Tangible Interaction and Industrial Degrowth

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Follow-up of a panel on environmental issues in tangible interfaces at ETIS 2022

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This position paper seeks to ground and outline a discussion on environmental issues related to tangible user interfaces. The discussion that we present here started during a panel on "Tangible Interaction and Industrial Degrowth" that took place during the ETIS European studio on tangible interaction in November 2022 [5]. The panel discussed the problem from various angles and took input from the participants of the studio in the form of an online mapping brainstorm. The topics covered ranged from environmental feedback aspects to low-tech alternatives, as well as systemic, methodological and regulation considerations. This position paper reports on the approaches that were discussed and, based on these first insights, suggests directions for sustainable tangible interaction.

CCS CONCEPTS • Human Centered Computing • Human Computer Interaction (HCI)

Additional Keywords and Phrases: tangible interaction, sustainability, industrial degrowth, eco-feedback, fabrication, materials, environmental awareness, situated visualization, mixed-reality, waste, hacking.

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1 INTRODUCTION

Tangible Interaction is concerned by understanding how people interact when the physical and the digital blend. As a design-led research area, it leverages material explorations to understand tangibility and materiality, physical embodiment of data, bodily interaction and the embedding of systems in real spaces and contexts [18]. In the past three decades researchers have explored how tangible interaction allows us to represent and manipulate digital information, enrich sensory experience and perception, enhance cognition, or mediate social and shared interactions.

Following scholarship in sustainable HCI, researchers in tangible interaction have explored various solutions for tangible systems that either reduce the environmental impact or influence people to adopt pro-environmental behaviors. However, as Dourish [12] points out "traditional HCI discourse obscures political and cultural contexts of environmental practice that must be part of an effective solution". Framing technological interventions around behavior change of individuals has limits [6], and technological "solutions" can lead to rebound effects [24].

To shed light on the challenges raised by the Anthropocene on tangible interaction, in line with the conference theme, ETIS (European Tangible Interaction Studio) 2022 [5] included a panel on the topic "Tangibility and Industrial Degrowth". The underlying idea was to contrast and discuss different approaches to tangible interfaces, from their usefulness in supporting green transition, to sustainable material approaches, and more critical reflections. This was followed up by a collaborative mapping exercise with the panel audience.

In this position paper we seek to summarize the outcomes of the panel and analyze them to suggest future directions for sustainable tangible interaction. The outline of the paper is as follows: first we present the participants' approaches as four complementary views (section 2), then we present the outcomes of the brainstorming session (section 3). Finally, we analyze and discuss the results and identify future directions for research in sustainable tangible interaction (section 4). Our objective is to make explicit the divergent approaches and underlying tensions, both in the section outlining the visions of the panelists and authors (section 2), and in the description of the ideas emerging from the mapping session (section 3). For the latter, the ideas produced by the participants will first be quoted as they are, then commented on by the authors of this position paper. The proposed analysis of the ideas suggested by the participants also incorporates the underlying tensions, including an analytical model that highlights the crises in the stages of a transition.

2 DIVERSE APPROACHES ON THE PROBLEM

In this section we summarize the contributions related to sustainability that were presented during the ETIS studio, either by the panelists or by the authors of accepted talks. Some approaches addressed feedback mechanisms while others discussed changing TUIs making process and materials through repurposing or recycling.

2.1 A material-centric approach

It was first discussed how tangible object design is still tech-led and not material-centric enough in contrast with non-digital objects. This is due to the fact that researchers and designers are used to taking off the shelving electronic components to create digital artifacts. An example of this is how we embed displays within interactive devices. Most approaches revolve around using manufactured displays which are limited in form factors (rectangular and mostly rigid). But new approaches are emerging considering programmable ink as digital material. This is the case of Fabricatink [15] proposing to upcycle e-ink particles from broken e-readers and to enable designers and researchers to use them in a more versatile way (e.g. create display of different shapes). Such an approach could be extended to other materials as well as for the case of display but also actuation and sensing. Overall It can be shown how bringing fabrication tools and knowledge to end-users could bring more user self-awareness of materials and how we consume them (changing the way we fix & recycle, reverting to a hacking society).

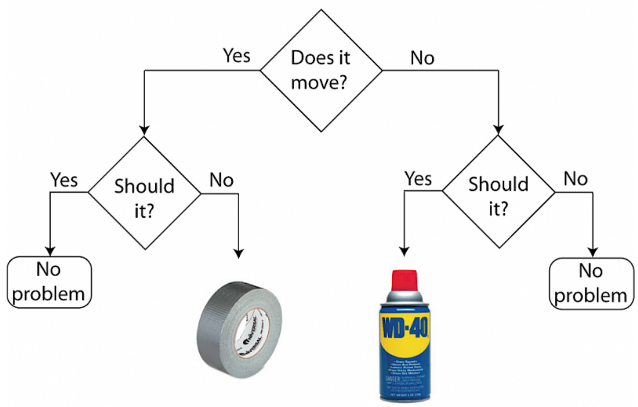

Figure 1. More user self-awareness of materials and how we consume them: changing the way we fix & recycle, reverting to a hacking society.

2.2 Understanding the impact of tangible interaction for pro-environmental behaviors

In another discussion, the question was about the concrete impact of tangible approaches for encouraging industrial degrowth, and pro-environmental behaviors in general. Indeed, many intuitions make us think that tangible interfaces may play a positive role for achieving these objectives. In particular, tangible interaction may stimulate engaging user experiences that can lead to virtuous actions. As an example *Erlen* illustrated in Figure 2 is a project whose goal is to help users reduce their personal electrical consumption by involving them in a tangible task. Such interfaces can be evaluated in terms of usability, attractiveness, or induced emotions for example. These are indicators that can inform us about the potential of such or such interfaces. On the other hand, their concrete impact on behavior change is still an open research question. Collaborations with experts in behavioral sciences seem to be a promising research direction.

Figure 2. With Erlen, the consumption of the electrical devices you use daily accumulates in a tangible object that you need to empty time to time

2.3 Users' decision making process using eco-feedback displays (smart plugs)

Another approach on eco-feedback described the latest insights into the ever topical issue of eco-feedback displays. Here, the work of Casado-Mansilla et al. [7] on smart plugs (see Fig. 3) highlighted how users are increasingly aware of such topics and expect more sophisticated features out of these devices. Examples include better models that describe that expected percentage of renewables in the grid at any given time (e.g., [25]); advanced information visualizations to better help users monitor, plan, and assess the source of the energy they consume; automation instead of voice controls or direct manual input; connection to other smart devices that provide, for instance, water consumption information; or remote access and customizable dashboards. The latter is well known in sustainable HCI [13], and still seems to resonate with users in 2023. But while various users reported on a wide range of ideas for future iterations of eco-feedback displays, others reported wanting less functionality and dependencies, for a simpler UX. This conflict has been highlighted before [16], and might explain the lack of mainstream adoption of more general home energy management systems (HEMS).

Figure 3. The fourth approach that emerged during the ETIS studio focused on users' decision making process using smart plugs as eco-feedback displays (e.g. [7]).

2.4 Situated visualizations and limits of low-tech sensing

A final approach discussed situated visualization of air pollution. Low-cost sensors have been hailed as promising resources for citizen science and citizen empowerment. However, cheap environmental sensors come with a number of limitations: they often capture data of poor quality, require proper calibration and specific working conditions (heat, humidity), only sense one specific chemical element, and can have high variability in space. Although they face such limitations, the precise numbers they output are often unquestioned and taken as truth. Alternatively lichens can act as living sensors (fig. 4), they can provide information about nitrogen deposition (NOx) from either anthropogenic or natural sources, and turn the environment into a visualization. Bio-monitoring is well known in biology, this approach has limitations in precision, but also benefits, including engagement and strong relationship to context, scalability in space (from bacteria to trees) and in time (little to no maintenance required over years), integrated sensing, processing and display abilities, and built-in messiness that surfaces sensing challenges.

Figure 4. Situated visualization

3 Online brainstorming with participants

3.1 A tangible journey

The panelists' presentations were followed by a session during which participants could suggest ideas on a Miro board. The board was pre-structured into themes to facilitate creativity during the brainstorming and to help participants figure out where to input their ideas and along which dimensions (fig. 5). Three additional free areas were also set for other ideas.

3.2 Results

In this section, we detail and comment on the participants' contributions, structured by the themes that were suggested in advance on the board (fig. 5). Some ideas were then grouped a posteriori by topic.

3.2.1 *Energy.*

The following ideas are about reducing energy consumption, either by changing energy sources or by reducing it.

Ideas.

- power harvesting tangibles: light powered tangibles, vibration, body heat, walking, interactions (cranks, buttons, etc), powered tangibles (e.g. PV-tiles [20])
- stop using power: mechanical tangibility
- the devices we build to save energy, use energy themselves
- offload computation to wearable AR/XR, instead of embedding electronics in everyday objects

Comments.
The theme of optimizing energy consumption is a classic digital sustainability theme - although energy consumption accounts for only half of the carbon impact of digital objects. The ideas suggested for changing the energy source are based primarily on recycled energy.
Regarding the idea to offload computation to wearable AR/XR, one of the least appealing prospects of a wide range of tangible and ubiquitous systems is the need to embed electronics into everyday items [14]. This

contributes to a rise in electronic waste, which toxins ultimately end up in our soil and water supplies[1]. While solutions looking into biodegradable electronics are appealing [9], another potential solution that can fulfill many of the ideals of tangible interaction is augmented or extended reality (XR). XR shares many of the same definitions of tangible interaction: systems should combine real and virtual elements; they should support real time and embodied interactions; and virtual elements should be registered in space as if part of the world itself [2]. But unlike tangible systems, XR requires only one device – one set of electronics – to provide arguably the same benefits and functionalities in everyday settings (when operated in a head-mounted form factor). However, the benefits of this trade-off are still to be defined: in order to operate, XR devices require vast amounts of computing power and thus a large carbon footprint inherent of advanced artificial intelligence systems [11]. The latter is ultimately necessary for XR devices to understand the world around them, to contextualize users' actions and goals, or to simply recognize and classify user input.

3.2.2 *Material resources & making.*

The ideas in this theme essentially deal with the use of alternative (e.g., edible, biodegradable) material or the creation of design methods that require less resources. This relates to the panelists proposed material-centric approach to promote upcycling, transformation and repairing as part of the design process. In addition, the contributions suggest changing regulations and rules to ensure that TUIs can be licensed and are used over a longer period of time.

Ideas:

- resources:
  - always have 2 versions of a tangible: natural/artificial material
  - reduce amount of resources needed as part of the design process
- biodegradable materials (food?)
  - growing interfaces (mushrooms, lichen, etc)
  - are some TUIs edible?
  - food waste to tangible interface?
- rules, regulation:
  - making license
  - minimum life-time for TUIs

Comments.
Some suggested ideas may seem provocative, such as using biological materials (growable or edible TUIs, or TUIs made from food waste). Some studies are already exploring biomaterial objects [3], sometimes for tangible interaction [1] or as a more-than-human centered approach [10]. These ideas perhaps also explore the concept of "consumption", underlying the current economic model. They also propose to rethink the life cycle of objects in a very concrete and material form, echoing the processes that we can assume are regulated in nature.

3.2.3 *Reuse / refurbish / repair.*

The ideas in this theme essentially deal with the way the lifespan of tangibles can be extended before they are disposed of.

Ideas.

- Places:
  - second-hand markets for tangibles
  - repair shops for tangibles
- Repurposing:

[1] https://www.theatlantic.com/technology/archive/2016/09/the-global-cost-of-electronic-waste/502019/

    - repurposing or reconfiguring old devices into new useful ones
    - creating modular designs that facilitate repurposing of parts / modules
    - TUIs should be useful as non tangibles as well (i.e. disconnected)
- Valuing tangibles by surfacing their history in a way that enriches them
- Broken devices:
    - using parts of broken devices to build something new
    - Q: what other types of broken devices could we recycle to use them differently?
- Rules, regulation:
    - legislation to make IP of parts open if company stops producing their own spares

Comments.
The HCI literature has been interested in repair and maintenance almost since its inception (Suchman's Plans and Situated Action discusses photocopier maintenance [26], see also Orr's work [23]). Yet this strand of research has often been overshadowed by the attraction for the design and experimentation with novel interactive devices. There is still a lot to explore in this area from understanding how devices break or become obsolete, to the way they could be repurposed, to regulations to foster lasting devices and the development of places that support the extension of device life.
One aspect not discussed during the mapping exercise is the notion developed by Jackson of "broken world thinking", i.e., that maintenance and repair are fundamental for our technical environment to stay remotely functioning. This relates to notions of seamfulness developed by Chalmers [8] on designing with and around breakdowns, rather than trying to provide fixes to all the shortcomings of technology.

3.2.4 *Disposal / end of life.*

The ideas in this theme centered around what happens once a tangible cannot be used, repaired, repurposed anymore, i.e., when it is discarded. The panelists and attendees discussed regulations and incentives, how to handle derelict devices, how to prevent their end-of-life, and how to dispose of building materials.

Ideas.
- regulation, rules:
    - develop economic incentives
    - TUIs should be thrown where they are fabricated
- lost & dead:
    - help to locate your lost TUI devices
    - dead devices (no power left)
- destructive feedback [21]: I hope that destructive feedback is a mechanism to start repair, rather than end of life. But if your interpretation is different that's cool.
- recycle:
    - unbuild thing to recover raw material that can be used again
    - they might be planted so that new ones grow

Comments.
The tangible community is very geared towards the creation of new technology and does not focus much on downstream implications, there are currently little thoughts on waste management although there is a growing awareness of the problem. The approaches discussed center on recovering material through recycling, avoid loss and death of devices, or creating incentives to extend the lifetime of devices.
One aspect that seems forgotten from the discussion is how much waste comes from the fabrication process itself (mining and manufacturing), not just the end of life of the device [19].
The idea of where to dispose of TUIs (TUIs should be thrown where they are fabricated) is surprising: it depends on where they are made. In particular, if it is in countries that do not use them, the idea is very unfair to the populations of these countries, and contradictory to a desire to be aware of the waste [28][29].

The idea of “destructive feedback” refers to a method of gathering user feedback about broken or malfunctioning devices dubbed ”Destructive Feedback” where the user deliberately ”breaks” the device, making it easier to detect visually and with sensors [21].

3.2.5 *Underlying infrastructures needed to make it work.*

The ideas developed in this theme relate to infrastructures enabling tangibles to function such as servers and networks, but also social infrastructures repair networks and tools. One question raised was the available resources that can be leveraged: from the environment (bio-indicators), available devices that could be repurposed, or feedback strategies to make disposal implications more tangible.

Ideas.

- low-fi:
  - low-fi interactions possibilities with objects
  - disclosure in bio-indicators
- use objects that users already possess
- discourage use:
  - traces of use (Waste example: do we show the end effect or the network of implications?)
  - multimodal display making bad thing not fun to used (bad smell or thing like that)
- Engaging with researchers from other disciplines
- repair
  - maintain & repair
  - tools to help (near) end-user modification/ repair that is safe/usable/legal
- machines:
  - not only about own device but also what the server needed behind (e.g. youtube)
  - Internet infrastructure

Comments.
The discussions did not delve into the infrastructures on which Tangibles rely, there was no mention of energy consumption, of distribution networks, or waste infrastructures. While identifying that collaboration with other disciplines whose work is more centered on these topics is important, we could still wonder whether the community should not consider some infrastructural issues as challenges that should be tackled or at least acknowledged when designing tangibles.

3.2.6 *Use & practices.*

The following ideas are a priori relevant to TUI users, as consumers or rather possibly active citizens.

Ideas.

- temporality:
  - consider both immediate and long-term rewards
  - try to anticipate the possible rebound effect
  - law against built-in obsolescence
- repair:
  - repair shops for tangibles
  - design for repairability
- design:
  - design for friction for the bad and ease of the good
  - PD design
- sharing:
  - communal use
  - shared tangibles in a building

    - design for share and evolution
- utility:
    - vote for device utility embedded in the objects
    - how to help people not be 'slaves to fashion' e.g. new facias for white goods

Comments.

What is proposed goes beyond a simple and passive use, with the possibility for the users themselves to repair the objects in stores, to share the objects, to express themselves on their real usefulness (why not with a design expressing the frictions), and to design them in a participative way.

The problem of temporality refers to consumption patterns, with in particular the problem of the rebound effect: over-optimized TUIs could indeed encourage excessive use. The complex issue raised here is that of regulated usage behavior, which also implies going beyond mindless passive usage.

3.2.7 *Don't.*

This theme was created to open up critical discussions and suggests practices that should be stopped altogether or progressively phased out, rather than fixed.

Ideas.

- don't use tangibles! (they will be tracked and withdrawn!!)
- don't use screens

Comments.

This theme received the least attention, which may hint at the difficulties the community has to reflect critically on its own impact on the environment. It may also hint at the fact the most critical scholars have left the community. Yet there is probably work to be done on understanding how to properly close and stop some activities [22], how to deal with the waste coming from IoT and other tangible interactive devices.

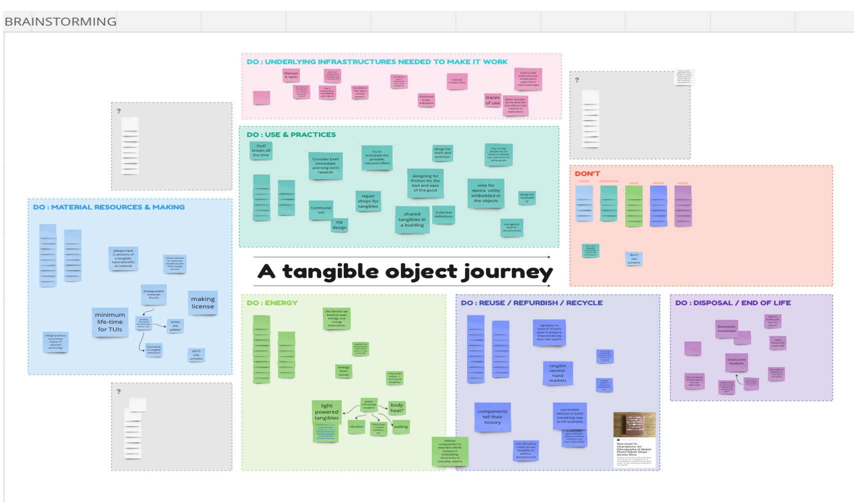

Figure 5. Screenshot of the miro board (https://miro.com/app/board/uXjVPKM8KiI=/).

4 Analysis and discussion

The themes that emerged from the brainstorming either promote better design of tangibles using diverse approaches (optimization, low tech, systemic, multidisciplinary, rules, fostering transition), or the adoption of different practices (sharing, repairing, forgoing or mitigating). In this section, we discuss two aspects: first, we were struck by the fact that the issue of sustainability of tangibles is perhaps a little different from other digital objects; second, it seems interesting to comment on the ideas of the brainstorming according to an analysis of the transitions currently at work in this field with respect to sustainability, and the transitions still to be made.

4.1 *Are there sustainability aspects specific to tangibles?*

The ideas suggested during the brainstorming bring out aspects that are perhaps specific to tangible interfaces, due to their materiality, which could make visible and possible things that are less directly possible with so-called "purely" digital artifacts. This may be the case for eco-feedback, material composition and collaboration.

Eco-feedback. Eco-feedback seems less on energy consumption and more on the devices themselves. Several ideas were suggested related to a kind of feedback: `components tell their history, discourage use, destructive feedback, TUIs should be thrown where they are fabricated`; the ideas seem maybe more related the materiality and actual utility of tangibles themselves, , than energy consumption - e.g. `vote for utility, don't use tangibles! (they will be tracked and withdrawn!!`.

Material composition. Furthermore, the material dimension of tangibles is also highlighted as objects whose design can be questioned (e.g. `design for friction for the bad and ease of the good`). Several ideas indeed highlighted the making and material dimensions (`other materials, built-in obsolescence, dead devices, repair, repurpose, recycle`). This could raise the question whether tangibles specifically highlight their materiality, as opposed to "pure" digital artifacts where this aspect is more hidden. This relates to the question of how pure digital artifacts could also disclose their materiality [8].

Collaborative dimension. Several ideas also highlighted the potential collaborative dimension in tangibles. Several ideas in different themes indeed relate to the possibility of sharing (e.g. `communal use, sharing in a building, design for share and evolution`) or reselling in second hand shops. The ideas of recycling and repair also support this collective dimension, since an object thrown away by one user can be repaired or redirected to other functions by others (`repair shops for tangibles`), especially since this possibility of repair would be open to all (`tools to help (near) end-user modification/ repair that is safe/usable/legal`).

4.2 *Transition analysis*

In order to help structure the ideas from the brainstorming, an X-curve analysis of these ideas was started live during the brainstorming. The analysis was then refined and finalized after the session. The general purpose of the X-curve analysis is to provide the dynamics of transitions as iterative processes of build-up and breakdown over a period of decades [17]. Figure 6 is borrowed from Hebink et al and shows the general principle: a descending curve depicts data along a breakdown curve from current normality to phase-out, while the ascending curve shows data emerging in the present and leading to a new normal located in a future after having overcome the crisis.

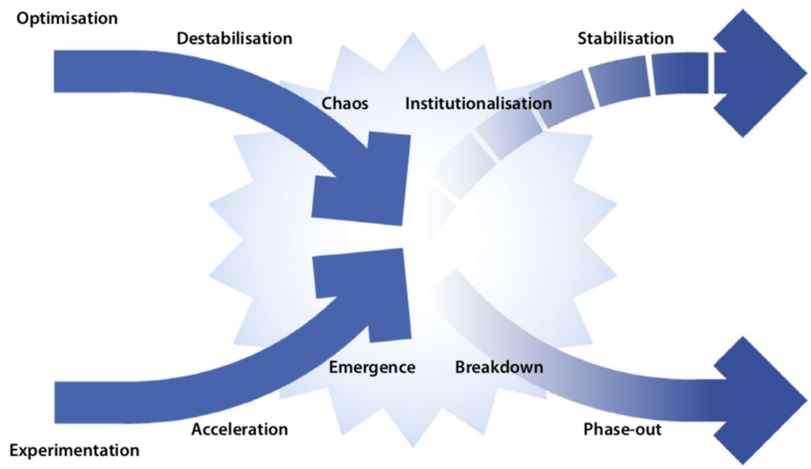

Table 1 Patterns of build-up and breakdown and underlying dynamics (Lodder et al. 2017, translated from Dutch)

Pattern	Of build-up	Pattern	Of breakdown
Experimentation	Radical new practices Radical new thinking	Optimisation	Improving the existing No doubts about the system
Acceleration	Alternatives are connecting Alternatives are visible and accessible	Destabilisation	Incidents lead to (sense of) urgency Fundamental discussions about desired the direction
Emergence	New structures become visible Need for transition is broadly accepted	Chaos	Contradictions and uncertainties Opposing interests and conflict
Institutionalisation	The new normal (thinking and doing) Solidifying new structures	Breakdown	Repelling and releasing former established order Losers of processes of change become visible
Stabilisation	Tweaking Optimising	Phase-out	Saying goodbye Dealing with loss

Figure 6. X-curve portraying the interaction of patterns of buildup and breakdown (based on [17]).

So, while the pre-structured areas were meant to facilitate creativity during the brainstorming, our purpose in doing this analysis is to classify the ideas as belonging these crisis transition steps, either as signs of breakdown or elements of a better future, and either as occurring in the present or to be expected in the future (figure y). We kept the colors assigned by the participants during the brainstorming, colors that were associated with the pre-structured areas (figure 7).

The rationales for positioning the ideas were the following:

- ideas related to optimization of energy or materials, that are already in use, have been placed on the start breakdown curve, which refer to improving the existing systems instead of replacing them with better ones ; this part of the curve also contains elements that can be changed right now
- we put the ideas describing the destiny of current systems (broken or lost, forbidden or abandoned) at the end of the breakdown curve
- the beginning of the build-up curve contains ideas that refer to currently emerging practices that explore better solutions for sustainable tangibles
- we put at the end of the build-up curve ideas about more stabilized practices, such as design methods, laws, and various regulations
- the beginning of the build-up curve refers to local practices, while the end refers to more global solutions

- we put ideas regarding awareness of sustainability issues or tensions in the middle of the breakdown curve, since they don't refer to future solutions, but rather to problems of current solutions

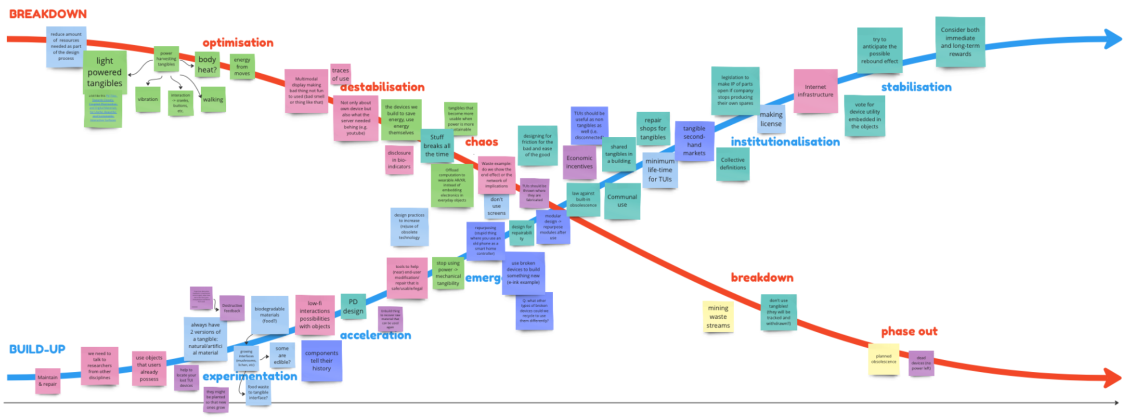

Figure 7. Analysis of ideas along breakdown and build-up X model curves.

This analysis raises questions regarding the status and timing of facts, explorations, methods, possibilities, etc that come to the mind when discussing sustainable TUIs. The two dimensions distinguish the status of the ideas: the ideas on the red curve are characterized as the current normal trying to survive by repairing itself, while the ideas on the blue curve represent a potential paradigm shift toward a new normal. The temporal dimension suggests the steps to be taken to move forward in the crisis.

Looking more closely at the x-curve, some questions arise, that could provide interesting directions for research:

- is sustainable TUI/TEI essentially related to energy optimization currently and eco-feedback?
- how far are the TUI/TEI practices on the curves? (maybe too early on the ascending curve?)
- can we leverage on current methods (e.g. participatory design) or practices (e.g. social navigation) to move forward?
- is there a need to develop and explore provocative incentives to move forward? (edible or growable TUIs, natural TUIs, design frictions)
- to which extent can we imagine regulations in the TUI/TEI domain?
- do we have the methods, principles, tools and resources to make it possible to share components, reuse them, etc? (critical HCI, permacomputing [27])

5 Conclusion

In this position paper, we have both reported on a panel held in November 2022 at the ETIS 2022 studio on tangible interaction [5], and attempted to follow up on that panel by analyzing the different approaches that were discussed. Through this presentation, tangible interaction appears both as an effective tool for awareness and decision support regarding sustainability, due to its materiality and integration in the physical world, but as a problem for the environment, also due to the material aspects of manufacturing tangible interfaces. It is not impossible that this materiality, which makes the environmental cost of TUIs physically visible, is also an inspiration for the design of other digital objects. One question that arises is whether the tangible interaction design community can mobilize its disruptive potential to shift design methods and principles toward more sober collective use of TUIs.

ACKNOWLEDGMENTS

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