Submission Template for ACM Papers

Sustainable Technological Futures

Moving beyond a One-World-World perspective

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In this critique, we problematize the framing of technological futures through rhetorical devices such as the *Futures Cone* which we contend promotes a *one-world-world perspective*, in that it assumes a collective (western) acceptance of a particular historicity and notions of time when used to consider and design technological futures. Instead, we adopt an alternate perspective which primarily draws from the work of Brazilian philosopher Alvaro Vieira Pinto who considered the past and the future as shaped by the present – a present that is open and creative due to constant change. In addition, we draw upon game design philosopher Ian Bogost's proposition *Alien Phenomenology* which allows us to better consider the notion of 'human' as part of complex assemblages of human and non-human actants in interdependent relationships but operating within independent perspectives. This framing enables us to begin to act on present orthodoxies of design and promote more sustainable practices that go beyond purely human considerations and to begin to accommodate futures for non-human entities, both technological and ecological (flora, fauna and climate). In this critique, we will develop this argument and present a series of examples that illustrate how it may be put into actionable design practice.

CCS CONCEPTS • Human-centered computing • Human computer interaction (HCI) • HCI theory, concepts and models

Additional Keywords and Phrases: Design Futures, Sustainable Technologies, More-Than-Human, Pluriversal Thinking

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1 INTRODUCTION

There is a rich tradition within the Human Computer Interaction (HCI) research of implementing, demonstrating, and testing new interactions or technologies through the creation of prototypes. Various user-centred design methods are used for the development of these prototypes to produce designs that are validated, efficient, and rewarding to use. However, such studies rarely shift their temporal focus to consider, in any significant detail, what it would mean for a technology to exist beyond their prototypical implementation, in other words how these prototypes might ultimately be adopted into everyday use. This has led to the suggestion that HCI projects are always projecting these prototypes towards some proximate future [1] in which the wider messy social implications of these technologies are left as "someone else's problem" [2]. This is one of the factors which has arguably led to what might be considered as a "speculative turn' in HCI whereby methods such as *critical design* [3], *speculative design* [4], *adversarial design* [5], *design fiction* [6], etc. are used to create speculative visions of potential futures in which these technologies have become mundane. Such speculations aim to facilitate discussions about the potential societal implications of technologies to be considered within the present before said possible implications come to pass. The creation of these futures is often presented through the application of the *Futures Cone* which is generally attributed to [7], who adapted it from the work of [8] and is also widely used by technology companies. Whilst variations on this cone are common in this we critique we problematize the use of the cone as an example of what sociologist John Law [9] calls a *one-world-world* (OWW) view promoted through Northern/European techno-science which assumes it is dealing with a single reality (OWW). Thus, using the *Futures Cone* as scaffolding for discussing potential futures starts from an already constrained perspective. Law highlighted the limits of this in relation to sustainability by contrasting how we consider our relationship with the world in contrast to aboriginal view:

> "In a European or a Northern way of thinking the world carries on by itself. People don't perform it. It's outside us and we're contained by it. But that's not true for Aboriginal people. The idea of a reified reality out there, detached from the work and the rituals that constantly re-enact it, makes no sense. Land doesn't belong to people. Perhaps it would be better to say that people belong to the land. Or, perhaps even better still, we might say that processes of continuous creation redo land, people, life and the spiritual world altogether, and in specific locations." [ibid]

It has further been suggested that this particular mode of thinking is also embodied in within *Human Centred Design* (HCD) in that in the name of *simplification* we obfuscate the reality that we humans exist within complex highly contextualised assemblages of human and non-human actants [10] and are thus separating our actions from the potential wider affects we may have on our own environment or the environment of others. This disassociation is at the heart of what Tony Fry [11] describes as *defuturing* in that, as we design towards enabling particular futures, we simultaneously defuture other potential future outcomes. Thus, if we are speculating upon the creation of more sustainable futures for our world, we must recognise the need to scaffold these futures in such a way that they acknowledge that a more sustainable world will require us to:

> "… transition from the hegemony of modernity's one-world ontology to a pluriverse of socionatural configurations." [12]

Significantly, Escobar [12] recognises how pronounced differences between the lived experiences of individuals and communities from around the world will also have significant implications for such a transition. This sentiment is also embodied in the Zapatista declaration *'Un Mundo Donde Quepan Muchos Mundos'* – *'A world in which many worlds fit'* [13]. In the subsequent sections of this paper, we will unpack this argument in more detail before presenting our alternative to the *Futures Cone* that facilitates design practice for such a plurality of futures that benefit non-human actants.

2 FRAMING FUTURES

The dominant approach when presenting potential futures is as scenarios based on qualifiers – the most common being probable, plausible, possible, and in some cases the addition of preferable. It is this framing which is presented through the previously discussed and much-hyped Voros *Futures Cone* [7], an example of which is shown in Figure 1. As these qualifications are subjective, they are open to interpretation but could be considered as: possible – might happen, plausible – could happen, and probable – likely to happen. The notion of 'preferable', which can occur within any of the qualifiers, has become increasingly contested as it is seen as often promoting the privileged vantages of the Global North [14] [15]. This is evident within the long history of design futures which arguably developed their prominence through events variously termed World Fairs, World Expositions, etc., that have often been used to present the technical prowess of particular countries to the rest of the world. These future visions are often developed through the auspices of technology corporations and are imbued with a rhetoric that these companies provide the gateway too efficient, desirable and benign technology driven futures [16].

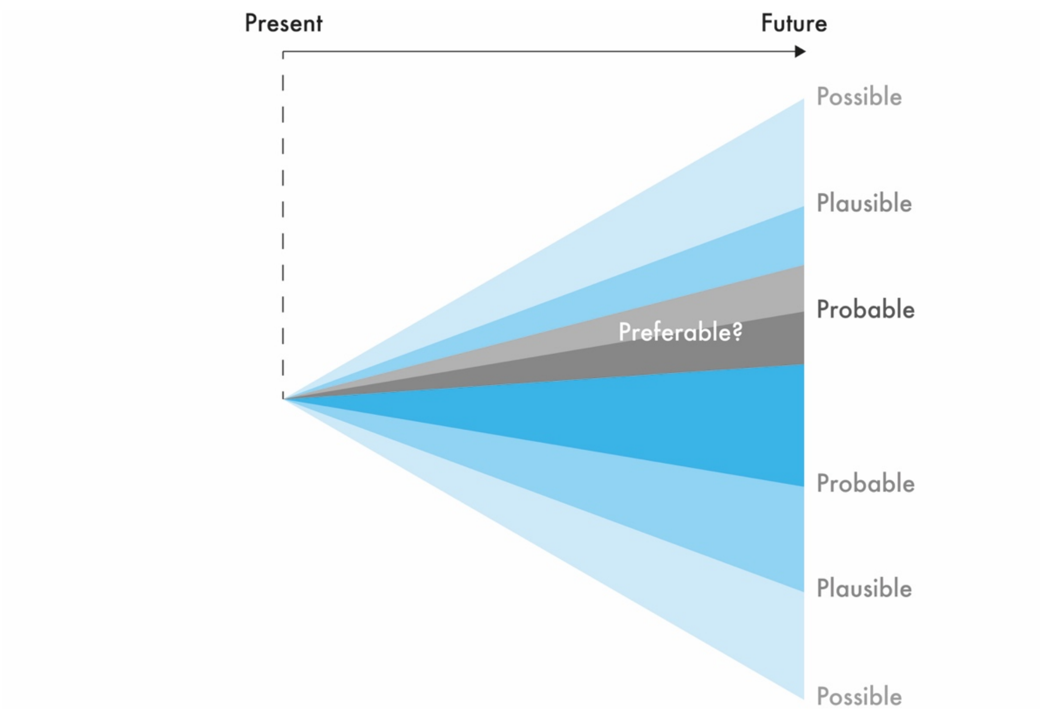

Figure 1: Example of the *Futures Cone* inspired by Voros [7], after [17]

2.1 Corporate Technological Futures

One famous example was *Futurama* which was designed by Norman Bel Geddes and exhibited at the New York World's Fair of 1939 through a commission by General Motors (GM). *Futurama* was akin to a fairground ride, that physically transported visitors over a huge diorama of a fictional section of the United States. It depicted a future defined by free-flowing movement of people and goods across the country, but with increased speed and efficiency. *Futurama* is widely credited for introducing the American public to the concept of a network of expressways connecting the nation. It painted a picture of a future where millions of cars, with millions of miles of roads to drive on, was desirable. *Futurama* set an agenda, significantly influenced transportation and planning policy, and seeded the affirmative narrative around automobiles, the 'product' that became one of the figureheads of American consumerism which was obviously desirable for GM. This type of corporate affirmative future has become even more prevalent in relation to digital technologies as evident from the rebranding of *Facebook* as *Meta* and their presentations relating to their ability to enable the so-called 'metatverse'. These visions have been dubbed as 'vapourworlds' as an extension of notion of *vapourware*, a term commonly used to describe software and hardware that is announced, sometimes marketed, but is never actually produced [16], and is behind the assertion that 'preferable' should be a critical question the designers ask of themselves within the design activity rather than an aim of the design [18]. Further, whilst 'possible' encompasses all potentialities when addressing particular challenges, it is 'plausible' and 'probable' which are most often utilized by designers, although for topics that cannot be easily defined and therefore many of its aspects could be considered as either 'plausible' or 'probable' dependent on your particular point of view. It has thus also been suggested to use 'plausible' to embrace both qualifiers to prevent discussions over the perceived differences in perceptions [Ibid].

2.2 Histories of the Futures

A further substantial problematic aspect of this cone is that it assumes a collective (western) acceptance of a particular historicity and notions of time when developing futures. The single point representing supposed accepted present reality and takes no account how history, beliefs, values, and fiction are all implicated in the cultural construction of past, present, and future realities. The *Futures Cone* is presented in a way that suggests a universally accepted consideration of the present, with no influence drawn from our perceived history or even how fictional representations of the world help to foster particular worldviews. The cone therefore at its heart embodies the notion of a OWW ontology. As a means of combatting this, we inspired by the work of Gonzatto, et al [19], shown in Figure 2, that draws from a characterization of historicity based on the work of work of Brazilian philosopher lvaro Vieira Pinto that encompasses the notion of *Existential Time*, or put simply, the social construction of time through historicity:

> "This temporality is both subjective and objective because it shapes experiences and material conditions for the production of existence. As such, it does not unfold as a straightforward course of action but as an existential challenge that involves choices, decisions, ethical dilemmas, contradictions, and politics as much as building, making, transforming, and doing." [20]

Whilst we now have a means of incorporating a much more nuanced view of how past, present, and future may be perceived we now need to address anthropocentrism within the creation of futures.

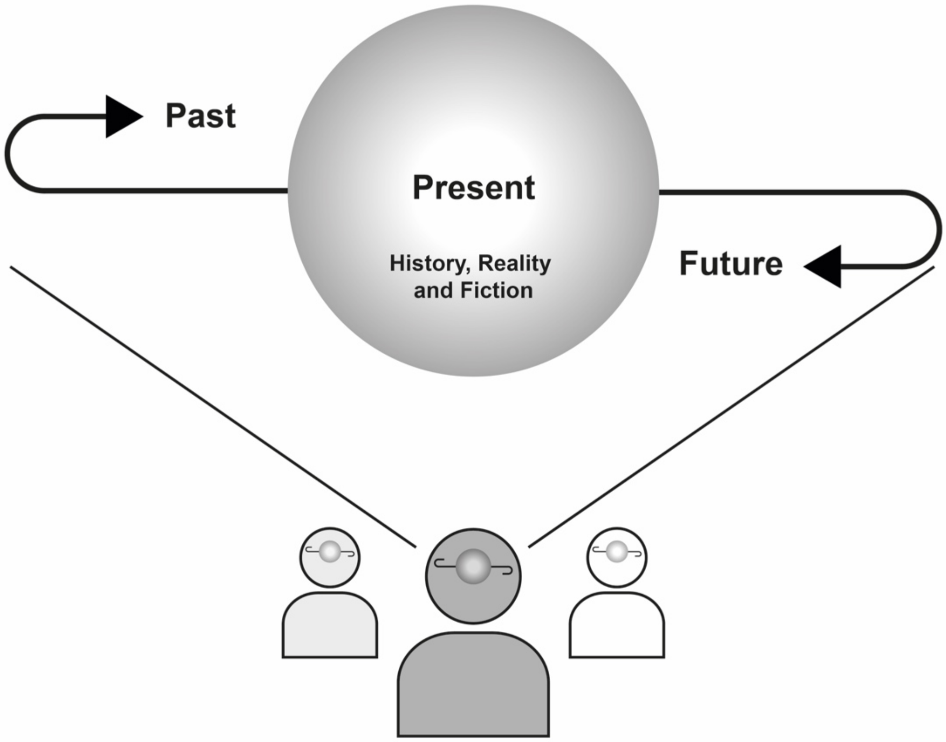

Figure 2: History as the possibility of redefining human pasts and futures, after [19].

3 MORE-THAN-HUMAN-CENTRED DESIGN

Arguably aspects OWW is significant part of established anthropocentric framings of design, particularly those framings enacted in the approaches associated with HCD [21] [22] [23]. In HCD, the human (predominantly conceived as the user) and their perceived task are placed at the centre of the design process and resultant designed activity. This myopia leads to an obfuscation of the wider implications of performing the activity, such as the social impacts or environmental effects. With this in mind, we explore the need for adopting *More-than-Human-Centred Design* approaches [10].

The origins of the term *More-than-Human* (MtH) appears to originate in the field of cultural geography [24] where it has been employed to promote a shift from largely anthropocentric perspectives to one that acknowledges our relationships to and within complex ecological assemblages. As [10] argue, designers need to acknowledge humans are rarely the centre of things but rather we exist within complex interdependences of human and non-human actants which are emotionally, economically, ecologically, and morally independent of each other. This creates the need for *More-than-Human-Centred Design.*

Although attaching the *More-Than* prefix infers a criticism of HCD, this does not extend to the entirety of what HCD encompasses nor all HCD-informed projects. Rather, the aim is to shift focus from the individual actant to what might be considered a focus towards what might be termed the 'common good', in that, an action by an individual is presented within the context of their membership of a community of numerous actants. Thus, in search for a better scaffolding for the creation of sustainable futures, we utilise MtHCD to explore the role of technological non-human actants within networked design assemblages and how these interrelations in turn impact upon ecological non-human actants – flora, fauna and climate – that exist within the said same assemblages.

The ubiquity and longevity of HCD is indicative of how it has been successfully leveraged to help design devices that are efficient, effortless, and edifying to use. A key factor in how HCD achieves this rests in its aim of reducing complexity (or conversely as it is oft interpreted, increasing simplicity). 'Simplicity', in HCD terms, echoes the Heideggerian notion of 'ready-to-hand' in that it suggests that the artefact being designed should fade into the background and become invisible [25]. In essence, any complexity that remains should be that of the underlying task and not of the tool designed to achieve the task [26].

Although HCD's invoking of simplicity is well reasoned and, in the right circumstances, can produce desirable outcomes, it is also true that "if simplicity is treated dogmatically, it can import risk into design processes" [10]. By obscuring the tangible, material affects that occur outside of the boundaries of the immediate task, design approaches that prioritise simplicity are increasingly problematic in relation to the evolving societal, economic and environmental challenges that today's cultures and communities now face. This problematising of HCD emphasises the need to develop MtHCD approaches which allow designers to make more robust considerations of the interdependent and independent perspectives of human and non-human (technological and ecological) actants that exist as part of today's networked design assemblages.

3.1 Object-Oriented Ontology

The MtH approach presented in this critque is based on the contemporary presentations of *Object-Oriented* philosophies as put forward by scholars including Graham Harman [27], Timothy Morton [28], and game design philosopher Ian Bogost [29]. Our key argument is for the use of *Object-Oriented Ontology* (OOO) and principally its rejection of *correlationism* – the notion that human minds and bodies are not the only actants worth countenancing. Differently, through OOO, we adopt a flat ontology perspective where all human and non-human actants – people, objects and the natural world – are given equal footing within the design assemblage. Adoption of this equilibrious standpoint is beginning to present challenges for those designers and technologists whose approach is predicated upon the ubiquity and dogma of HCD which places the human-object relationship at the centre of the technological design process [30]. Importantly, whilst we are problematising HCD, rather than a complete rejection of its principles, our argument is primarily against how HCD manifests itself in the creation, and consequently, use of many of our designed artefacts. We do this to promote encompassing socio-technical outcomes that curtail anthropogenic dominance and instead begin to support the common good in relation to climate change and planetary sustainability.

4 FUTURING/DEFUTURING

Whilst design futures can help to highlight potential benefits of designing emerging technologies with greater consideration for sustainability, it also operates in tandem with *defuturing*. As previously highlighted, corporate visions regularly present futures which invoke a rhetoric that suggests that the products and services of the particular organisation are (or soon will be) the inevitable deliverers of particular futures [16]. In his book *Defuturing: A New Philosophy*, Tony Fry [11] stresses the active role that designers play in creating unsustainable futures through the design and implementation of the products and services that we create. Fry asserts that because we materially consume large amounts of natural resources through our design activities, we are negating potential futures for both ourselves and for the other non-human actants with whom we share this planet. He argues we do this because:

> "Fundamentally, we act to defuture because we do not understand how the values, knowledge, worlds and things we create go on designing after we have designed and made them." [11]

Fry's observation embodies much of our previous argumentation, specifically the need move towards MtH approaches as well as emphasise that designers should broaden their perspectives when considering a particular design challenge. To this end, Fry suggests designers should seek to:

> "Disclose the bias and direction of that which is designed and how it is totally implicated in the world we conceptually constitute, materially produce, waste (rather than consume), occupy and use as an available material environment." [11]

Putting all these discussions together leads us to our alternative to the *Futures Cone* shown in Figure 3. This novel rhetorical frame for *sustainable futuring* helps us to move beyond a OWW perspective and allow for a plurailty of human/nonhuman perspectives to be considered by designers in their praxis.

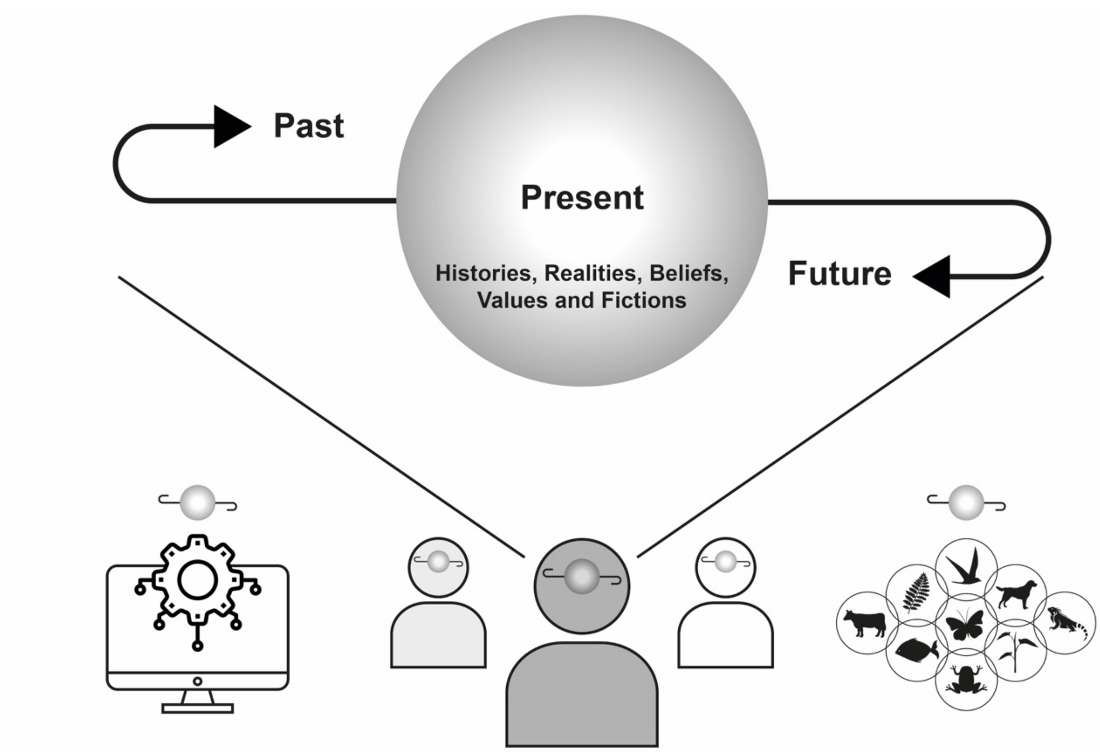

Figure 3: A Rhetorical Frame for Pluriversal, MtH Sustainable Futuring

As a means of initiating sustainable design futuring endeavors based on this frame, we have also found inspiration from Coulton and Lindley's [10] introduction of *constellations* which seek to expose the independent and interdependent perspectives that exist throughout networked assemblages. Constellations can be conveyed through what Bogost [29] describes as *ontographs* or collections of the ontological modalities as possible relationships an object(s) may take. Bogost draws upon his notion of *Alien Phenomenology* to suggest a perspective of ontography which acts as a record of the "things within". This recording of objects can then be defined further by their "collocation" to not only the things within the ontograph, but also those around it. As a practical example, our *Futuring/Defuturing ontograph* (Figure 4) illustrates the defuturing potential of such human/non-human design assemblages and places particular emphasis on the multidimensional impacts which arise due to the production, operation and disposal of present day, networked *Internet of Things* (IoT) devices and related services.

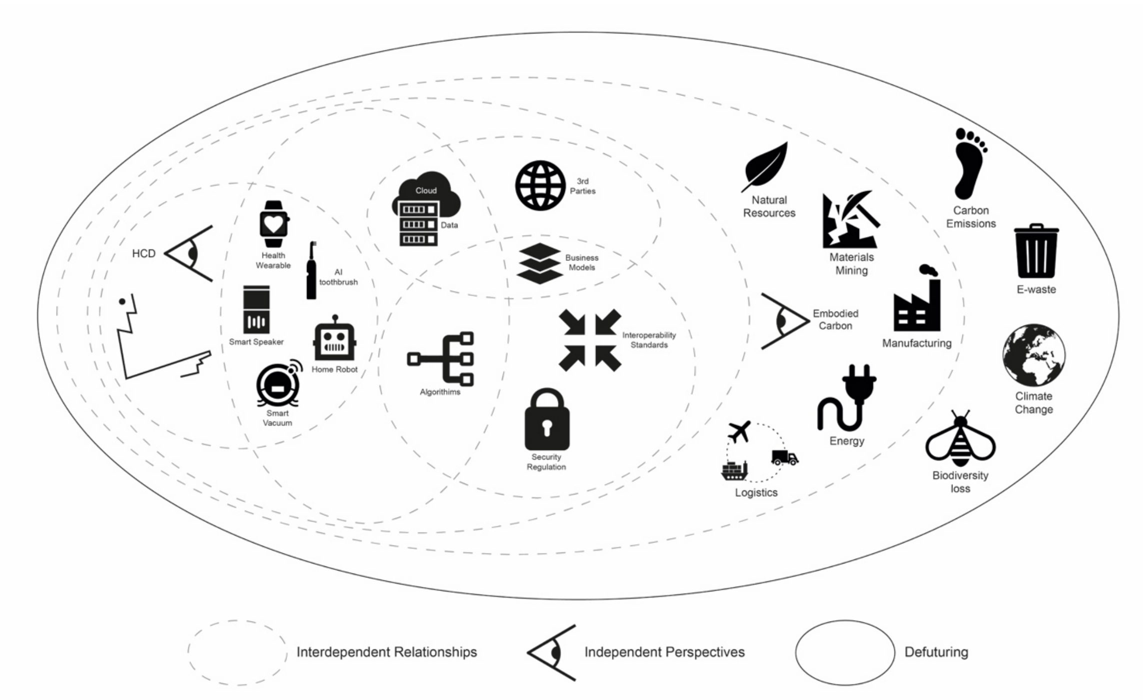

Figure 4: Futuring/Defuutring Ontograph, building upon [10].

5 DESIGNING SUSTAINABLE TECHNOLOGICAL FUTURES

To develop the outlined approaches and further cement the need to move beyond a OWW perspective, we will now discuss examples of actionable practice for designing *sustainable technological futures* that accommodate pluriversal MtH design assemblages. We will continue to explore the impacts of networked IoT devices and services in this practice. Significantly, we utilise the concept of *spimes* as a lens to allow us to envision sustainable and pluriversal design futures for this expanding technological paradigm.

5.1 Spimes

The increasing 'networkification' [31] of computationally enabled devices is fundamentally changing our relationships with physical products. This leads to a growing disparity for users – between what these IoT devices "actually are and do and the ways in which they are presented as things for use" [32]. The addition of networked services compounds this, as it arguably leads to a shortening of the lifespan of such devices through *systemised obsolescence*, in that, while software for IoT products can (for a period at least) be upgraded via remote installation, we increasingly see their hardware rapidly rendered obsolete due to manufacturers' and service providers' constant drive to extend the functionality and data capture capabilities of these devices and services. Such redundancy increasingly results in ever-greater volumes of IoT electronic waste (e-waste) as well as contributes to growing material scarcity issues.

Spimes provides a timely lens through which to explore the environmental implications of contemporary IoT devices and services. The term *spimes* denotes a class of near future, sustainable, Internet-connected manufactured objects, which, unlike the unsustainable IoT products which permeate our society today, would be designed so that they can be managed sustainably throughout their entire lifecycle. This would have the goal of making the implicit environmental consequences of hardware/software obsolescence and disposal more explicit to potential users [33]. The concept of *spimes* was originated by Bruce Sterling [34] who viewed digital technologies as having the potential to lay bare 'the reality that underlies all manufactured objects… [leading to a paradigm where] manufactured items will be more practical, efficient, and user- and environment-friendly'. Sterling [35] describes *spimes* as potentially being 'material instantiations of an immaterial system… they are designed on screens, fabricated by digital means and precisely tracked through space and time throughout their earthly sojourn.' Outlining their inherent environmental credentials, [33] envisions *spimes* to be made from "materials which are ecologically safe and durable but also highly versatile. When a spime object is no longer required, they can be cheaply returned into the production process as a raw material for future spime objects."

To enact *sustainable technological futures* that accommodate pluriversal MtH assemblages directly *within design practice*, we applied the *Speculative Design* technique *Design Fiction as World Building* (DFasWB) [6] to recharacterise the IoT as future spime-like devices and services.

5.2 Speculative Design

Our following application of *Design Fiction* (DF) should not be seen as an attempt to predict the future or method for generating specific 'sustainable IoT product solutions' but as a strategy for enabling more inclusive debate about how and why socio-technical futures are being designed and what they might mean. Importantly, the concept of *world building* is core to this research. As Coulton et al [6] assert, collections of DF prototypes, when viewed together, scaffold a proximate fictional world in which new technologies can plausibly exist and then be more thoroughly considered – by practitioners and wider audiences alike.

In the following sections, we embody visions for MtH technologies as spime-like prototypes all of which exist within the same DF world. As Figure 5 illustrates, our spime prototypes act as key 'entry points' into the said world while at the same time represent views of the world at a range of scales. Furthermore, by moving away from tropes like storytelling, narrative and characters, we use DFasWB to place importance on the technological implications and values inferred by the fictive world and how this focus might form a *discursive space* amongst potential audiences [6].

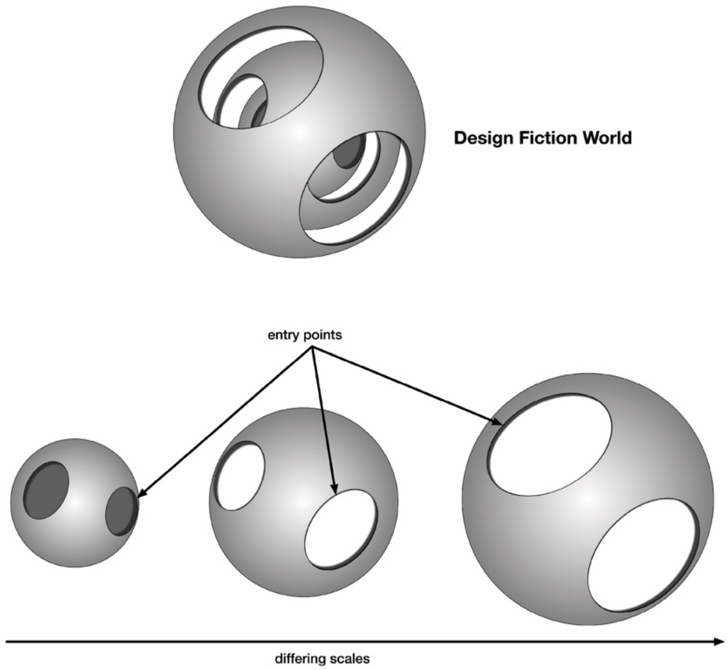

Figure 5: Design Fiction As World-building. The artefacts that build DF worlds represent views of those worlds from a range of scales while also acting as ‘entry points’ to the world, after [6]

Given that DF prototypes are also free of commercial constraints such as usability, aesthetics and cost, the following spime prototypes are able to go beyond standard cycles of socio-technical innovation [36] [37]. Ultimately, our designs provide a foundation for how to consider a MtH approach that might manifest in potential sustainable IoT oriented technological futures which address *the common good in relation to planetary sustainability*.

5.3 Do-It-Yourself Medical Devices

To develop a series of spime DF prototypes which help audiences to consider pluriversal and sustainable MtH perspectives, we chose to frame our fictional designs in relation to the concept of a multi-purpose *Do-It-Yourself* (DIY) medical wearable device and associated platform called *Healthband*. Ensuring adequate provision for patients is becoming more and more challenging due to ever increasing demands on healthcare services around the world. DIY healthcare has therefore become a significant topic of discussion in medical and financial forums in recent years as the potential of smart and wearable devices is being optimised as a means provide greater accessibility to health monitoring and facilitate care directly in patients’ homes [38]. One of the drivers for these discussions is the proliferation of commercially produced IoT wearable devices like fitness and activity trackers which monitor aspects of their environment and their users’ lives, display real-time telemetry data, and also share said data with other devices and platforms. The popularity of such data-driven devices is helping to make the practice of self-tracking an everyday practice amongst wider publics. Accordingly, technology designers and manufacturers are seeking ways to identify opportunities to create devices that effectively monitor (and potentially aid users in better managing their) more serious health conditions.

In light of the above, we concluded that a spime-like DIY medical wearable would be a near future IoT product that a plurality of audiences could easily identify with. In recent years, technological practices like *open-source* hardware, *crowdfunding* and the *Maker Movement* have often also been cited as more environmentally friendly alternatives to the established, proprietary and centralised strategies that currently characterise IoT device development [39] [40]. This is said to be primarily because decentralised, DIY products are usually designed for specific purposes in smaller production runs which often reduces their overall environmental impacts. This sits in contrast to the copious amounts of resources consumed (for example, energy, water and raw materials) during the mass manufacturing of commercial devices and throughout their associated global supply networks. Consequently, the notion of DIY production and consumption of medical devices also provides us with a compelling lens through which to consider more sustainable and pluriversal futures for the IoT.

5.3.1 HealthBand

Interest in developing DIY medical devices has seen a resurgence in recent years, particularly through association with the so-called *Maker Movement*; a grass roots technology centric culture in which participants aim to create new devices, repair and reuse old ones, or simply ‘tinker’ [41]. Activities such as these are being enabled by the decreasing cost of electronic componentry, the flexibility of experimental open-source hardware platforms such as *Arduino* and *Raspberry Pi*, and new forms of decentralised production technologies like *Additive Manufacturing* (3D printing) which can easily be accessed via community-centred *fab labs* and *maker spaces*. Drawing upon this discourse, we developed the fictive *HealthBand* (HB) DIY medical device (Figure 6).

As part of the HB proposal, we seek to address the question of how DIY development devices might possibly be supported – both technologically and financially – if the expectation is that it would effectively exist outside the ‘closed’ profit-driven innovation models that characterise current product development and manufacturing cultures. Presently, commercial designers and manufacturers exploit internal assets and intelligence to develop standardised, proprietary devices [41]. Contrastingly, Von Hippel [42] put forward the term *Democratised Innovation* (DI) to denote a more participatory form of product development whereby devices and services are designed and fabricated by the same people who ultimately use them. Unlike ‘closed’ proprietary models, the knowledge, resources and technologies relating to socially driven democratised products can be diffused quickly, efficiently, and more often than not, ‘freely’ through networks of online and offline communities. This collaborative activity has resulted in products which directly benefit those who created them and frequently also have positive impacts on society at large [42]. Through the HB prototype, we begin to embody the notion that such participatory and meritocratic innovation practices could also provide positive benefits for planetary sustainability and helping to enact design futures which are pluriversal and MtH in particular.

In the case of DIY medical devices, DI is being evidenced in the way fab lab-based 3D printing provision has facilitated wearers of prosthetics with new opportunities for designing and modifying their own prostheses [43]. Another notable example is that of *Nightscout* which is an open-source platform developed and run by a global community of patients with type-1 diabetes. The platform combines a CGM (Continuing Glucose Monitor) device which provides constant updates on glucose levels, a DIY data transmitter, and freely available software which enables the CGM data to be shared throughout the community via cloud data storage [44].

Figure 6: A patient wearing *HeathBand* – a fictional DIY medical device.

When treating complex conditions such as dementia, individual patients' needs and symptoms can be quite varied and unfortunately a range of other challenging health issues often develop concurrently. Further, as dementia is a degenerative illness, the needs of a particular patient will vary over time. Technological solutions should therefore be designed so that they aim to address different aspects of a condition and the resulting platform flexible enough to allow devices to be configured and reconfigured in order to meet the dynamic needs of users. With this in mind, we chose to integrate significant modular attributes into the HB design. It is argued that *modularisation* will likely be a core design specification for future, sustainable IoT devices [45]. The modular specifications of our HB prototype were heavily inspired by the *Blocks* smart watch which was first developed during the tech giant *Intel's Make It Wearable Challenge 2013*. Finalists in the competition, the *Blocks* project team received $50,000 in start-up funding. They then sought further capital to enable increased production via the *Kickstarter* crowdfunding platform [46]. The team's dependency upon crowdfunding exemplifies the way in which many IoT product-services are presently being financed. We therefore posit that DIY wearables would also potentially be crowdfunded in the future. Given that healthcare wearables are a popular trope of the IoT, our appropriation of the crowdfunding model lends a level of *plausibility* to the spime DF ('it could happen'), particularly if the potential audience is familiar with developments in IoT.

Importantly, if device creation and consumption are no longer mutually exclusive activities in the near future and design expertise and tools are more widely dispersed across communities, more open, democratised design-innovation practices would likely broaden the types of people who would engage in such practices. To reflect this plurality of actants, we illustrate how and why each module was created through three short HB module ‘developer stories’. In the fictional world, the three developers have each produced their HB modules for different contextual reasons and then shared the designs in an altruistic manner through decentralised networks rather than for monetary gain. The first story (Figure 7) draws inspiration from the aforementioned *Nightscout* exemplar and describes how Gary and Phil from Manchester, UK, working against an increasingly privatised UK health service and exorbitant treatment costs, sought to crowdsource funding to produce the initial HB module – a diabetes monitor – to help manage Gary’s young cousin’s Type 1 symptoms. Ultimately, the story aims to highlight how the designers leverage modularisation and open-source technologies, in an effort to provide continued, wider personalisation of HB as a platform by encouraging other ‘DIYers’ to innovate additional distinct yet shareable modules.

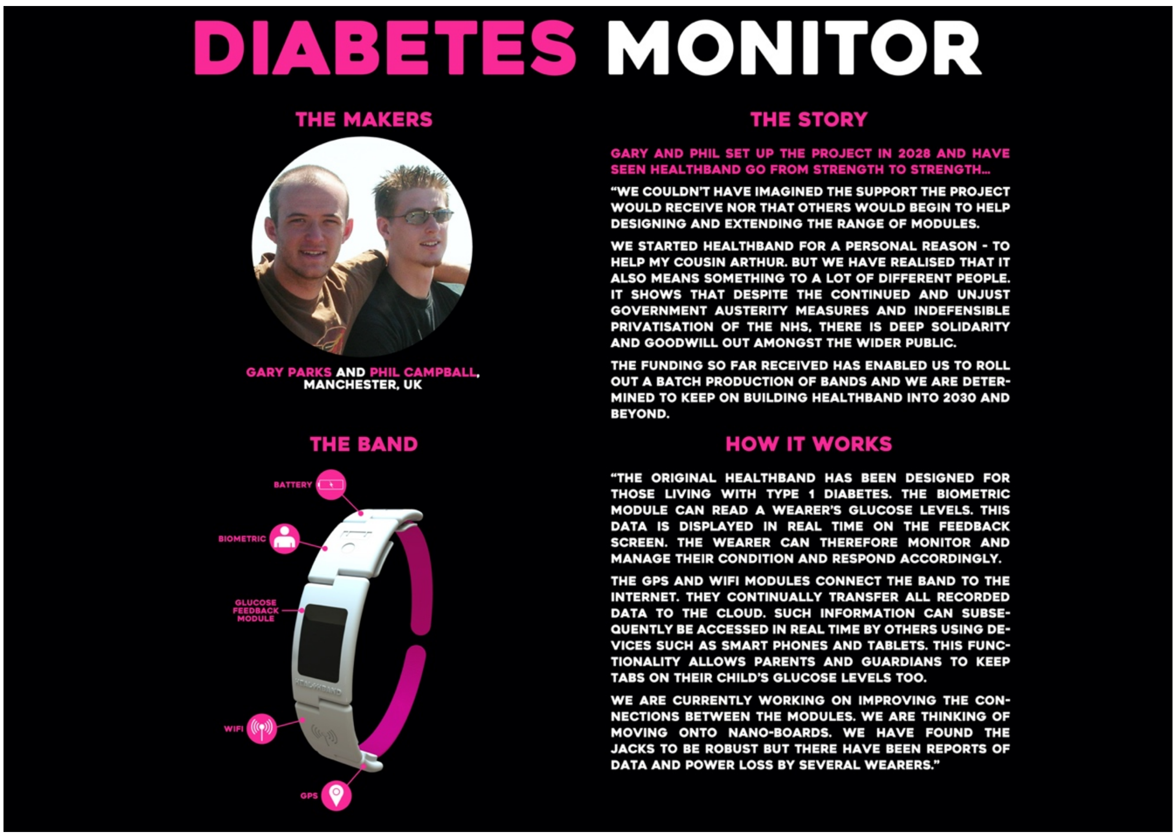

Figure 7: The Diabetes Monitor module developer story.

The second story (Figure 8) concerns ‘Alicia’ based in Williamsburg, New York, USA, who, having been excited by seeing the original diabetes monitor, decided to create a memory aid tracker module. Alicia was inspired to design the module both due to the prevalence of Alzheimer's in her family, and in response to the difficulties faced by many in the USA of obtaining health insurance. In terms of the DF, it draws from health reports from the *Alzheimer's Society* [47] who highlight that Alzheimer's is the most common cause of dementia, affecting 62 per cent of people diagnosed with the syndrome. There are currently 850,000 people with dementia in the UK, with numbers set to rise to over 1 million by 2025 and are further expected to soar to 2 million by 2051. Introducing the USA perspective not only highlights that dementia is a global issue, but also emphasises that individual countries have particular problems with access to healthcare, in this case access to affordable, comprehensive medical insurance in the USA.

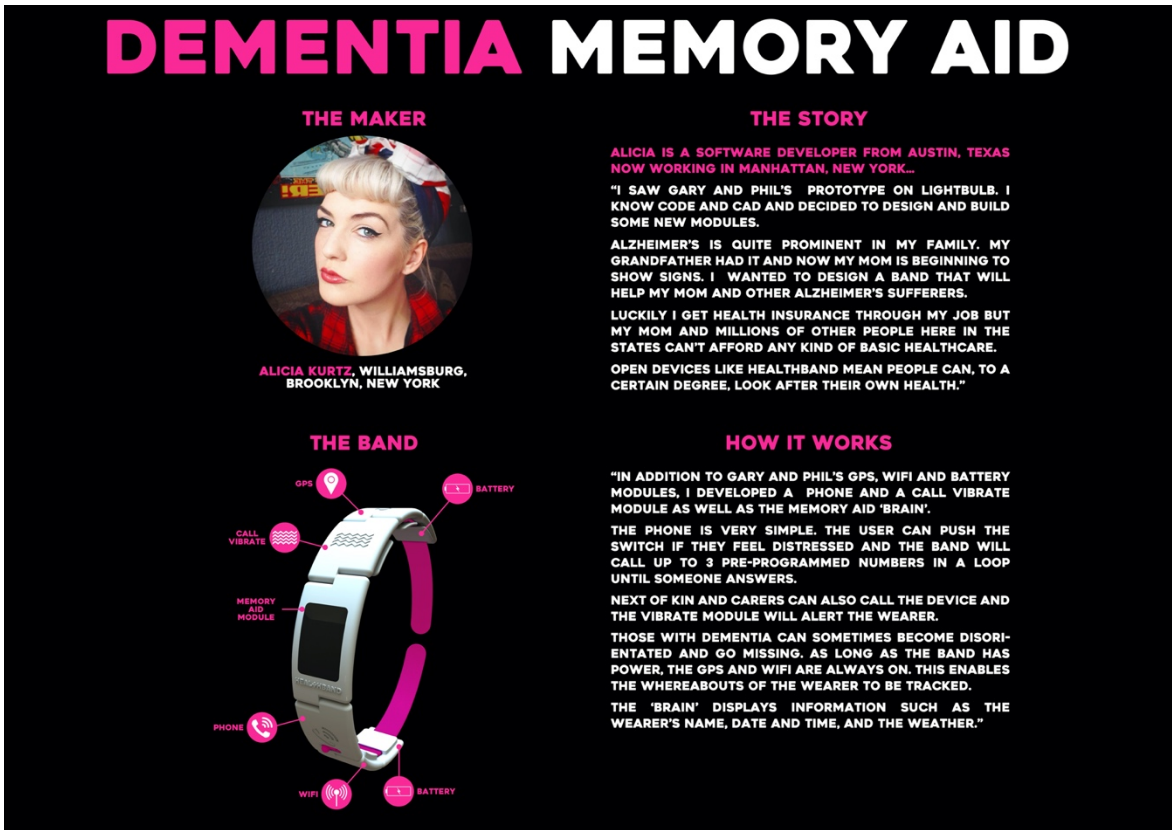

Figure 8: The Dementia Memory Aid module developer story.

The final story (Figure 9) features 'Emi' from Japan which highlights the issue of their increasingly aged society. Indeed, Japan's population is expected to see the number of over 65s to grow to nearly 50% by 2060 [48] while also experiencing a declining birth rate [49]. In this story, Emi has developed HB modules which are specifically designed to stabilise hand tremors which are a common symptom of Parkinson's disease. We contend that his story, in part highlights that symptoms exhibited by patients vary from individual to individual which in turn emphasises the need for a flexible and reconfigurable design solution.

Figure 9: The Parkinson's Stabiliser module developer story.

Whilst the set of developer stories originate from a western-centric view of DIY healthcare (Gary and Phil's UK oriented story), through the second and third stories, we have sought to start to move beyond a restricted and often privileged OWW perspective by offering more pluriversal examples of how an open-source platform like HB could constitute a sustainable spime-like IoT technological future. We live in a deeply heterogeneous world where people's needs, desires, opportunities, and challenges can be highly context specific. Thus, Alicia and Emi's stories focus on developing HB related solutions which hold clear forms of meaning and value for them as well as for their relational surroundings – their local community, resources, landscape and climate. Moreover, this framing allow us to utilise practice-based approaches to begin to counter the OWW nature of the typical *Futures Cone*, in that, the stories seek to demonstrate how history, beliefs, values, and fiction are all implicated in the cultural construction of past, present, and future realities, in this case, these factors are embodied through the three different HB modules.

Crucially however, by also actively participating and helping to develop the wider HB platform, the three developers are also contributing to the wider societal and environmental *common good*. This brings us back to the importance of acknowledging the independent *and* interdependent perspectives that exist throughout networked design assemblages. As illustrated in our *Futuring/Defuturing Ontography* (Figure 4), the production, operation and disposal of present day, and indeed future IoT devices and related services like HB, have multidimensional impacts for both human and non-human actants. Further, we have thus far presented HB as principally having positive social and sustainable impacts. In the next section, we look at how designing a technological platform like HB could potentially also have some undesirable consequences for people and planet, in other words, how such a development might also *defuture the future*.

5.3.2 Risking Rare Earths

If we briefly return to the example of *Blocks*, it is representative of the ongoing volatility that marks IoT development, in that it is a constantly evolving landscape with devices, services and companies entering and leaving the marketplace at a rapid rate. Despite numerous release dates being announced since early 2016, the *Blocks* device appears to have suffered the same fate as many other IoT devices [50]; it has become *vapourware* as it never 'materialised' as a fully functional device which end-users could actively purchase [16]. From a sustainable perspective, *Blocks'* stagnation could be viewed as a positive form of *obsolescence*. Having been limited to only prototypes, the project will not have a larger impact upon the world, that is, *Blocks* devices will not consume raw materials and energy during their production, generate carbon emissions throughout their lifecycles nor will they end their life in landfill as unrecyclable e-waste. If HB were to exist in a near future world, issues regards resources, e-waste and material scarcity, would no doubt arise, both in terms of individual modules and the platform as a whole:

> "The 'sustainability' of individual ICTs must be considered within the 'ecology of devices' within which they are connected, and within the wider context of practices which constrain an individual's potential interactions." [51]

Knowles et al's observation echoes our discussion on the independent and interdependent nature of networked design assemblages, particularly that of the IoT. Whilst exploring the impacts of hardware and software in HCI research has a long lineage (for example, the important work of Blevis [52] on *Sustainable Interaction Design*), privileging non-human – flora, fauna and climate – over human-centred considerations as part of such assemblages been less explored. E-waste is the fastest growing waste stream in the world and primarily consists of discarded household consumer products and appliances. In the EU for example, currently, less than 40% of e-waste is subject to any form of sustainable recovery, that is, 'post-lifespan' processes such as material recycling and the harvesting of reusable componentry [53]. E-waste is consequently a significant contributor to the rise in harmful carbon emissions which are fuelling global climate change and biodiversity loss. Thus, the drive to develop new ways to extend and improve the lifespans of electronic devices feeds into wider societal efforts to keep global temperature increases to a maximum of 1.5 °C, as well as to meet ambitious Net-Zero decarbonisation targets by the year 2050 [54].

It is estimated that by 2030 there will be over 25 billion active IoT physical devices worldwide [55]. Through planned hardware and systemised obsolescence, the IoT will no doubt continue to make growing contributions to global e-waste streams in the next decades [56]. IoT devices are primarily composed of materials that are non-recyclable such as thermoplastics and others which are finite like precious metals and rare earth elements (REEs) [56]. The latter are increasingly being mined to be used in electronic device hardware manufacture. Thus, despite the positives that would come with embracing greater democratisation and open-source practices, the expansion of HB and other platforms like it would likely still feed into global REE mining and material scarcity issues. Globally, China possesses the most REE deposits and the impact on communities and workforces in many mining locations is growing as they are often characterised by the exploitation of workers through low pay and dangerous working conditions as well as adverse local environmental hazards such contaminated water supplies and soil pollution [57]. REEs are therefore becoming an important focus in the design of sustainable futures, particularly as these same materials are critical to the production of a number of apparent environmentally friendly technologies like electric vehicle batteries, solar panels and wind turbines [58]. Figure 10 begins to explore these impacts by depicting an excerpt from a fictional future report by *Greenpeace* and the *United Nation Sustainable Development Goals* committee which rates different countries sustainable governance in relation to REEs.

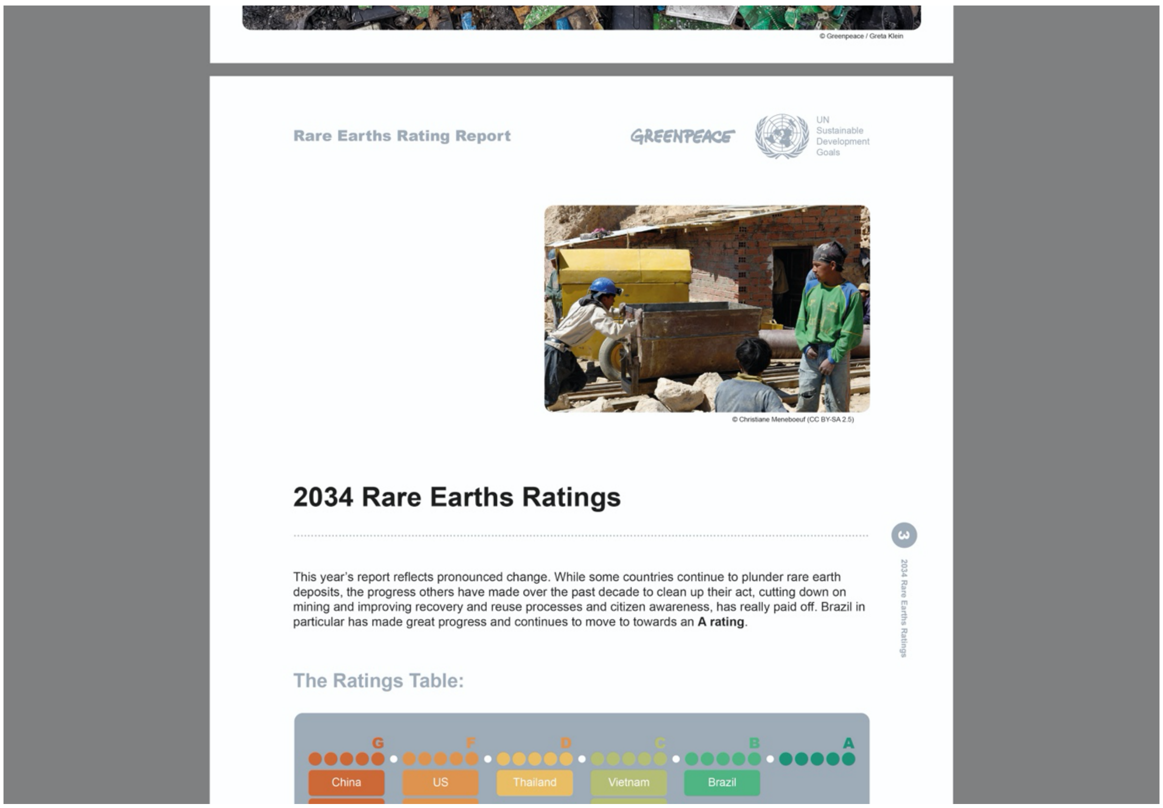

Figure 10: Greenpeace's/UN Sustainable Development Goals' *2034 Rare Earth Ratings Report*.

The role of everyday citizens in producing their own devices like HB – as opposed to simply using them – is a powerful, egalitarian idea. However, such practices also carry forward risks associated with individuals taking technologies upon which their life depends, into their own hands. Moreover, working with parts and components made from problematic substances like REEs and the tools and machines used to process them would also amplify these safety issues. So, whilst DIY medical devices are garnering considerable attention in the media, academia and industry, they are drawing from a design-maker culture which are often less complex than those which manufacturing practices they seek to challenge, that is, the centralised mass-production of real, operational devices. The modular aspect of the HB speculation is therefore particularly useful for extending the scope of the fictional DIY medical device world to include other criteria which may present very different challenges than those currently envisioned, specifically the safety challenges. There is a need to consider how trust can be facilitated in the citizens creating DIY products, and to ensure some level of accountability amongst device developers, health service providers and legislators. Such a task is of course highly complex and whilst we are not realistically suggesting this as a solution as part of the DF, to begin considering notions of accountability, we created a *Domestic Safety & Sustainability Fabrication Permit* (Figure 11) which empowers a particular Brazilian citizen with diabetes the authority to work safely with tools and materials like REEs to produce DIY medical devices, which themselves can function safely delivering the required healthcare. The fabrication permit is not being offered as the solution to certification but rather providing a starting point for deliberations on what the actual requirements of a new certification process might be.

The permit acts primarily as a means of linking current medical device certification with potential ways of how this might be adapted to allow DI and medical device production on a more individual level. There are possibilities that the permit leaves unanswered, for example, how is it obtained and what are the requirements for applicants regards fabrication qualifications, liability, insurance etc. As it is a 'fabrication' rather than 'developer' permit, it also suggests that designs might be outsourced to certified individuals, or even machines, to be built thus allowing innovations to be disseminated through open-source practices. Whilst the permit primarily presents a positive perspective, that is, that citizens would be able to make their HB style medical devices, it might also initiate more negative questions. Could a black market for permits and devices emerge? How such actions might be mitigated? This corresponds with Sterling's initial thoughts that in addition to the sustainable advantages that a spime-based paradigm would create, like any other previous techno-culture, a shift to spimes would also bring about disadvantages. He pointedly states that the concept "is not a vision of utopia… are there dark sides to this vision? Oh yes indeed. Genuine menaces" [34]. Ultimately, the permit allows us to further explore the implications of adopting DIY medical devices from additional perspectives, in Figure 11's case a Brazilian DIYer. It also reflects the likely real-world evaluations and discussions that would arise around policy and legislation in regards to open-source hardware/software platforms.

Figure 11: A diabetic Brazilian citizen's *Domestic Safety & Sustainability Fabrication Permit.*

The notion of plurality is further explored in Figure 12. As 'networkification' and 'smartness' penetrate and add a layer of software-based functionality and associated services to more and more material things, we posit that new economies of repair, recycling and remanufacturing could also develop around the IoT in the near-future. Today, smart phones, laptops and tablets currently dominate the high street repair economy in both the Global North and South [59] [60]. Figure 12 depicts an advertising hoarding for a smart device repair shop in Accra, Ghana. Although the advertisement appears in the mundane context of a bus shelter, the location of Accra is important – the city is home to the *Agbogbloshie*, the largest illegal e-waste dump in the world. Unsafe e-waste reuse business models already exist around sites like *Agbogbloshie* as local citizens scavenge and sell on the valuable materials and parts that make up devices including REEs to brokers [61]. Whereas the above permit is focused on the individual producer, Figure 12 instead envisions a new form of safe, localised sustainable community enterprise which is run by trained staff as opposed being limited to the often profit-driven product maintenance remits of top down, proprietary technology firms.

Figure 12: A bus shelter advertising a local smart device repair service in Accra, Ghana.

The wide-reaching ripple effects of technological design are keenly felt by fellow human *and* non-human actants across networked assemblages and can subsequently *defuture* other potential futures. Building upon the spimes concept to develop aspects of the HB proposal allows us to convey the above examples of *defuturing* as well *futuring*. Western designers and technologists in particular must break out of the myopia of OWW thinking [9] and start to evaluate the *defuturing* impacts of their work – even if they are trying to design a product or service that they intend to be 'sustainable', it will likely have unintended consequences – both in the Global North and the Global South. The environmental scholar Elizabeth Kolbert [62] notes this paradox by describing efforts to implement sustainable technologies and practices often result in "people trying to solve problems created by people trying to solve problems."

6 REFLECTIVE DISCUSSION

The HB proposal envisions a future world which is characterised by various societal, environmental and technological *trade-offs*. We begin to highlight this uncertainty and complexity through our application of the DFasWB technique. It allows us to emphasise the broader implications that democratically produced spime-like IoT devices such as HB might yield, specifically the opportunities for MtH futuring *and* defuturing. Our interrelated artefacts to this by providing different ‘points of entry’ at different scales, contextualising the HB concept within a more fully rounded world. Coulton [63] surmises that speculative proposals can ‘operate’ as either ‘far’ or ‘near’ futures. He asserts that *‘the present is the future mundane.’* [37] is more reticent regards the notion of ‘far futures’. He argues that for these types of design proposals to be ‘successful’, one must ensure:

> “careful management of the speculation; if it strays too far into the future to present implausible concepts… the audience will not relate to the proposal.” [37]

Our artefacts are therefore presented in forms that are likely to be recognisable in relation to potential audiences’ everyday reality (a confluence of history, beliefs, values, and fiction) and it is through this mundanity that said audiences’ own lived experiences might come into relief. We argue that situating the artefacts within a *plausible* near future helps to facilitate, rather shutdown, multiple ‘readings’ or interpretations of this future world, allowing audiences to consider the pros and cons (futures/defutures) of the fictional platform and the theoretical issues and ideas it embodies. With this inclusiveness in mind, we have also strived to resist the temptation of echoing the tired dystopian and utopian tropes that often typify visions for sustainable futures. Indeed, many scholars and practitioners foresee a planetary *non-future* on the horizon and contend that to avoid a climate catastrophe, we should eschew technological progress and effectively readopt pre-industrial craft cultures and values [64] [65]. Others take a utopic and deterministic stance, arguing that advanced technologies will one day provide the answers for ameliorating most of our environmental problems. Until then they assert, societies should learn to *love their monsters*, that is, openly embrace the Frankenstein-like consequences that existing technologies have already wrought upon the planet [66] [67] [68]. This dichotomy in sustainable narratives is persistent and persuasive. It can lead to inertia amongst policymakers and publics in regard to the best ways to redress unsustainable processes and practices. It can create tensions amongst designers who are aware of the disciplines lamentable environmental record but who also want to innovate novel strategies for restabilising our biosphere.

The propensity of some to promote idealistic and overly solutionist visions of the future should be seen as a form of what futurist writer William Gibson [69] terms *postalgia*. Similarly, hagiographic interpretations of the past contain elaborations and constructions which can distort history as well as conceal its flaws [70]. We argue that it is time to move away from sustainable technological futures being defined through the reductive binary of *utopias* and *dystopias*. What might be described as dogmatic *mono-futures* are not inspiring the type or level of sustainable change needed. Such hardline visions can disengage people from taking part in the important dialogue surrounding the need for making sustainable transitions. Through our practice then, we seek to facilitate such inclusive discourse by situating the speculative arfetacts and their future implications as a mundane and ‘everyday concern’.

A more useful way to look at the issue of global unsustainability is to view it as a *hyperobject* [28]. Massive in scale and continually evolving, it is a ‘wicked problem’ [71] which is becoming increasingly difficult to solve outright. Escobar’s [12] concept of the *pluriverse* reinforces the complexity and uncertainty of designing for sustainable futures. One community’s vision of a sustainable future might present unsustainable challenges for others. This way of thinking can also be traced back to the famous *Our Common Future* report [72]. Stating that the *‘the earth may be one, but the world is not’*, the report is noted as an originator of the term ‘sustainable development’, which it argues it is the goal of reducing environmental and resource consumption while maintaining economic standards of living and social equity. Echoing our augmentation of MtH design assemblages, the report asserts that ‘environment’, ‘society’ and ‘economy’ should never be considered in isolation but collectively; they are fundamentally interconnected. Our *Futuring/Defuturing ontograph* (Figure 4, p8) illustrates this inherent independency/interdependency of actants.

Perhaps running counter to traditional *philosophy of technology* positions, our stance could be seen to align with *Bright Green Environmentalism* which advocates the convergence of technological innovation, social responsibility, and radical design processes to shape positive, practicable and *participatory* sustainable futures. “We can’t build what we can’t imagine… the fact that we haven’t compellingly imagined a thriving, dynamic, sustainable world is a major reason we don’t already live in one” argues *Bright Green* progenitor Alex Steffen [73].

7 CONCLUSION

As the focal point for the majority of design, the human as user still dominates technology-oriented practice and research. Most HCI designers and technologists continue to implement systems that align with traditional forms of HCD thinking. Given the extent to which anthropogenic activities are now impacting Earth’s natural systems, through this paper we call for the design of sustainable technological futures that facilitate a more pluriversal form of human participation, futures which are imbued with consideration of, and indeed contributions from, those outside a distinctly westernised OWW vantage. Crucially, we also argue for such practices to proactively accommodate non-human participants – flora, fauna and climate – as equal stakeholders in future technological design. Placing purely human needs at the centre of design decisions is fundamentally no longer just nor tenable for our planet.

As such, the primary aim of our speculative proposal is to raise awareness, provoke debate and perhaps even begin to shift perceptions regards the adoption of emerging paradigms like the IoT and the implications of such apparent advances for facilitating forms of *sustainable technological futures.* Having said this, we do not view our speculative design process or others like it as a panacea for eradicating the problem of planetary unsustainability. We deem our approach as a useful lens to both critique the unsustainable issues arising from contemporary technological design cultures, and a way to argue for more sustainable approaches to said praxis. It is designers who help to drive obsolescence by limiting the lifecycles and interoperability of electronic device hardware and software. Yet, the natural fluidity and reflexivity of design as a discipline means that it can also be reoriented to challenge its own unsustainable status quo.

By conducting *More-than-Human-centred Design*, we foreground technological progression in a sustainable design narrative; one in which creativity is key to changing our future ways of living. Fundamentally, it is not our material objects nor technological infrastructures that have led us into an era of unsustainability, but how we have continued to design those objects and infrastructures to be *human-centred*. "We shape our tools, and thereafter they shape us" noted Culkin [74]. Designers must now harness their agency and begin to rebuff and rethink the OWW ontology and aid societies in reducing their impacts upon the planet’s natural systems and resources for the benefit of everyone *and everything*, everywhere.

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by selecting the grant sponsor text and apply style ‘GrantSponsor’. After this, select grant no and apply ‘GrantNumber’ from style panel. Example of Grant sponsor: Competitive Research Programme and example of Grant no: CRP 10-2012-03.

REFERENCES

[1] Paul Dourish, and Genevieve Bell. 2011. Divining A Digital Future: Mess and Mythology In Ubiquitous Computing. MIT Press.

[2] Joseph Lindley, Paul Coulton, and Miriam Sturdee. 2017. Implications for Adoption. In Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems. ACM, New York, (CHI 2017). May 6-11, Denver, Colorado, USA. 265-277.

[3] Jeffrey Bardzell and Shaowen Bardzell. 2013. What is "critical" about critical design? In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '13). Association for Computing Machinery, New York, NY, USA, 3297–3306. DOI: https://doi.org/10.1145/2470654.2466451

[4] Richmond Y Wong, and Vera Khovanskaya. Speculative Design in HCI: From Corporate Imaginations to Critical Orientations. In: Filimowicz, M., Tzankova, V. (eds) New Directions in Third Wave Human-Computer Interaction: Volume 2 - Methodologies . Human–Computer Interaction Series. Springer, Cham. https://doi.org/10.1007/978-3-319-73374-6_10

[5] Carl DiSalvo. 2015. Adversarial design. MIT Press.

[6] Paul Coulton; Joseph Galen Lindley, Miriam Sturdee, and Michael Stead. 2017. Design Fiction as World Building. In Proceedings of the 3rd Biennial Research Through Design Conference. Edinburgh, UK, pp. 1–16. doi: 10.6084/m9.figshare.4746964.

[7] Joseph Voros. 2003. A Generic Foresight Process Framework. Foresight, 5(3), 10-21.

[8] Trevor Hancock and Clement Bezold. 1994. Possible futures, Preferable Futures. The Healthcare Forum Journal. Vol. 37. No. 2.

[9] John Law. 2015. What's Wrong With A One-World World?. Distinktion: Scandinavian Journal of Social Theory 16, no. 1): 126-139.

[10] Paul Coulton, and Joseph Galen Lindley. More-than Human Centred Design: Considering Other Things. The Design Journal, 22(4), 463-481.

[11] Tony Fry. 2009. Defuturing: A New Design Philosophy. Bloomsbury Publishing.

[12] Arturo Escobar. 2018. Designs for the Pluriverse: Radical Interdependence, Autonomy, and the Making of Worlds. Durham: Duke University Press.

[13] Marisol De la Cadena, and Mario Blaser, eds. 2018. A World of Many Worlds. Duke University Press.

[14] Luiza Prado de O. Martins and Pedro Oliveira. 2014. Questioning the “Critical” in Speculative & Critical Design. https://medium.com/a-parede/questioning-the-critical-in-speculative- critical-design-5a355cac2ca4, last accessed 01/04/2022.

[15] Ivica Mitrović. 2018. Western Melancholy / How to Imagine Different Futures in the ‘Real World’? http://interakcije.net/en/2018/08/27/western-melancholy-how-to- imagine-different-futures-in-the-real-world/ last accessed 01/04/2022.

[16] Paul Coulton and Joseph Galen Lindley. 2017. Vapourworlds & Design Fiction: The Role of Intentionality. The Design Journal, 20(sup1), S4632-S4642.

[17] Anthony Dunne and Fiona Raby. 2013. Speculative Everything. MIT Press.

[18] Paul Coulton, Daniel Burnett and Adrian Gradinar. 2016. Games as Speculative Design: Allowing Players to Consider Alternate Presents and Plausible Features, in Lloyd, P. and Bohemia, E. (eds.), Future Focused Thinking - DRS International Conference 2016, 27 - 30 June, Brighton, United Kingdom. https://doi.org/10.21606/ drs.2016.15.

[19] Rodrigo Freese Gonzatto, Frederick MC van Amstel, Luiz Ernesto Merkle, and Timo Hartmann. 2013. The Ideology of the Future in Design Fictions. *Digital creativity* 24, no. 1: 36-45.

[20] Frederick MC van Amstel and Rodrigo Freese Gonzatto. 2021. Existential Time and Historicity in Interaction Design. Human–Computer Interaction: 1-40.

[21] Carl DiSalvo and Jonathan Lukens. 2011. Nonanthropocentrism and the nonhuman in design: possibilities for designing new forms of engagement with and through technology. In From social butterfly to engaged citizen: urban informatics, social media, ubiquitous computing, and mobile technology to support citizen engagement, Marcus Foth, Laura Forlano, Christine Satchell and Martin Gibbs (eds.), MIT Press, 421--437.

[22] Laura Forlano. 2017. Posthumanism and design. She Ji: The Journal of Design, Economics, and Innovation, 3(1), 16-29.

[23] Anne Galloway, A. 2017. More-than-Human Lab: Creative Ethnography After Human Exceptionalism. In The Routledge Companion to Digital Ethnography (pp. 496-503).

[24] Sarah Whatmore. 2006. Materialist Returns: Practising Cultural Geography In & For A More-than-Human World. Cultural Geographies, 13(4), 600-609.

[25] Martin Heidegger. 2010. Being & Time. Suny Press.

[26] Donald A Norman. 1998. The Invisible Computer: Why Good Products Can Fail, The Personal Computer Is So Complex, & Information Appliances Are The Solution. MIT Press.

[27] Graham Harman. 2018. Object-Oriented Ontology: A New Theory of Everything. Penguin UK.

[28] Timothy Morton. 2013. Hyperobjects: Philosophy & Ecology after the End of the World. University of Minnesota Press.

[29] Ian Bogost. 2012. Alien Phenomenology, Or, What It's Like To Be A Thing. University of Minnesota Press.

[30] Joseph Galen Lindley, Haider Ali Akmal, and Paul Coulton. 2020. Design Research and Object-Oriented Ontology. Open Philosophy, 3(1), 11-41.

[31] James Pierce and Carl DiSalvo. 2017. Dark Clouds, Io&#!+, and [Crystal Ball Emoji] Projecting Network Anxieties with Alternative Design Metaphors. In Proceedings of the 2017 Conference on Designing Interactive Systems (pp. 1383-1393).

[32] Sabrina Hauser, Johan Redström and Heather Wiltse. 2021. The Widening Rift Between Aesthetics & Ethics In The Design of Computational Things. In Journal of AI and Society. https://doi.org/10.1007/s00146-021-01279-w

[33] Michael Stead. 2020. Spimes: A Multidimensional Lens for Designing Future Sustainable Internet Connected Devices. PhD Thesis. Lancaster University. https://doi.org/10.17635/lancaster/thesis/997

[34] Bruce Sterling. 2004. Subject: Viridian Note 00422: The Spime – 'When Blobjects Rule The Earth. http://www.viridiandesign.org/notes/401-450/00422_the_spime.html, last accessed 01/04/2022.

[35] Bruce Sterling. 2005. Shaping Things. MIT Press.

[36] Julian Bleecker. 2009. Design Fiction: A Short Essay on Design, Science, Fact and Fiction. http://drbfw5wfjlx on.cloudfront.net/writing/DesignFiction_WebEdition.pdf, last accessed 01/04/2022.

[37] James Auger. 2013. Speculative Design: Crafting The Speculation, Digital Creativity, 24;1, 11–35. DOI:10.1080/14626268.2013.767276

[38] Zhibo Pang, Lirong Zheng, Junzhe Tian, Sharon Kao-Walter, Elena Dubrova & Qiang Chen. 2015. Design of A Terminal Solution for Integration of In-home Health Care Devices and Services Towards The Internet-of-Things. Enterprise Information Systems, 9(1), 86-116. DOI:10.1080/17517575.2013.776118

[39] Adrian Smith and Anne Light. 2017. Cultivating Sustainable Developments With Makerspaces. Liinc EmRevista, 13;1, 162-174. DOI: 10.18617/liinc.v13i1.3900

[40] Cindy Kohtala and Sampsa Hyysalo. 2015. Anticipated Environmental Sustainability of Personal Fabrication. Journal of Cleaner Production, 99, 333–344.

[41] Chris Anderson. 2012. Makers: The New Industrial Revolution. Random House Business Books.

[42] Eric Von Hippel. 2005. Democratizing Innovation. Cambridge: MIT Press.

[43] Erin Buehler, Stacy Branham, Abdullah Ali, Jeremy J. Chang, Megan Kelly Hofmann, Amy Hurst, Shaun K. Kane. 2015. 'Sharing Is Caring: Assistive Technology Designs On Thingiverse,' in Proceedings of the 2015 CHI Conference on Human Factors in Computing Systems CHI' 15. (pp. 525-534). ACM. DOI:10.1145/2702123.2702525

[44] Joyce M. Lee, Emily Hirschfeld and James Wedding. 2016. A Patient-Designed Do-It-Yourself Mobile Technology System For Diabetes: Promise and Challenges For A New Era In Medicine, JAMA, 315(14), 1447-1448. DOI:10.1001/jama.2016.1903

[45] Author

[46] Blocks. 2022. https://www.kickstarter.com/projects/2106691934/blocks-the-worlds-first-modular-smartwatch, last accessed 01/04/2022.

[47] Alzheimers.org.uk. 2019. Key Publications About Dementia. https://www.alzheimers.org.uk/get-support/publications-factsheets/publications-dementia, last accessed 01/04/2022.

[48] Justin McCurry. 2016. Japan Running Low on Workers as Proportion of Over-65s Hits Record Levels. Guardian Online. https://www.theguardian.com/world/2016/jun/30/japan-census-over-65s-record-27-population-immigration, last accessed 01/04/2022.

[49] Jonathan Soble. 2017. Japan's Falling Birth Rate Posing Serious Problems for Economy. http://www.independent.co.uk/news/world/asia/japans-falling-birth-rate-posingserious-problems-for-economy-a7770596.html, last accessed 01/04/2022.

[50] Wareable.com. 2019. The death of the Blocks modular smartwatch – burned backers have their say. https://www.wareable.com/smartwatches/blosk-backers-have-their-say-7770, last accessed 01/04/2022.

[51] Bran Knowles, Oliver Bates, and Maria Håkansson. 2018. This Changes Sustainable HCI. Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems. Association for Computing Machinery, New York, NY, USA, Paper 471, 1–12.

[52] Eli Blevis. 2007. Sustainable Interaction Design: Invention & Disposal, Renewal & Reuse. CHI '07. ACM Press, New York, NY, 503-512.

[53] EC.Europa.EU. (2021). Recycling Rate of E-waste. https://ec.europa.eu/eurostat/databrowser/view/T2020_RT130/bookmark/table?lang=en&bookmarkId=a69be825-957e-473c-a81f-f02866dc9141, last accessed 01/04/2022.

[54] IPCC. (2021). AR6 Climate Change 2021: The Physical Science Basis: Sixth Assessment Report. https://www.ipcc.ch/report/ar6/wg1/, last accessed 01/04/2022.

[55] Statista. (2021). Number of Internet of Things (IoT) Connected Devices Worldwide from 2019 to 2030, By Use Case. https://www.statista.com/statistics/1194701/iot-connected-devices-use-case/, last accessed 01/04/2022.

[56] Authors

[57] Michael Standaert. 2019. China Wrestles with the Toxic Aftermath of Rare Earth Mining. https://e360.yale.edu/features/china-wrestles-with-the-toxic-aftermath-of-rare-earth-mining, last accessed 01/04/2022.

[58] Hongqiao Liu. 2017. As China Adjusts for "True Cost" of Rare Earths, What Does It Mean for Decarbonization? https://www.newsecuritybeat.org/2017/03/china-begins-adjusting-true-cost-rare-earths-decarbonization/, last accessed 01/04/2022.

[59] Nicolas Nova and Anaïs Boch. 2021. Dr. Smartphone: an ethnography of mobile phone repair shops. IDP Publishing.

[60] Sucharita Beniwal, 2020. New Worlds With Some Tinkering. In R.M. Leitao, L.A. Noel, & L. Murphy (Eds.), Proceedings of PIVOT 2020: Designing a World of Many Centers (246-251), 4 June.

[61] Kevin McElvaney. 2014. Agbogbloshie: the world's largest e-waste dump – in pictures. https://www.theguardian.com/environment/gallery/2014/feb/27/agbogbloshie-worlds-largest-e-waste-dump-in-pictures, last accessed 01/04/2022.

[62] Elisabeth Kolbert. 2021. Under A White Sky: The Future of Nature. Bodley Head.

[63] Paul Coulton. 2016. Design Futures through Design Fiction. Talk for EINA Barcelona. https://www.slideshare.net/MysticMonkey/design-futures-through-design-fiction, last accessed 01/04/2022.

[64] Stuart Walker. 2014. Designing Sustainability: Making Radical Changes In A Material World. Oxon: Routledge.

[65] John Thackara. 2005. In The Bubble: Designing In A Complex World. London: MIT.

[66] Bruno Latour. 2011. Love Your Monsters: Why We Must Care For Our Technologies As We Do Our Children. In M. Shellenberger, & T. Nordhaus (Eds.). Love Your Monsters: Post-environmentalism and the Anthropocene (pp. 19-26).

[67] John Asafu-Adjaye, Linus Blomqvist, Stewart Brand, Barry Brook, Ruth DeFries, Erle Ellis, Chris Foreman, David Keith, Martin W. Lewis, Mark Lynas, Ted Nordhaus, Roger Pielke, Jr., Rachel Pritzker, Joyashree Roy, Mark Sagoff, Michael Shellenberger, Robert Stone, Peter Teague. (2015). 'An Ecomodernist Manifesto.' https://static1.squarespace.com/static/5515d9f9e4b04d5c3198b7bb/t/552d37bbe4b07a7dd69fcdbb/1429026747046/An+Ecomodernist+Manifesto.pdf, last accessed 01/04/2022.

[68] Bill Gates, B. 2021. How to Avoid A Climate Disaster: The Solutions We Have and the Breakthroughs We Need. Penguin Books.

[69] William Gibson. 2020. William Gibson Interviewed on BBC Radio 4 Today Programme, Mon 20 Jan 2020, 06:00-09:00. https://www.bbc.co.uk/programmes/m000dj9g

[70] Jan De Vries, J. 1994. The Industrial Revolution and the Industrious Revolution. The Journal of Economic History, Vol. 54, No. 2, Papers presented at the Fifty-Third Annual Meeting of the Economic History Association (Jun, 1994), pp. 249-270.

[71] Horst. W.J. Rittel and Melvin. M. Webber. 1973. Dilemmas in a General Theory of Planning, Policy Sciences, 4:155, 155–169, DOI: 10.1007/BF01405730

[72] World Commission on Environment and Development. (1987). 'Report of the World Commission on Environment and Development: Our Common Future.' https://sustainabledevelopment.un.org/content/documents/5987our-common-future.pdf, last accessed 01/04/2022.

[73] Alex Steffen. 2016. Cited in Rinde, M. 2016. Imagining a Postcarbon Future. Distillations, 2:3, 24-33.

[74] John. M. Culkin. 1967. A Schoolman's Guide to Marshall McLuhan. Saturday Review, pp. 51-53, 71-72.