Future feasibility analysis on modular smartphones

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ABSTRACT

A smartphone has become an essential partner in our daily life. The demand for new devices is rapidly increasing and thus the large number of electronic waste (E-waste) has become big issues. Premature obsolescence is one of the main reasons why the longevity of smartphone is much shorter than expected. This results in the fact of generating a huge amount of E-watses from smartphones. We find that the human-device relationships play an essential role in the premature obsolescence issues. In order to reduce E-wastes, a new concept of modularity was introduced and is considered as a good solution. The modular smartphone project by Google, Project Ara (2013), seemed very likely to be the mainstream at that time. The analysis on the development of Google Ara shows great potential on the economic, social, and environmental sustainability. However, many challenges, including immature technologies such as the connectors that are compatible with external modules and the lack of uniform standards, still impede the development of modular smartphones. In 2016, the project Ara was cancelled by Google unexpectedly. Modular smartphones have shown to have significant positive impacts on the material culture, the way how smartphones are used, and longevity extension for most components, even if they are difficult to be the mainstream now.

1 Keywords

E-waste, Modular smartphone, sustainability, Google Project Ara, life cycle, obsolescence

2 Introduction

E-waste is increasing rapidly throughout the whole world as the demand for new technologies is growing rapidly [1]. Mobile devices contribute significantly to the E-waste growth [2]. In 2019, 53.6 million metric tons (Mt) E-waste was generated in total, including 17.4 Mt mobile devices (32.5%) [3]. However, only 12% of them were recycled appropriately [3]. E-waste can result in significantly negative impacts on public health as well as the environment by improper disposal because of their complex chemical compositions.

Among the total mobile device waste generation, smartphones constitute a significant proportion [4]. The rapidly sales growth of smartphones results mainly from frequent model updates and increasing demands for telework. [5] [6]. According to the data from a research company Gartner, smartphones

sales increased by 11% in 2020 in comparison to only 3.6% in 2013. In America, the average life cycle of smartphones is only 22 months while it is expected for 57 months [5]. Most devices were discarded when they were still working. From the research of Wieser in 2018, 70% of smartphone users replaced their devices because of the partial performance degradation including the decrease of storage space, low battery capacity, and obsolete cameras [7]. As a result, 150 million smartphones are discarded every year [5]. One of the main reasons causing so many wastes is that the consumers are forced to buy a new entire device for upgrades of one or a few components. According to the report from Apple, 75 kg CO2 is generated during one iPhone SE life cycle and 82% of it is generated during production [8]. The excessive replacement of smartphones has greatly increased the demand for new devices. As a result, more extra pollutions are caused from the new devices production. The global GHG emissions from smartphones increased from 17 Mt in 2010 to 125 Mt in 2020, which was a 730% increment in 10 years [2]. Extending product life cycle is usually considered as the most sustainable solution for smartphones future development [9].

Reducing obsolescence is a crucial factor of circular economy (CE). It directly affects the life cycle of the product. From the previous analysis of the reasons for smartphones replacement, it is clear that durable physical devices alone are not enough to reduce the discard of smartphones. When research on the longevity of smartphones, it is important to consider the special role of smartphones in our daily life, that is to say, pay attention to the social meanings including the relationship between the device and its owner. For smartphones, functional durability is as vital as physical durability. That means the functions of a smartphone should always keep up with the technology development [10].

The concept of modularity shows great potential for longevity extension. In 2013, Dave Hakkens, a Dutch design student, proposed the concept of Phonebloks on YouTube. The video has been watched 25 million times. Phonebloks is a kind of modular smartphones, allowing users to replace any broken or outdated components. In a modular smartphone (Figure 1), all Bloks, with non-permanent interconnected interfaces, are connected to each other separately on a base board in such a way that it is easy to replace any of them. Due to the flexibility and personalization of modularity, consumers do not need to buy an entire smartphone for partial upgrade. All Bloks can be purchased from the online Blok-Stores. The online Blok-stores are similar to the App-Store that supported by different technology companies and individual developers. When the Google project Ara cooperated with Phonebloks, the concept of modular smartphones was expected to reach market maturity. This made it possible to be a realizable solution for sustainable future of smartphones. However, in 2016, three years after the idea was proposed, Google decided to cancel the Project Ara with no comments.

Figure 1: Google Ara

According to previous research, four questions are raised in this study: First, what caused smartphones premature obsolescence? Second, how can modular smartphones prolong the longevity of devices? Third, what can we learn from the Google project Ara from the perspectives of economic, social, and environmental sustainability. Fourth, what potential issues the modular smartphones may cause after mainstreaming in the future?

This study has been divided by five parts to answer the questions above. Section 4 explains some fundamental concepts about modularity and mass customization. Section 5 analyzes the reasons of obsolescence and the effects modularity can bring to the longevity of devices. Section 6 makes a case study on the Google's project Ara from the perspectives of economic, social, environmental sustainability. Section 7 analyzes the potential issues in the future according to the research made in section 4, 5, 6. Section 8 makes an evaluation model to show how

modular smartphone can reduce e-waste. Section 9 summarizes the important findings, limitations, advice for future research of modular smartphones development.

3 Literature Search

This study uses a qualitative research, including two stages for literature search. First, it has collected secondary data from webpages related to modular smartphones and other modular concepts, especially the webpages about Project Ara and Phonebloks, videos and other reports from modular smartphones project conferences and news articles. Secondly, it reviewed the abstract and citation database Scopus and other literature retrieval engines including google scholar and ScienceDirect by keywords "Modular smartphone, Mass customization, Modularity, Fairphones, Google project Ara, life cycle of smartphones, E-waste, circular economy".

To answer the research questions, this paper first presents the theoretical background based on the literature review on the concept of modularity and its premature obsolescent issues. It is followed by a case study on the Google Project Ara, through the interviews made by Hankammer [11] in 2015 and 2017 with both the experts in modular smartphones and the staff in the project.

4 Sustainable Mass Customization and Modularity

Mass Customization (MC) was proposed by Joseph Pine in 1993. It aims at providing everyone what they want by developing, producing, marketing and delivering affordable, various, and customized services and goods [12]. Low costs and various customization choices are considered as two crucial factors for MC strategies to meet the different individual needs [11]. However, these two factors are hard to be achieved at the same time. The rapid development of information technologies makes it possible for MC to combine both factors. MC products consider a consumer as a designer and a developer more than a simple purchaser. They actively integrate the consumers into the design and development process of the products [13]. Modularity is the indispensable factor for the MC, which means a product includes various combinatorial methods with standard modules [14]. Compared with an integrated product, it is easier for the users to change a specific module in a modular product. The users can update a single module that they want instead of being forced to replace the entire product.

MC strategies have been shown to have the potential of sustainable development in many studies [15] [16] [11]. Co-design in MC is considered as a crucial way to approach sustainable development [15]. The concept of modularity shifts the life cycles from open-loop to closed-loop, which creates many extra life cycles to prolong the longevity of the products [16]. When evaluating the sustainability of MC or modular products, it is important to focus on the relationship between society and environment including social and cultural changes from the new concept [16]. So, this research also focuses on the perspectives of society and environment when analyzing the previous modular smartphones projects.

5 The impacts of modularity for smartphones longevity

5.1 Obsolescent and obsolete issues

As it was mentioned in the previous sections, users are an important factor to decide the actual life cycle of the products. In this part, we analyzes the reasons of obsolescence from the perspective of the relationship between users and products. Most consumers are used to using the excuses of minor malfunctions or performance deficiency to buy new devices even if the current devices are working normally [17]. This behavior becomes especially more obvious when the technical companies launch new products, because in this period the products will depreciate in the users' mind [18]. The manufacturers

and product designers also intentionally encourage the consumers to replace their devices and decrease the actual life cycle of devices for making more benefits and keeping the products attractive [19].

A smartphone is a special device that not only meets the actual needs such as making calls, sending messages and surfing the Internet, but also has been integrated into our daily life and socio-culture. This increases and widens the users' desires on the device [20]. Premature obsolescence is an active behavior, or considered as outdated. It greatly reduces the life cycle (as compared to the expected life cycle). The consumers are used to ignoring the responsibility of prolonging the life cycle of the devices [18]. At the same time, they are constrained by the predefined durability from the manufacturers because of the limited knowledge about phone design and using/maintaining/caring/repairing methods to the device [21] [22]. As a result, most consumers casually replace their devices without careful consideration. This kind of habits of the consumers and manufacturers create a special material culture that encourages devices with short life cycle [22]. Under this situation, the material production moves to short-lived trend, and thus greatly increases the number of waste [23] [24] [25].

According to the previous studies, five main factors that cause obsolescence issues are concluded:

1. Material quality deficiency (low physical durability).

2. Functional deficiency (low functional durability).

3. Economic benefits difference, which refers to the benefit from maintenance including repair is lower than that from new devices[25].

4. The material culture of encouraging short life-cycle products.

5. Limited knowledge of the customers to the devices.

5.2 Modularity for longevity of devices

Increasing the value of a device to the user is essential for extending the life cycle [22]. For smartphones, improving functional durability is more imminent than physical durability. One reason is that a smartphone is considered as a digitalized constant companion in the daily life now. In other words, our personal life is highly dependent on smartphones [26]. It provides various essential functions for daily life including making social interactions, connecting to other intelligent devices such as home robots, and simplifying daily life tasks. Hence it is important to make smartphones reliable, information secure, and easy maintenance [22].

As mentioned above, most smartphones are replaced when they are still working. Sometimes some elements show extremely higher performance after updates, making the original devices can no longer meets the needs of users. However, current integrated smartphones cannot make separate updates. As a result, the users are forced to replace the entire device.

Modularity ensures the devices have continuous functions [22]. A modular smartphone can prolong the longevity of the device not only by repairing and updating separately, but also by adapting functions including changing existing functions and adding new functions[22]. This functional adaptation makes it possible to keep up with the technology development in different fields. In modern society, people become more and more interested in solar charging, health monitoring, and environment monitoring[11]. These are not specific features for a smartphone, but they can meet some special needs of other specific user groups. It is impossible to adapt these functions on a traditional smartphone. Modularity transforms a smartphone to a "master key" that can be connected to various external products. It significantly contributes to the human-device interaction[22] and removes smartphone black-box[27]. When people understand his smartphone better, it creates a stronger sense of attachment to the smartphone because it is designed by themselves [28]. This greatly increases longevity of most elements in the

smartphones. The variability and flexibility of modular smartphones have great potential to change the current material culture and to explore more possibility of sustainable development.

However, modular smartphones also have some potential issues, which will be discussed in section 7.

6 Case Study

Hankammer summarized most published modular smartphone projects and published in 2018[11]. He divided the modular smartphones into three types. The first type is complete modular smartphone such as Phonebloks and Project Ara. All modules of these smartphones can be separated including CPU, battery, external modules, cameras, and speakers. Another type is partial modular smartphone such as Z-family LG G5, Fairphone 2 shift, Eco-Mobius, and Vsenn. This type of smartphone allows to separate small integrated parts that combines several modules in every blocks. The third one is DIY modular smartphone such as Rephone. It has only one main block with basic functions (limited replacement) and the users need to add other external modules for adding more functions. This research focuses on Google's project Ara.

6.1 Google's project Ara

This project started when Dave Hakkens uploaded a video about the concept of customizable modular smartphone on Youtube [29]. He was a student majored in designing. His main idea was to reduce E-waste by a modular smartphone that supports to replace or update a part of the device. The modules are sold in the online stores, which is similar to app-stores like Google Play Store [30]. This project attracted many smartphone manufacturers. Finally Hakkens decided to cooperate with Motorola. And Motorola was bought by Google soon after this. At that time, Motorola had another similar project on modular smartphones. Eventually two projects were combined to one project named Project Ara [30]. Afterwards, Google released the specifications of endoskeleton, the basic module that can be connected to other external modules, in order to attract more cooperators [11].

In January 2015, Google showed the prototype device, Spiral 2, with limited functions, to the public [31]. In 2015, Google improved this modular smartphone to Spiral 3 with better functional and physical durability, 3G calls, and module hot-swapping (Figure 2). Also in that year, Google started to make a market pilot in Puerto Rico[32]. However, in September 2016, Google decided to cancel the Project Ara without any comments. As a result, this project was only on trial for three years. The last version of Ara modular smartphone was still not completely modular [11].

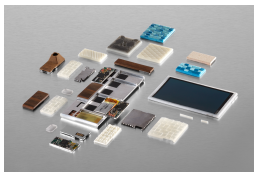

Figure 2: Spiral 3

6.2 Sustainable assessment from economic perspective

Google combined the MC market strategies with modularity as their business model. The users only need to buy a basic module (endoskeleton) and add the modules with different functions that they want from online-stores. This idea was inspired from the shared concept on software app-stores[11]. By online-stores, more companies and individuals can develop their own modules. This could add more functional options to make Ara smartphone differentiate against other smartphone companies[33]. By this platform, a modular smartphone can also be customized like apps [34]. Shared concept is the most important element in this model. One crucial factor of the shared concept is that Google should have a reasonable standard to share the benefits with module developers [35]. Google planned to get 30% of the benefits from the developers, the same as they got in the Google Play

Store. And the rest of revenues from module-stores could attract many module developers including many famous technology companies and individuals [11].

The new concept of modular smartphones allows the users to design their unique smartphones, which was a positive innovation to attract more consumers. Google could get more information about the consumers to adapt the Ara smartphone to the consumers. After a period of time, Google could find a stable and sustainable business model by this increasing attraction and data analysis[11]. However, modularity is not free now. It needs extra material to package the modules, extra connectors, and extra support modules for some functions [9]. As a result, a Ara smartphone required 25% larger size modules on average to provide the same functions as a traditional smartphone [36]. This means Ara smartphone lost efficiency for modularity and the initial price was higher than traditional smartphones. As a result, it lost the users who prefer to small devices [11].

6.3 Environmental and social assessment

Modular smartphones were designed for sustainable usage of material. Ara smartphones also include this concept. Google created a business model of sustainable concept called collaborative design (co-design). The consumers could reject redundant functions in the design process. This was helpful to reduce useless modules. Google designed the longevity of Ara endoskeleton for 6 years and designed the average longevity of the modules for 5 years [11]. Compared to current average longevity of traditional smartphones mentioned above in Section 2 is 22 months (less than 2 years), modular smartphones greatly prolong the longevity. Modular smartphones make it possible and easier to replace any modules separately. That is the reason that when the smartphones become modularity, it will become sustainable at the same time. From the research by smartphone manufacturers such as Apple and Sony, most CO2 emission (around 80%) are generated during the production process [37] [8]. Hence, prolonging longevity of smartphones significantly contributes to the sustainable development. Google also planned to make a circular loop for the modules by making a secondary market to extend the longevity of modules by reusing them [11]. This idea not only reduced the waste of modules, but also reduced the demand for new modules.

Ara smartphones could be connected to external modules. This made it possible to connect to other electronic devices with high performance such as professional cameras and fixed navigation systems with high precision. Google also planned to design radiation meters modules and glucometer modules to realize more functions of other fields[11]. This was considered as a good application to improve the social sustainability. Meanwhile, this could also reduce the demand for other individual electronic devices, which also had a high potential of environmental sustainability.

Governments and consumers are also two essential factors for sustainable environment development.From the perspective of governments, it is essential to make regulations and incentives that are related to sustainable electronic products including motivating e-waste reduction, limiting obsolescence strategies, and enhancing the competitiveness of modular products [38]. Taxing electronic products that generate large number of wastes and pollutions is a good example [11]. More companies can be persuaded to produce sustainable devices by more attractive benefits.

The attitudes to the new concept of modular smartphones from consumers are more important than the government intervention [11]. Modular smartphones give the decision-making power of discarding or updating to the consumers. This significantly contributes to change the behavior and mentality of the consumers. As a result, consumer electronic products are transformed to the concept of environmental sustainability products and more consumers will keep the entire smartphone or at least most modules for longer time [22].

Ara smartphones were technologically feasible and eco-friendly but more expensive than traditional smartphones because of the extra demand for more material as mentioned in Section 6.2, as well as the lack of government supports. This was one of the

crucial failure factors of the project. [11] [22]

7 Challenges and Potential Future Problems

Although the shared concept can promote the development of modular smartphones, it also needs to prevent rebound effects. As more developers start to provide their modules, oversupply will be one of the risks that reduce the environmental sustainability. There will be many low-price modules on the market. As a result, many users will start to buy many redundant modules for fun, and it will cause large number of extra E-waste [11].

The platform design model also faces some technology difficulties. Ara smartphone has a basic module, called endoskeleton, to be connected to other external modules. It means all external modules need to be interact and be integrated with the endoskeleton. It is still difficult to develop such an applicable connector for the endoskeleton [11]. Due to this technology difficulty, Ara smartphone still could not replace some modules like CPU, battery, and screen when the project cancelled. Although such a connector is developed in the future, some potential issues such as responsibility attribution will happen. Most consumers think that they should not be responsible for the durability and efficiency of the device [22]. Thus, designers or manufacturers need to be responsible for this. However, it is common that different modules might be supplied by different companies or individuals to cooperate to realize one function. As a result, it is difficult to divide the responsibility separately.

In terms of the modular smartphone itself, modularity is more complex and needs more connectors and more support elements. This will greatly increase the risk of additional component failures [11] [9].

8 Evaluation model

Figure 3 shows a causal model of how the modular smartphones can reduce e-waste. As discussed in Section 5 and 6, a stronger sense of attachment to the modular smartphone from the consumers is proved to be able to prolong the actual longevity of the device to five years (60 months). Compared to the current actual longevity of 22 months (Section 1), it is possible to reduce 60% of the e-waste in the future. External functions of other fields from modular smartphones have shown great potential in the reduction of the demand for other small electronic devices (Section 5 and 6). From the statistics made by Forti in 2020, the e-waste from small IT equipment and monitors was 6.7 Mt (12% of total e-waste) [3]. The modular smartphone is possible to reduce these e-waste generation in the future. However, there could be potential risks that additional e-waste may be generated from modular smartphones. The complex components might bring additional risk of component failures. According to the research conducted by Simons in 2018, the average failure rate of phone modules is 12% [39]. This will result in 12% of extra waste from the additional component failures. In addition, due to a lack of research on the impacts from cheap and low-quality modules and oversupply, this model cannot provide accurate predictions on these two factors. Based on the previous experience, 10% of extra e-waste could be assumed from them [11] [22]. As a result, it is reasonable to estimate at most 40% of smartphone e-waste reduction by modular smartphones and 13% of total e-waste reduction, where smartphone e-waste accounts for 32.5% of total e-waste [3].

9 Conclusion

In this paper, it discussed the background and potential development of modular smartphone. First, it found that premature obsolescence is an active behavior. Prolonging longevity by making a sustainable material culture and changing the behavior of the consumers is considered as the best solution for the premature obsolescence issues. We conclude five main reasons that cause obsolescence: material quality deficiency, functional deficiency, economic benefit difference, the short-life-cycle material culture, and limited knowledge of consumers

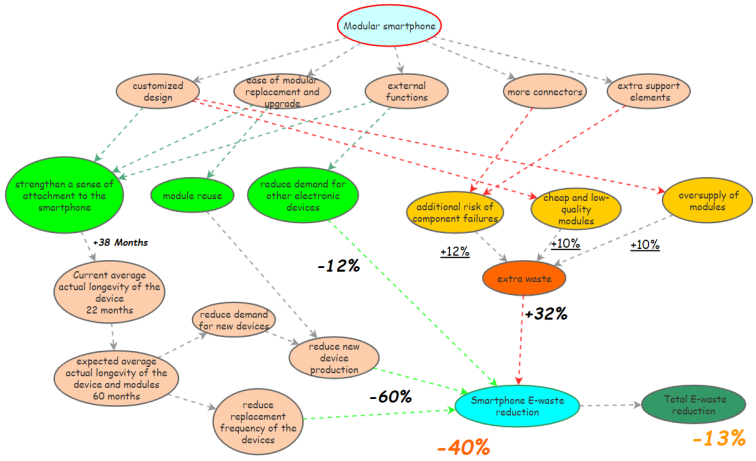

Figure 3: Simulation model

to the device. From the analysis on the modular smartphone, it found that modularity has continuous functionality and better interaction to the consumers. It can flexibly change to meet the needs of different user groups. Hence, the modular smartphone will have a stronger sense of attachment to the consumers, which contributes to a longer longevity for the device. At the same time, the material culture will also transform from short-life-cycle products to long-life-cycle products by the changing of consumers usage habits. This is helpful to mainstream sustainable products.

After researching on the basic background of the concept of modular smartphone, this paper analyzed the case of Google Project Ara to explore feasible strategies to mainstream the modular smartphone from the perspectives of economy, society, and environmental sustainability. It found that the platform provided by Google is helpful to make all developers focus on a narrow field that they are familiar with. It is essential to ensure the developers can get considerable benefits on the platform under shared business model. This business model can also attract wider user groups by more customized modules. Finally, it will have a stable economic sustainability.

And then this paper researched on the environmental and social sustainable potential on the Google project Ara. It noted that modular smartphones have great potential of increasing the longevity of most modules. Meanwhile, the Ara smartphone could also change the daily life of the users and include both social and environmental sustainability by integrating functions of wider fields such as health care monitoring into the smartphone.

At last, the paper concluded a few challenges and proposed some potential future issues from the perspectives of technology, society, and environmental sustainability. Currently, it is hard to develop a common connector for the endoskeleton. It also lacks module developers. This impedes the development of external modules for complete functions. Although technology issues can be solved in the future, we still need to form a special standard for the new concept including the responsibility attribution issues. On the economic side, oversupply by the online-module-stores will also cause negative effects on the environmental sustainability.

In the next few years, modular smartphone is hard to become the mainstream because of the immature technologies and related institution systems. It showed a strong potential on the economic, social, and environmental sustainability. Thus, modular smartphone will probably revolutionize the mainstream of smartphones in the future.

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