MORE DISPOSABLE THAN EVER?
CONSEQUENCES OF NON-REMOVABLE BATTERIES IN MOBILE DEVICES

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Mobile devices like smart phones, tablet computers and ultraportable laptops are experiencing rapid worldwide market growth and have relatively short lifespans. Recently, embedded (non-removable) batteries were introduced that cannot be replaced by consumers. This study traces the environmental and social consequences of the introduction of embedded batteries throughout the value chain: from the original equipment manufacturers, to the users of mobile devices, to the repair, refurbishment and end-of-life recycling companies. It shows that the introduction of embedded batteries was mainly technology and design-driven, that original owners are hardly aware of embedded batteries (unless they seek to prolong the life of their phones), that embedded batteries have contributed to a thriving but mostly unauthorized repair and refurbishment market and finally that recyclers have difficulties removing the batteries. From a social and environmental sustainability perspective, reintroducing removable batteries is preferable, but the study shows this may not be feasible and examines alternative options.

1. INTRODUCTION

Information and Communication Technologies have often been applauded for their ability to dematerialize our lives. In spite of this potential, the average material flows per capita are still increasing [1]. This is certainly true for mobile devices like smart phones, tablet computers and ultraportable laptops, which experience rapid worldwide market growth and have relatively short lifespans: mobile phone replacement cycles in the USA and UK were for instance 22 months in 2010 [2]. Recently, embedded (or non-removable) batteries were introduced in these high-end devices. As consumers cannot replace the batteries themselves, and as it is normal for batteries to degrade over time and render the device less and less useful, it could be argued that this results in devices that will be prematurely disposed of, or in other words: that are more disposable than ever.

This goal of this paper is to establish whether or not this argument is valid: do embedded batteries indeed shorten the useful life of mobile devices? The paper uses literature review and interviews to trace the origins of embedded batteries to technology and design-driven developments, and it studies the ripple effects of these throughout the value chain: how do mobile device users experience embedded batteries? How do embedded batteries affect the self-repair, refurbishment and recycling of mobile devices?

The paper is organized in five sections. First, a brief exposition of the study's methodology. Second, a section that examines the reasons for the introduction of embedded batteries. Next, a review of the environmental impacts of mobile devices. The fifth section looks at user awareness of embedded batteries and the sixth section at the consequences of built-in batteries for the end-of-life value chain. A concluding discussion rounds off the paper.

2. METHODOLOGY

This study is related to the innovation diffusion theory of Rogers [3] but instead of focusing on the adoption of an innovation (the innovation being embedded batteries in mobile devices), it focuses on the *consequences* of this adoption. We would like to emphasise the explorative character of this study. We agree with Rogers that "the unpredictability of an innovation's consequences, at least in the long term, is one important type of uncertainty in the innovation process" (p436).

This study intends to improve our understanding by tracing the consequences of the adoption of built-in batteries throughout the value chain: from their origins at the OEMs (original equipment manufacturers), to the users of mobile devices, to the repair and refurbishment services and finally to the recycling companies that need to deal with mobile devices at end of their useful lives. The study focuses in particular on the environmental and social consequences for these stakeholders. It does not intend to give definitive answers. Instead, it provides a snapshot of a moment in time (2013/14) and place (Europe) and shows how the adoption of embedded batteries is an on-going and dynamic process, with positive and negative, and anticipated and unanticipated consequences, to which all stakeholders are constantly adapting.

The research methods used are literature review and interviews with OEMs and companies active in refurbishment and recycling of mobile devices (n=4) and with users (n=15). This is by no means a representative sample and we make no claim as to the generalization of our findings. The interviews were used to identify relevant themes that need further exploration. The main result of this study is an empirical analysis of the environmental and social consequences of the adoption of embedded batteries in mobile devices. To our knowledge this has not been done before. In the concluding sections of the paper, we will briefly touch upon possible future directions.

3. INTRODUCTION OF BUILT-IN BATTERIES

The history of built-in batteries in mobile devices is relatively short and spans over roughly 14 years. In that period they have gone in and out of use, and currently we're seeing both embedded and removable batteries in the market. In the early 2000s a range of pocket PCs (handheld computers) was developed that lacked a removable battery. This was because of technical necessity: the user data was stored in RAM, which meant that removing the battery would cause the device to lose all of its data [4]. Manufacturers abandoned this because it wasn't practical for users. Also, selling extra batteries turned out to be a business in itself. For a period of almost a decade, removable batteries were the norm until embedded batteries reappeared in the newest generations of mostly high-end mobile devices [5].

Why did OEMs embed batteries in mobile devices? Apart from commercial motives (which are hard to prove), a literature review identified the following factors as contributing to the decision to embed.

3.1 Performance related factors

Embedded batteries allow for more battery capacity. Without the internal casing for the removable battery compartment, the battery size and capacity can be enlarged without adding weight. This is an important added value for mobile devices. Battery capacity hasn't kept pace with computing power: over the past decade, the power needed to perform a computing task has fallen by half every 1.5 years, allowing mobile devices to become smaller and less power consuming and making many more mobile computing applications possible [6]. The gains in power consumption were traded in for extended functionality, with battery capacity increasing much slower: only 3.5% between 1996 and 2008, according to Pentikousis [7]. As a result, battery life has remained more or less constant. Finding ways to increase battery capacity (and thus battery life) without compromising on weight is therefore important for mobile device manufacturers.

A recent trend is the use of soft-pouch Lithium Polymer (LiPo) batteries, with an enclosure of polymer-coated aluminum foil instead of a hard case. This allows for the production of light and very slender cell designs [8] with a relatively high energy density. LiPo soft-pouch batteries do however need extra support in the battery compartment (for reliability), which is one of the reasons such batteries are embedded in mobile devices, with safety considerations being another reason.

3.2 Design related factors

Embedded batteries allow for a more flexible arrangement of interior components. This enables the development of slim devices. A slender device is equated with style and modernity, according to smartphone advertisements, and is to this day considered desirable (the 2014 introduction of the Sony's Xperia T3 Smartphone for instance read: "the world's slimmest 5.3-inch smartphone").

Designers embraced the freedom of form that embedded batteries offered. Nokia Designer Marko Ahtisaari, for example, explained the design of their Lumia smartphone [9]: "It's a product that's made out of two pieces, the polycarbonate monobody and the glass that flows into it. We wanted to make it… build it better. That means it's solid…"

3.3 Use related factors

A device with a sealed back cover allows for a simpler and more rigid construction, with the battery less likely to sustain damage when dropping the device. Original owners are unlikely to experience much battery degradation, provided they replace their devices regularly. Battery degradation is wear over time resulting in shorter battery life between recharging cycles. From an original owner perspective, having embedded batteries may allow for relatively carefree use of the device. This may of course not necessarily be true for subsequent owners.

In conclusion, there is not one dominant answer to the question of why batteries were embedded in mobile devices. Important factors are the increasing functionality and power demands on the one hand and the desire for lightweight, slim, safe and reliable devices on the other hand, that together led to the development of devices with built-in batteries.

4. SUSTAINABILITY

Over the past decade numerous life cycle assessment (LCA) studies on the environmental impacts of mobile devices across their life cycle phases have been performed. An analysis of mobile phones in China by [10] concludes that manufacturing accounts for 50% of the total energy consumption, the use phase for 20% and the supporting infrastructures for less than 1%. Fehske and Fettweis [11] in studying the global carbon footprint of mobile communications arrive at comparable findings. In their analysis the operation of mobile phones (i.e. the charging of batteries and standby consumption of chargers) accounts for less than 10% of the overall carbon footprint, whereas the production of these devices takes up approximately 30%. Frey et al. [12] in a study from 2006 note: “High upstream burdens from extraction, manufacture, and transport compared to the use phase support the case for keeping an old phone for much longer.” In their scenario where production and use efficiency improve by 10% per year a phone can be kept for 10 years before it reaches the environmental ‘break-even point’. Deng et al. [13] conclude their hybrid LCA study on a laptop computer with the observation that the manufacturing phase represents 62-70% of total primary energy of manufacturing and operation. They conclude that extending the lifespan of a laptop computer can be an important strategy to manage the device’s life cycle energy. A study by Prakash and Schischke [14] showed that a 10% energy efficiency increase in new notebooks would justify their replacement from an environmental break-even point only after 33 to 89 years.

The study by Teehan and Kandlikar [15] is one of the first to include more modern devices such as smart phones and tablet computers. Looking at the production phase only, the “embodied greenhouse gas emissions for newer products are 50−60% lower than corresponding older products with similar functionality, largely due to decreased material usage, especially reductions in integrated circuit content.” (p.3997). Williams [16] likewise finds that the environmental impact per unit functionality declines over time.

The LCA studies that were reviewed converge towards the overall conclusion that, in spite of modern advances in materials usage, the environmental impact during manufacturing of ICT devices is a bigger proportion than during use. According to Williams [16], “This is partly because manufacturing computers is energy intensive, and partly because rapid obsolescence leads to computers being purchased more often...” From a sustainability perspective, continuous efforts to decrease materials impact and increase product longevity should be focal areas. Extending the useful life of mobile devices by for instance a factor of 2 will contribute to a significant reduction in material throughput and therefore environmental impact.

5. USER AWARENESS

This section asks to what extent users are aware of the embedded batteries in their mobile devices. The data collection of the study consisted of a series of semi-structured interviews with 15 original users of mobile devices (mostly smart phones). These semi-structured interviews were conducted in person and took place in 2013. The participants were approached via the networks of the authors, which explains a bias towards Europe. The interviews usually started with a remark on the device. “Is that the latest ‘brand X’ you have there? What’s it like?” The idea was to have a casual conversation about the qualities of the device and gradually steer the topic towards maintenance (“How often and when do you charge?”) and the non-removable battery (“Can you replace the battery yourself? Would you want to be able to replace the battery?”).

Based on Cox et al. [17] the expectation was that the participants, all original owners of relatively new devices, would have accepted (and perhaps even embraced) the rapid updating and replacement of their devices, and would not be particularly concerned about a non-removable battery.

The results showed a larger than expected divergence in opinions. Although the results cannot be generalized, it was possible to distinguish four typical “attitudes” towards embedded batteries, which could serve as a basis for a more extensive exploration and validation (see table 1). The majority of the people interviewed were either unaware or ‘passively’ aware of the embedded batteries (they accepted decreasing battery life as normal, or to be expected). This is in line with the expectations. Three participants were ‘actively’ aware of embedded batteries: either because the service life of their batteries had decreased dramatically and they were confronted with malfunctioning devices, or because they considered it a challenge to prolong battery life through active battery management.

N	User responses	Typical quotes
9	Unaware of the presence of an embedded battery & never had problems with the device	When asked whether they were aware that their device contained an embedded battery: • "Is that true? Really? I had no idea." (female, ± 30 years) • "I've never given it any thought. It comes with the package." (male, ± 55 years) • "Why, is that a problem?" (male, ± 40 years) •"My phone works just fine. I've had it for almost two years now and I charge it every night. Then it works all day, no problem." (male, ± 30 years)
3	Aware of the presence of an embedded battery & accepting declining battery performance as a given	• "I've noticed a bit of degradation but this is to be expected, I think." (male, ± 20 years) • "My phone is 8 months old and battery life is going down slightly. Might be because of my charging routine; mostly at night." (male, ± 20 years)
2	Aware of the presence of an embedded battery & expressing frustration	• "I've had this laptop for just over two years now. It won't last two hours with a full battery; I'm constantly charging. But I can't replace the battery myself. I'll have to have it serviced but you know, this takes time..." (male, ± 50 years) • "I remember the battery of my phone stopped working right after the warranty period was over. I went all the way to The Hague to have my battery replaced by some guy doing cheap repairs." (male, ± 45 years)
1	Aware of the presence of an embedded battery & actively managing battery life	• "My smart phone is three years old and the battery is like new. You have to know how to care for your battery. Like, you should turn off Wi-Fi when you're not using it. [He demonstrates a number of options]. I only need to charge this phone once every three or four days or so." (male, ± 25 years)

Table 1. Results from interviews with original users

When asked what the interviewees considered a normal lifespan for mobile phones the answers ranged between 1.5 and 4 years. Most indicated two years, as this was the length of their contracts. As modern batteries can outlast the average replacement cycle of roughly two years without much difficulty (i.e. without major degradation), original users of the device may never be confronted with the need or desire to replace batteries. This perhaps explains why the majority of the interviewees are unaware or 'passively' aware of the embedded batteries.

Most interviewees indicated that after replacing their device, they would either give their old device to family or friends, or try to sell it. It would be interesting to interview users of such second-hand devices for their experiences with the battery degradation of embedded batteries.

6. END OF LIFE

Getting mobile devices to consumers ('the system of provision') is a relatively straightforward process compared to what happens at the end-of-life of these devices. The end-of-life value chain of mobile devices and other electronic products ('the system of disposal') is complex and contains both authorized and unauthorized companies and organisations, such as repair shops, refurbishers, resellers and both OEM and non-OEM remanufacturers. This section asks to how embedded batteries have affected the end-of-life value chain. Data was gathered through semi-structured interviews with one refubisher and three recyclers.

6.1 Repair and refurbishment

Service and repair centers are wide spread. Unauthorized repair services claim to offer faster and/or cheaper repairs than the services offered by brand manufacturers. These services can range from professional businesses with call centers, to students running a repair/service business on the side, to self-repair websites. For these service providers, embedded batteries are a business opportunity and some repair businesses are currently experiencing rapid growth.

Resellers acquire used phones and other devices from businesses and consumers through donation and buy-back programs. Devices that are in good shape will be refurbished and the rest will be sold to a recycler. High-end refurbished devices may be offered on the local market, but the majority is sold to Africa and other emerging economies. The reseller interviewed claimed she hadn't seen many devices with embedded batteries come back to them yet and was therefore unable to comment on whether this had changed their usual refurbishment process. She was also unable to comment on the challenges embedded batteries might pose for emerging economies.

6.2 Recycling

At recycling facilities mechanized processing (shredding) of the mobile devices takes place. Prior to this, hand sorting is done to remove the batteries (these must be removed to be treated separately, as stipulated in the European Battery Directive [18]). The batteries are sold as a separate waste stream to dedicated recyclers. Their removal is not only motivated by legal and economic reasons, there are health and safety reasons as well. A professional (P1) at a recycling facility who was interviewed said:

"If we don't remove the batteries before we start processing we run the risk of explosions or fires in the shredder. Also, we've found that these batteries sometimes emit a gas that irritates our workers' respiratory tracts."

This was confirmed by two other professionals in different recycling businesses in Europe (P2, P3). As leaving the batteries in is not an option, embedded batteries make the manual sorting more time-consuming and thus expensive. P1:

"It feels a bit like we've stepped back in time. Of course we can develop ways to mechanically remove the batteries from these devices, but we'll need serious volumes for that. Maybe this can be done in a year or two, when more of these products enter the waste stream. Until then removing embedded batteries is a labor-intensive and expensive process."

A second recycling professional (P2) was asked whether embedded batteries were a problem for recyclers. In his answer, the recycler reflected on the fact that the recycling industry is not really in a position to exert influence:

"Well … a problem… I'd rather call it a challenge for the recycling industry. But what can we do, there is no fine for bad design."

The actors in the end-of-life value chain are currently in the process of adapting to devices with embedded batteries. For some businesses, in particular repair centers, this is already profitable, for others it may become so in time. In the short term, embedded batteries present recyclers with extra costs, but once the waste streams of these devices start to grow, it may become economically viable to develop an automated solution for separating the battery from the device.

7. DISCUSSION: CONSEQUENCES AND OPTIONS

It would be rather straightforward to argue that batteries should once again be removable by consumers, but it's not that simple. In February 2013, the electronics industry published a position paper on embedded batteries, as a response to the European Battery Directive that asks for 'readily removable' waste batteries [19]. The position paper argues that batteries should be removable by either consumers or by professional services, where in the latter case the batteries may be embedded. The main arguments in favor of embedded batteries put forward in the position paper revolve around the technological development of batteries. With modern batteries increasingly smaller and more powerful, industry argues, it can be expected that future developments will include ultrathin and bendable batteries, to be used in e.g. electronic paper. Such batteries are designed to be integrated onto circuit boards and will therefore be non-removable by consumers.

For the current soft-pouch batteries safety and reliability issues require embedded batteries, for instance: "removability by professional services … avoids the danger of an unwanted chemical reaction or electric shock due to puncturing or damaging the battery." Also, embedded batteries will prevent consumers using non-approved and low-quality replacement batteries that could render the product unsafe. The paper also notes an environmental benefit: "batteries removed by professional services are delivered to waste batteries collection and recycling facilities thus leading to their efficient collection and proper treatment."

While these are sound arguments, several problematic consequences of embedded batteries remain unaddressed. Current battery lifetime can surpass the useful life of the product, but usually only for the original owner. Subsequent owners, or original owners wanting to make their devices last longer, often need to deal with degraded batteries. This has led to a thriving grey market with unauthorized repair and refurbishment shops (and non-approved replacement batteries), selling fast repairs at low prices and competing successfully with the more expensive authorized repair centres. A second consequence has been the increasing interest in self-repairs, enabled and encouraged through semi-commercial organisations like iFixit. Self-repair may be hazardous if not done carefully and for OEMs, potentially unreliable (self)-repairs may be a risk for their brand equity. Finally, the difficult and time-consuming removal of embedded batteries by the recycling industry hasn't been taken into account at all, and neither has it been considered that many refurbished devices end up in developing economies where recycling infrastructures are nascent or non-existent, and manual battery removal at end of life may be polluting and dangerous if not done with care [20].

This illustrates how embedded batteries have been the result of a 'technology and design push', without much consideration for the social and environmental consequences at end of life. It also shows that OEMs have so far been slow on capturing residual value from their devices. This was understandable in a time when technological innovation necessitated rapid replacement cycles, but for the past two years technology critics have been arguing that high-end phones have reached an innovation plateau, with each new model just incrementally better than the last ("the latest and greatest phone won't be all that much better than the one you're using now, so there's less pressure to upgrade.") [21]. With mobile devices reaching technological maturity, it may be interesting for OEMs to explore new business models that allow them to capture value over the entire, prolonged, device lifecycle, while at the same time taking responsibility for the social and environmental impacts at end of life. One of the leading concepts in this area is the circular economy [22] where "products are designed and optimized for a cycle of disassembly and reuse (p7)."

8. CONCLUSIONS

Embedded batteries in mobile devices put short product lifespans (due to rapid replacement cycles) into sharp perspective. With major environmental impacts related to the manufacturing of mobile devices, a sustainability case can be made for extending their useful life. Embedded batteries may hinder this lifetime extension, because they eliminate the 'easy' options, such as people replacing the batteries themselves.

Our research showed that built-in batteries do not necessarily cause a further decrease in the lifespans of mobile devices (these already have short lifespans), but instead, embedded batteries seem to be an almost logical *consequence* of these short lifespans. The introduction and integration of embedded batteries supports the (already established) practice of frequently replacing devices and tends to lock people into this practice. In this sense, mobile devices have become more disposable than ever. The interviews with mobile device users showed how they, almost unconsciously, have adopted these new constraints into their lives. They only become aware of the limitations when the batteries in their devices malfunction prematurely. Only a limited number of people were interviewed for this study. It would be interesting to validate the findings in a larger-scale survey, and to include non-original owners of devices in order to ask how they experience embedded batteries.

In tracing the consequences of the adoption of built-in batteries throughout the mobile device value chain, the paper has shown that this adoption is an ongoing and dynamic process. Some actors are reaping the benefits (e.g. repair centers) whereas others (e.g. recyclers) are still struggling to adapt.

This raises questions about future battery developments: if technology and design continue their current trajectory towards more integrated and less materially intensive battery solutions (e.g. for application in wearable electronics and smart textiles), will this result in similar end-of-life problems and opportunities, and what will be the sustainability consequences of such innovations?

A future research project might furthermore consider exploring the role of the circular economy as a potential stimulus for positive systemic change. Could this lead to mobile devices that are optimized for multiple product lifecycles?

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