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Modularity as One Principle in Sustainable Technology Design – A Design Case Study on ICT

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Abstract: Within design of information and communication technology (ICT) we need to first shape and then follow a vision to take responsibility for the futures that design materializes. Although research and literature on both sustainable technology and sustainable interaction design grow significantly, both fields with their (im)material character, are less often thought together and seen as mutually shaping. Hence, this paper examines the state-of-the-art in modularity as one sustainable design principle for the mobile phone and related ICT, utilizing a review of design (concept) cases in form of their multimedia representations. Matching the findings from the concrete exemplars with generic scientific research results within modular designing informs a discussion on value preservation (promotion of reuse over recycling and the like), portraying nowadays insufficiencies on the one hand and desirable, meaningful futures on the other. It describes both the employment of and the confidence in modularity for accomplishing sustainability, digital materiality or the soft matter, and the demandingness of modularly upgradable architectures. Supposedly by help of the critical design practice in an academic context - which translates to fundamental creativity-based research driven by envisioning new possibilities - further research shall build on the insights gained here. Our vision may thus be called sustainable technology and interaction design, which as an acronym gives STaID.

Introduction

We have proposed to engage more with the politics of technology through preceding research into societal views on the phenomenon "Planned Obsolescence" (Junge & van der Velden, 2018). By means of a critical discourse analysis, we addressed overcoming the persisting view of 'technology as neutral'. This study on ICT carries on with technology as the manifestations related to this discourse (Jäger, 2001). Modularity is for this paper chosen to represent one principle within sustainable technology design. An in-depth study was reasonable to apply due to clear boundaries for what is considered modular, the good literature base and the amount of design cases found. I draw on sustainability related design frameworks, such as Critical (Malpass, 2017) and Transition Design (Tonkinwise, 2015) as they represent the vision to take responsibility for the futures that design materializes. Modularity may show in how far a design principle can counter commercial design, whose job seems to remain "building alternatives in response real-time analytics, rather than to pursue a vision" (Tonkinwise, 2015, p. 88).

Approach to a modularity review

To identify the state-of-the-art in ICT design and thus characterize its design space, a review of cases was conducted. It started out in the academic literature, where certain examples of technology to describe and argue are frequently used. A follow up search for design cases was initiated, outside academic literature in multi-media resources of economic/entrepreneurial, educational or entertaining kind: video-channels, (non-)commercial websites, blogs, popular science and engineering publications etc. Through the nature of such media the search was conducted in a snow-balling manner leading to many design cases that characterize the potential design space. Though the review spans wide, it does not claim to be complete.

Results and discussion of the design case review

The collected design cases within modularity (see Figure 1) have been clustered to cover: i) definite modular phone concepts, published in the recent decade, that only reached a prototype phase with no market entry (yet); ii) marketed (semi-)modular phones or components, that have passed the former's prototype stage; iii) related modular ICT in R&D or early market. Besides promoting modularity in a more or less profound manner, every design case has its unique feature(s). What often distinguishes them is their origin, their development history, story and creators. The distinguishing features shall be highlighted in and through the following discussion of modularity as a sustainable design principle.

What all cases have in common is that devices consist of components and at least all main components are easily switchable modules. Module means a structurally independent element, i.e. a part, component or sub-assembly that has non-permanent interconnections (interfaces) to other modules (Schischke, Proske, Nissen, & Lang, 2016). Modular devices most often have a base unit and can be upgraded in terms of a new screen, CPU, GPU, camera, battery and RAM (main units of ICT) simply by switching out individual modules. Some sort of mounting mechanism holds the modules tightly so they usually will not disconnect even under impact or fall.

Nevertheless, the definition of 'module' is vague as different devices have different demarcations of those. The liveliest description of demarcation is for the Puzzlephone speaking of the three main modules as the Spine (display, speakers, microphones), the Heart (battery) and the Brain (main electronics). For the Fairphone 2 one speaks of the transceiver (or core) unit, the display unit & the receiver module and the rear camera module & speaker unit. These distinct and cascading orderings show how much room for interpretation there is, involving several factors, making the demarcation a complex endeavour.

Modularity's main capacity, in terms of sustainability in the use-phase, is to extend the useful lifespan of products through easier repair, maintenance and upgrading (Sonego, Echeveste, & Galvan Debarba, 2018, p. 200). The Fairphone 2 is again an example here, as thanks to its modular architecture anyone should be able to do basic maintenance.

Important measures to establish modularity are achieving interchangeability between modules, by independence between components and/or their lifecycle processes, as well as fostering that components and processes in a module are similar. It creates functional independence, due to which modularization "has been called the goal of good design" (Gershenson, Prasad, & Allamneni, 1999, p. 1), as Fry ("Good Design / Inkahoots," n.d.) and Rams ("Dieter Rams 10 Principles of 'Good Design' | ArchDaily," n.d.) promote. There is a body of literature systematically reviewed in (Sonego et al., 2018), which is concerned with modular repairability and modular upgradability (Agrawal, Atasu, & Ülkü, 2016) in particular. It seems to exist a widespread belief in modularity as a "sure way to achieve sustainability" (Sonego et al., 2018), as the literature promotes the benefits stronger than the limitations associated with it.

Several have issued modular design concepts, in particular for the smartphone in the middle of the current decade. Examples are the LG G5 with its accessory slot at the bottom, which allows users to remove the battery and to swap in different modules. The ZTE Eco Moebius has a similar sliding track design and it also envisions various screen sizes available by three different frames all capable of utilizing the same (besides the LCD) modules for the device. The Facebook's XBEAM concept's strategy is also to facilitate for different sized and shaped display units. On a general basis Phonebloks, an early initiative within modular phone conceptualizing (Hankammer, Jiang, Kleer, & Schymanietz, 2016), continues promoting the strive for modularity in consumer electronics. Fonkraft must be mentioned for its special mounting mechanism for a tight holding display that can only be removed by pushing a frame button whereof a special slider under the display unblocks all the modules, hindering unintended disconnection (impact or fall). More such issued concepts would fit here, but will follow later.

Some concepts were even published together with modular design frameworks, such as the three evaluation charts by (Ishii, 1998) exemplified on hand of a hypothetical family of inkjet printers. Since little had reached market entry, research started examining why and how modularly upgradable designs would not become valued and widely adapted (Agrawal et al., 2016). It found that generalizing empirical observations and extrapolations onto new

modularization cases bear the risk that qualitative details are overlooked, for example when transferring modularly upgradable architectures prevalent in industrial markets (Agrawal et al., 2016) to the consumer electronics industry where such architectures have yet to be proven a strong concept.
One specialty that comes in with consumer electronics is software, for example in form of the operating system (OS). When we see OSs as modules, then modular repairability and upgradability also come into play for the soft matter. Vsenn with its modular smartphone proposal envisioned the possibility to swap operating systems and to promise four years' worth of guaranteed software updates. Also BLOCKS Project OpenWatch proposed to try the idea of a modular Android-software open to system developers of wearables. This stands in contrast to earlier experiences within smartphone evolution, examined by (Farman, 2017), who brings up issues around nine major releases of iOS between 2007 and 2014, where especially apps "rarely preserve[d] backward compatible versions for older iOSs" (Farman, 2017, p. 21). "Older iOSs", synonymous to older devices, i.e. hardware, are characterized as not even "allowed" to have the latest version installed or running.[1] Not only but also such technology-evolutional issues remind us that modularization is "not necessarily the most sustainable design option" (Schischke et al., 2016). The two concepts overlap, but are not completely congruent. For one, modularity demands more material in the first place, since additional sub-structures become necessary or the product increases in volume when a "maximum potential configuration" (Schischke et al., 2016, p. 1) is incorporated. An example for a "maximum potential configuration" is Microsoft's Surface Phone (Andromeda): Its hybrid, foldable form factor with a modular hinge allows for independent units (i.e. devices) to be used together (when folded or unfolded) or separately (when unfolded and detached). Modularity is also "demanding" more material and volume when a fit to possible future technologies is anticipated. Here modularity overlaps largely with future-proofing, another design principle in the larger scope in my research.
Besides the described demandingness it secondly depends on the intention of users (and producers) whether actually broken modules are replaced or rather frequently exchanged "to keep pace with latest technology features" (Schischke et al., 2016, p. 4). Google project ARA started out like this without promoting sustainability as a core aim or reason for modularization. Compared to ARA, the announced (and never released) Xiaomi Magic Cube concept pictures only a more asymmetric layout of modules in a smartphone. In fact, there seems to have been a 'run' on modularity among tech-developers in the sense that it is invested in extra material & functionality to raise turnover and/or profit [19] or just to show willingness to follow this tech-trend. In the case of Moduware (Modular Smartphone Case), a community of developers has quickly come up with 300 ideas for extra-functionality modules as add-ons. The distinction here is that it was open to a large community of developers to contribute, not a single large cooperation profiting from a resulting large product portfolio.
Yet, such intentional frequent introduction and replacement of modules causes accelerated obsolescence (Sonego et al., 2018) and thus bears the risk to cause significant rebound effects: The limiting factor can be soon recognized when in particular the aforementioned interfaces and sub-structures trigger an increased consumption of critical or scarce raw materials (Schischke et al., 2016). An example here could be the design of the module-interface as click-on mechanism with strong magnetic surfaces able to hold the modules tightly together (as for Google project ARA). It might encounter problems like much more neodymium necessary than resources provide (Möller et al., 2014). Given that with such rebound effect "the greatest environmental impact can be generated" (Sonego et al., 2018, p. 202), it is worrying how understudied the user and the use phase in respect to modularity and sustainability is.
Further disadvantages the literature finds in modular designs span across: redundant structures, overdesigned products with

[1] By contrast, one of the newest releases, namely the September 2018 issued iOS 12, promised to make older phone hardware workable again, which would mean a major shift in backward compatibility [48]

sacrificed performance, that are perceived less durable, difficult to use and onerous to maintain, less reliable and safe (Schischke et al., 2016; Sonego et al., 2018). In addition, it is considered that modularity might not promote an increase in the product's lifespan but rather reuse and recyclability of parts of the product, such that products can profit from future efficiency gains (Sonego et al., 2018).

This issue relates to standardization, which often inevitably follows modularization efforts: Complying to standards for compatibility reasons becomes an obsolete commitment as soon as higher performance and efficiency are reached through R&D which "grow" into a new standard. An example are standardized power supplies for mobile phones, micro USB-B connectors, soon replaced by USB type-C for higher data transfer and power transmission (Schischke et al., 2016).

A third point of view in research is to handle modularity as more widely disseminated than usually perceived, i.e. when the demarcation of module is down to "every part". For example tablets are shown to be "already arranged in modules", as they consist of "clearly distinct parts" (Schischke et al., 2016, p. 2). The same can be stated for smartphones with their similar assembly structure. Inspiration or role models can be drawn from the laptop/tablet-PC design world, f.i. from XO Infinity, a tough modular multi-OS laptop concept for kids, or the iameco D4R (design for reuse) laptop. The art of modularity for smartphones boils down to 'squeezing' well-known modules into the small size a phone complies with (Schischke et al., 2016). In that wider sense modularity appears at different levels, according to (Schischke et al., 2016) these are: add-on-, material-, platform-, repair- and mix&match modularity. Many examined design cases comply with these. For add-on modularity the Modu Phone/Modu T (first modular mobile phone concept before the smartphone age) can examplify: The small, rectangular device came with "jackets" in form of camera, Qwerty keyboard, fitness band etc. *adding* functionalities. Other examples are: Moto Mods, Motorola smartphone add-ons of type camera, power pack, docking, projector, speakers and many more; the Moduware Modular Smartphone Case - an external smartpack or smartphone case for several, respectively 3 different modules; as well as MODR - a case for smartphone and tablet features and expansion options, that can host 2 reModules simultaneously for functionalities such as Micro SD reader, flash/-light, customizable NFC button, (solar) battery pack, projector, Bluetooth speakers, zoom lenses, wireless charging (Qi). Those add-on examples at the same time blend into platform modularity.

Design cases for platform modularity are the RePhone and the imasD: Click ARM Tablet (mainboard) with its Advanced Removable Modules technology, which allow for individually configured units out of various electronics modules (Schischke et al., 2016). The B-Squares Modular Electronic Devices, the Kite DIY modular phone, and integrative tablet/-smartphone technology platforms like the XPX Life 7 (a low-spec 7-inch modular tablet with proposed modular phone) and the SHIFT 12 tablop (building on Shiftphone modules), range in the same category. The Lifebook modular laptop (concept) that "combines all gadgets into one" as well as the SHIFTmu and the concepts Graalphone and Seedphone expand the modularity understanding towards including whole devices as modules in higher performance devices. Besides, modular forms of related ICT exist like the Blocks Modular Smartwatch, Samsung SIMband and Tma-2 modular Headphones, which complement the platform idea.

The provided (re)configurability is important for to build a "shared product platform", where the relevant modules and not overdesigned whole devices can be reused for an adapted purpose. This can be other applications after for example the first life as a mobile phone, such as microcomputers and home automation devices. The Puzzlecluster - a first computer cluster platform based on recycled modular technology (plus the envisioned PuzzleTab, PuzzleTV, PuzzleIoT, PuzzleRobots, as well as cellRobot) and the environmental conceptual computer igglu are examplary for this. In a product platform each part or module can play a new role in a smaller or bigger, less or more complex device, without risking to be "downcycled" like whole devices in so-called upcycling applications (f.i. contemporary smartphone as fish-tank surveillance) tend to be ("Upcycling," n.d.). The mostly through platform and repair modularity addressed value preservation is as mentioned still dependent on users and a purposeful use.

The value of a broken Shiftphone for instance is appreciated through a deposit-payment on return. When we take this as an example for the much-welcomed extended producer responsibility we may also think of take-back of and deposits on each module: The Fonkraft concept advertised already for a web shop for new and used modules that could also be manufactured by third party companies.

Towards Sustainable Technology and Interaction Design (STaID) with modularity for value creation

Furthermore, the value of a product is first realized during the use, not fully contained in itself (Sonego et al., 2018). When we depart from an economic perspective towards a "concept [of value] that also embraces environmental and social aspects" (Sonego et al., 2018, p. 203), we can comprehend the importance of the consumption phase as key for the creation of sustainable value.

Nevertheless, creating sustainable value and preserving value root deep in the lifecycle's design phase with according consequences for the use-phase. It is concluded that the design of ICT that is value preserving - be it through modularity or other design principles - needs to be of a critical design practice kind. Critical design (Malpass, 2017) within an academic context - i.e. fundamental creativity-based research driven by envisioning new possibilities - is said to serve overcoming the contemporary complex problems and insufficiencies. It shall even be obliged to find out what is meaningful, desirable and therefor sustainable.

With the presented design case study the inquiry into both the desirable possibilities and the existing insufficiencies has started. Two main concerns for further research may be inter-usability and inter-operability as described in (Rowland, Goodman, Charlier, Light, & Lui, 2015) to be applied on the ICT in focus here. It shall lead to concrete answers how to overcome overlooked details in transfers, rebound effects, real-time responsive design, and in general how to promote values in technology creation, that go beyond the financial dimension. Modularity plays a significant role as one principle in the envisioned Sustainable Technology and Interaction Design (STaID!).

Figure 1. Modular design cases reviewed. © Phonebloks (*) and author's drawings.

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