair was successful, P7 shared a subsequent account where the AC developed another fault. *"I spent a couple of hours investigating, was not able to reach that conclusion exactly what was faulty. . . I was stuck. But, realistically, and my partner is much more sensitive to hot weather temperature for sleeping at night than I am, and I totally agreed [to replace the unit]."* Adding *"my first technical instinct is no, let me have a go at repairing it. So I did that successfully, we got another six years out of it. This time I became really stuck, and it was pretty easy to say — yes, we shall get a new air conditioner. If I spent another 50 hours, I might find it [the fault], but really is it worth it? A divorce would cost me far more than, a two and a half thousand air conditioner."*

In contrast, P8, an industrial designer and advocate for replacing devices that require repair, believes that consumers should let experts deal with technology. They however describe the one device they most frequently repair themselves, their dishwasher. They explain, the cost of repair is more than the value of the appliance itself, and they did not wish to wait for the replacement if they bought a new one, given its frequent use — *"It was an old dishwasher, I really wanted it to work! because I didn't want to wash the dishes! So, I pulled it apart and fixed it and put it back together again."* They drew on their training as an industrial designer to repair the appliance, stating *"yeah I had like three kids in nappies and seriously (laughter) because desperation called!"* — highlighting external factors influencing the motivations for unmaking, even if for the sake of identifying faults and repairing the appliance to extend its life.

Table 2: Final Unmaking Declarations

#	Declaration
D1.	Best practices around technology design, materiality, and interconnectivity are necessary to facilitate unmaking literacies and value judgment
D2.	Material decisions and compatibility options have consequences on sustainable unmaking possibilities and trajectories
D3.	Unmaking has a fractious relationship with capitalism, but technology must be designed to be both commercially viable and unmaking-friendly
D4.	Folk strategies developed through repeated unmaking highlight unsustainable unmaking trajectories in current technology design and suggest ways for how to design better for sustainability
D5.	Social practices and community engagement around a plurality of motivations should be leveraged to foster an unmaking culture

Understanding the plurality of motivations behind unmaking can make it a more pervasive social practice, so we extend D5^{i} into the final version of the fifth declaration as:

> D5^{ii}. Social practices and community engagement around a plurality of motivations should be leveraged to foster an unmaking culture

5 DISCUSSION

Unmaking has been of significant interest to the HCI community, with special attention towards understanding the pragmatics of unmaking [75]. Extant discourse about unmaking and sustainability has identified the challenges associated with planned obsolescence [72], the importance of visual inspection [68], and how the industry has disincentivized releasing products that allow for repair or restoration [24] — all which have also emerged as relevant topics in our findings. Our study supports these concepts with current, vivid perspectives through first-hand accounts from people practically engaged in e-waste unmaking, adding depth to the way the research community thinks about these issues and their impact on the lives of people. This paper hence, concretizes themes identified in previous work, by offering supporting evidence that grounds the findings and reveals novel folk strategies around unmaking. Below we unpack the unmaking declarations developed in the findings (See: Table 2) to highlight the implications of this work for the HCI community.

5.1 Unpacking the Unmaking Declarations

The section is organized as follows: we present each declaration, followed by a one-sentence description, a discussion of the declaration in light of extant literature, and the relevant implications for unmaking and sustainable technology design.

> D1. Best practices around technology design, materiality, and interconnectivity are necessary to facilitate unmaking literacies and value judgment

The first declaration relates to how the materiality of the components (e.g., colours, chip content, and weight among other attributes), played a vital role in determining how unmaking can be used to create awareness, and educate the unmaker, about the components, as well as capture and salvage valuable materials. Within the current landscape where we are faced with increasing resource constraints (e.g., semiconductor shortage [6]), leveraging this avenue becomes increasingly important. The use of materiality to judge value has been highlighted by Rifat et al. [68] previously, who present the case of the *'bhangari'* (e-waste recycler) community in Bangladesh. Our findings reinforce the value of this approach, where visual assessments play a central role in determining value as demonstrated by P11 and P12, who share details of how chip value is determined based on visual aesthetic, weight, and colour. This finding highlights how similar practices are prevalent across geographic and socio-economic boundaries, and the role physical materials can play in supporting unmaking for salvaging value.

Furthermore, the use of visual prompts and indicators is quite common in electronics e.g., (FCC) logos [31] and European Commission (CE) marking [28]. However, these symbols are not meant to be instructive for end users in the way other symbols designed particularly for end users are (e.g., Bluetooth, Wi-Fi, battery icons). There is precedence of semiotic indicators being of interest within HCI literature (e.g., [49, 56, 66]) to develop literacies for end users. In our findings, P10 highlighted how they attempted to have custom circuit boards printed to support additional functionality i.e., be playful and inviting for children to tinker with; while P11 and 12 also highlighted how visual elements are used to inform value decisions. Extending this notion of leveraging materiality and semiotic, visual indicators, we can consider how to design components that have more instructive content on them to facilitate unmaking literacies. These indicators might include annotations in the form of (1) details on the board itself e.g., coloured segments on breadboard showing connections, links, and pathways; (2) text-based annotations (i.e., names or descriptors of components within the tech chassis); (3) component level pathways e.g., QR codes for components which lead to video resources or in-text manual locations; and (4) numbers to highlight sequence e.g., in what order to remove subassemblies. These elements can be either printed on the components or added as stickered labels — augmenting component level awareness and knowledge. This enables us to understand the technology and how elements fit together at a component level and can also feature aspects such as value of components (e.g., how much rare metals are used), or even details about connections/tools required for disassembling them. We contend that this is a promising avenue to explore for sustainable unmaking — leveraging symbols, semiotic indicators, and iconography on electronics to develop a visual, component level vocabulary for unmaking and sustainability;

a mechanism to create meaningful information for both industry and end users.

There are no universal device construction guidelines or best practices that lead to standardized techniques such as being consistent with screws when designing a device. Beyond that, there is no requirement for designers to declare how the devices are put together. At this point where we are actively involved in both the design and proliferation of emerging technologies, can we as an HCI community address this? Can we try to develop a set of heuristics that allow standardization of components, but also the flexibility to add/modify/change the heuristics — so they are not simply inhibitors to innovation? Across these questions lies a central challenge that kept resurfacing with participants, which is having some form of consistency for screws and joints. The need to first identify the type of connector, and then acquire specialist tools for unmaking certain consumer electronics was seen as very problematic. There are already examples such as the European Union's push to standardize all smartphone cables [64] (which has been met with a lot of pushback from industry), however can something similar be done for how we design the assemblies of technologies? These literacies are foundational building blocks to facilitate unmaking at scale — to develop better unmaking support tools, mechanisms, and decision-making systems, to better judge value and unmaking possibilities.

> D2. Material decisions and compatibility options have consequences on sustainable unmaking possibilities and trajectories.

The second declaration captures how the material decisions made during the construction and assembly of the technology products, had direct consequences for how participants could engage with unmaking the products when they were transformed into e-waste. These material decisions can either act as enablers or deterrents for certain unmaking trajectories and possibilities, such as reusing or repurposing device components. For instance, using plastic that is coated with fire retardant (P12) directly limits the possibilities of what can be done with the plastic during unmaking, rendering it predominantly unrecyclable, and making destruction the only viable unmaking outcome. This speaks to the levels of unmaking we as technology designers need to consider, even if only speculating about the aftermath of using plastic [57]. When designing interactive technologies, our HCI community must do more to consider how each decision during the construction process, can limit or create opportunities for unmaking trajectories. Materiality has been of significant interest within contemporary HCI discourse (e.g., [47, 48, 82, 92]), and is an important factor for us to consider from the perspective of unmaking, during construction of products i.e., how we can more deliberately leverage materiality to generate more sustainable outcomes, beyond simply using recycled materials as device components during construction, but also consider the consequences for unmaking trajectories. The same applies for post-unmaking component compatibility. Moments of disassembly and repair are seen as creative opportunities, starting from the broken and ephemeral rather than the new and novel [23, 45, 59, 85, 96] — our data too demonstrates similar instances of creative opportunities through unmaking, such as P6 trying to hack together a Bluetooth button as a camera trigger for smart glasses. The more technology we can unmake, dismantle, and pull apart while understanding how the underlying systems work and interconnect, the more opportunities we have for using unmaking to create innovate alternative, creative outputs.

> D3. Unmaking has a fractious relationship with capitalism, but technology must be designed to be both commercially viable and unmaking-friendly

The third declaration relates to how there is a pronounced, inherent tension between the competing commercial interests of technology manufacturers with design that facilitates sustainable unmaking trajectories. This is where participants highlighted how manufacturer-led decisions about product design were incompatible with, or rendered certain unmaking practices impossible. Closed ecosystems, proprietary components, warranties, and built-in obsolescence are just a few aspects that as they currently stand, are incompatible with true sustainability. The theme of *"unmaking and capitalism"* [32] underscores many of our findings, with participants commenting on the profit-centric motives of industry at the expense of consumer interests. Revisiting SID principles, Roedl, Odom and Blevis ask *"can capitalist economies survive without planned obsolescence, and if so, how?"* [72], suggesting that *"even with the ability to identify and understand the dynamics of obsolescence, how may designers and researchers avoid contributing to cycles of invention and disposal? This begins with first considering what problems actually merit a designer's (or researcher's) attention"* [72], which we extend to Grzeslo et al.'s [39] argument of what scale of influence do designers and researchers even have? Although this finding has been reported in previous work [32, 73], it is important to emphasize the frustrations of end users — as illustrated through their unmaking folk strategies and practices — and their sentiment about the systems that govern and distribute technology. Dourish [24] characterises this as a systemic challenge that needs to be addressed at multiple scales of influence and control. While not enough on its own, unmaking still provides a mechanism for users to reclaim control and ownership over the technologies they use. We as designers of these systems should do whatever we can within our realm of influence to facilitate this.

To realise any of the design recommendations, it is important to consider responsibility, accountability, and buy-in across the value chain. Afterall, systemic change requires policy, regulation, commercial interests, and consumer behaviour to all work together for any practical traction [15, 22, 24]. An obvious yet trivial takeaway here is that we should attempt to make design more unmaking-friendly at a policy level. But the frustration i.e., the lack of buy-in or inability to influence systemic change at the policy or large organization levels, is why unmaking also needs to become a folk practice. If we create more contexts and opportunities for unmaking, i.e., develop both unmaking literacies and possible trajectories/applications for unmaking — the diffused knowledge and interactions within these tightly-closed technological environments might spread out the frustration, and lead to a more systemic change through more bottom-up unmaking activism.

In addition to folk practices and policy changes, commercial initiatives can play an imperative role here. *Apple* for instance has recently expanded its *Self Service Repair* program [3], intended for providing individuals who have the knowledge and experience of electronic device repair, to access repair manuals, order parts, and buy or rent repair toolkits [4]. This is a step towards making unmaking more accessible to end users. In similar vein, the concepts such as the *modular phone* are seen as utopian archetypical visions for sustainable technology design. Many such concepts have failed to get traction e.g., *Project Ara* by *Google* [38, 63], where component subassemblies could be swapped, replaced, and upgraded; *LG* developed modular components for their *G5* smartphone [53]; and *Facebook* (now *Meta*) filed for a patent for modular devices as well [26]. Still a more successful modular smartphone is the *Fairphone* [30] a device that is a 100% e-waste neutral, uses fair materials, is built to last, and aims to be the easiest to repair in the industry — which indicates that such concepts can be realised and successful. Contemporary movements for democratizing sustainable technology production practices have also gained traction, such as the *Gathering for Open Science Hardware* [36] and *Open Source Hardware Association (OSHWA)* certifications [36, 62]. As it stands, a vision of modular, sustainable consumer electronics has not been successfully realised — but we have small pockets of examples where commercially successful/viable options do exist. We also recognise the promising and perhaps necessary role that automation might have in supporting unmaking at an industrial scale, given the current rate and projected growth of e-waste generation. However, to develop automated decision-making systems and support tools for unmaking, understanding folk strategies and practices of individuals engaged in e-waste unmaking is a necessary foundational step; revealing possible application areas where automated support systems can facilitate unmaking.

> D4. Folk strategies developed through repeated unmaking highlight unsustainable unmaking trajectories in current technology design and suggest ways for how to design better for sustainability.

The fourth declaration highlights how folk strategies developed by participants illustrate how sustained engagement with e-waste unmaking reveals pathways that may subvert systems intentionally designed to be unsustainable for unmaking. Unmaking in the literature is often closely aligned to, or is seen to have a strong affinity with sustainability. However, as illustrated by our participants, unmaking in practice can have unsustainable manifestations e.g., P11 detailing the destruction of gaming consoles due to legal liability and warranty concerns, or P12 using unmaking to destroy/smash old electronics as a means of stress relief. Constructs such as *"elimination for good"* advocate for critical and pragmatic approaches to determine if products, objects and technologies are worth the environmental harm they cause [35, 84]; similarly salvaging materials, recycling and repurposing components all have noble intentions; yet unmaking does not always entail these values. Our data illustrates 'unsustainable' unmaking — cases where instead of helping improve the environment, unmaking can lead to further resource loss or outcomes incompatible with sustainability. We must then ask what this means in terms of our understanding of unmaking? What consequences do unsustainable unmaking activities actually have? These questions can suggest opportunities to improve our approach towards policies, regulations, and how we consider the end-of-life of devices.

As presented in our findings, those engaged with unmaking often develop their own folk strategies through their experiences, e.g., developing the practice of rubbing one's finger on device stickers to locate hidden screws (P4, P12). The human brain is inherently predisposed towards processing information through the hands [93], this was highlighted in our findings, where P3 and P4 talk about the hands being our first tool, and P4 sharing they look for inherent weaknesses by feeling the material. The importance of the hands is illustrated through the concept of the *Homunculus,* a representation of a distorted human form, where each feature of the body is depicted in proportion to its use, from a neural map of the brain [77]. Blair & Rillo [10] argue that *"your hands are the search engines of your mind"* when talking about the role of hands in design activities. Rifat et al. [68] also highlight the importance of the hands as a tool for unmaking. This profound connection between the brain and hands means the hands are not only tools to gather information and manipulate matter, but also assist in cognition and creation of meaning [37]. Indicators such as markings may become a means of guiding material explorations, to better equip individuals to get a richer sense of how to unmake e-waste (e.g., P12 commented on how batteries and anything harmful, or that could explode, must be removed before unmaking-by-smashing should take place). Indicators might also help identify and locate what materials are (or can be) compatible, and which ones cannot (or should not) be used together. However, by understanding how people use their hands — among other folk practices — we better understand how the process of unmaking unfolds. This insight in return can help us design technology better suited for unmaking.

> D5. Social practices and community engagement around a plurality of motivations should be leveraged to foster an unmaking culture

The fifth declaration highlights the critical role social practices and motivations play in fostering a culture that encourages unmaking through necessary practices, rituals, and behaviours. Within our findings, unmaking predominantly related to utility-based approaches of dismantling e-waste. However, as an ideology, unmaking also lends itself to social activism (e.g., [32, 73]). Within our data there is also the case of crowdsourcing the *'smashing'* of e-waste (P12). This reveals a unique opportunity to foster and develop social and cultural activities that instil values of unmaking. This is a vital finding for the HCI community as it exemplifies how unique practices like this exist in the social world, and it radically shifts how we might think about the unmaking ecosystem. In this paper, we have presented the case of two organisations sharing e-waste resources to have end users come and *'unmake'* them to a state that is of value to both. This finding also reiterates the importance of conducting rich, contextual, bottom-up research about unmaking in the real world, if even to explore how theoretical concepts from HCI discourse practically manifest. This helps not only identify potential blind spots for how HCI understands unmaking, but also reveals how people engage with unmaking and potentially uncover unique and interesting application possibilities.

The discourse around unmaking predominantly looks at the practice as a means to foster sustainability. However, in reality there are many possible answers to the question *'why do we unmake?'* This includes economic motivations, individual values and beliefs, but also social factors. There are numerous goals, applications, and purposes behind unmaking. Repair is a commonly highlighted one [42, 44, 45], which was also observed in our data (e.g., P8 attempting to fix their dishwasher; P7 attempting to repair their AC unit; P5 repairing their joystick). However, there are far more diverse and nuanced motives for unmaking, including unsustainable reasons (e.g., console destruction for warranty P11; smashing e-waste to release stress P12), salvaging materials (e.g., screws being salvaged from various e-waste P1; collecting valuable elements from e-waste P11. P12), and creating new innovations (P6 connecting Bluetooth button with smart glasses). Understanding these various motives for how and why unmaking is done helps establish a better appreciation for how we might design technology. These trajectories provide deeper insight into what possibilities and opportunities exist when designing for *'end-of-life'* of technologies [39], and to better design for *'disposal'* [11].

5.2 Towards Sustainable Unmaking

Grzeslo et al. [39] have concluded that technology scholars and designers hold limited influence on technology once it enters the real world. In practice, many aspects that influence the design and manufacturing of current technologies, even prior to being put into the real world, are inhospitable to unmaking. They come directly from the disincentives of companies and designers whose interests are not aligned with those that foster sustainable technology design. Therefore, if the entities dictating and controlling technology design are actively working against sustainable unmaking, it is important for us to reflect on what can we do within the realm of our control as an HCI community to create a step-change and disrupt the status quo. We must closely consider how we may create avenues that facilitate unmaking, to promote, and support sustainability at an individual level, and also get traction at a more systemic level.

Song and Paulos [80] argue that *'sustainable "unmaking"'* plays a critical role in actioning Blevis's [11] call for *"promoting renewal and reuse"*, and *"linking invention and disposal"*. It is only through more nuanced understanding of applied cases of unmaking at the individual levels, such as those presented in this paper, that we can locate creative alternative means to disrupt the current norms of technology production and consumption. These folk practices exist in real-world settings, therefore understanding the social contexts within which they manifest, reveals rich pragmatic considerations and strategies for us to explore further. Perspectives that advocate for critical and pragmatic approaches to evaluate the environmental costs of technology [35, 84] or whether we should use technology at all [65] can see through our participants' accounts, how individuals are practically reclaiming control over technology through unmaking. Even with the unsustainable technology systems that persist, there is room for successful practices and strategies to create impact. This could mean adding visual indicators about component value (learning from P11 and P12), or something as basic as what tools/toolkits might be required to dismantle certain electronics, printed on the device chassis. Further, power structures and imbalances that dictate design decisions need to be critically recognised and appraised across the technology design and unmaking lifecycles. We must consider *'how'* change can be driven through the different levels of influence.

The examples presented in the findings demonstrate how people at a grassroots level are engaging with unmaking praxis. Without profound supporting policy and regulations, and buy-in from the industry, individual-scale strategies and practices provide evidence of encouraging possibilities for sustainable unmaking within these functional, broken systems [46]. As technology researchers and designers, we come from a unique position of opportunity, to create informed decisions that might help support bottom-up unmaking approaches. We can learn from real-world engagements and entanglements with unmaking to better design technology that invites (and even encourages) unmaking possibilities. Micro-level interventions can add up and help further this movement. The declarations derived from the findings, identify key areas of focus through which we might better design technology that facilitates unmaking. The folk strategies presented in this paper are a departure from more traditional, expert driven approaches towards unmaking; instead, they are a by-product of sustained, and on ground, lived experiences of individuals engaged with unmaking e-waste. They reveal a catalogue of diverse and pragmatic considerations, of how individuals understand, decipher, negotiate, and traverse the unmaking process. The folk strategies provide unique, individual-centric, situationally grounded perspectives, which are not driven by the theoretical ideals of unmaking. Hence, they enable us to not only see real-world applications of unmaking concepts, but also forecast examples of (possibly unchartered) alternative approaches towards unmaking. The practice-based knowledge generated through these folk strategies collectively is quite robust, as it has been developed and curated over multiple, sustained engagements with e-waste unmaking, demonstrating how different individuals negotiate similar challenges and activities. Applying this knowledge to inform the design of technology, enables us to explore possibilities for democratizing unmaking, by creating scalable products that are more considerate of folk unmaking practices, and therefore possibly more relatable and useful in advocating for unmaking to a larger audience — creating more opportunities for unmaking.

Some of these findings might in certain cases seem trivial or mundane, but the fact remains that the industry and academia are already aware of what might characterise the interventions and solutions needed for sustainability. Yet we still struggle to get traction when it comes to designing sustainable technologies that grant users agency, control, ownership — including the right to unmake them. Moments of disassembly and repair are creative opportunities (as illustrated by our findings) that originate from the broken and ephemeral rather than the new and novel [23, 45, 59, 85, 96]. The value of these accounts, including practices and strategies, lies in how instructive they are for how we can design better — even if they are mundane. We need more studies with folk accounts that expand our understanding of unmaking in the e-waste landscape. Taking on such a pragmatic orientation highlights unique possibilities for what it means to engage with e-waste, such as crowdsourcing the destruction of elements that might otherwise require intensive mechanical processing, and turning what is otherwise a mundane, factory-based process into one that might become a social practice and an avenue for creating awareness and advocacy for sustainability.

Many of the examples used in this paper focus on unmaking in the physical world, particularly regarding hardware components.

However, the insights can be extended to encompass both hardware and software. For instance, we can broaden our perspectives to consider whether folk strategies can be applied to digitally unmake systems. This expansion may involve exploring questions about repurposing, utilizing, and adapting legacy infrastructure, systems, and software. We can also investigate how to unmake software as a way to comprehend system complexities, or reconfigure and optimize them by eliminating inefficiencies and redundant code, removing outdated code blocks, and adopting purpose-fit, forwards compatible software packages that facilitate repurposing old hardware.

To realise the suggestions presented in the unmaking declarations, we need systemic change [24]. Practical steps can be taken, such as standardizing tools, joints, and connectors across devices. Additionally, we can explore avenues for cultural shifts, such as engaging the community through crowdsourced unmaking and considering how the end-of-life of technology can become a space for social involvement. However, it is crucial to critically evaluate the impact of these changes on end users in order to achieve success. For example, does revealing hidden screws behind stickers invite tampering and compromise the safety of end users? Does standardizing screws/connections and moving away from glued components affect functionality and user experience? Understanding the tradeoffs associated with designing technology that supports unmaking is essential. There is no singular solution, but rather a mosaic of incremental steps that, when combined, can help transition us from a throwaway society to an empowered, unmaking society.

6 CONCLUSION

If we look beyond the technology producers' commercial agenda, even the e-waste recycling industry operates on tonnage, i.e., weight, but the greater the sizes of the devices or weight (or rarity of materials) is not necessarily good for the environment. Not all countries are equipped with the capability or capacity to process and harvest valuable materials e-waste — resulting in the e-waste being sent overseas and redistributed. There is a very real risk we lose materials such as rare earth materials in trace amounts into landfill. There is no self-sustaining form of e-waste recycling as it stands — but even beyond that if we look at more established infrastructure such as general recycling, there is not enough awareness nor standardization of practices globally. Within Australia alone, questions as foundational as does the pizza box with grease stains go into recycling or landfill bins changes based on where you are [97]. Local e-waste systems therefore need to operate in ecosystems of e-waste, not just stand alone at points in the value chain. We must therefore spend greater time and effort understanding how unmaking of e-waste happens across multiple touchpoints, in various settings. This study acts as an archetypical exemplar of how taking a pragmatic orientation towards studying unmaking with e-waste, across multiple domains, enables us to better understand the nuances of how possible trajectories and opportunities for designing more sustainable technologies. By locating folk practices, strategies and values adopted by multiple stakeholders, and uncovering social motivations and consequences of unmaking makes clear the value of investigating diverse domains. Song and Paulos [80] contended *"invention should not be made without a detailed plan for disposal of materials that will result"* Our findings highlight distinct, yet obvious steps that the HCI community can take to practically embed these plans within the actual materials that we design. Our paper presents a window into the real-world, that illustrates how some of the concepts we understand in theoretical discourse, practically manifest; whilst also revealing nuanced depictions of those that might not be fully appreciated. Dourish [24] citing Lewin [52] states *"there is nothing as practical as a good theory"* — while Dreyfus [25] argues that the world is its own best representation i.e., real-world accounts are far more valuable in understanding practices. Hence it is imperative to continue to paint vivid, data-driven pictures, with rich, practical accounts of contemporary unmaking in the real world through bottom-up studies. We hope this work can further our efforts to develop a shared ontological understanding for unmaking in HCI as researchers, but also helps establish the basis for developing more participatory approaches towards understanding sustainable unmaking.

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REFERENCES

[1] Steven Alan Scott, Awais Hameed Khan, and Ben Matthews. 2022. First Impressions: A Visual Catalogue for Understanding Interactions with Novel Interfaces in Augmented Reality. In *Sixteenth International Conference on Tangible, Embedded, and Embodied Interaction*, ACM, Daejeon Republic of Korea, 1–14. DOI:https://doi.org/10.1145/3490149.3502259
[2] Apple. 2022. Trade In. *Apple*. Retrieved April 26, 2022 from https://www.apple.com/shop/trade-in
[3] Apple. 2022. Self Service Repair. Retrieved August 24, 2022 from https://support.apple.com/self-service-repair
[4] Apple. 2022. Toolkit Rental. Retrieved August 24, 2022 from https://selfservicerepair.com/tool-kit-rental
[5] Michael F. Ashby. 2012. *Materials and the environment: eco-informed material choice*. Elsevier.
[6] Chris Baraniuk. 2021. Why is there a chip shortage? *BBC News*. Retrieved April 11, 2022 from https://www.bbc.com/news/business-58230388
[7] María Puig de la Bellacasa. 2017. *Matters of Care: Speculative Ethics in More than Human Worlds*. University of Minnesota Press, Minneapolis. Retrieved April 30, 2023 from https://muse.jhu.edu/pub/23/monograph/book/50528
[8] Hugh Beyer. 1998. *Contextual design: defining customer-centered systems / Hugh Beyer, Karen Holtzblatt*. Morgan Kaufmann, San Francisco, Calif.
[9] Heidi R. Biggs, Jeffrey Bardzell, and Shaowen Bardzell. 2021. Watching Myself Watching Birds: Abjection, Ecological Thinking, and Posthuman Design. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems*, ACM, Yokohama Japan, 1–16. DOI:https://doi.org/10.1145/3411764.3445329
[10] Sean Blair and Marko Rillo. 2016. *Serious Work: How to Facilitate Meetings & Workshops Using the Lego Serious Play method*. ProMeet, Erscheinungsort nicht ermittelbar.
[11] Eli Blevis. 2007. Sustainable interaction design: invention & disposal, renewal & reuse. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (CHI '07), Association for Computing Machinery, New York, NY, USA, 503–512. DOI:https://doi.org/10.1145/1240624.1240705
[12] PA Bontinck, J Bricout, T Grant, and G Legoe. 2021. *E-product stewardship in Australia: Evidence Report*. Commonwealth Department of Agriculture, Water and the Environment, Sydney, Australia.
[13] Virginia Braun and Victoria Clarke. 2006. Using thematic analysis in psychology. *Qualitative Research in Psychology* 3, 2 (January 2006), 77–101. DOI:https://doi.org/10.1191/1478088706qp063oa

[14] Brisbane City Council. 2023. E-waste in Brisbane. Retrieved May 13, 2023 from https://www.brisbane.qld.gov.au/clean-and-green/rubbish-tips-and-bins/reducing-waste-at-home/types-of-household-waste/e-waste
[15] Hronn Brynjarsdottir, Maria Håkansson, James Pierce, Eric Baumer, Carl DiSalvo, and Phoebe Sengers. 2012. Sustainably unpersuaded: how persuasion narrows our vision of sustainability. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, ACM, Austin Texas USA, 947–956. DOI:https://doi.org/10.1145/2207676.2208539
[16] Marisa Leavitt Cohn. 2016. Convivial Decay: Entangled Lifetimes in a Geriatric Infrastructure. In *Proceedings of the 19th ACM Conference on Computer-Supported Cooperative Work & Social Computing* (CSCW '16), ACM, New York, NY, USA, 1511–1523. DOI:https://doi.org/10.1145/2818048.2820077
[17] Commonwealth. *Recycling and Waste Reduction Act 2020.* Attorney-General's Department. Retrieved June 2, 2023 from https://www.legislation.gov.au/Details/C2021C00501/Html/Text, http://www.legislation.gov.au/Details/C2021C00501
[18] Department of Agriculture, Water and the Environment. 2023. Submissions received | Stewardship for Consumer and Other Electrical and Electronic Products | Have Your Say - Agriculture, Fisheries and Forestry. Retrieved May 13, 2023 from https://haveyoursay.agriculture.gov.au/e-stewardship/widgets/376048/documents
[19] Department of Climate Change, Energy, the Environment. 2023. E-Stewardship in Australia. Retrieved May 13, 2023 from https://www.dcceew.gov.au/environment/protection/waste/e-waste
[20] Department of Climate Change, Energy, the Environment. 2023. National Television and Computer Recycling Scheme. Retrieved June 2, 2023 from https://www.dcceew.gov.au/environment/protection/waste/product-stewardship/products-schemes/television-computer-recycling-scheme
[21] Kristin N. Dew and Daniela K. Rosner. 2019. Designing with Waste: A Situated Inquiry into the Material Excess of Making. In *Proceedings of the 2019 on Designing Interactive Systems Conference*, ACM, San Diego CA USA, 1307–1319. DOI:https://doi.org/10.1145/3322276.3322320
[22] Carl DiSalvo, Phoebe Sengers, and Hrönn Brynjarsdóttir. 2010. Mapping the landscape of sustainable HCI. In *Proceedings of the 28th international conference on Human factors in computing systems - CHI '10*, ACM Press, Atlanta, Georgia, USA, 1975. DOI:https://doi.org/10.1145/1753326.1753625
[23] Tanja Döring, Axel Sylvester, and Albrecht Schmidt. 2013. A design space for ephemeral user interfaces. In *Proceedings of the 7th International Conference on Tangible, Embedded and Embodied Interaction* (TEI '13), Association for Computing Machinery, New York, NY, USA, 75–82. DOI:https://doi.org/10.1145/2460625.2460637
[24] Paul Dourish. 2010. HCI and environmental sustainability: the politics of design and the design of politics. In *Proceedings of the 8th ACM Conference on Designing Interactive Systems* (DIS '10), Association for Computing Machinery, New York, NY, USA, 1–10. DOI:https://doi.org/10.1145/1858171.1858173
[25] Hubert L Dreyfus. 2002. Intelligence without representation – Merleau-Ponty's critique of mental representation. *Phenomenology and the Cognitive Sciences* 1, (2002), 367–383.
[26] Baback Elmieh, Alexandre Jais, Rex Wenters Crossen, and Andrew Alexander Robberts. 2017. Modular Electromechanical Device. Retrieved August 6, 2022 from https://pdfaiw.uspto.gov/.aiw?PageNum$=$0&docid$=$20170208700&IDKey$=$B9F3E5F9FEF5&HomeUrl$=$http%3A%2F%2Fappft.uspto.gov%2Fnetacgi%2Fnph-Parser%3FSect1%3DPTO1%2526Sect2%3DHITOFF%2526d%3DPG01%2526p%3D1%2526u%3D%2Fnetahtml%2FPTO%2Fsrchnum.html%2526r%3D1%2526f%3DG%2526l%3D50%2526s1%3D20170208700.PGNR.%2526OS%3D%2526RS%3D
[27] Environment Protection Authority Victoria. 2021. About e-waste | Environment Protection Authority Victoria. Retrieved May 13, 2023 from https://www.epa.vic.gov.au/for-business/find-a-topic/manage-e-waste/about-ewaste
[28] European Commission. 2022. CE marking. Retrieved June 19, 2022 from https://ec.europa.eu/growth/single-market/ce-marking_en
[29] eWaste Watch Institute. 2023. eWaste Watch. *eWaste Watch*. Retrieved May 13, 2023 from https://ewastewatch.com.au/
[30] Fairphone. 2022. Fairphone | The phone that cares for people and planet. *Fairphone*. Retrieved December 12, 2022 from https://www.fairphone.com/en/
[31] Federal Communications Commission. 2022. FCC Seals and Logos. *Federal Communications Commission*. Retrieved June 19, 2022 from https://www.fcc.gov/logos
[32] Giuseppe Feola. 2019. Degrowth and the Unmaking of Capitalism: Beyond 'Decolonization of the Imaginary'? *ACME: An International Journal for Critical Geographies* 18, 4 (September 2019), 977–997.
[33] Vanessa Forti, Cornelis P. Balde, Ruediger Kuehr, and Garam Bel. 2020. *The Global E-waste Monitor 2020: Quantities, flows and the circular economy potential.* United Nations University/United Nations Institute for Training and Research, International Telecommunication Union, and International Solid Waste Association. Retrieved September 11, 2022 from https://collections.unu.edu/view/UNU:7737#viewAttachments
[34] Tony Fry. 2008. *Design Futuring: Sustainability, Ethics and New Practice.* Bloomsbury Academic, Oxford; New York.
[35] Tony Fry. 2018. A Political Lexicon on Design. *The Studio at the Edge of the World*. Retrieved September 6, 2021 from https://www.TheStudioattheEdgeoftheWorld.com/lexicon.html
[36] Gathering for Open Science Hardware. 2023. Gathering for Open Science Hardware. Retrieved May 13, 2023 from https://openhardware.science/
[37] David Gauntlett. 2007. *Creative explorations: New approaches to identities and audiences.* Routledge.
[38] Samuel Gibbs. 2016. Google cancels modular smartphone Project Ara. *The Guardian*. Retrieved August 3, 2022 from https://www.theguardian.com/technology/2016/sep/02/google-cancels-modular-smartphone-project-ara
[39] Jenna Grzeslo, Akshaya Sreenivasan, and Steve Bien-Aimé. 2016. ICTD or Technology Graves: Exploring ICT Lifecycle Management in Development Projects. In *Proceedings of the Eighth International Conference on Information and Communication Technologies and Development*, ACM, Ann Arbor MI USA, 1–4. DOI:https://doi.org/10.1145/2909609.2909621
[40] Lon Åke Erni Johannes Hansson, Teresa Cerratto Pargman, and Daniel Sapiens Pargman. 2021. A Decade of Sustainable HCI: Connecting SHCI to the Sustainable Development Goals. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems*, ACM, Yokohama Japan, 1–19. DOI:https://doi.org/10.1145/3411764.3445069
[41] Kristina Höök and Jonas Löwgren. 2012. Strong concepts: Intermediate-level knowledge in interaction design research. *ACM Transactions on Computer-Human Interaction (TOCHI)* 19, 3 (2012), 23.
[42] Lara Houston, Steven J. Jackson, Daniela K. Rosner, Syed Ishtiaque Ahmed, Meg Young, and Laewoo Kang. 2016. Values in Repair. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems* (CHI '16), Association for Computing Machinery, New York, NY, USA, 1403–1414. DOI:https://doi.org/10.1145/2858036.2858470
[43] Elaine M. Huang and Khai N. Truong. 2008. Breaking the disposable technology paradigm: opportunities for sustainable interaction design for mobile phones. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (CHI '08), Association for Computing Machinery, New York, NY, USA, 323–332. DOI:https://doi.org/10.1145/1357054.1357110
[44] Steven J. Jackson. 2014. Rethinking Repair. In *Media Technologies*. The MIT Press. DOI:https://doi.org/10.7551/mitpress/9780262525374.003.0011
[45] Steven J. Jackson and Laewoo Kang. 2014. Breakdown, obsolescence and reuse: HCI and the art of repair. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, ACM, Toronto Ontario Canada, 449–458. DOI:https://doi.org/10.1145/2556288.2557332
[46] Steven J. Jackson, Alex Pompe, and Gabriel Krieshok. 2011. Things fall apart: maintenance, repair, and technology for education initiatives in rural Namibia. In *Proceedings of the 2011 iConference* (iConference '11), Association for Computing Machinery, New York, NY, USA, 83–90. DOI:https://doi.org/10.1145/1940761.1940773
[47] Heekyoung Jung and Erik Stolterman. 2011. Form and Materiality in Interaction Design: A New Approach to HCI. In *CHI '11 Extended Abstracts on Human Factors in Computing Systems* (CHI EA '11), ACM, New York, NY, USA, 399–408. DOI:https://doi.org/10.1145/1979742.1979619
[48] Awais Hameed Khan, Stephen Snow, Scott Heiner, Robert Hardgrove, Sarah Matthews, and Ben Matthews. 2020. The Politics of Materiality: Exploring Participatory Design Tools, Methods & Practices. In *DRS2020 Synergy*, Brisbane, Australia. DOI:https://doi.org/10.21606/drs.2020.246
[49] Awais Hameed Khan, Stephen Snow, Scott Heiner, and Ben Matthews. 2020. Disconnecting: Towards a Semiotic Framework for Personal Data Trails. In *Proceedings of the 2020 ACM Conference on Designing Interactive Systems*, ACM, 327–340. DOI:https://doi.org/10.1145/3357236.3395580
[50] John Law and Michel Callon. 1992. The life and death of an aircraft: a network analysis of technical change. In *Shaping technology/building society studies in sociotechnical change*, Wiebe E. Bijker and John Law (eds.). MIT Press, Cambridge, Mass.
[51] Eldy S. Lazaro Vasquez, Hao-Chuan Wang, and Katia Vega. 2020. Introducing the Sustainable Prototyping Life Cycle for Digital Fabrication to Designers. In *Proceedings of the 2020 ACM Designing Interactive Systems Conference*. Association for Computing Machinery, New York, NY, USA, 1301–1312. Retrieved July 2, 2022 from http://doi.org/10.1145/3357236.3395510
[52] Kurt Lewin. 1951. Field theory in social science: selected theoretical papers (Edited by Dorwin Cartwright.). Harpers, Oxford, England.
[53] LG. 2016. LG debuts the G5, its first ever modular smartphone. *LG Australia*. Retrieved August 6, 2022 from https://www.lg.com/au/about-lg/press-and-media/lg-debuts-the-g5-its-first-ever-modular-smartphone
[54] Huan Li, Elsayed Oraby, and Jacques Eksteen. 2021. Cyanide consumption minimisation and concomitant toxic effluent minimisation during precious metals extraction from waste printed circuit boards. *Waste Management* 125, (April 2021), 87–97. DOI:https://doi.org/10.1016/j.wasman.2021.02.033
[55] Cindy Lin Kaiying, Silvia Lindtner, and Stefanie Wuschitz. 2019. Hacking difference in Indonesia: The ambivalences of designing for alternative futures. In *Proceedings of the 2019 on Designing Interactive Systems Conference*, 1571–1582.

[56] Joseph Lindley, Haider Ali Akmal, Franziska Pilling, and Paul Coulton. 2020. Researching AI Legibility through Design. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems*, ACM, Honolulu HI USA, 1–13. DOI:https://doi.org/10.1145/3313831.3376792

[57] Kristina Lindström and Åsa Ståhl. 2020. Un/Making in the Aftermath of Design. In *Proceedings of the 16th Participatory Design Conference 2020 - Participation(s) Otherwise - Volume 1*, ACM, Manizales Colombia, 12–21. DOI:https://doi.org/10.1145/3385010.3385012

[58] Ezio Manzini. 2014. Making Things Happen: Social Innovation and Design. *Design Issues* 30, 1 (2014), 57–66.

[59] Mohsen Mostafavi and David Leatherbarrow. 1993. *On Weathering: The Life of Buildings in Time* (First Edition edition ed.). The MIT Press, Cambridge, Mass.

[60] Open Repair Alliance. 2020. How we celebrated essential repair on Repair Day 2020. *Open Repair Alliance*. Retrieved May 13, 2023 from https://openrepair.org/announcements/repair-day-2020-wrapup/

[61] Julian E. Orr. 1996. *Talking about Machines: An Ethnography of a Modern Job*. ILR Press, Ithaca, N.Y.

[62] OSHWA. 2022. Open Source Hardware Association. *Open Source Hardware Association*. Retrieved June 21, 2022 from https://www.oshwa.org/about/

[63] Luke Pensworth. 2019. What Happend to Project Ara: Is It Finally Over? *DailyWireless*. Retrieved August 3, 2022 from https://dailywireless.org/mobile/what-happened-to-project-ara/

[64] David Phelan. 2020. Apple Challenges Europe's Mooted Lightning Cable Ban. *Forbes*. Retrieved April 11, 2022 from https://www.forbes.com/sites/davidphelan/2020/02/11/apple-challenges-europes-mooted-lightning-cable-ban/

[65] James Pierce. 2012. Undesigning technology: considering the negation of design by design. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, ACM, Austin Texas USA, 957–966. DOI:https://doi.org/10.1145/2207676.2208540

[66] James Pierce. 2016. Design Proposal for a Wireless Derouter: Speculatively Engaging Digitally Disconnected Space. In *Proceedings of the 2016 ACM Conference on Designing Interactive Systems*, ACM, 388–402. Retrieved from http://dl.acm.org/citation.cfm?id$=$2901908

[67] Productivity Comission. 2021. *Right to Repair*. Canberra. Retrieved May 13, 2023 from https://www.pc.gov.au/inquiries/completed/repair/report/repair.pdf

[68] Mohammad Rashidujjaman Rifat, Hasan Mahmud Prottoy, and Syed Ishtiaque Ahmed. 2019. The Breaking Hand: Skills, Care, and Sufferings of the Hands of an Electronic Waste Worker in Bangladesh. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems*, ACM, Glasgow Scotland Uk, 1–14. DOI:https://doi.org/10.1145/3290605.3300253

[69] Chanpory Rith and Hugh Dubberly. 2007. Why Horst WJ Rittel matters. *Design Issues* 23, 1 (2007), 72–91.

[70] Horst Rittel. 1984. Second-Generation Design Methods. In *Developments in Design Methodology*, Nigel Cross (ed.). John Wiley & Sons, 317–327.

[71] Horst WJ Rittel and Melvin M. Webber. 1973. Dilemmas in a general theory of planning. *Policy sciences* 4, 2 (1973), 155–169.

[72] David Roedl, William Odom, and Eli Blevis. 2017. Three principles of sustainable interaction design, revisited. In *Digital Technology and Sustainability: Engaging the Paradox*, Mike Hazas and Lisa Nathan (eds.). Routledge, London. DOI:https://doi.org/10.9774/gleaf.9781315465975

[73] Samar Sabie, Steven J. Jackson, Wendy Ju, and Tapan Parikh. 2022. Unmaking as Agonism: Using Participatory Design with Youth to Surface Difference in an Intergenerational Urban Context. In *Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems*, Association for Computing Machinery, New York, NY, USA, 1–16. DOI:https://doi.org/10.1145/3491102.3501930

[74] Samar Sabie, Robert Soden, Steven Jackson, and Tapan Parikh. 2023. Unmaking as Emancipation: Lessons and Reflections from Luddism. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems*, ACM, Hamburg Germany, 1–15. DOI:https://doi.org/10.1145/3544548.3581412

[75] Samar Sabie, Katherine W Song, Tapan Parikh, Steven Jackson, Eric Paulos, Kristina Lindstrom, Åsa Ståhl, Dina Sabie, Kristina Andersen, and Ron Wakkary. 2022. Unmaking@CHI: Concretizing the Material and Epistemological Practices of Unmaking in HCI. In *CHI Conference on Human Factors in Computing Systems Extended Abstracts*, ACM, New Orleans LA USA, 1–6. DOI:https://doi.org/10.1145/3491101.3503721

[76] Samsung. 2022. Trade in for a new Galaxy Phone today. Retrieved April 26, 2022 from https://www.samsung.com/au/tradeup/

[77] G D Schott. 1993. Penfield's homunculus: a note on cerebral cartography. *J Neurol Neurosurg Psychiatry* 56, 4 (April 1993), 329–333.

[78] Herbert A. Simon. 1968. *The Sciences of the Artificial*. MIT press.

[79] Katherine W Song, Aditi Maheshwari, Eric M Gallo, Andreea Danielescu, and Eric Paulos. 2022. Towards Decomposable Interactive Systems: Design of a Backyard-Degradable Wireless Heating Interface. In *Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems* (CHI '22), Association for Computing Machinery, New York, NY, USA. DOI:https://doi.org/10.1145/3491102.3502007

[80] Katherine W Song and Eric Paulos. 2021. Unmaking: Enabling and Celebrating the Creative Material of Failure, Destruction, Decay, and Deformation. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems*, Association for Computing Machinery, New York, NY, USA, 1–12. Retrieved December 7, 2021 from https://doi.org/10.1145/3411764.3445529

[81] Erik Stolterman. 2008. The nature of design practice and implications for interaction design research. *International Journal of Design* 2, 1 (2008).

[82] Ignaz Strebel, Alain Bovet, and Philippe Sormani (Eds.). 2019. *Repair Work Ethnographies: Revisiting Breakdown, Relocating Materiality*. Springer Singapore, Singapore. DOI:https://doi.org/10.1007/978-981-13-2110-8

[83] TechCollect. 2019. TechCollect. Retrieved May 13, 2023 from https://techcollect.com.au/

[84] Cameron Tokinwise. 2013. Design Away: Unmaking Things. Retrieved from https://www.academia.edu/3794815/Design_Away_Unmaking_Things

[85] Vasiliki Tsaknaki and Ylva Fernaeus. 2016. Expanding on Wabi-Sabi as a Design Resource in HCI. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems* (CHI '16), Association for Computing Machinery, New York, NY, USA, 5970–5983. DOI:https://doi.org/10.1145/2858036.2858459

[86] United Nations. 2015. *Transforming Our World: The 2030 Agenda for Sustainable Development*. Retrieved June 19, 2022 from https://sdgs.un.org/sites/default/files/publications/21252030%20Agenda%20for%20Sustainable%20Development%20web.pdf

[87] United Nations. 2021. *The Sustainable Development Goals Report 2021*. Retrieved June 14, 2022 from https://unstats.un.org/sdgs/report/2021/The-Sustainable-Development-Goals-Report-2021.pdf

[88] Jonovan Van Yken, Naomi J. Boxall, Ka Yu Cheng, Aleksandar N. Nikoloski, Navid R. Moheimani, and Anna H. Kaksonen. 2021. E-Waste Recycling and Resource Recovery: A Review on Technologies, Barriers and Enablers with a Focus on Oceania. *Metals* 11, 8 (August 2021), 1313. DOI:https://doi.org/10.3390/met11081313

[89] Dhaval Vyas, Awais Hameed Khan, and Anabelle Cooper. 2023. Democratizing Making: Scaffolding Participation Using e-Waste to Engage Under-resourced Communities in Technology Design. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems* (CHI '23), Association for Computing Machinery, New York, NY, USA, 1–16. DOI:https://doi.org/10.1145/3544548.3580759

[90] Dhaval Vyas and John Vines. 2019. Making at the Margins: Making in an Under-resourced e-Waste Recycling Center. *Proc. ACM Hum.-Comput. Interact.* 3, CSCW (November 2019), 1–23. DOI:https://doi.org/10.1145/3359290

[91] Stuart Walker. 2017. *Design for life: Creating meaning in a distracted world*. Taylor & Francis.

[92] Mikael Wiberg. 2014. Methodology for materiality: interaction design research through a material lens. *Pers Ubiquit Comput* 18, 3 (March 2014), 625–636. DOI:https://doi.org/10.1007/s00779-013-0686-7

[93] Frank R. Wilson. 1999. *The Hand: How Its Use Shapes the Brain, Language, and Human Culture* (1st Vintage Books Ed edition ed.). Vintage, New York; London.

[94] World Bank. 2022. Digital Development. *World Bank*. Retrieved June 20, 2022 from https://www.worldbank.org/en/topic/digitaldevelopment/overview

[95] Shanel Wu and Laura Devendorf. 2020. Unfabricate: Designing Smart Textiles for Disassembly. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems*, ACM, Honolulu HI USA, 1–14. DOI:https://doi.org/10.1145/3313831.3376227

[96] Amit Zoran and Leah Buechley. 2013. Hybrid Reassemblage: An Exploration of Craft, Digital Fabrication and Artifact Uniqueness. *Leonardo* 46, 1 (February 2013), 4–10. DOI:https://doi.org/10.1162/LEON_a_00477

[97] 2018. Can you recycle a used pizza box? *ABC News*. Retrieved September 16, 2022 from https://www.abc.net.au/news/2018-04-08/can-you-recycle-a-used-pizza-boxes/9625498