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# Display Repair

## Battling Premature Obsolescence in Smartphones by Stimulating Repair Actions


TU Delft

MB

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MSc Integrated Product Design
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# I Abstract

With over 6 billion smartphones in use worldwide, high emissions and a considerable amount of e-waste, there is a need for a more sustainable approach. One such an approach is prolonging the use-times of smartphones, and for that repair should be popularised. This thesis examines how to prolong the use-time of smartphones through stimulating repair actions. The most occurring defect is to the display, while using the smartphone for one more year after a display repair saves about 20 percent in greenhouse gas emissions. For users to choose repair over replacement, repair needs to be affordable, accessible, and attractive, which current repair options do not adequately deliver. Smartphones can also be designed more reliable and repairable to support repairs and prolong use-times. These strategies need to be balanced with the smartphone's competitiveness for a sizeable impact.

Therefore, a repair platform is proposed for stimulating repair, alongside a repairable smartphone that aims at further triggering repair actions and competing with high-end smartphones for a sizeable impact.

A collaboration between repair shops and manufacturers needs to deliver value to the user. The proposed system delivers accessibility by creating a repair network of independent shops, which gains user trust by offering original parts and warranty. It makes repair more attractive by reducing the time and effort it takes and giving users insight into their environmental contribution. This creates value for repair shops by delivering customers and enabling quicker turnaround times. The manufacturer benefits by receiving the old parts, being more in control of their supply chain and gaining a strengthened competitive positioning. By being more accessible and attractive, users are more motivated to repair. Affordability is the third factor necessary for favourable repair yet this is only achieved in part by quicker repair times. It needs to be further investigated how to reduce the costs of spare parts. This thesis contributes by combining the need for a repair network with repairable smartphones. A repair network needs more repairable smartphones, and a repairable smartphone needs a well-functioning repair network.

# II Glossary

The definitions below have been retrieved from Oxford Languages unless indicated otherwise.

**Circular Economy**
: a systems solution framework that tackles global challenges like climate change, biodiversity loss, waste, and pollution. It is based on three principles, driven by design: eliminate waste and pollution, circulate products and materials (at their highest value), and regenerate nature (Ellen MacArthur Foundation, n.d.)

**e-waste**
: discarded electronic appliances such as mobile phones, computers, and televisions

**Greenhouse Gas (GHG) emissions**
: emissions from gasses contributing to climate change, according to the Kyoto protocol (IPCC, 2007), including: Carbon Dioxide ($CO_2$), Methane ($CH_4$), Hydrofluorocarbons (HFCs), Nitrous Oxide ($N_2O$), Perfluorocarbons (PFCs), Sulphur Hexafluoride ($SF_6$) and Nitrogen Trifluoride ($NF_3$)

**Integrated Circuit (IC)**
: an electronic circuit formed on a small piece of semiconducting material, which performs the same function as a larger circuit made from discrete components

**Kilogram carbon dioxide equivalent (kgCO2e)**
: the damage of a range of greenhouse gasses from the Kyoto Protocol, specified as the mass of $CO_2$ with the equivalent effect (Ecometrica, 2012)

**Life Cycle Assessment (LCA)**
: the systematic analysis of the potential environmental impacts of products or services throughout their entire life cycle (Sphera, 2020)

**Modularity**
: the quality of consisting of separate parts that, when combined, form a complete whole (Cambridge Dictionary, n.d.)

**Premature Obsolescence**
: the disposal of a product at a point in its 'life' where it is still physically functioning, or in need of (minor) repair (van den Berge & Thysen, 2020)

**Product-Service System (PSS)**
: a system of products, services, supporting networks and infrastructure that is designed to be competitive, satisfy customer needs and have a lower environmental impact than traditional business models (Mont, 2001)

**Reliability**
: the quality of being trustworthy or of performing consistently well

**Smartphone**
: a mobile phone that performs many of the functions of a computer, typically having a touchscreen interface, internet access, and an operating system capable of running downloaded apps

**Use-time**
: how long a product is used, it includes both the duration in operation and the duration in stand-by (Wieser, Tröger, & Hübner, 2015)

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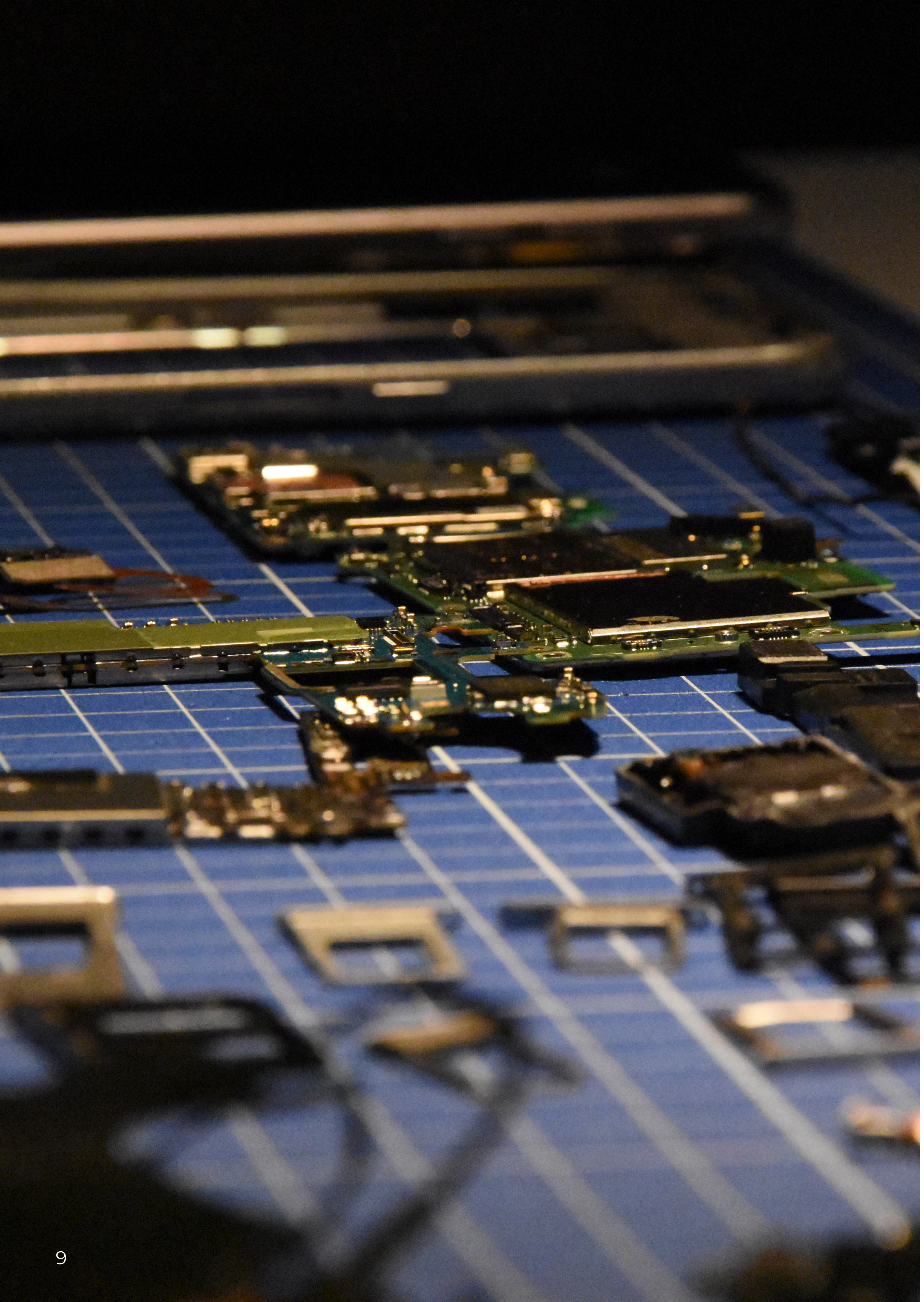




# 1 Introduction

Smartphones are a large part of modern day to day life and with over 6.3 billion smartphones in use (Statista, 2021), more than 80 per cent of the worldwide population owns one (Turner, n.d.). From 2016 onwards, on average over 1.5 billion smartphones were sold worldwide annually (Statista, 2021). Considering a smartphone is responsible for about 57 kgCO2e (Ercan et al, 2016), this means a total of 85.5 billion kgCO2e was emitted every year in creating them. Discarded smartphones end up mostly as landfill and generated a total of 435 kilotons e-waste in 2016, while the raw materials still hold a value of €9.4 billion (Baldé et al, 2017).

The circular economy aims at keeping this value inside the system. It is gaining momentum (Geissdoerfer et al, 2019) and within it, there are different strategies possible to get to more sustainable solutions (Figure 1). Common strategies are recycling, remanufacturing, and refurbishing of devices, to ultimately give the materials or products another use. Many opportunities lie in all of these strategies, yet smartphones have the issue of short use-times (Wieser et al, 2015), low repair numbers (Wieser & Tröger, 2018) and little recycling (Baldé et al, 2017). Prolonging the lifetime by stimulating repair actions is therefore a promising strategy (Cordella et al, 2020b). Add to that the current light on Right to Repair by the European Parliament (European Parliament, 2020), urging the Commission to make repairs more appealing, systematic and cost-efficient, and there is a need for a strategy that favours repair over replacement (Jaeger-Erben et al, 2020).

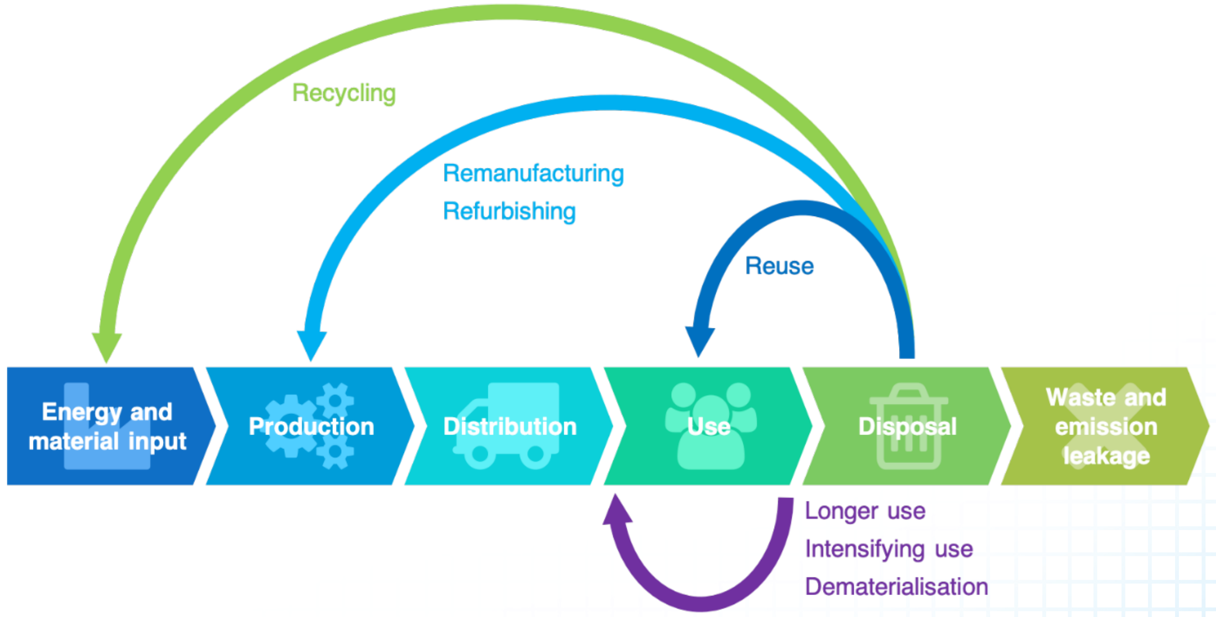



*Figure 1 - Different strategies in the circular economy (Geissdoerfer et al, 2019)*

## 1.1 Problem Statement

Users expect their smartphones to last for 5.2 years, yet the average use-time for smartphones is about 2.7 years (Wieser et al, 2015). While some smartphones that are disposed of are beyond repair after their use-time, a much larger part still fully functions or needs (minor) repair (Wieser & Tröger, 2018). This phenomenon is called premature obsolescence and is happening when products are disposed of while still functioning or in need of repair (van den Berge & Thysen, 2020). There are multiple reasons that this is occurring, ranging from a restricted functionality, or users wanting a newer smartphone because it performs better than the current model (Wieser & Tröger, 2018), to costly repairs pushing users towards replacing the smartphone instead of repairing it (Jaeger-Erben & Hipp, 2018). A study from (Wieser & Tröger, 2018) in Austria showed that only 34% of broken smartphones get an attempt to repair them. Most defects in smartphones are to the display, 67.4% of damaged smartphones have display damage (Clickrepair, 2019).

These repair numbers should be higher if the use-times are to be prolonged to reduce the amount of e-waste and get more value out of the materials. By stimulating display repair, the use-time can be prolonged and thus the amount of e-waste as well as the emissions will be decreased.

## 1.2 Research Questions

This thesis will explore different replacement reasons, and why repair is not always considered. Different types of obsolescence will be listed, repair options assessed, and the impact investigated. The goal of this thesis is to prolong the use-time of smartphones by stimulating repair, thus the main question is:

***How to prolong the use-time of smartphones through stimulating repair actions?***

Answering this question requires a problem analysis which focuses on the current situation and the behaviour of the user. This will be addressed in the following chapters, each with a more specific research question.

RQ1. Why do users replace instead of repair?
- 1.1. Why do users replace their smartphones?
- 1.2. What are the barriers for repairing a smartphone?
- 1.3. What considerations do users make when deciding to repair or replace?

RQ2. How can repair offers be stimulated?
- 2.1. What is offered on the smartphone repair market?
- 2.2. Are users willing to repair?
- 2.3. What problems do users experience when repairing?

RQ3. How to prolong the use-time of smartphones?
- 3.1. What different prolongment strategies are available?
- 3.2. What is the environmental impact of prolonged use?

RQ4. What makes a repairable smartphone competitive?
- 4.1. What does the competitive landscape look like?
- 4.2. What specifications make a smartphone competitive?

RQ5. How are smartphones constructed?
- 5.1. What components are in a smartphone?
- 5.2. What methods of construction are used?
- 5.3. What makes a smartphone repairable, reliable and/or competitive?

## 1.3 Project Methodolgy

The double diamond model (Design Council, 2005) was used and it consists of four phases: discover, define, develop, and deliver. Each of these phases included different activities to get to the result.

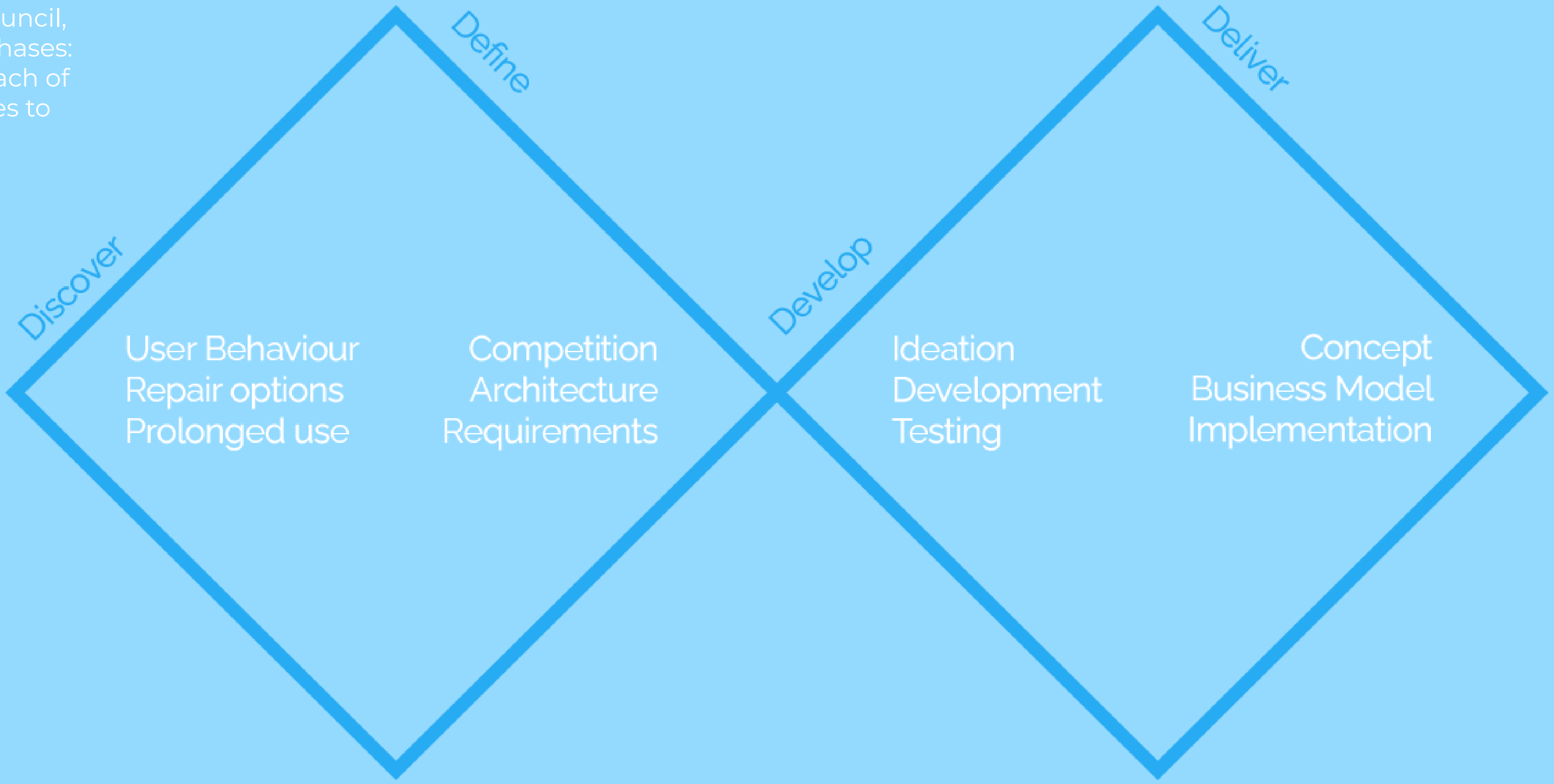



*Figure 2 - Process: Double Diamond*

In the discovery phase, the literature regarding user behaviour and use-time prolongment was reviewed. From the literature, a behaviour model was set u, that aided in designing a solution. Furthermore, the existing repair options were identified and assessed.

The define phase was about distilling that into requirements for the to be designed solution. The smartphone competition was identified, and the smartphone architecture was analysed. It concluded with design requirements.

The development phase consisted of generating concepts, selecting the most promising one, and developing that into a version ready to be tested with users, which was done after.

To deliver the concept, the solution was further developed with the user feedback. A concept platform in combination with a repairable smartphone was created, to present the user with a more affordable, accessible and attractive repair journey.


# Discover

# 2 User Behaviour in Replacement versus Repair

This chapter aims at answering RQ1, to assess why repair is not always the first option for users. The behaviour of users around replacement and repair is therefore examined, by investigating the existing literature on both topics. From the literature, a decision-making model is deduced to map how users arrive at the decision to either replace or repair.

## 2.1 Replacement Behaviour

Users consider whether they get their money's worth out of a product while using it, in the form of a mental book value (Okada, 2001). The mental book value consists of the positive difference between the initial purchase price of the current smartphone and the total of the experienced benefits of the smartphone. Users compare the expected future benefits of the current smartphone (E0) with the expected future benefits of the intended new smartphone (E1) and the accompanying purchase price (P1). If E0 is high, users have a higher probability to replace when E1 is higher or P1 is low. Thus, users replace if:

$$(E1-E0-P1)>0$$

A good user experience results in a low mental book value, meaning the user has got a large part of their money's worth out of a product. This reduces the mental cost of having to replace it, yet also increases the value of E0, and thus decreases the net benefit of the intended purchase. It means that when users are satisfied with the performance of their smartphone thus far, they expect that for the future as well, and replacement is less likely.
The decision to replace a smartphone is a trade-off between this mental book value of the currently owned smartphone and the expected value and costs of the new smartphone (van den Berge et al, 2021). Repeated use of the currently owned device influences the relationship between the perceived value and the intention to replace, and thus ultimately leads to product replacement (Hou et al, 2020). This decision making is modelled by van den Berge et al (2021), and gives an overview of how the relative values are influenced and how the decision to either retain or replace is made. The model compares the values of the owned product to the new product, leading to either retaining the device or replacing it. This decision making is important for longer use-times, and retention could mean having to repair it.

Looking into the user's reasons for replacement, they can be put into four categories (van Nes & Cramer, 2005):
**Wear and tear**: the product get replaced because it does not function as it should or not at all
**Improved utility**: the product is replaced for more than one reason, the product does not function properly, and there is a desire for an improvement in terms of the safety and the economics of the use of the product
**Improved expression**: the product is replaced for more than one reason, the product does not function properly, and there is a desire for an improvement in terms of the comfort of use, the quality and/or design of the product
**New desires**: the product is replaced because the user has new desires, the product is not defective

This can be compared to different kinds of obsolescence as are described in the literature. In the decision process, there are multiple reasons for a product becoming obsolete. (Packard, 1960) describes three different types: obsolescence of quality, obsolescence of function (or technological obsolescence) and obsolescence of desirability (or psychological obsolescence). (Cooper, 2004) adds a fourth type, economic obsolescence.
**Quality obsolescence**: when the product no longer functions as it should
**Technological obsolescence**: when people are attracted to new functions in newer models
**Psychological obsolescence**: when users are no longer attracted to products or peer-pressured into getting a new one
**Economic obsolescence**: it is no longer worth keeping in use, due to non-efficiency or high maintenance or repair cost
Next to this, there is also a distinction in whether the obsolescence is absolute or relative; absolute obsolescence occurs when the smartphone is physically worn down or broken, while relative obsolescence depends on the users' perception of the smartphone (van den Berge & Thysen, 2020). Table 1 compares the obsolescence types and replacement reasons and gives a definition of what it means for smartphone replacement.

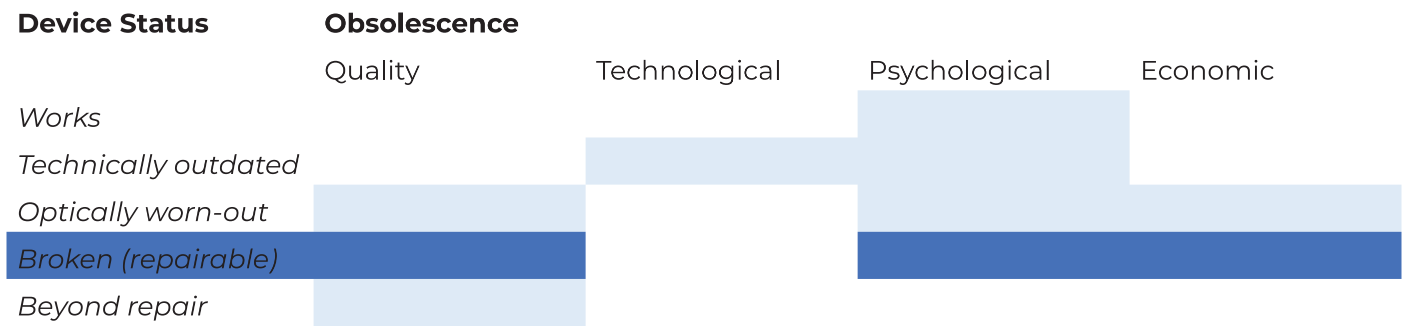
*Table 1 - Types of obsolescence compared to replacement reasons (van den Berge & Thysen, 2020)*

| Obsolescence | Absolute/ Relative | Replacement reasons | Definition |
|---|---|---|---|
| *Quality* | Absolute/ Relative | Wear and Tear | Absolute: a smartphone does not function as it should anymore<br>Relative: a decline in performance of the smartphone is perceived (example is reduced battery life) |
| *Technological* | Absolute/ Relative | Wear and Tear, Improved utility, improved expression, new desires | Absolute: a new innovation prevents the smartphone from functioning properly (example is no support for WhatsApp anymore)<br>Relative: new innovations perform better in newer models of smartphones |
| *Psychological* | Relative | Improved expression, new desires | Users are no longer attracted to their smartphone |
| *Economic* | Relative | Improved utility | The smartphone is no longer worth keeping in use, due to high maintenance or repair costs, or getting a free upgrade |

Besides reasons for replacement, there are certain levels of the device status that can be linked to the different types of obsolescence (Proske, 2016) (Table 2). The psychological obsolescence plays a large role in most cases, only excepted when the device is broken beyond repair. Most interesting for repair is the interconnection between the quality, psychological end economic obsolescence when the smartphone is broken but repairable.

(Wieser & Tröger, 2018) state that the replacement decision is often a combination of multiple factors, contributing to this interconnection between the different types of obsolescence. The most given reasons for replacing a smartphone can be seen in Figure 3 (Wieser & Tröger, 2018), where a defective device is the most common reason for replacement, followed by a desire for a new smartphone with better specifications. There are multiple motivations at the same time possible, although for a defective device it is often the only reason with 20% of all replacement cases. This supports mainly the connection between quality and economic obsolescence, because when a smartphone does not function as it should anymore, the user feels it is no longer worth keeping it in use. Psychological obsolescence adds to this if the phone has been used and satiation pushes the user towards replacement as users feel they are done with their current smartphone.

*Table 2 - levels of device status compared to obsolescence types (Proske et al, 2016)*



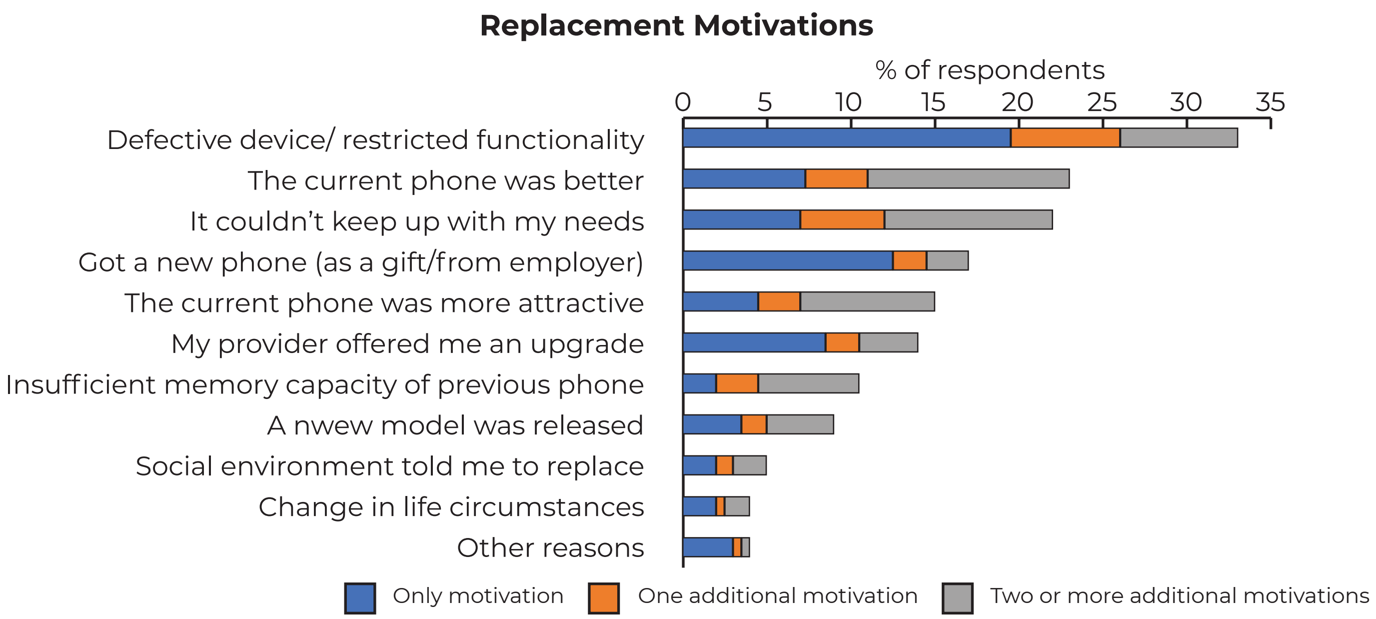




*Figure 3 - Replacement motivations in Austria (n=971) (Wieser & Tröger, 2018)*



## 2.2 Repair Behaviour

Repair is part of a wider spectrum of product care activities, which is defined as all activities undertaken by the consumer that lengthen the product's lifetime (Ackermann et al, 2018). Besides repair, this also includes maintenance to prevent defects, like cases or screen protectors. Where maintenance isanticipatory, repair is a reactive decision (Hernandez et al, 2020). The product care activities can be executed by either the consumer itself or an external service as addressed by (Ackermann, et al, 2018), who look into the aspects that influence consumers to take care of their product, based on Fogg's behaviour model (Fogg, 2009) (Figure 4).
Fogg's model is based around three factors: motivation, ability, and triggers. A user needs a motivation to take care, ability to do it, and triggers to bring about a repair action. In Table 3, different factors are listed, along with their effects on product care. The table is adapted from (Ackermann et al, 2018) for display repair performed by professional repairers. The pleasure and functionality a smartphone delivers, is related to the mental book value of the device and determines its utility value.

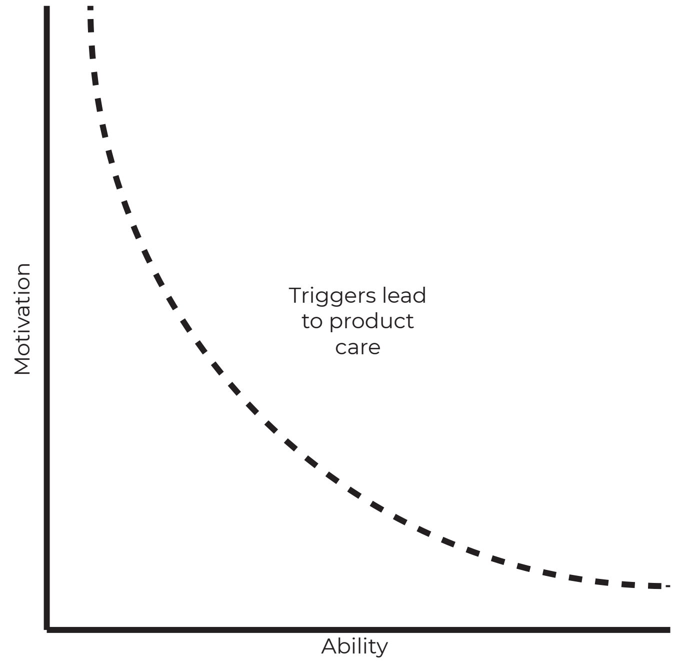



*Figure 4 - Specified Fogg's model based on the uncovered factors of motivation, ability, and triggers for product care (Ackermann et al, 2018)*

*Table 3 - Factors and their influence on repair behaviour, adapted from (Ackermann et al, 2018)*

| | **Factor** | **Definition** |
|---|---|---|
| *Motivation* | Financial aspects | High of-the-shelf value of the smartphone |
| | | Low spare parts price |
| | Intrinsic motivation | General attitude towards longevity |
| | Pleasure | Fun or joy provided by the smartphone |
| | Functionality | High functionality and therefore regular use of the smartphone |
| *Ability* | Awareness | User knows where and how to take care |
| | Time and effort | User has enough time to take care |
| | Repairability | The fact or the assumption that the product can (not) be repaired in general |
| *Triggers* | Appearance triggers | Product does not look nice anymore |
| | Social triggers | Influence of the social environment |
| | Previous repair experiences | Previous repair experience was positive |

Jaeger-Erben et al (2020) state that repair is not a one-time decision, but it relates to a process of constant valuation and devaluation of a product, its utility value (how well does it perform) and its trade value (what it is still worth if sold) in comparison to newer products. During this process, the ability, motivation, and triggers are important factors. Users are willing to repair (Sabbaghi & Behdad, 2018), yet there are a few reasons that draw people away from repairing their devices (Figure 5).

These reasons for not repairing can be linked to the product care model from (Ackermann et al, 2018), as described earlier. The trigger could be an appearance trigger, a social one or a positive previous repair experience. The reasons mentioned above can therefore be divided into either lack of motivations or lack of ability (Table 4). For users, the main barriers are:

**Time**: the time they don't have access to their own device
**Price**: the costs for repairing a smartphone
**Effort**: the effort it takes to have it repaired

The time barrier consists of reasons that have to do with the time it takes to get a smartphone repaired, the price barrier has to do with the costs associated with repair in relation to the extension of the lifetime and the effort barrier has reasons that have to do with the effort for the user associated with repair and the awareness of repair options.

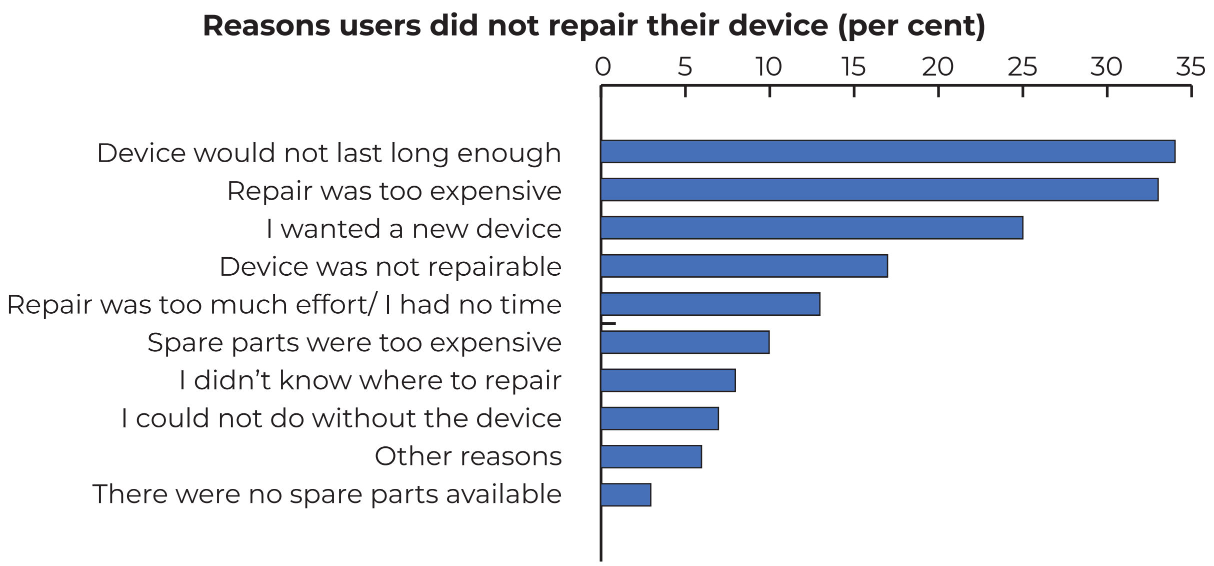



*Figure 5 - Reasons users did not repair their device (Jaeger-Erben & Hipp, 2018)*

*Table 4 - Barriers towards repair from the user*

| **Barrier** | **Reason** (Jaeger-Erben & Hipp, 2018) | **Behaviour** (Fogg, 2009) |
|---|---|---|
| *Time* | I could not do without the device | Ability |
| | Too much effort/I had no time | Ability |
| *Price* | Device would not last long enough | Motivation |
| | Repair was too expensive | Motivation |
| *Effort* | Too much effort/I had no time | Ability |
| | I didn't know where to repair | Ability |



Building upon the reasons that users had for not repairing their devices, are the reasons that a repair shop could not fix a smartphone. In a study among 2170 repair technicians in the US, (Sabbaghi et al, 2016) found the reasons that repair shops had for not being able to repair the device (Figure 6). Thus, for repair shops, the main barriers are:

**Repair time**: the time it takes them to repair one smartphone
**Cost**: the costs for spare parts
**Resources**: they don't have access to repair documentation or the right tools
**Availability**: of the spare parts, they either cannot get them at all, or it takes long to deliver

These barriers can also be linked to the reasons for not repairing and to the behaviour model (Table 5). The repair time barrier is made up of reasons that make the repair lengthier, the cost barrier is related to the price of the spare parts and the resources barrier has to do with the inaccessibility to the resources needed to repair the smartphone. The availability barrier has to do with either original spare parts not being available at all, or them having long delivery times.

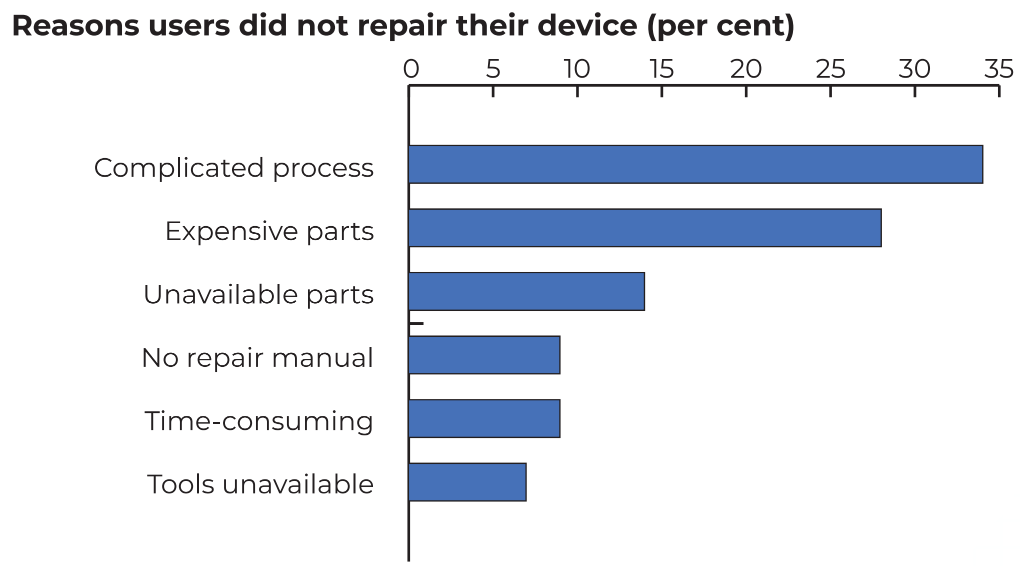



*Figure 6 - Reasons repair shops could not repair (Sabbaghi et al, 2016)*

*Table 5 - Barriers towards repair from the repair shop*

| **Barrier** | **Reason** | **Behaviour** (Fogg, 2009) |
|---|---|---|
| *Repair time* | Time-consuming repair | Ability |
| | Complicated process | Ability |
| *Cost* | Expensive spare parts | Motivation |
| *Resources* | No repair manual | Ability |
| | Unavailable tools | Ability |
| *Availability* | Unavailable spare parts | Ability |

## 2.3 Behaviour Model

The presented findings from the literature can be used to construct a decision-making model (Figure 7). Along this decision-making process, there are different factors at play. It starts with the different obsolescence types, after which users compare the mental book value of the current smartphone to the expected value and costs of the new smartphone, and this is input for the decision to repair or not. That decision to repair is ultimately made if the motivation, ability, and trigger are right.

The obsolescence of quality always occurs in cases with a broken display. Then it is the question whether psychological and/or economic obsolescence are adding to it. Economic and psychological obsolescence negatively influence the decision making, meaning they skew it towards replacement. Repair actions can be performed to battle the obsolescence types. A smartphone is brought to an improved state by repair, meaning the obsolescence of quality is reduced.
Before the repair is actually performed, the user compares the mental book value of their current smartphone with the expected value and costs of a potential new smartphone. This comparison results in input for the decision to repair, as motivation. The motivation can be driven by financial reasons, intrinsic motivation or the pleasure and functionality the user gets out of the smartphone. The pleasure and functionality are tied to the mental book value, while the intrinsic motivation can come from a range of reasons. Research into intrinsic motivation concluded that users seek challenge, control, cooperation or competition, curiosity, and recognition (Malone & Lepper, 1987). For stimulating repair, cooperation and recognition of the user's actions have potential, as repair is more sustainable than replacement and thus users can be made to feel their contribution.
Besides the motivations, the user needs to have the ability to repair, which is determined by the awareness of options, the time and effort a repair takes and the general repairability of the smartphone. A trigger is needed to set a repair in motion, a usual one is the sudden damage to the smartphone, yet with a more slowly degrading display the user needs something else. Other types of triggers for repair can be social triggers, an influence from the social environment, and positive previous repair experiences.

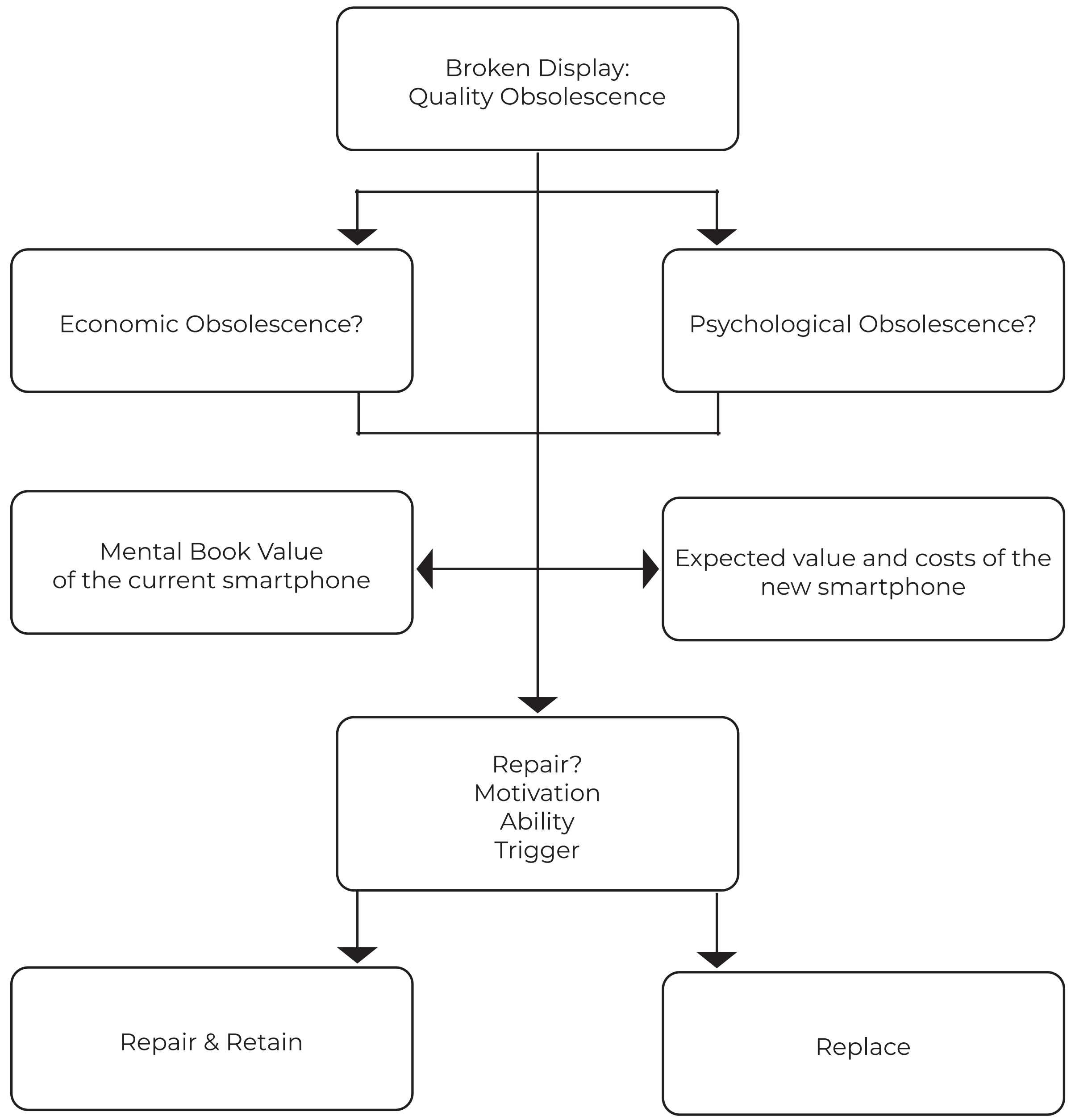



*Figure 7 - Decision making process, adapted from van den Berge et al (2021)*

## 2.4 Conclusions

So, in general, users replace their smartphones for a variety of reasons. When looking at the cases with a defective device, there are three types of obsolescence at play, for which their relationship is important; obsolescence of quality is the main type and always occurs for broken smartphones, while psychological obsolescence and economic obsolescence can add to that. Psychological obsolescence can render a defective smartphone obsolete if the user is abundantly satiated by using the device. Economic obsolescence can render it obsolete when the repair costs are high or when the costs for an alternative new device are low. Economic and psychological obsolescence need to be reduced to increase repair actions, which reduce obsolescence of quality by improving the state of the smartphone.

For users to consider repair as an option, they need motivation, ability, and a trigger. To make sure that they have that, certain barriers need to be taken away in the motivation and ability. Motivation barriers can be financial or intrinsic. Financial barriers are expensive repairs, or the disbelief in the device's proper continuation of its use, while intrinsic barriers come from wanting a new device. Intrinsic motivation can come from a general positive attitude towards longevity and can be stimulated by making users feel they contribute to a more sustainable world, as cooperation and recognition spark intrinsic motivation. Ability barriers are the lack of awareness of repair options, the time and effort it takes to repair, and the general lack of repairability in smartphones. This all means that repair needs to be affordable, accessible, and attractive to users. Affordability will stimulate the users' motivation to repair, as will the attractiveness. Accessibility will aim for the ability to repair, meaning the time and effort repair takes need to be reduced while the repair shops can be better equipped to handle repairs by improving their access to tools, manuals, and spare parts.

So, this begs a few follow-up questions to dive into in following chapters. Chapter 3 will investigate the reasons users find repair too much effort. Chapter 4 will find strategies to make repairs more accessible. Chapter 5 will investigate what makes smartphones competitive and thus how users can experience pleasure and functionality from a device for a long time, making repair more likely. Chapter 6 will dive into the general repairability of smartphones.



*Table 6 - Takeaways chapter 2*

| | Needs | Factor | Insights |
|---|---|---|---|
| ***Affordability*** | *Motivation* | Financial | Repair is too expensive |
| | | | The device would not last long enough |
| ***Accessibility*** | *Ability* | Awareness | Users don't know where to repair |
| | | Repairability | Repair is a complicated process |
| | | | Lack of access to manuals, tools, and spare parts for independents shops |
| ***Attractiveness*** | *Motivation* | Intrinsic | Making users feel they contribute can stimulate repair actions |
| | | Pleasure | Fun provided by the smartphone itself makes repair more likely |
| | | Functionality | High functionality of the smartphone makes repair more likely |
| | *Ability* | Time and Effort | Time consuming repairs for repair shops |
| | | | Costs user too much effort/ user had no time |
| | | | User could not do without the device |
| | *Triggers* | Previous repairs | Users with an earlier positive repair experience are more prone to repair |
| | | Social | The social environment has an influence on the decision to repair |

# 3 Smartphone Repair Options Analysis

To determine how repair can be stimulated, the current options are analysed. Firstly, the different repair options for the largest manufacturers are investigated, after which user input was generated to gain insights into what users consider to be desirable options. It is followed by mapping that information in a user journey map to determine where the limitations of the repair options originate.

## 3.1 Smartphone Repair Options

The largest manufacturers of smartphones in Europe are listed in Figure 8. A full year is selected to correct for differences in launch dates of new smartphones. The largest are Samsung (32.21%), Apple (32,11%), Huawei (13.57%), and Xiaomi (10,78%). Smaller ones are Motorola (1.56%), Oppo (1,34%), LG (1.13%), OnePlus (0.96%), and Sony (0.86%). A small percentage is unknown (1.29%). Huawei is on the decline, due to regulatory issues (CNET, 2021). LG has announced their withdrawal from the smartphone market (Techradar, 2021).

The repair options that are offered for different manufacturers are evaluated to investigate what the strengths and weaknesses are. The ten largest manufacturers all offer options for repairing smartphones, and they come in different forms. There are physical service centres, websites, customer service, and offering a service through a retailer, meaning the retailer takes in the phone and handles sending it in to the manufacturer. Next to the services offered by the manufacturer, there are two other options: a repair partner or an independent shop. Repair partners are companies such as Mediamarkt, Coolblue or Amac. This type of service is available for Samsung, Apple, Huawei, and Oppo. Lastly, there is the option to go to an independent shop for repair. These shops mostly have a physical location, yet there are also shops that offer the service by sending the phone in.

Considering these options, going to a store, either a manufacturer, partner, or independent shop, is the quickest option to get a smartphone repaired. If the user wants to repair at a shop, they need to travel to it. Figure 9 and Figure 10 show the locations of different types of repair shops in the Rotterdam-The Hague region. The options for Samsung repair at the manufacturer itself and with a repair partner are shown, where the blue pin stands for the manufacturer service centre and the orange pins for partners. The green pins represent independent repair shops.
It becomes apparent that the independent shops have a much larger occurrence rate than the stores from the manufacturer and the repair partners. This means the travel time to them is shorter, costing the user less time and effort to get to them. Independent shops in urban areas are well reachable within 15 minutes, while manufacturers and partners have less locations and they thus take longer to get to for more users. As will be further explored in the chapter 3.2, users perceive advantages and disadvantages to both options.

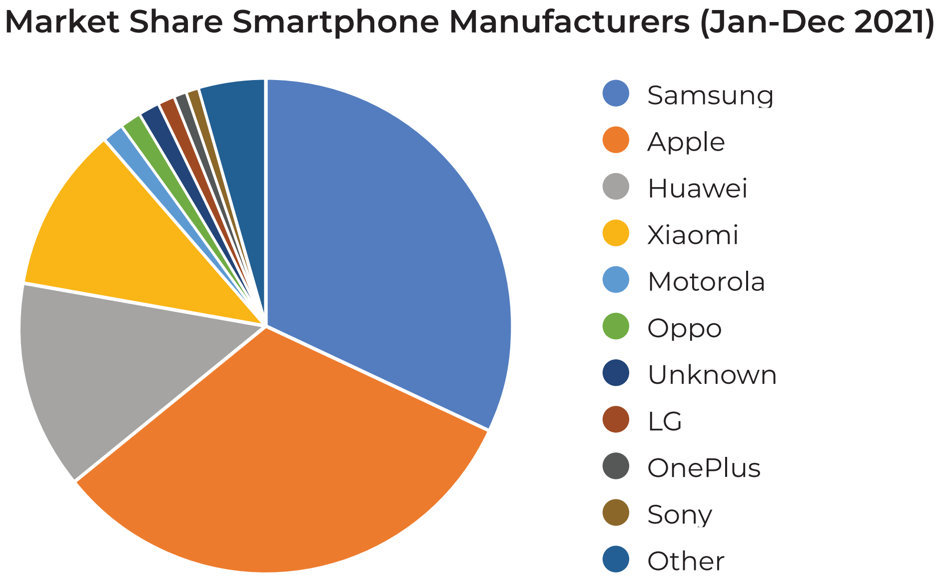



*Figure 8 - Market share of smartphones in Europe in 2021 (Statcounter, n.d.)*

*Table 7 - Repair options*

| | **Manufacturer** | **Repair partner** | **Independent shop** |
|---|---|---|---|
| *Samsung* | 1-2 hrs (store)/3 days | 1-2 hrs (store)/3 days | 1 hr (store)/3 days |
| *Apple* | 1-2 hrs (store)/6-8 days | 1-2 hrs (store)/3 days | 1 hr (store)/3 days |
| *Huawei* | 14 days | 1-2 hrs (store)/3 days | 1 hr (store)/3 days |
| *Xiaomi* | 14 days | - | 1 hr (store)/3 days |
| *Motorola* | Through retailer | - | 1 hr (store)/3 days |
| *Oppo* | 6-7 days | 1-2 hrs (store) | 1 hr (store)/3 days |
| *LG* | Through retailer | - | 1 hr (store)/3 days |
| *Oneplus* | 7-9 days | - | 1 hr (store)/3 days |
| *Sony* | Through retailer | - | 1 hr (store)/3 days |

**Samsung**

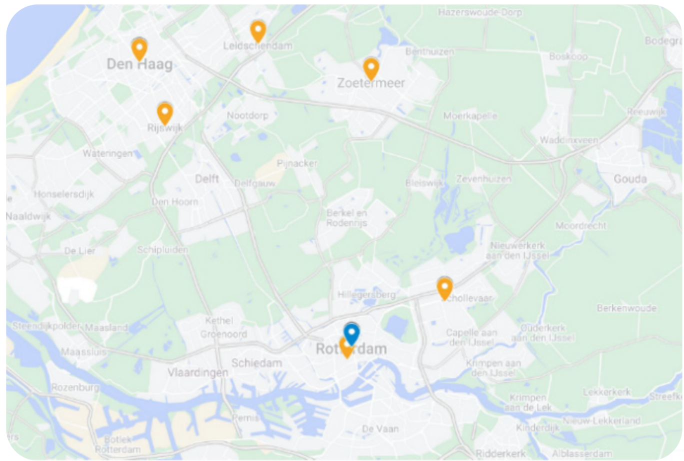


*Figure 9 - Samsung repair options in the Rotterdam-The Hague region (manufacturer and partners)*

**Independent Shops**

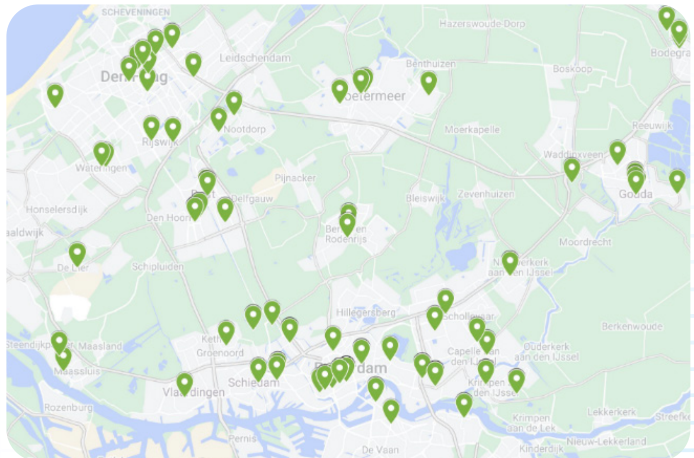


*Figure 10 - Independent shops in the Rotterdam-The Hague region*

## 3.2 User Assessment Repair Options

Users were asked to assess the existing repair options. A questionnaire was sent out to obtain data from 25 respondents to find out whether users are willing to repair and what options they do consider if they want to. The target group consists of young adults, since these are the heaviest smartphone users (Deloitte, 2019) and replace their smartphones earlier than other groups (Nolsoe, 2020). If they have repaired before, they were asked why they have done it and if they are not willing to repair, they were asked for their reasoning. The results from this analysis can be found in Appendix B, alongside a full description of the method.

Respondents were asked questions related to their repair behaviour of the past and their willingness-to-repair. Overall, the respondents are willing to repair, yet there is careful consideration in place. Respondents indicated that they, in correspondence with the behaviour model as introduced in chapter 2.3, compare the value of their devices to the expected value and costs of a new smartphone. Respondents indicated that they are generally willing to repair, but the costs are obstructing them. Other reasons can accelerate the decision to replace, such as receiving a new smartphone or just wanting a new one. The ease of replacing is also listed as a reason to choose replacement over repair.

The respondents were then asked which repair options they would consider and why. The repair options consist of the three professional options as identified in the market analysis and added to those are two options for self-repair: you do it yourself of have it done by a capable friend. Those results can be found in Table 8.

Where the manufacturer and the repair partner have the best service in terms of quality and warranty, they both have the disadvantage that they are perceived as expensive and taking a lot of time for a repair. The independent repair shop is perceived as a quicker, cheaper alternative, yet the respondents stated that they fear they repair with non-original parts and assume there is no warranty on the repair. This is not the case for all repair shops, yet the fact users perceive this to be the case means an unawareness of the available options. Repairing themselves or having it done by a friend that would be capable of it is sometimes perceived as an option, but it is stated that there is a high risk involved here and most respondents avoid it.

*Table 8 - Respondents' considerations of the different repair options*

| | **Manufacturer** | **Official repair partner** | **Independent repair shop** | **Friend** | **DIY** |
|---|---|---|---|---|---|
| *Considered by* | 17 | 19 | 17 | 9 | 7 |
| *Pros* | Quality | Quality | Quick | Low price | Low price |
| | Official parts | Quicker than manufacturer | Good price | Proximity | Challenge |
| | Warranty | Proximity | | | |
| *Cons* | Takes long | Takes long | No warranty | High risk | High risk |
| | High price | High price | No original parts | | Effort |

## 3.3 User Journey

Considering the trade-off between the time users must do without their device getting original spare parts, there are two repair options with minimised downsides:

- Sending in the smartphone to get it repaired with verified original parts
- Going to a repair shop in the vicinity to get it repaired with non-original parts

Although some manufacturers offer repairs in physical locations, they are very limited in their amount, even with the help of official repair partners. This limits the number of options there are for repair with original spare parts. Therefore, for these providers sending the smartphone in has been picked as a situation suitable for more users. The repair shops have the advantage of being more widespread, resulting in shorter travel times and more accessibility to users. This option is picked, with the sidenote that spare parts are not original. For both options, a customer journey map is created, showing what the steps are in repairing with that option, and where the disadvantages are to both.

Four different phases for repairing the smartphone are identified: searching, booking, repairing, and continuing use. Following are the steps the user must take, along with the time it takes them to perform them, and the touchpoints they encounter. The painpoints users experience along the journey are listed below.

Firstly, the journey map for the option of sending it in and having it repaired with original spare parts, it can be found on the following pages (figure 11). In this case, the user must find a repair option, book the repair, send their phone in, wait, pay, and receive their smartphone back to continue the use. After sending it in, it takes roughly three days for the fastest options available. This is a long waiting time to be without a smartphone and should be avoided, as the time and effort a repair takes deters users from repairing their smartphone. One way of having to spend less time without the device is to bring it to a repair shop in the vicinity.

Going to a repair shop (figure 12), the user must find a repair option, book it, go to the shop, deliver the phone, wait, receive the phone, and pay, travel back, followed by the continued use. Traveling takes about 15 minutes, while the waiting time is about an hour. Where with a repair from the manufacturer, original parts are used and there is prolonged warranty for the repair, this is not always the case with independent repair shops. This deters users from repairing their smartphone as it cannot deliver the reliability of a repair they are looking for.

# Manufacturer Repair

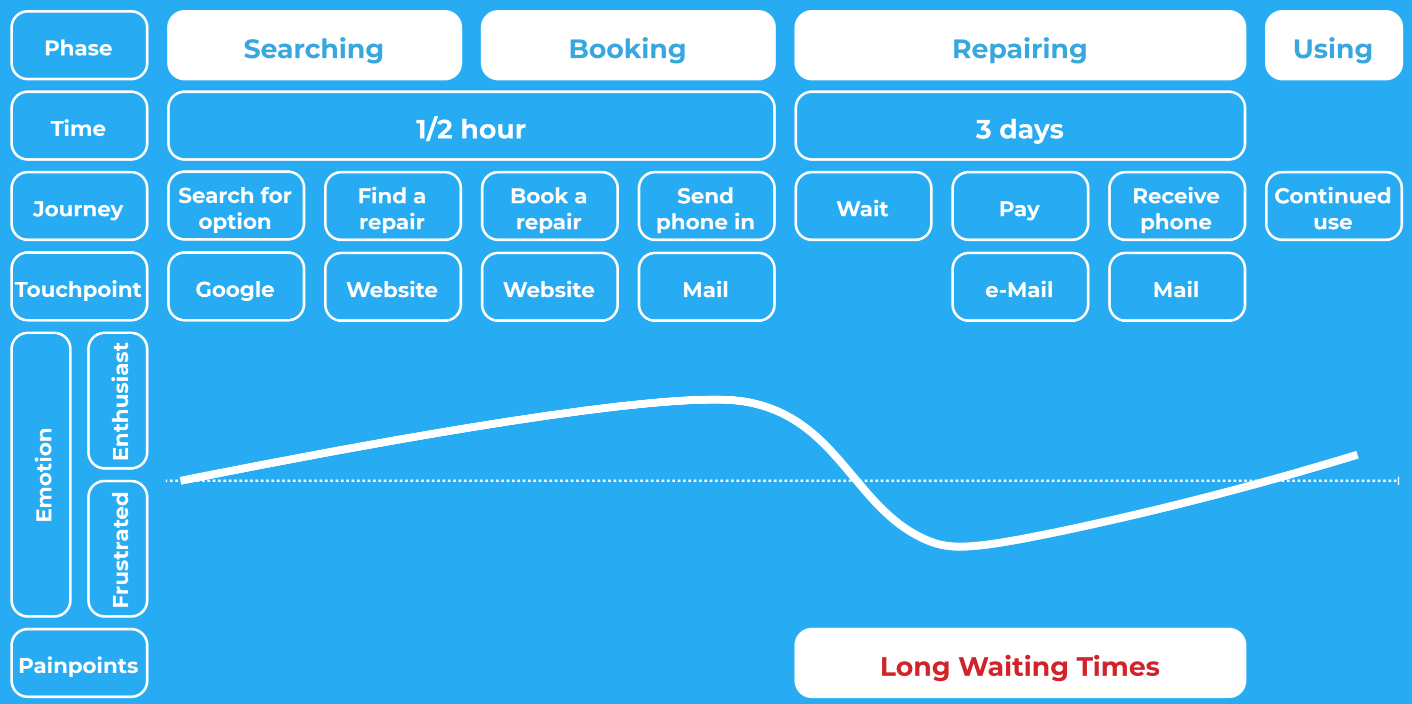



*Figure 11 - Journey map sending in for repair*

# Independent Shop Repair

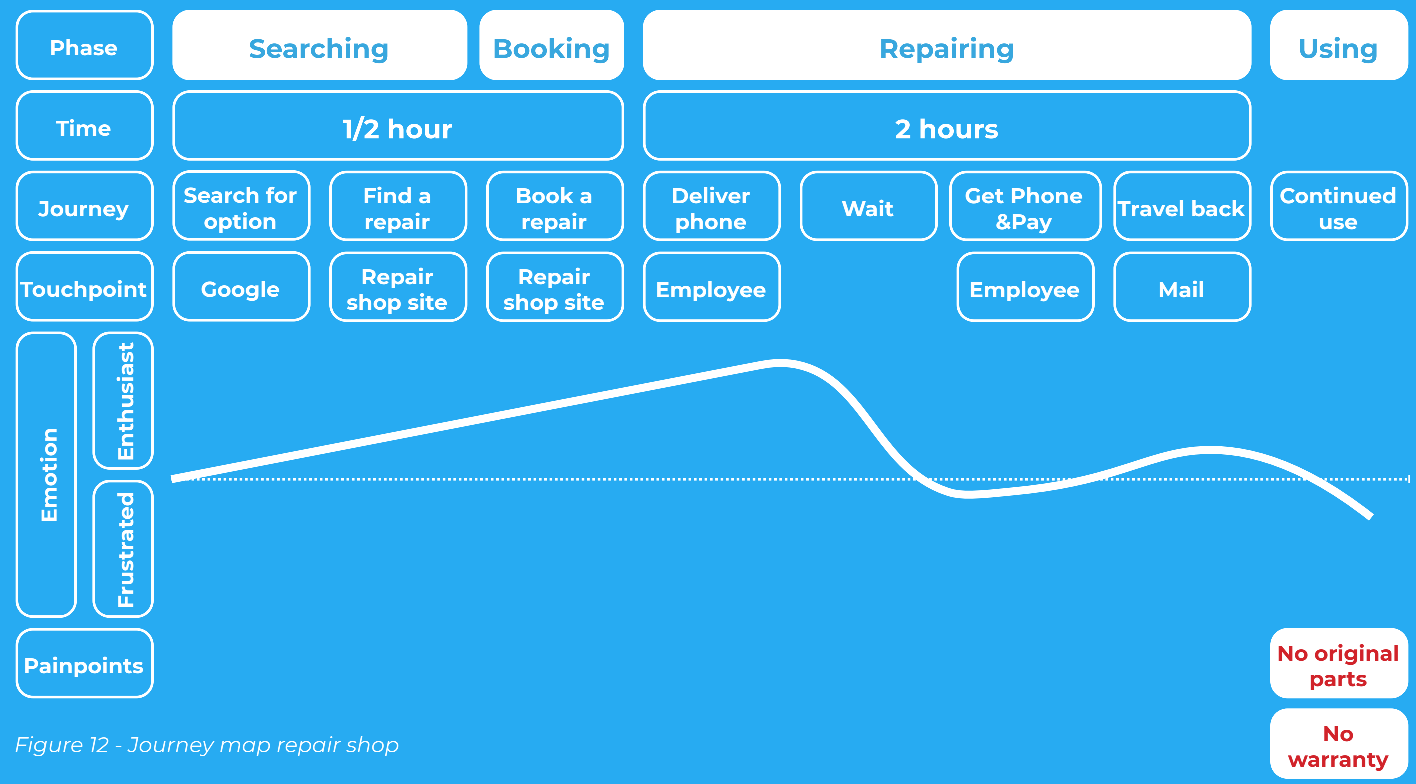



*Figure 12 - Journey map repair shop*

## 3.4 Conclusions

Once a smartphone is broken, the user has different options to repair it. The ten largest manufacturers all offer repair services in different forms, which can be divided into two main options: sending the smartphone in for a repair or going to a shop to have it repaired. The three largest manufacturers offer repair services in shops, either their own or official repair partners. Their number of locations is limited. Other offers for repair are provided by independent repair shops, which have a higher occurrence rate and are thus reachable for more users. Some of them also offer repairs by sending the smartphone in.

Users consider these professional options roughly the same, yet some advantages and disadvantages are noted for the options. The quality, the official parts and warranty are perceived as advantageous for manufacturers and repair shops, while users think that the downside is that it takes a long time to repair, and it is expensive. Independent repair shops are perceived to offer a quicker repair, for a better price than the manufacturers and repair partners. Users note they are not sure whether they get original parts and warranty.

The two main options for repair, sending it in or going to a shop, can be assessed by looking at the availability. The advantages of an official repair are available to everyone when sending it in, as going to a manufacturer shop or a repair partner shop takes some travel time for some users. Independent repair shops are in more places, and their advantage of quick repairs is best utilised when going to their shop. This means there are roughly two options that are widely available and utilise the advantages of that option best: sending it in for a repair to the manufacturer (or repair partner) or going to an independent repair shop.

Both options have their own shortcomings, which should be solved to make repair more popular. One option is to decrease the time it takes to send a smartphone in and deliver it back to the user, yet there is always some time lost in the transportation routes of the delivery. The other option is to increase the trustworthiness of the independent repair shops, by ensuring they use original parts, can give warranty, and advertise that to users. That way, manufacturers utilise the existing repair network of independent shops, while the value for the user is increased.

*Table 9 - Takeaways chapter 3*

| | Needs | Factor | Insights |
|---|---|---|---|
| ***Affordability*** | *Motivation* | Financial | Repair is too expensive |
| | | | Independent shops offer a good price |
| | | | Official repair options are expensive |
| ***Accessibility*** | *Motivation* | ***Trust*** | Users need reliable repair options |
| | *Ability* | Awareness | Users are not completely aware of the repair options |
| | | ***Network*** | Bringing repair closer to users means there is a need for a large repair network |
| | | Repairability | |
| ***Attractiveness*** | *Motivation* | Intrinsic | Users are willing to repair, but are deterred by high costs |
| | | Pleasure | |
| | | Functionality | |
| | *Ability* | Time and Effort | Independent shops are widespread, but seen as less reliable as they do not always deliver original parts and warranty |
| | | | Official repair options are seen as more reliable, but physical locations are thin spread and sending it in takes a long time |
| | *Triggers* | Previous repairs | |
| | | Social | |

# 4 Prolonged Smartphone Use

In this chapter, prolongment strategies for smartphones are listed and evaluated. Since the implementation of repairability in a smartphone should not result in it breaking more often, reliability is included in this chapter. The chapter concludes with what impact prolonging the use-times can have.

## 4.1 Prolongment Strategies

Cordella et al (2020b) identify two main strategies for prolongment of smartphone use: repairability and reliability. Huang et al (2016) make a case for more repairable devices and describe different ways of achieving that. Repair is more environmentally friendly than remanufacturing, refurbishing, and recycling, because it avoids complex processes to collect devices and return them to processing facilities, yet it must be noted that the logistics of spare parts would need to be enhanced, resulting in more emissions. Cordella et al (2020b) aim at making smartphones more reliable to reduce the occurrence of premature obsolescence and prevent early replacements.

Repairability, more specifically for the display, means that the display is removable in limited steps, and non-removable fasteners like adhesive are avoided (Cordella et al, 2020b). Schischke et al (2016) state that modular design concepts is crucial, as modularity increases the repairability of the smartphone, and thus longer product use-times. They state different levels of modularity (Table 10). For this thesis, the repair modularity is of most interest and is defined by easily exchangeable key components, such as the display and the battery.

Another main strategy for prolonging the use-time is increasing the reliability. It can prevent the need for a repair, or if a repair will be performed on the device, it can deliver reassurance that it will not break again within a short amount of time. It should focus on compliance to drop tests and IP68 (Cordella et al, 2020b). There is also interaction between repairability and reliability, meaning there are reliability measures that are conflicting with the repairability of the smartphone and vice versa. For both the drop test and the IP rating, strong adhesion of components is necessary, and this means that the device is harder to open and thus it is harder to repair (Cordellaet al, 2020b). There are also measures that are compatible with both strategies, such as scratch resistance, as well as providing documentation, tools, and spare parts to repair shops.

Two different smartphones, compatible with the different strategies can be compared to a more regular counterpart (Table 11). The Fairphone 4, which qualifies as a repairable smartphone with repair modularity, and the Cat S62 Pro, a smartphone with a high reliability, can be compared to a regular smartphone, the Oneplus Nord CE. It has a similar sized display and is loaded with similar specifications as the Fairphone and the Cat.

From the comparison, it can be concluded that both modularity and reliability have a size and weight penalty in relation to regular smartphones. The Fairphone is larger than its regular competitor due to internal module housing (Fairphone, n.d.) and different coupling methods. The Cat smartphone is larger because it has comprehensive drop test compliance and IP69 (Cat, n.d.), which means more protection all around the smartphone. The size and weight penalty means both strategies need to be balanced with the competitiveness of the smartphone.

*Table 10 - Modularity levels (Schischke et al, 2016)*

| **Modularity level** | **Characteristics** |
|---|---|
| *Add-on modularity* | Range of peripheral functionalities can be attached to a given core (display-CPU unit for example) |
| *Material modularity* | Some components, such as covers and batteries can be easily separated |
| *Platform modularity* | Product can be configured for a range of individual specifications; configuration requires a basic technical knowledge |
| *Repair modularity* | Key components, such as the battery and display, can be easily exchanged |
| *Mix & match modularity* | Range of specification for all modules, joint backbone and/or standardized module interfaces, maximum flexibility; includes repair modularity |

*Table 11 - Comparison Fairphone 4, Cat S62 Pro and Oneplus Nord CE 5G*

| | **Oneplus Nord CE 5G** | **Fairphone 4** | ***Difference*** | **CAT S62 Pro** | ***Difference*** |
|---|---|---|---|---|---|
| |  |  | |  | |
| | *(DxOMark, 2021)* | *(Fairphone, n.d.)* | | *(Cat, n.d.)* | |
| *Price* | €329 | €579 | +76% | €629 | +91% |
| *Display* | 6.43 inch | 6.3 inch | | 5.7 inch | |
| *Length* | 159.2 mm | 162 mm | +2% | 158.5 mm | 0% |
| *Width* | 73.5 mm | 75.5 mm | +3% | 76.7 mm | +4% |
| *Thickness* | 7.9 mm | 10.5 mm | +33% | 11.9 mm | +51% |
| *Weight* | 170 g | 225 g | +32% | 248 g | +46% |

## 4.2 Environmental Impact

The environmental impact of smartphone use is given as the carbon footprint, which is measured in kg CO2 equivalent (kgCO2e), which encompasses the total greenhouse gas (GHG) emissions. There are seven greenhouse gasses which contribute to climate change according to the Kyoto Protocol (IPCC, 2007), they are: Carbon Dioxide (CO2), Methane (CH4), Hydrofluorocarbons (HFCs), Nitrous Oxide (N2O), Perfluorocarbons (PFCs), Sulphur Hexafluoride (SF6) and Nitrogen Trifluoride (NF3). It encompasses the total global warming effect of all these gasses, specified as the mass of CO2 that has the equivalent effect. The carbon footprint of smartphones can be divided into three different categories: manufacturing, distribution, and use.

The environmental impact is analysed for a range of smartphones from the largest manufacturers of the market analysis (Figure 13). Data is acquired for Apple (Apple, n.d.), Huawei (Huawei, n.d.), and Sony (Ercan et al, 2016), while for the rest of the manufacturers LCA data is unavailable. Only the high-end smartphones are included, and from those the base models with the minimal storage option, yet higher storage options have a higher carbon footprint (Apple, n.d.). The data is corrected to display the same use-time of 2.7 years.

Aside from the division in phases, there are also different parts that contribute in different amounts to the carbon footprint during the manufacturing. These are not specifically defined for all analysed smartphone models, yet an estimate can be constructed from the analysis of the Sony Xperia Z5, since Ercan et al (2016) distinguish the emissions per part (Figure 14).

Since the internal circuitry takes up the majority of smartphone emissions, it is key that those remain in use. The rest of the components contribute significantly less towards the carbon footprint, and it makes sense environmentally to replace those when they are broken. For further calculations into how much can be saved with longer use-times and repairs, the averages of the smartphones mentioned in Figure 13 are used (Table 12).

*Table 12 - Averaged carbon footprints of smartphones*

| | Carbon footprint (kgCO2e) |
|---|---|
| *Manufacturing* | 58.9 |
| *Distribution* | 3.5 |
| *Yearly use* | 2.8 |
| *Display repair* | 4.4 |
| *Battery repair* | 1.8 |

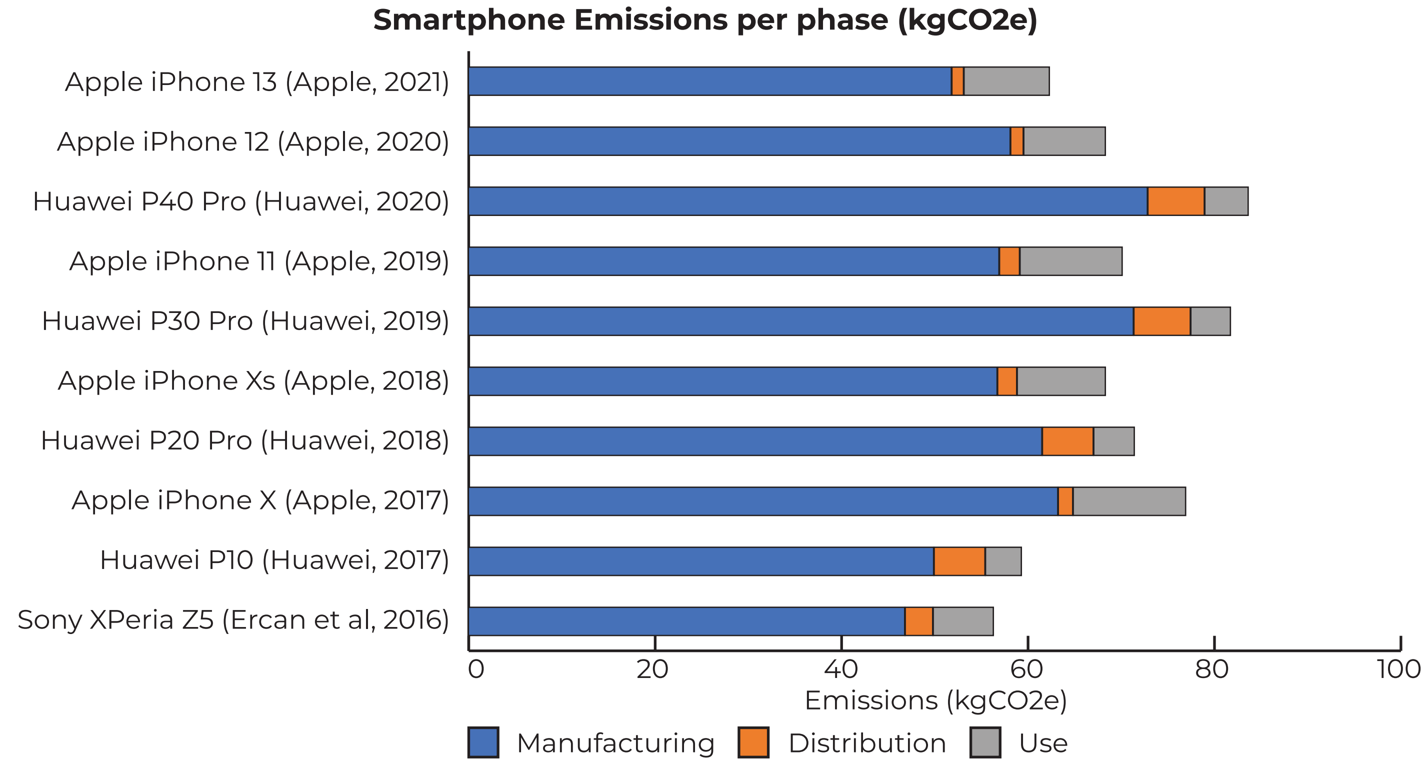



*Figure 13 – Smartphone emissions per phase (kgCO2e)*

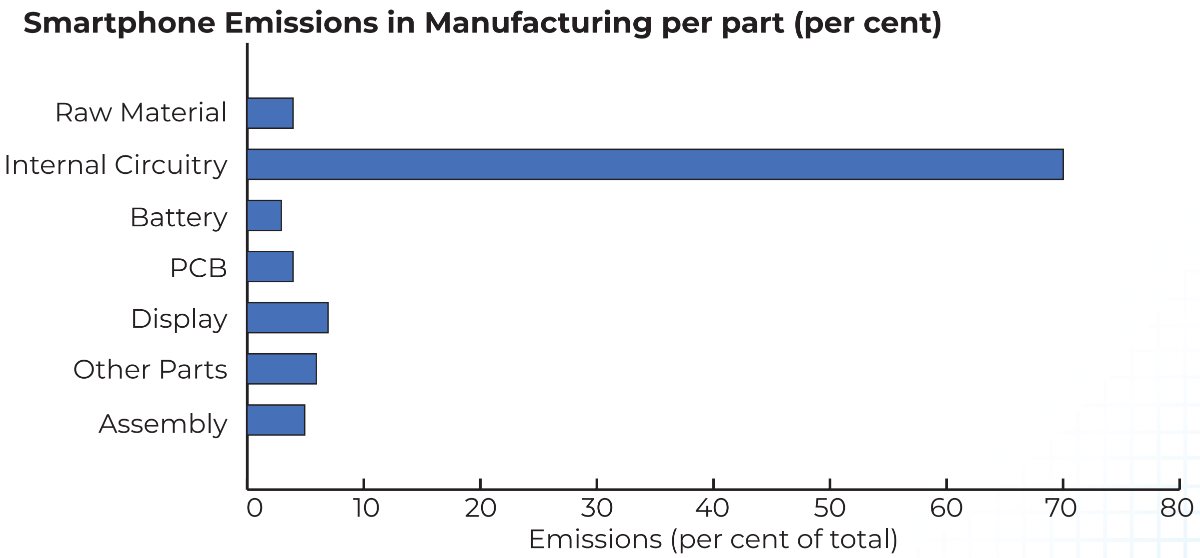



*Figure 14 - Smartphone emissions by part (Ercan et al, 2016)*

Having the averages of the carbon footprint for different phases, and for the display repair, the yearly impact of the smartphone use can be calculated (Table 13). (Benton et al, 2015) propose a method of calculation for the yearly impact, which is used; taking the impact of the raw materials, production and transport and dividing over the number of years the smartphone is used and adding to that the yearly emissions of the use phase. Figure 16 shows the decreasing yearly impact over the number of years the smartphone is used.

When calculating with a repair action, the impact of the replaced component is added. For the use-time, 2.7 years is used for the current situation, and this is compared to one year of extra use and to the expected use time of 5.2 years (Wieser et al, 2015). The baseline consists of the total of the manufacturing and the distribution phase (62.4 kgCO2e), then it is divided over the total use-time in years, after which the yearly emissions of the use phase are added (2.8 kgCO2e).

For the longer use-times, the same totals for manufacturing, distribution and use are utilised, and the use in years is higher, resulting in a lowered yearly impact and thus a GHG emission saving. A display replacement requires the use of spare parts, so the manufacturing and distribution emissions of the spare part have been added in repair scenarios. Using a smartphone for longer, reduces the yearly impact, since the manufacturing and distribution footprints can be divided over a higher number of years. One year of extra use, with a display replacement reduces the yearly emissions by 20%. If the lifetime could be extended to what users expect their smartphone could last, 5.2 years (Wieser et al, 2015), the savings could even be around 40%.

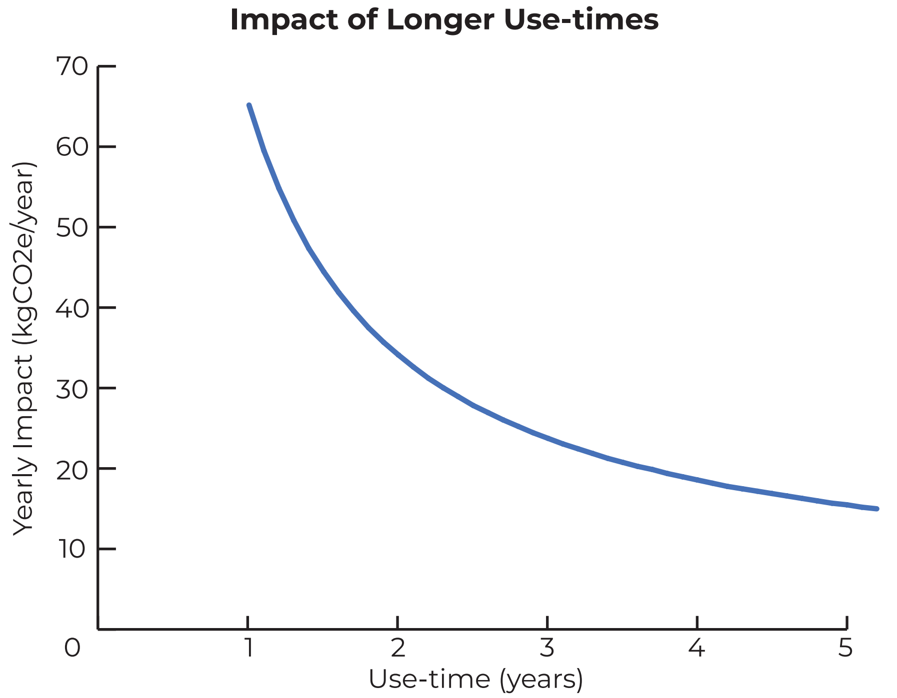



*Figure 15 - Impact of longer use-times without a repair*



*Table 13 - Emission savings with a longer use of smartphones*

| Scenario | Use (years) | Impact per year of use (kgCO2e/year) | GHG emissions saved (%) |
|---|---|---|---|
| *Average use* | 2.7 | 25.9 | |
| *Extra year* | 3.7 | 19.7 | 24 |
| *Extra year with display replacement* | 3.7 | 20.8 | 20 |
| *Extra year with battery replacement* | 3.7 | 20.1 | 22 |
| *Extra year with display and battery replacement* | 3.7 | 21.3 | 18 |
| *Longer life* | 5.2 | 14.8 | 43 |
| *Longer life with display replacement* | 5.2 | 15.6 | 40 |
| *Longer life with battery replacement* | 5.2 | 15.1 | 42 |
| *Longer life with display and battery replacement* | 5.2 | 16.0 | 38 |

## 4.3 Conclusions

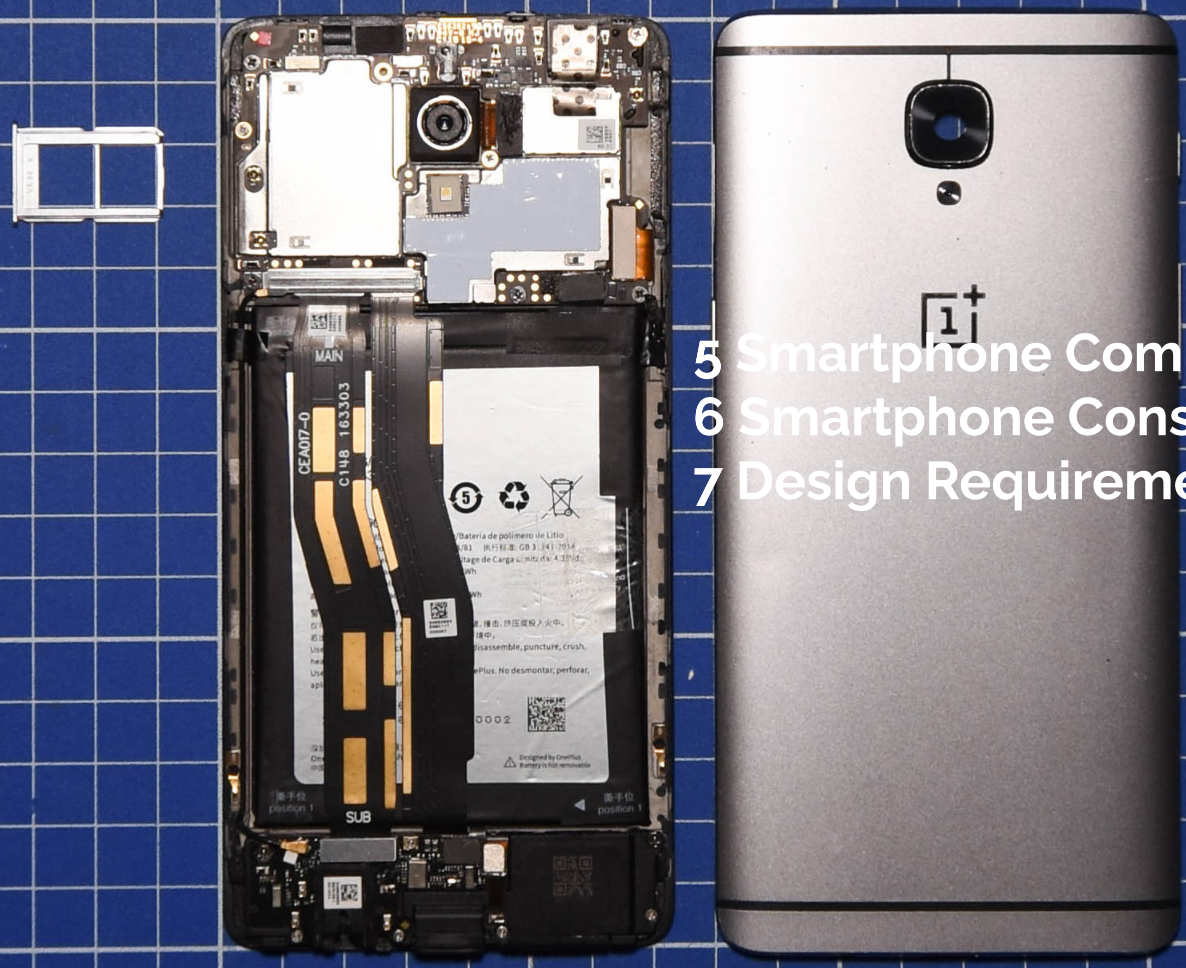
Prolongment of smartphones can be accomplished by implementing either repairability or reliability strategies, or a combination of both. This also needs careful balancing with the competitiveness of the device, but there is promise in a smartphone that would last long and can be repaired when it breaks.

Most of the carbon footprint of a smartphone stems from the manufacturing phase, and the IC is the componentry with the largest impact on the footprint. The rest of the components have a relatively low impact and are thus eligible for repair to ensure the preservation of the IC. Using a smartphone for an extra year by replacing the display reduces the yearly impact on the environment by one-fifth.

*Table 14 - Takeaways chapter 4*

| | Needs | Factor | Insights |
|---|---|---|---|
| ***Affordability*** | *Motivation* | Financial | |
| ***Accessibility*** | *Motivation* | Trust | |
| | *Ability* | Awareness | |
| | | Network | |
| | | Repairability | Repairability is a strategy for prolongment |
| ***Attractiveness*** | *Motivation* | Intrinsic | Display repair and one more year of use saves 20% of GHG emissions |
| | | Pleasure | Prolongment strategies need to be balanced with competitiveness of the smartphone, it still needs to be desirable |
| | | Functionality | Reliability is a strategy for prolongment |
| | *Ability* | Time and Effort | |
| | *Triggers* | Previous repairs | |
| | | Social | |

# Define



# 5 Smartphone Competition

The proposed strategies for prolonging smartphone use-time, repairability and reliability, need balancing with the competitiveness of the smartphone, so an analysis of what makes a smartphone competitive is needed. This chapter aims at answering RQ4 and looks at the competitive landscape of smartphones and at what specifications a smartphone should possess to be competitive.

## 5.1 Competitive Landscape

The manufacturers as identified in chapter 3 have been rated on the range of smartphones they are making, whether they are considered low-end or high-end smartphones, and on the repairability of the devices (Figure 16). Low-end versus high-end was determined by looking at the specifications and the price of the smartphone. The repairability is equal to the score the smartphones have gotten on iFixit (iFixit, n.d.). Since older phones are no longer representative for the current way of operating of the manufacturer, they have been excluded. Cordella et al (2020a) argue that smartphones have a potential to last about 5 years, which means that smartphones from 2018 and onwards could still be in use or bought and have some life in them in some cases, so they are analysed. Because the repairability scores from iFixit are used, there are some manufacturers missing from the analysis, since there is no score for them for the relevant smartphone models.

Since only smartphones that have been previously analysed on the iFixit website are included, there are gaps in this analysis. Looking at the figure, there are two things that seem to be missing, being low-end hard to repair smartphones and high-end repairable smartphones. The reason for the low-end smartphones blind spot is that iFixit tends to analyse flagship models. There are low-end smartphones available, yet they have not been rated by iFixit and thus are not included in the competitive landscape map. It is unlikely that they would equal the repairability scores of Fairphone and Shift though, since construction of the low-end devices shows more similarities to the high-end counterparts of their manufacturers than to repairable smartphones.

The other gap is high-end smartphones that are repairable. There are opportunities in this area, while the question remains on why this gap exists. Part of the reason is that both Fairphone and Shift do not have the research and development departments to match large manufacturers like Samsung or Apple, so managing to create a competitive deal in that area is hard. Fairphone sold almost 95,000 smartphones in 2020 (Fairphone, 2020), compared to the almost 200 million smartphones sold by Samsung in the same year (Goasduff, 2021). Meanwhile, this means that large manufacturers are not offering repairable smartphones, while they certainly could develop them.

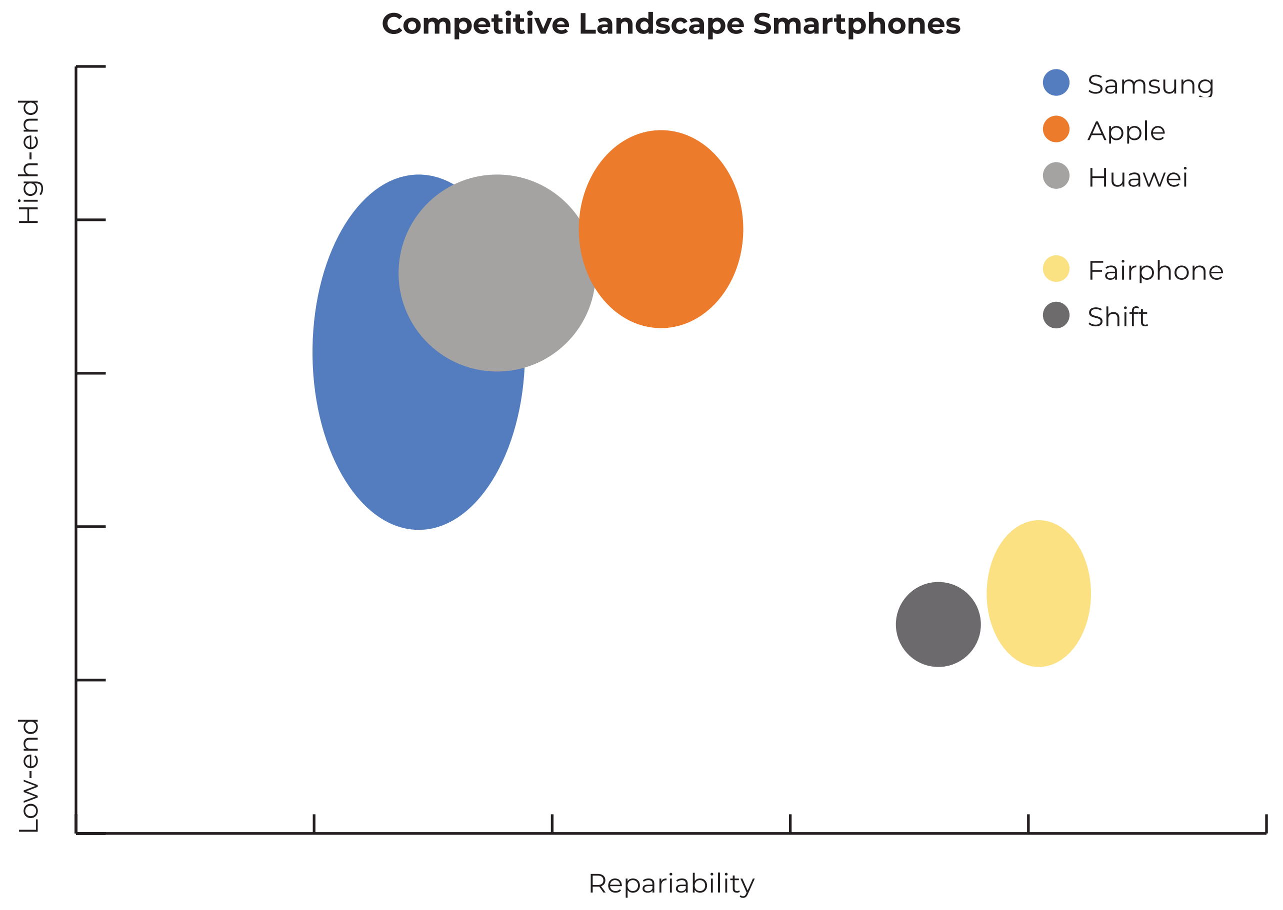



*Figure 16 - Competitive landscape map Smartphones, Repairability vs quality*

## 5.2 Smartphone Specifications for Competitiveness

Then the question arises how high-end smartphones can be made more repairable, while competing with other smartphones in the same market. To figure out what makes high-end smartphones competitive, different models from the largest manufacturers are analysed (Table 15). High-end models were the starting point and chosen are the base-model high-end smartphones. That means ultra, plus, pro max, and foldable models are not considered. Smartphones from the largest manufacturers from chapter 3 have been included, except from LG as they have stopped making smartphones. The specifications are compared to those of the Fairphone 4 as well, to investigate what the differences are.

Looking at the competitive field of high-end smartphones, a lot of similarities arise, and some differences. It must be noted that Apple is on a different operating system and therefore the specification of the smartphone has different needs. Its apparent lower specs results in similar or better performance. The differences of these smartphones to the Fairphone 4 are largely in the display, the size, the CPU, and the IP rating. It uses a different display technology, that is also less expensive to replace than others, and it has a lower-end CPU than smartphones in the high-end market. Because of its repairability, it is larger than others and with the removable rear cover and easily replaceable display the IP rating is lower.

*Table 15 - Comparison high-end smartphones*

| | **Samsung Galaxy S21** | **Apple iPhone 13** | **Huawei P40 Pro** | **Xiaomi Mi 11** | **Motorola Edge 20 Pro** | **OPPO Find X3 Neo** | **Oneplus 9** | **Sony Xperia 5 III** | **Fairphone 4** |
|---|---|---|---|---|---|---|---|---|---|
| |  |  |  |  |  |  |  |  |  |
| | *(Samsung, n.d.)* | *(Apple, n.d.)* | *(Huawei, n.d.)* | *(Xiaomi, n.d.)* | *(Motorola, n.d.)* | *(Oppo, n.d.)* | *(Oneplus, n.d.)* | *(Sony, n.d.)* | *(Fairphone, n.d.)* |
| *Price* | €779 | €909 | €679.99 | €749 | €699 | €699 | €689 | €999 | €579 |
| *Dimensions* | 151.7 x 71.2 x 7.9 mm | 146.7 x 71.5 x 7.7 mm | 158.2 x 72.6 x 8.95 mm | 164.3 x 74.6 x 8.06 mm | 163.4 x 76.1 x 7.99 mm | 159.9 x 72.5 x 7.99 mm | 160.2 x 74.2 x 8.7 mm | 157 x 68 x 8.2 mm | 162 x 75.5 x 10.5 mm |
| *Weight* | 171 g | 173 g | 209 g | 196 g | 189 g | 184 g | 192 g | 168 g | 225g |
| *Display* | 6.2" Full HD AMOLED | 6.1" Super Retina XDR | 6.58" OLED | 6.81" AMOLED | 6.67" OLED | 6.55" AMOLED | 6.55" Full HD AMOLED | 6.1" HDR OLED | 6.3" full HD IPS |
| *Battery* | 4000 mAh | 3095 mAh | 4200 mAh | 4600 mAh | 4500 mAh | 4500 mAh | 4500 mAh | 4500 mAh | 3905 mAh |
| *Cameras* | 12 MP<br>12 MP wide<br>64 MP tele | 12 MP<br>12 MP wide | 50 MP wide<br>40 MP ultra-wide<br>12MP tele | 108 MP wide<br>13 MP ultra-wide<br>5MP tele | 108 MP<br>16MP wide<br>8MP tele | 50MP<br>16MP wide<br>13MP tele | 48 MP<br>50 MP wide | 12 MP<br>12 MP tele<br>12 MP wide | 48 MP<br>48 MP ultra-wide |
| *Storage* | 128GB | 128GB | 256GB | 128GB | 256GB | 256GB | 128GB | 128GB | 128GB |
| *RAM* | 8GB | 4GB | 8GB | 8GB | 12GB | 12GB | 8GB | 8GB | 6GB |
| *CPU* | 2.9 GHz Octa core | Hexacore | Octa core | 2.9 GHz Octa core | 3.2 GHz Octa core | 2.8 GHz Octa core | 2.9 GHz Octa core | 2.9 GHz Octa core | 2.2 GHz Octa core |
| *Connectivity* | 5G, eSIM | 5G, eSIM | 5G, eSIM | 5G | 5G | 5G | 5G | 5G | 5G |
| *IP rating* | IP68 | IP68 | IP68 | ≈IP68* | IP52 | IP68 | IP68 | IP68 | IP54 |

** Xiaomi Mi11 does not have an official rating, yet manufacturer claims are similar to IP68*



## 5.3 Conclusions

There are opportunities in manufacturing high-end repairable smartphones, yet this is not on the market as is. For it to compete with other high-end smartphones, such a device would need specifications that match or exceed those, listed in Table 16 . From these specifications, there are elements that influence repairability and reliability.

The limited thickness makes implementing repairability and reliability measures more difficult, but it is not impossible. The IP ratings the high-end smartphones feature have a positive effect on reliability. The architecture of smartphones, and what that means for repairability and reliability, is further analysed in chapter 6.

*Table 16 - Takeaways chapter 5*

| | **Needs** | **Factor** | **Insights** |
|---|---|---|---|
| ***Affordability*** | *Motivation* | Financial | |
| ***Accessibility*** | *Motivation* | Trust | |
| | *Ability* | Awareness | |
| | | Network | |
| | | Repairability | There are opportunities in offering repairable smartphones, making repair more accessible |
| ***Attractiveness*** | *Motivation* | Intrinsic | |
| | | Pleasure | |
| | | Functionality | There are specifications are repairable smartphone needs to be competitive:<br>1. The price should be between €800-100<br>2. The display should be 6-6.5 inches large, at 1080p at least<br>3. Needs to be less than 10mm thick<br>4. Needs to be as thin as possible<br>5. The battery needs to be at least 4000 mAh<br>6. Needs to feature at least two cameras; a standard and wide-angle<br>7. Is preferred to feature a third camera; with a tele lens<br>8. Needs to have 128gb storage at least<br>9. Needs to have 8gb of RAM at least<br>10. Need to have a top-of-the-line CPU<br>11. Needs to have IP54 at least<br>12. Is preferred to feature IP68<br>13. Needs to feature 5G connectivity |
| | *Ability* | Time and Effort | |
| | *Triggers* | Previous repairs | |
| | | Social | |

# 6 Smartphone Construction Analysis

A technological analysis into smartphone componentry and construction methods was conducted to find an answer to RQ5 and find out how smartphones are built and what effects that has on the repairability, reliability and competitiveness of the devices. The chapter will start off with smartphone architecture, identifying the different parts in a smartphone and analysing the methods of construction. That will be followed by a repairability-reliability-competitiveness analysis of the different combinations of construction found in contemporary smartphones.

## 6.1 Smartphone Architecture

The smartphone architecture is examined in four different steps; identification of the components, investigation of different chassis types, looking into different methods of constructing components to the chassis and inspecting different ways components communicate. The identification of components is the first step since it determines what options to examine in the following steps. The chassis types are an important choice which will affect the construction of the whole smartphone. The different methods of attaching components, both constructional and electronical, is the final step in tying the components together. For this analysis, a teardown of 11 smartphones was conducted, as well as a further analysis of 63 models from the iFixit website (iFixit, n.d.). There is overlap in the models selected between the self-performed teardown analysis and the ones from iFixit. The analysis can be found in Appendix C.

From the analysis, it becomes apparent that most smartphones consist of at least the following main components, as can be seen in Figure 17:

- Chassis
- Display
- Rear cover
- Motherboard
- Battery
- Cameras
- Ports

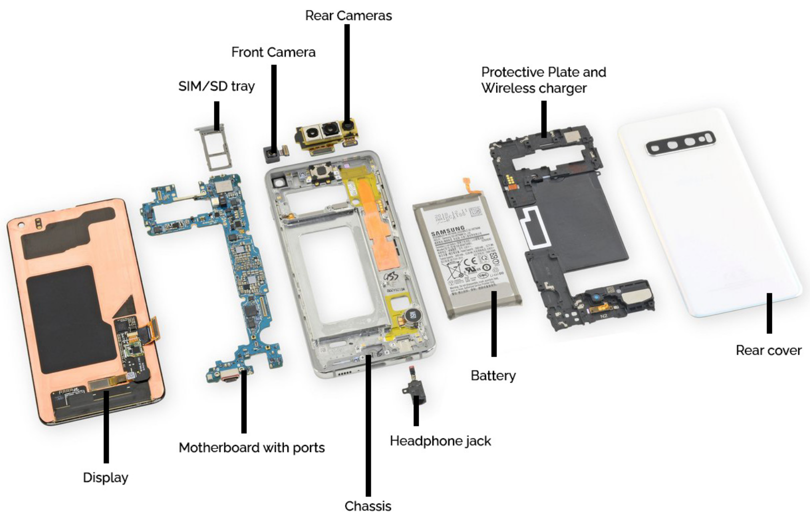



*Figure 17 - Smartphone parts, Samsung Galaxy S10 (iFixit, 2019)*



The methods of construction for all these components are analysed, yet since the focus of this thesis will be on display repair, two parts are of main interest: the display itself, and the chassis. The chassis types are assessed, because it determines what the display is attached to and what components are easily accessible for repair. The three methods for constructing the chassis of a smartphone from the analysis are: inner chassis, rear chassis, or display chassis (Table 17).

The downside of the display chassis is that all parts of the smartphone are attached to the display, making replacing it a lot of work. The rear chassis does not have this disadvantage but trying to repair anything other than the display means removing the display and it is thus vulnerable. The inner chassis offers the most options in terms of repairing, yet in most phones it still requires removing the rear cover first to disconnect it and remove the display.

*Table 17 - Chassis options*

| **Inner chassis** | **Rear chassis** | **Display chassis** |
|---|---|---|
|  |  |  |
| *Figure 18 - Inner chassis Samsung Galaxy S10 (iFixit, 2019)* | *Figure 19 - Rear chassis Apple iPhone 12 Pro (iFixit, 2020)* | *Figure 20 - Display chassis Oneplus 6 (iFixit, 2018)* |
| The chassis is placed in between the display and other components. One side is closed off by the display, the other by the rear cover | The chassis encloses all components, it is closed off by the display | The components are attached to the display, it is closed off by the rear cover |

Next to the construction of the chassis of the smartphone, four different options arose from the analysis for connecting the display of a smartphone to the chassis and the rest of the components (Table 18).

Screws are a good way of connection if the smartphone needs to be opened and reassembled. Adhesive is often used when smartphones are compliant to drop tests and IP ratings, yet it makes detaching the display and replacing it harder. There are different adhesives on the market though, and some are harder to remove than others. Clips are not a common method, as the only analysed phone that uses it is the Fairphone2, yet it makes removing the display easy. The difference between fused and adhered is with adhesive the process is reversible and it can be removed with some effort, while with a fused chassis and display this is not possible without damaging the fragile display. As stated earlier for the display chassis, fusing the display to a chassis in a display assembly is not a repairable approach, as it requires removing all the other parts to replace the display.
For adhesive, there are multiple different types available, and they each have different characteristics (Table 19.).

Firstly, there is 'regular' adhesive, this is the type that is used in most smartphones with an IP68 rating. The downside to this type is that it is very tough, and it takes time and effort to remove, while risking breaking the rear cover or the display. There is an alternative for this, a foam type adhesive that is just as waterproof, yet it is a little easier to remove when in need of a repair. Finally, there are pulltabs that can be attached to adhesive. This is a stretch-type adhesive and can be removed by pulling it from one end. It is mostly used for attaching batteries and is tough but can be removed without costing too much time and effort. Adhesive usually needs heating before it can be removed, and this is true for the first two types, yet heating a battery is risky and for that reason pulltabs can be used.

Besides the construction of the smartphone, the components need to communicate with one another. That can be achieved by a range of different options, shown in Table 20.

Press-fit sockets are a common method in contemporary smartphones, and are often utilised for attaching the display, the battery, or the daughterboard to the motherboard. The pogo pin connector is more durable and easier to detach and attach, yet it takes up more space than a press-fit socket. Contact pads are often used to attach the vibration motor and different buttons to the motherboard. Finally, there is including it on the motherboard itself, which is often done for the SIM card slot, and sometimes for the charging port. For the charging port, this poses a repairability issue, because replacing it is nearly impossible when it breaks, and it is a component that sometimes malfunctions.



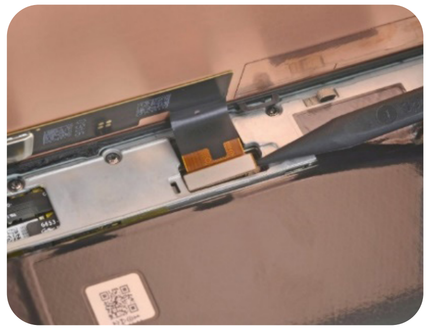
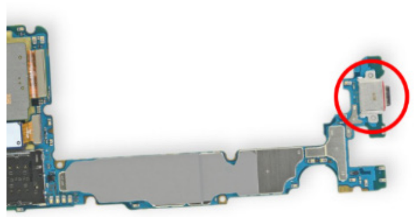
*Table 18 - Construction options*

| **Screws** | **Adhesive** | **Clips** |
|---|---|---|
|  *Figure 21 - Screws for display in the Apple iPhone 6 (iFixit, 2014)* |  *Figure 22 - Adhered display of the Samsung Galaxy S10 (iFixit, 2019)* |  *Figure 23 - Sliding clips on the Fairphone 2 (iFixit, 2015)* |

*Table 19 - Types of adhesives found in smartphones*

| **'Regular' adhesive** | **Foam adhesive** | **Pulltabs** |
|---|---|---|
|  *Figure 24 - Adhesive Galaxy S10 (iFixit, 2019)* |  *Figure 25 - Foam adhesive Pixel 3 XL (iFixit, 2018)* |  *Figure 26 - Pulltabs iPhone 11 (iFixit, 2019)* |

*Table 20 - Connector options*

| **Press fit sockets** | **Pogo pin connector** |
|---|---|
|  *Figure 27 - Press-fit socket Google Pixel 5 (iFixit, n.d.)* |  *Figure 28 - Pogo Pin Connector Fairphone3 (iFixit, 2019)* |
| **Contact pads** | **Soldered on logic board** |
|  *Figure 29 – Contact Pads (iFixit, 2018)* |  *Figure 30 – USB port on motherboard Samsung Galaxy S10 (iFixit, 2019)* |

## 6.2 Assessment of Construction Methods

This section addresses the repairability and reliability aspects of the construction methods, as well as the consequences for the competitiveness of the smartphone. Different methods of connecting the display and chassis are examined, and conclusions are drawn on the effects (Table 21.). The icons with colours indicate the effects on respectively the repairability, reliability, and competitiveness, from red being negative to green being positive. The smartphones in the table have been chosen as examples for the corresponding category.

Not every option shown is occurring as often. Most contemporary smartphones with IP-ratings utilise adhesives to accomplish that and are constructed with either a rear or an inner chassis. Screws to attach the display are becoming less common, yet it is used in repairable smartphones, as shown by the Fairphone 3. Apple also uses screws, albeit in combination with adhesive. Clips can only be found in the Fairphone 2.

For repairability, using screws to attach the display is positive, as it is an easily re-usable fastener. The display chassis method on the other hand has a negative effect on repairability, because all the components are attached to a display-chassis combination. This mean all components must be removed to replace the display. An inner or rear chassis in combination with adhesive makes removing it a bit harder, but professional repairers are perfectly capable of this. Finally, clips make removing the display easiest, yet it has a trade-off as will be discussed later.

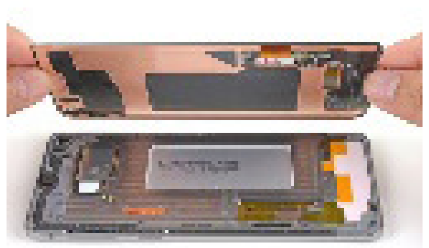
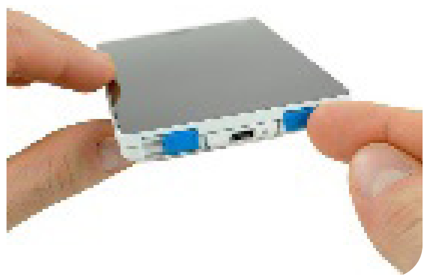
Adhesive scores well for reliability as it makes high IP-ratings and good drop test scores possible. The adhesive can seal the device against dust and water, and prevent rattling, which is good for drop tests. Clips have the suspicion they might wear over time, but unless the display is removed daily it should hold up. The more pressing disadvantage for reliability is that it does not offer ingress protection and the construction is questionable for drop tests. With screws, some ingress protection is possible, but high ratings are not seen.

Ingress protection is also one of the elements that score well for competitiveness, which is why adhesives score well for this. Clips, on the other hand, are a trade-off between quick repairs and the space they take. Since they take up more space than screws or adhesive, the device must be larger, which has a negative effect on the competitiveness. Screws are relatively space-efficient, yet they cannot offer the high IP-ratings that compete well.

Overall, it can be stated that the display chassis is not favourable. It has a greatly negative effect on the repairability of the smartphone, and it does not offer any advantage in terms of reliability or competitiveness. Clips are great for repairability, yet high IP-ratings are not possible, which excludes it from competing with high-end smartphones. For this competitiveness, using adhesive is also a promising method of construction. It does have a negative effect on the repairability, but a professional repairer would know how to handle this. The last consideration to be made is between the inner and the rear chassis. The rear chassis is positive for display repairs, as it is the first component to come off the device. It also encompasses the components, which is good for drop test. It does, however, mean that repairing any other component requires removing the display with a chance of breaking it. The inner chassis potentially does not have this disadvantage as the display is located on one side of the chassis, while other components are placed on the opposite side. However, in most cases, the connector for the display is located on the rear, which means removing the rear cover first to decouple the display from the motherboard.



*Table 21 - Construction of a smartphone: chassis and display*

| | Inner chassis | Rear chassis | Display chassis |
|---|---|---|---|
| *Screws* |   *Figure 31 - Fairphone 3 Display removal (iFixit, 2019)* |   *Figure 32 - iPhone 6 display removal (iFixit, 2014)* |   *Figure 33 - LG G5 display removal (iFixit, 2016)* |
| *Adhesive* |   *Figure 34 - Galaxy S10 display removal (iFixit, n.d.)* |   *Figure 35 - iPhone 11 display removal (iFixit, n.d.)* |   *Figure 36 - OnePlus 6 display removal (iFixit, 2018)* |
| *Clips* |   *Figure 37 – Fairphone2 Display removal (iFixit, 2015)* | | |

## 6.3 Conclusions

From the analysis, different methods of construction and their effects on the repairability and reliability become apparent. Smartphones can be constructed in roughly three different ways: with an inner chassis, a rear chassis, or a display chassis. The display chassis is not considered to be an option from a repairability perspective, and it also does not contain any benefits for reliability. The rear chassis has benefits from a display repair perspective, yet it makes repairing other components a riskier procedure. The inner chassis has the most potential for repairability, while reliability in terms of waterproofing and drop test compliance can still be accomplished.

To include more repairability, the display needs to be removable without having to remove the rear cover. Removing the rear cover takes extra steps in the repair process, which is not wanted for quick repair times. The display connector would therefore need to be moved to the same side as the display. To make removing it for repair easier, a foam adhesive can be used. The components inside would be attached to the opposite side of the chassis, covered by the rear cover. The battery can be attached with pulltabs, and the rear cover with the same type of adhesive as the display. Inside the smartphone, the same type of screws should be utilised for attaching components, as this makes repair easier to perform. For repairability, ports that can break should not be located on the motherboard itself, but rather on a separate daughterboard or separate altogether. For connecting it to the motherboard, press-fit sockets can be used, or contact pads for other components.

*Table 22 - Takeaways chapter 6*

| | Needs | Factor | Insights |
|---|---|---|---|
| ***Affordability*** | *Motivation* | Financial | |
| ***Accessibility*** | *Motivation* | Trust | |
| | *Ability* | Awareness | |
| | | Network | |
| | | Repairability | There are certain things that make a smartphone more repairable:<br>- Display detachable without anything else<br>- Not removing display for repairing other components, as it risks breaking it unnecessarily<br>- Foam type adhesive makes for a usable adhesive<br>- Screws used should be of the same type and length |
| ***Attractiveness*** | *Motivation* | Intrinsic | |
| | | Pleasure | |
| | | Functionality | |
| | *Ability* | Time and Effort | |
| | *Triggers* | Previous repairs | |
| | | Social | |

# 7 Design Requirements

From all the main takeaways from the chapters above, requirements for the design can be deduced. The requirements are divided into those for the service elements of the to be designed solution, and those for the smartphone. The service elements are further divided into requirements for the users, the repair shops, and the manufacturers. The smartphone elements are further divided into repairability requirements and competitiveness requirements.

## Service

***For the user, the service:***

1. Needs to ensure repair is equally priced or more affordable than the current situation
   Repair should be popularised to prolong use-times. Charging users will make adaptation less likely, since users are already having problems with the cost (Chapter 2 and 3)

2. Needs to be accessed within 15 minutes of travel time
   The time and effort it takes the user to get it repaired should be as low as possible (Chapter 2) and within 15 minutes should be achievable in urban areas (Chapter 3)

3. Repair needs to be as accessible to users as possible
   The time and effort it takes the user to get it repaired should be as low as possible (Chapter 2)
4. Needs to advertise the sustainability of repair to users
   User motivation is needed for repair, and feeling cooperation towards sustainability is one way of achieving that (Chapter 2)

5. Needs to recognise the users' actions
   User motivation is needed for repair, and feeling recognition for their actions is one way of achieving that (Chapter 2)

6. Needs to motivate users to repair as much as possible
   User motivation is needed for repair (Chapter 2)

7. Needs to make sure users know where to repair
   Users need the ability to repair, and awareness is a large part of that (Chapter 2)

8. The repair needs to be as reliable as possible
   Users need to trust the repair location, and be confident that the smartphone will last for a long time (Chapter 3 and 4)

9. Needs to reduce the environmental impact of smartphone user by 20%
   A positive environmental impact is needed for user motivation (Chapter 2) and this amount is possible with a display repair and one more year of use (Chapter 4)
10. Needs to reduce the environmental impact as much as possible
    A positive environmental impact is needed for user motivation (Chapter 2)

***For the repair shop, the service:***

11. Needs to make original spare parts available to repair shops
    Repair shops need to be given the ability to properly help users to repair (Chapter 2 and 3)

12. Needs to give repair shops the ability to acquire the correct tools
    Repair shops need to be given the ability to properly help users to repair (Chapter 2 and 3)

13. Needs to supply repair shops with repair documentation
    Repair shops need to be given the ability to properly help users to repair (Chapter 2 and 3)

14. Needs to provide the repair shops with as much customers as possible, within the limits of its operational capacity
    Repair needs to be popularised to make more impact (Chapter 4), while it needs to be worth it for repair shops (Chapter 3)

**For the manufacturer, the service:**

14. Needs to increase customer loyalty
    So users are in their ecosystem instead of a competitor's

15. Needs to provide them with a widespread repair network
    As the problem with repair with original parts is the lack of locations (Chapter 3)

16. Needs to increase control over their supply chain
    Control over supply chain reduces cost

17. Needs to advertise the manufacturer's sustainability efforts
    The users need to know the manufacturer's efforts

18. The broken parts should be returned to the manufacturer
    To reduce the amount of e-waste and to give the manufacturer materials back to their supply chain to reduce costs

19. Needs to return broken parts to the manufacturer as much as possible
    To reduce the amount of e-waste and to give the manufacturer materials back to their supply chain to reduce costs

## Smartphone

***For repairability, the smartphone:***

20. Needs to ensure the display can be repaired within 30 minutes
    Users face problems of long waiting times (chapter 2), repair currently takes about 1 hour (chapter 5), cutting the repair time in half makes the wait for users significantly shorter, while the smartphone architecture still allows for the use of adhesives, which are good for reliability and competitiveness

21. The display needs to be replaceable in as little time as possible
    The device needs to be repaired as quickly as possible (Chapter 3)

22. Other important parts need to be replaceable within limited time
    Display repairability should not hinder the repair of other parts, as the device needs to be repaired as quickly as possible (Chapter 3), and this is one way to achieve that (chapter 6)

23. Adhesives used need to be removable
    The device needs to be repaired as quickly as possible (Chapter 3), and this is one way to achieve that (chapter 6)

24. It is preferred that screws used are of the same type and length
    The device needs to be repaired as quickly as possible (Chapter 3), and this is one way to achieve that (chapter 6)

***For competitiveness, the smartphone:***

For all the requirement below: to compete with high-end smartphones, it needs specifications that are in line with that (Chapter 5)

25. The price should be between €800-1000

26. The display should be 6-6.5 inches large, at 1080p at least

27. Needs to be less than 10mm thick

28. Needs to be as thin as possible

29. The battery needs to be at least 4000 mAh

30. Needs to feature at least two cameras; a standard and wide-angle

31. Is preferred to feature a third camera; with a tele lens

32. Needs to have 128gb storage at least

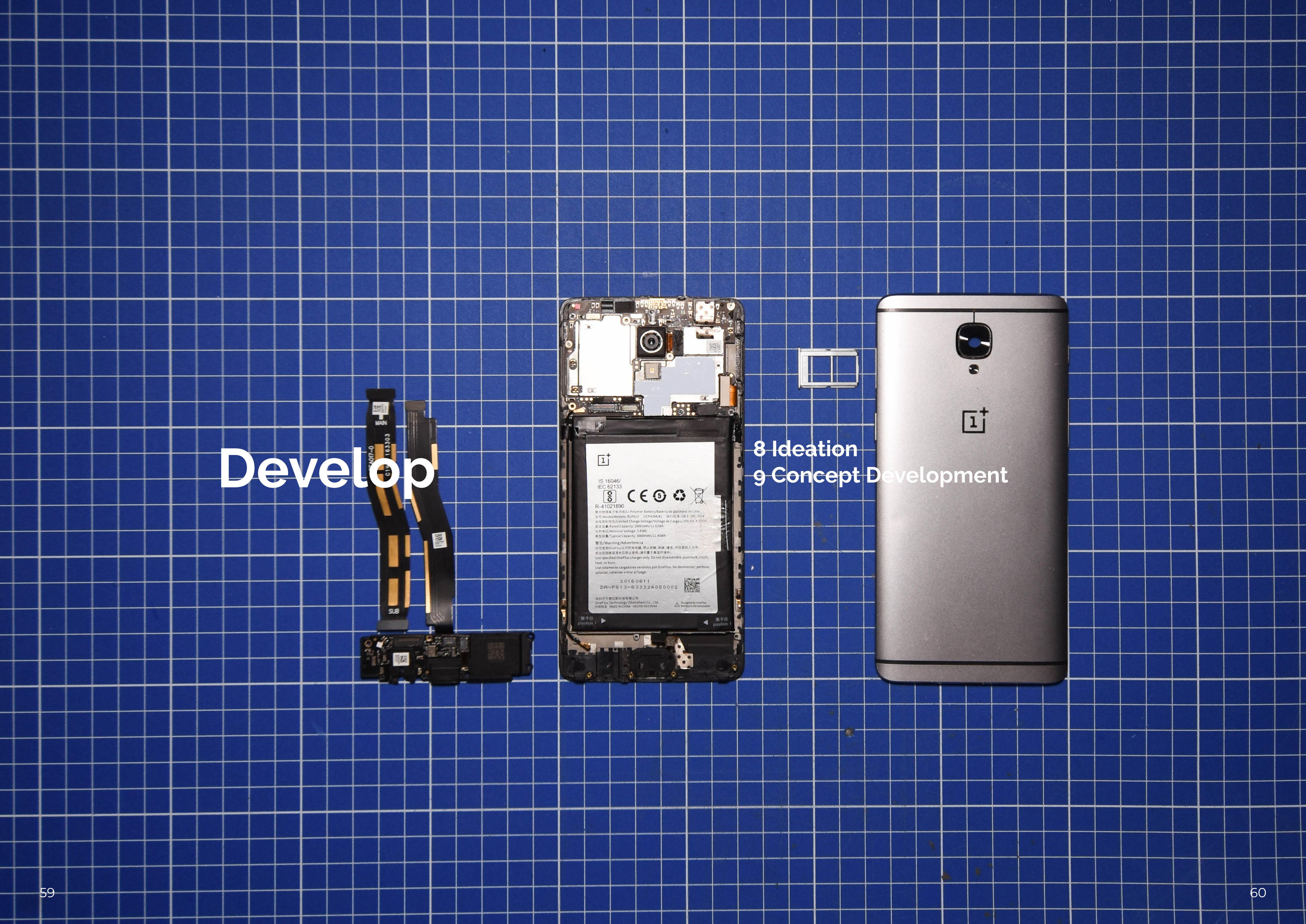
33. Needs to have 8gb of RAM at least

34. Need to have a top-of-the-line CPU

35. Needs to have IP54 at least

36. Is preferred to feature IP68

37. Needs to feature 5G connectivity




# Develop

# 8 Ideation

This section goes into the ideation phase of the process. The aim is to find a solution that caters to the needs of multiple stakeholders. The manufacturer thinks about their revenue, but it is ultimately the largest party and capable of creating change in this system. Together with repair shops, they can think about how to service the user best. The user needs to be informed well about repair and get enthusiastic about it to prolong the use-time of devices. This chapter will start off with a brief description of the process and gets into the concepts and their implications for the stakeholders.

## 8.1 Brainstorm

The ideation consisted of two different sessions, one with two design students to generate external input, and one containing how-tos to solve sub-questions of the problem. Both contributed to combining different ideas and forming the concepts.

The rounds for the brainstorm were:

- How to make repair exciting?
  This round originates from RQ2 and aimed at finding attractiveness in smartphone repairs, by focussing on finding exciting elements for users to choose repair over replacement
- How to make having an older, repaired phone cool?
  This round originates from the goal of prolonging use-times and aimed at the pleasure and functionality of smartphones.
- How to upgrade the appearance through display repair?
  This round originates from the pleasure and functionality of smartphones and aimed at how that could be upgraded through a repair.
- Discussion
  This round aimed at evaluating the earlier rounds, and created a further, open discussion on how smartphone use-times can be prolonged.

The brainstorm resulted in a range of directions, spanning from the ambience of the repair shops to educating users and stimulating repair actions or adding uniqueness during repair. Furthermore, how-tos were used to generate multiple directions of ideas. The how-tos were derived from the analyses above and divided into the service side of the equation and the smartphone design side. The how-tos aided in creating the different concepts. They were:

- How to make repair quicker?
- How to make repair more reliable?
- How to increase the value during repair?
- How to stimulate repairs?
- How to make repair more affordable?
- How to make users aware of repair options?
- How to make repair accessible?
- How to make having an older phone cool?
- How to prioritise display repair?
- How to attach a display? (Constructional and electronic)
- How to waterproof?

## 8.2 Concepts

From the brainstorm and how-tos, four different concepts were developed. They can be found on the following pages:


- Fiksall on page 63-64
- SwapFoon on page 65-66
- Upgrade-o-Phone on page 67-68
- PhoneHome on page 69-70

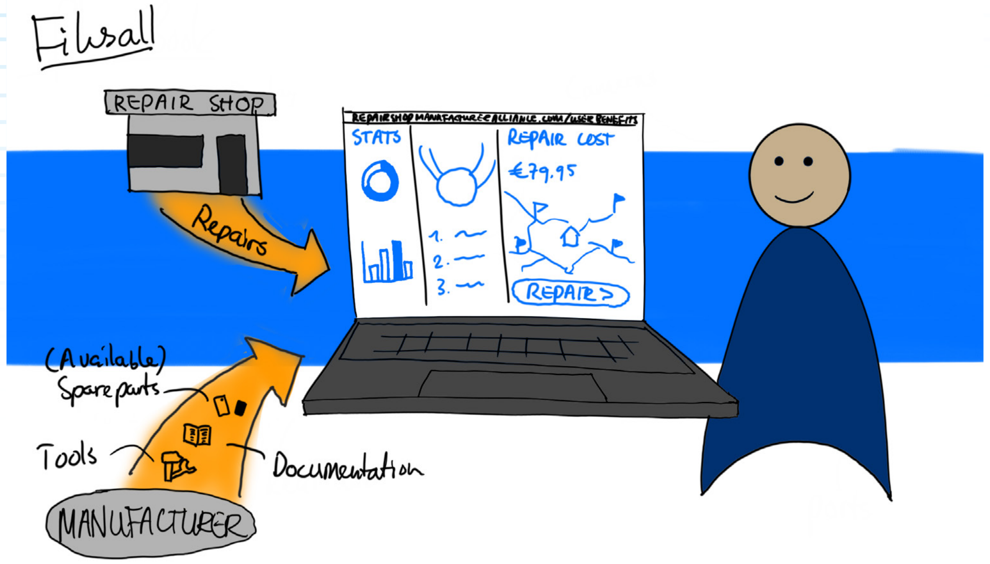



*Figure 38 - Fiksall concept description*

The Fiksall concept introduces an additional service that connects manufacturers, repair shops, and users. A widespread repair network is delivered to manufacturers, while repair shops gain a better ability to repair. Broken parts are returned to the manufacturer, to be recycled and enter the supply chain again. This provides the user with an easier, more affordable, and quicker way of repairing.

The user goes to the Fiksall website, which will need to be advertised. The website will provide information on repair, advertising the sustainability and what users contribute if they repair. They can find out which repair shops in their vicinity offer the repair and have the parts in stock. The user can book a repair and go to the shop to have it repaired. Because the manufacturer is involved, original parts are supplied and warranty is provided.

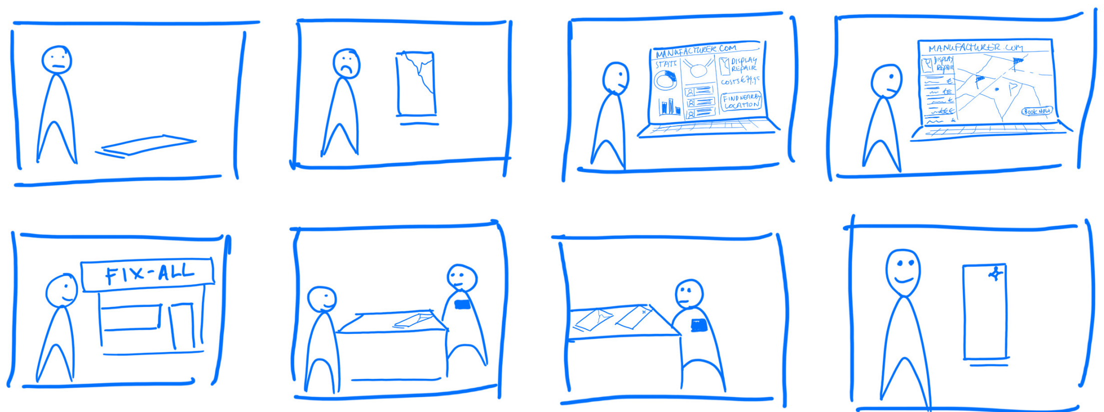



*Figure 39 - User Journey Fiksall*

Manufacturers provide spare parts, tools, and documentation, and gain a repair network and returned broken parts, which can enter the supply chain after recycling. They also gain loyalty, as a better repairability (Lemke & Luzio, 2014) and a better user experience (Zomerdijk & Voss, 2010) results in returning customers. It also means that the user utilises their smartphone for longer. Independent repair shops gain knowledge on repair and access to spare parts and tools, while they are provided with customers through the platform. They bring in fees for the platform, and with other shops they form the repair network.



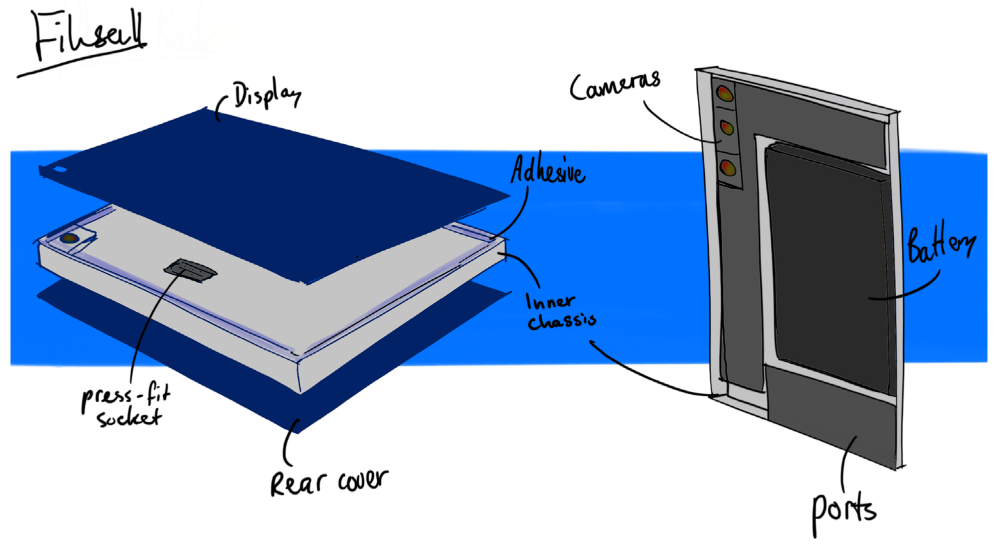



*Figure 40 - Fiksall smartphone*

*Table 23 - Fiksall gains, concerns, and requirements*

| | |
|---|---|
| | **User** |
| *Gains* | Repair options, reliability, quicker repair |
| *Concerns* | Time and effort to go to shop |
| *Requirements* | Users need to be motivated |
| | **Manufacturer** |
| *Gains* | Better repair service, higher spare parts sales, user loyalty |
| *Concerns* | Repair reliability, repair shop interaction |
| *Requirements* | Provision of parts, tools, and information |
| | **Independent repair shop** |
| *Gains* | Revenue, improved service |
| *Concerns* | Service multiple manufacturers, stock, repair times |
| *Requirements* | Deliver quality |
| | **Repair platform** |
| *Gains* | Organised repair offers |
| *Concerns* | Introducing the middleman might make it more expensive |
| *Requirements* | Advertise, promote, and stimulate repair actions |

Smartphones need to be optimised for this, as a quicker repair means less time and effort for the user, as well as a lower repair cost. Easier repairs also have less chance to go wrong, and this means more reliability in repairs. The smartphone will be built with an inner chassis, making the display accessible from one side, and the rest of the components from the opposite side.

Advantages of this concept are relatively contemporary smartphone design, meaning easier implementation, and an easy flow for users. Possible disadvantages are the introduction of a middleman, which adds complexity, and that it needs a lot of repair shops to reach the potential. The platform also needs to be promoted strongly for users to regard it as the go-to option for a repair.

*Table 24 - Fiksall vALUe*

| | |
|---|---|
| | **Fiksall** |
| *Advantages* | Awareness, Single space for repair, similarity to current smartphones |
| *Limitations* | Repair on user initiative, 'middleman', dependent on network |
| *Uniqueness* | Connecting stakeholders, Repair network |

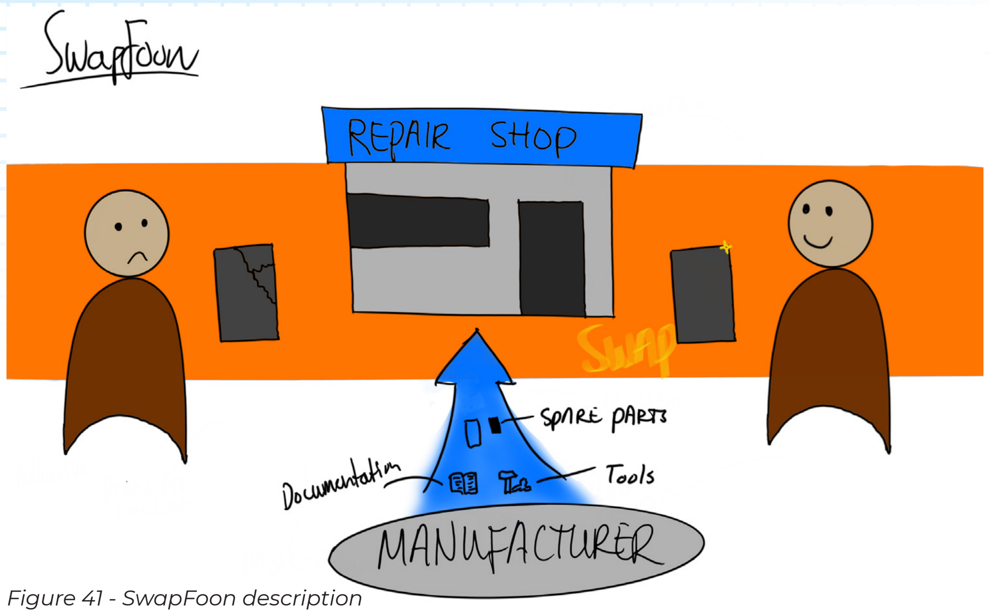



*Figure 41 - SwapFoon description*

SwapFoon aims at implementing a PSS model for smartphones. The user pays a monthly fee and is ensured a continuously working device. A flexible payment with a decreasing fee motivates users to keep the same device. If users switch to a newer model, the fee increases. Users thus pay less for a smartphone that is older than for a brand-new one. This way the user is recognised for their sustainable behaviour.

Repair is an integral part of this model, so users should be very aware of the options and the sustainability of using a device for longer. If the smartphone breaks, the user notifies the manufacturer, which arranges for it to be swapped at a local shop. The user can go to the repair shop, where the swap will take place. Data from the phone is backed up online and can be restored on the new smartphone.

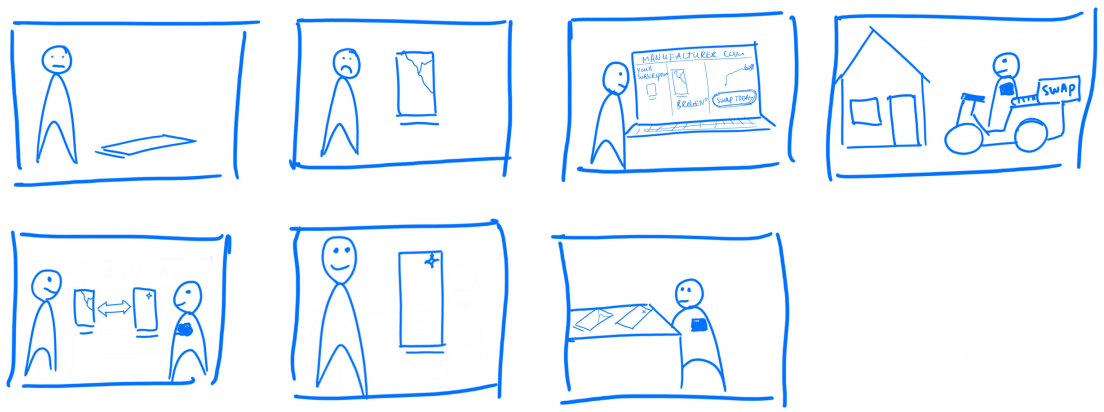


*Figure 42 - User Journey SwapFoon*

The manufacturers work with the repair shops, having them handle the swapping of smartphones and the repairs to get them to another user. Therefore, the repair shops are provided with the documentation, tools, and spare parts, and are paid by the manufacturer for their services.



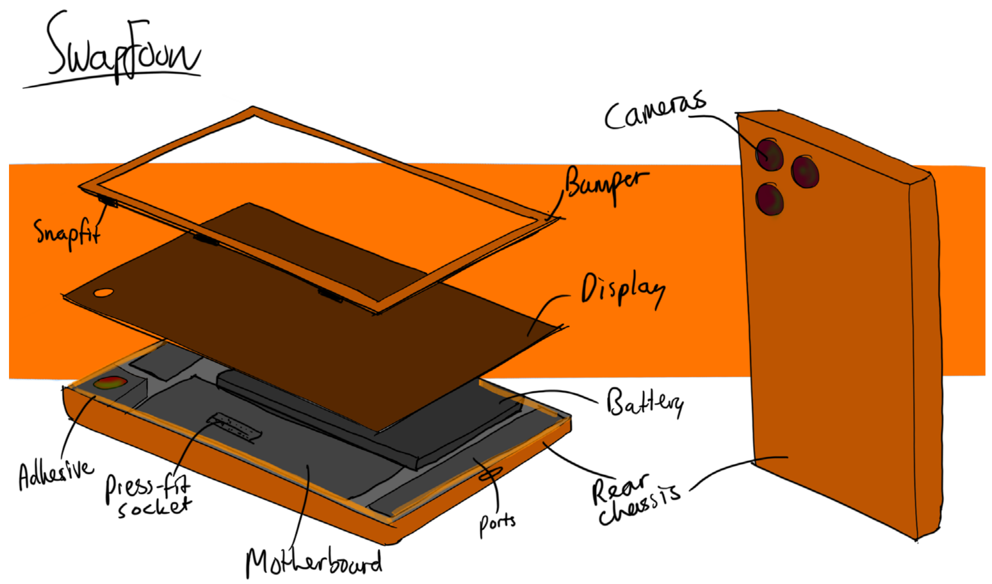



*Figure 43 - SwapFoon smartphone*

*Table 25 - SwapFoon gains, concerns, and requirements*

| | |
|---|---|
| | **User** |
| *Gains* | Continuous working phone, no high costs when breaking |
| *Concerns* | Not the owner, might be less careful |
| *Requirements* | Care for phone, stay in PSS |
| | **Manufacturer** |
| *Gains* | Loyal customers |
| *Concerns* | Close collaboration with local shops |
| *Requirements* | Shift in operating mode, set up a network |
| | **Repair shop** |
| *Gains* | More business, direct contract, better reliability for repair |
| *Concerns* | Dependent of manufacturer |
| *Requirements* | Quick response, work with manufacturer |

The smartphone for this PSS should focus on reliability, as users tend to be less careful with devices they do not own. The smartphone also needs to have the ability to be repaired and be brought back into service to another user. The device utilises a rear chassis, making the casing of the smartphone more rigid. The display needs to be protected from the sides against drops, with a small bumper. This means that the smartphone will be larger than contemporary models.

Advantages of this concept are quick service for users and almost guaranteed repairs, as users have to deliver it for repair. Possible disadvantages are the rebound effect, fuelled by users taking less care for devices that they do not own. This is bad for the environmental impact and might make the system unnecessarily expensive. The willingness to lease a smartphone should be further investigated.

*Table 26 - SwapFoon vALUe*

| | |
|---|---|
| | **SwapFoon** |
| *Advantages* | Repair is guaranteed |
| *Limitations* | But only if someone is willing to use that model of phone |
| *Uniqueness* | PSS |

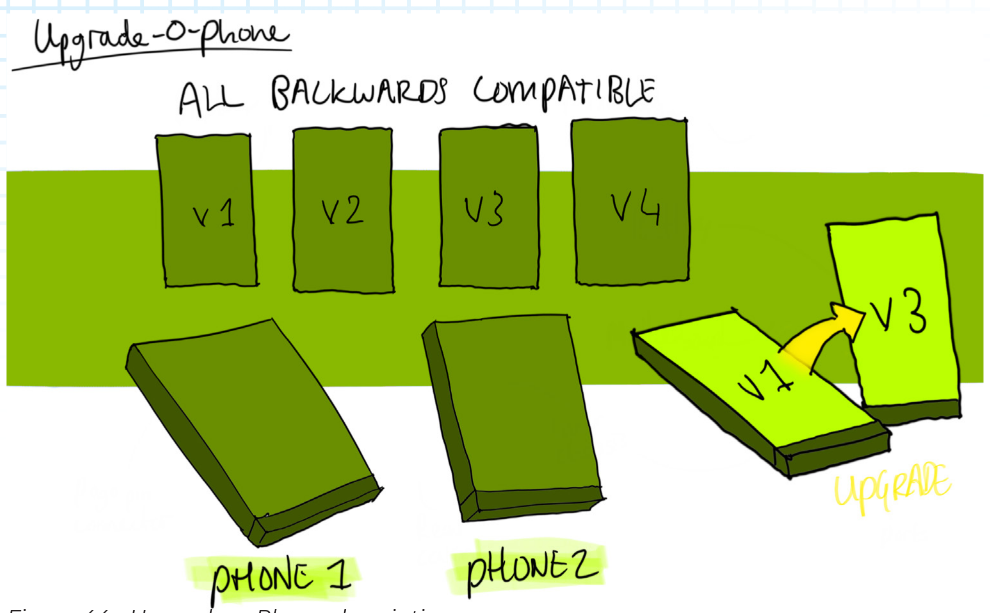



Figure 44 - Upgrade-o-Phone description

The Upgrade-o-Phone focusses on futureproofing smartphones. Instead of returning to a state it was previously in, it adds functionality to the smartphone during repair. This can counter the attractive power of a new smartphone. The marketing campaign for the smartphone should make clear this is possible when the smartphone is broken. A base model is introduced every two years, while the display and the battery, the most important components (Flipsen, Huisken, Opsomer, & Depypere, 2019), can be continuously developed.

When the user breaks the smartphone, the device can be repaired with the same component or upgraded to a newer version. The manufacturer can advise in this and refer the user to a local repair shop that can perform the repair or upgrade.

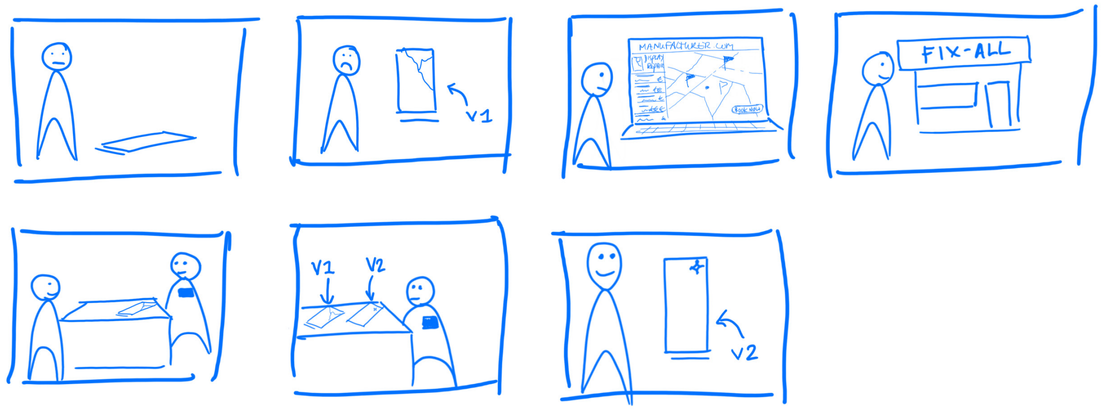



Figure 45 - User Journey Upgrade-o-Phone

The focus in development will shift from smartphone development to component development, and the offers from the manufacturer will gradually increase in hardware functionality. The repair shops need to be able to work with this and will need to keep spares for the devices, while returning broken parts to the manufacturer.



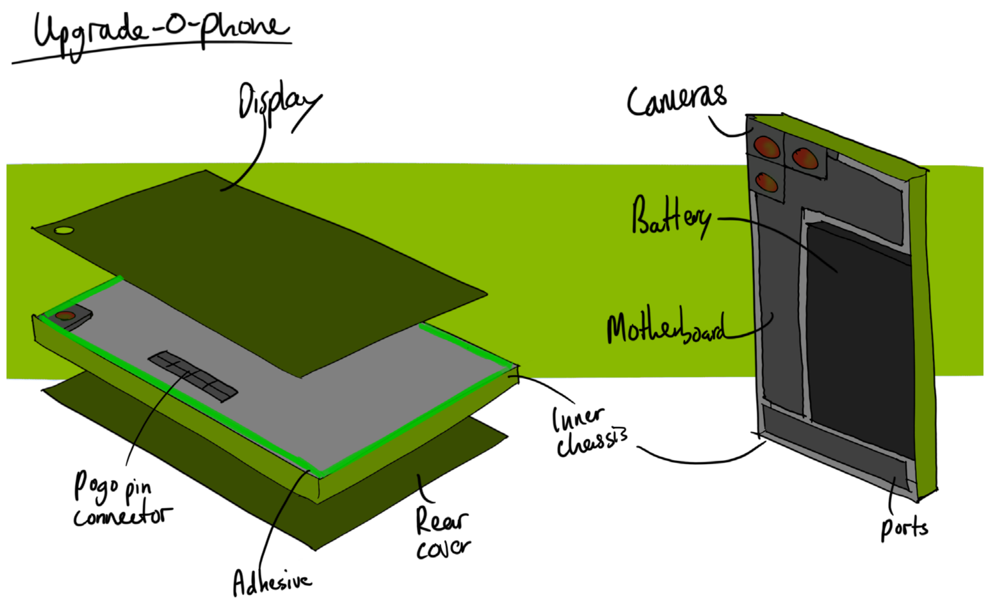



Figure 46 - Fiksall smartphone

Table 27 - Upgrade-o-Phone gains, concerns, and requirements

| | |
|---|---|
| | **User** |
| *Gains* | Upgradeability |
| *Concerns* | Extra costs |
| *Requirements* | Awareness |
| | **Manufacturer** |
| *Gains* | Sell repair and upgrades |
| *Concerns* | Incorporate backwards compatibility (could slow innovation) |
| *Requirements* | Development of components instead of full phones |
| | **Independent repair shop** |
| *Gains* | More business |
| *Concerns* | Stock of older spare parts |
| *Requirements* | Knowledge of repair and upgrades |

This requires a smartphone specifically developed for upgrading, and backwards compatibility. The smartphone will have to be quickly repairable to make the service desirable. The smartphone will be constructed with an inner chassis, to allow for both display and battery upgrades to be performed quickly. The focus on backwards compatibility needs specific connectors that can stay the same.

The main advantage of the concept is the attractive power of adding new functionality during repair, which can battle newer smartphones. Possible disadvantages are slowing innovation due to backwards compatibility, and chances of unnecessary upgrades. These will be a problem when devices are also shorter lived, yet if that means the use-time gets longer, there could be gains. Using the smartphone for one more year instead of buying a new device still means a 20% reduction in environmental impact.

Table 28 - Upgrade-o-Phone vALUe

| | |
|---|---|
| | **Upgrade-o-phone** |
| *Advantages* | Makes repair more exciting |
| *Limitations* | Development model changes |
| *Uniqueness* | Upgrades |

# PhoneHome

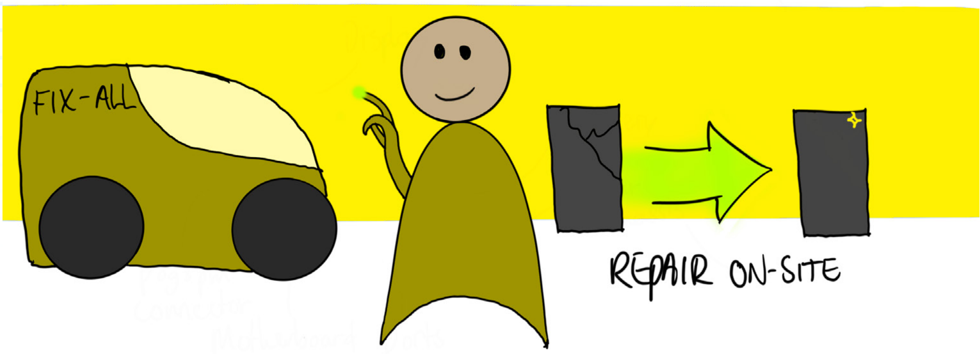



Figure 47 - PhoneHome description

The PhoneHome concept is a collaboration between manufacturers and local repair shops and aims at bringing the repair to the user. The service gets a repairman to the location of the user to repair their device on the spot. The service therefore reduces the time and effort it takes the user, and the goal of this is to make repair more likely.

For the user, this reduces the time and effort a repair takes greatly. If a repair is compared to acquiring a new smartphone, it takes way more time and effort, and the price is often high as well, especially when comparing that to the mental book value of the smartphone. The user can book a repair through the website, and a repairman comes to their location to take care of the device for them.

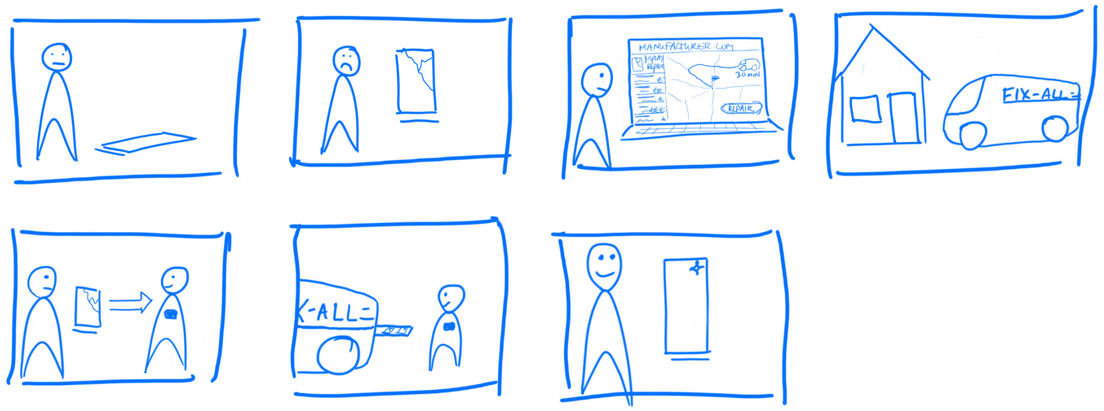


Figure 48 - User Journey PhoneHome

The main part of the service is in the hands of the local repair shops, who shift in their business model from users coming to them to them going to the users. Provided with enough spare parts, tools, and documentation by the manufacturer, they can go out and repair smartphones. The manufacturer needs to play an active role in this and encourage the local shops to perform these repairs. Since the repairman is on the road for some time, the repair needs to be quick and simple to counter the time that takes.



# PhoneHome

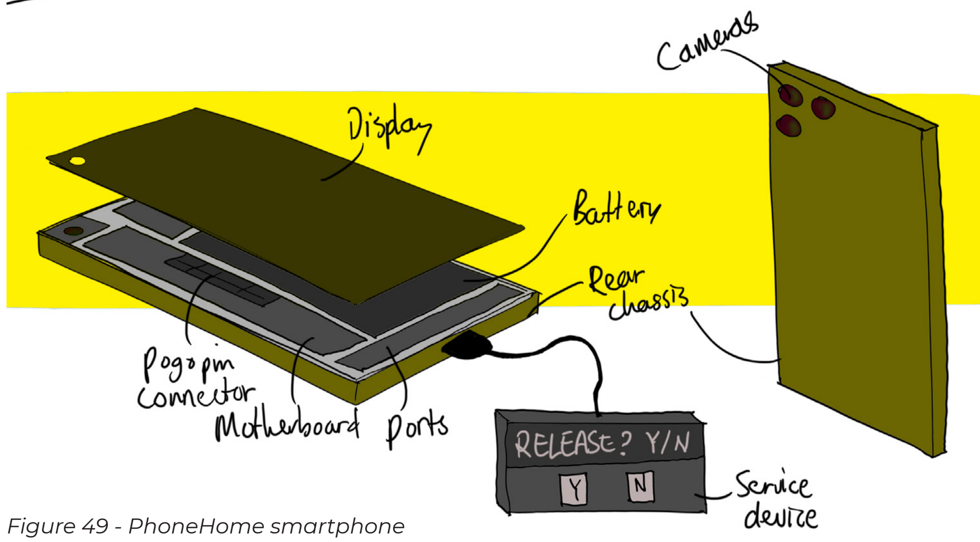



Figure 49 - PhoneHome smartphone

Table 29 - PhoneHome gains, concerns, and requirements

| | |
|---|---|
| | **User** |
| *Gains* | Less effort, less time |
| *Concerns* | Design optimised for repair might mean less attractive smartphone |
| *Requirements* | Awareness |
| | **Manufacturer** |
| *Gains* | Quicker repair service |
| *Concerns* | Time-consuming service |
| *Requirements* | Connecting to independent repair shops |
| | **Independent repair shop** |
| *Gains* | More business |
| *Concerns* | Expensive service |
| *Requirements* | Investments in equipment |

The travel time and travel cost of the repairman needs to be compensated in some way. A quicker repair will make the total time (travel + repair time) shorter, and less time is also less expensive. The design needs to be highly optimised for display repairability for this scenario, and this has consequences on the weight, thickness, and design of the smartphone. Also, being this highly repairable would mean that a large part of users is able to perform the repair themselves, although whether they are also willing to (and believing in themselves) is a different question.

The main advantage of this concept is the minimum time and effort it takes the user. Possible disadvantages are low adaptation, since not everyone might desire this as it can be privacy sensitive. It also works best if the repair routes can be optimised, for which it would need a high adaptation. Finally, it takes large investments for the repair shops, which can be a large risk considering they rely on the manufacturers to make this possible in the first place.

Table 30 - PhoneHome vALUe

| | |
|---|---|
| | **PhoneHome** |
| *Advantages* | Less effort, less time |
| *Limitations* | Time-consuming service for the repairman |
| *Uniqueness* | Minimal user effort |

## 8.3 Selection

This section aims at selecting the most promising of the concepts, and it does this by using the quantitative requirements as criteria for a weighted objectives analysis. These requirements are scaling, and the concepts can be ranked along them. The following requirements are included in the selection process:

3. Repair needs to be as accessible to users as possible
6. Needs to motivate users to repair as much as possible
8. The repair needs to be as reliable as possible
10. Needs to reduce the environmental impact as much as possible
14. Needs to provide the repair shops with as much customers as possible, within the limits of its operational capacity
21. Needs to return broken parts to the manufacturer as much as possible
23. The display needs to be replaceable in as little time as possible
30. The smartphone needs to be as thin as possible

Each of the criteria is assigned a weight, to rank its importance within the weighted objectives (Table 31). The weights are assigned by order of importance, the accessibility of repair options is the most important for large-scale adaptation. Following that are the motivation users have to repair, the repair time, and the sustainability of the solution. The motivation and the repair time are important for adaptation, while sustainability is the reason to repair. The reliability, number of customers to the repair shops and the circularity are important respectively for the user, the repair shop, and manufacturer. The repair shop needs additional customers to participate, while for the manufacturer reducing costs in the supply chain is an advantage. The thickness of the device is important for the competitiveness of the smartphone yet stimulating repair and improving the repairability of smartphones is prioritised.

*Table 31 - Weighted Objectives Concepts*

| | | **Fiksall** | | **SwapFoon** | | **Upgrade-o-Phone** | | **PhoneHome** | |
|---|---|---|---|---|---|---|---|---|---|
| ***Objective*** | **weight** | **score** | **points** | **score** | **points** | **score** | **points** | **score** | **points** |
| *3. accessibility* | 20 | 4 | 80 | 3 | 60 | 3 | 60 | 5 | 100 |
| *6. motivation* | 15 | 4 | 60 | 5 | 75 | 3 | 45 | 3 | 45 |
| *8. reliability* | 10 | 5 | 50 | 5 | 50 | 4 | 40 | 5 | 50 |
| *10. sustainability* | 15 | 5 | 75 | 4 | 60 | 2 | 30 | 3 | 45 |
| *14. customers* | 10 | 4 | 40 | 5 | 50 | 2 | 20 | 2 | 20 |
| *21. circularity* | 10 | 4 | 40 | 5 | 50 | 3 | 30 | 4 | 40 |
| *23. repair time* | 15 | 5 | 75 | 2 | 30 | 5 | 75 | 5 | 75 |
| *30. thickness* | 10 | 5 | 50 | 1 | 10 | 3 | 30 | 1 | 10 |
| ***Total*** | **100** | | **445** | | **395** | | **315** | | **380** |

The PhoneHome concept scores highest for accessibility as user effort is minimised. Fiksall follows, as it aims at reducing travel times. SwapFoon and Upgrade-o-Phone do not actively address the collaboration between manufacturers and repair shops.

The motivation is maximised for SwapFoon, as it is an integral part of the system to repair when the smartphone is broken. Fiksall follows as it actively targets users.

Reliability is highest for all concepts except upgrade-o-phone. The concepts address the proper use of original parts, while with upgrade-o-phone it is not ensured.

The sustainability score is highest for Fiksall, as it targets users to repair and promotes the recycling of broken parts. SwapFoon follows but has the disadvantage of a possible rebound effect where users break their device more often. Upgrading might enable this behaviour even further, merely because users want a new feature. PhoneHome could have the advantage of more efficient travel routes, but only with high adaptation, which is not guaranteed.

The amount of customer to repair shops is estimated as the highest for the SwapFoon because repair is inherent to the system, followed by Fiksall, which aims at generating marketing efforts to reach users. The Upgrade-o-Phone and the PhoneHome score lower since they potentially have less reach.

With SwapFoon, the most parts are returned to the manufacturer, as it is an inherent part of the system. Fiksall and PhoneHome follow, as they aim at returning parts, yet is not guaranteed. Upgrade-o-Phone has different types of parts, making this harder to keep track of.

The repair time award the maximum scores for the Fiksall, Upgrade-o-Phone and the PhoneHome concept since they reduce the removal of the display to two steps, and thus reduce repair time to a minimum. The SwapFoon has an extra protection barrier for reliability, meaning it takes longer to repair, thus it scores lower.

For thickness, the Fiksall concept scores highest, as that keeps the thickness to a minimum. The Upgrade-o-Phone would be thicker because of some modularity needed for the upgradeable components, while the SwapFoon would be even thicker than that for reliability reasons, and the PhoneHome for including a release mechanism.

Apart from the weighed objectives, there are some disadvantages to overcome for every concept. For the Fiksall that would be that it needs large scale implementation to work, since the aim is to have a repair network that is as widespread as possible. The SwapFoon needs rigorous reliability measures to counter the effect that users might break it more often because they do not actually own it, and this hinders repairability. The Upgrade-o-Phone has a low likeliness of implementation by the manufacturer, as few initiatives have regularly provided hardware upgrades in the past. The PhoneHome concept is not suited for large implementation, meaning the impact would be smaller, because the up-front investments are high and demand uncertain. Of all of this, the disadvantage of the Fiksall concept would be the likeliest to overcome.

Fiksall therefore has been chosen as the concept to continue development with, because it has the highest score on the weighted objectives and the biggest disadvantage is the likeliest to overcome. The concept shows most potential for combining the users' aspects, the business aspects, and the smartphone design aspects.

# 9 Concept Development

In this chapter, the Fiksall concept is further developed. Both the service and smartphone elements of the concept will be described as they both need each other for optimal functioning. A repair service needs redesigned smartphones as the repair time can be decreased by optimising the device for display repair, as described in chapter 6. On the other side, a repairable smartphone only makes sense when there are enough places where it can get repaired (chapter 3). For stimulating users to repair instead of replace, the user journey needs to be improved. The journey needs to be improved for not deterring users that want to repair and for convincing users that currently would not consider repair to repair. After that, it needs looking into how the involved stakeholders can deliver what the user needs. The functions of the prototype are outlined in this chapter, as well as how the smartphone can add to this improved user journey. Finally, the concept is tested with users.

## 9.1 User Journey

The user journey is the first thing that needs attention, since this determines how the user will be motivated to repair instead of replace. Users considering repair should be kept in their journey to repair and not be deterred from repairing anywhere along the line, and other users should be attracted to repair instead of replace by an effortless journey.

The main change in relation to the current situation is that there is now an option to get both a quick repair and a reliable repair in one place, and not having to choose between the two. This reduces the waiting times compared to having to send it in for a repair and improves the continued use by providing warranty and original parts.

To show how the service can be offered to the user, a service blueprint has been created, visualising the contributions of Fiksall, the manufacturer and the repair shop, as well as the user actions.

The searching and booking phase are taken care of by the Fiksall platform, which attracts customers by listing the advantages, and handles the booking part by taking the scheduled repairs and sending them to the repair shops. The repair shop can then get to work by preparing the repair, checking whether they have enough spare parts in stock, and whether they have the right documentation and the correct tools.

Once the user has delivered the smartphone, it is assessed, and the right parts are collected, after which it is repaired. The smartphone is then returned to the user, while the broken parts are returned to the manufacturer to be recycled so they can enter the supply chain again. What rests for the user, is paying and travelling back to continue the use of the smartphone.



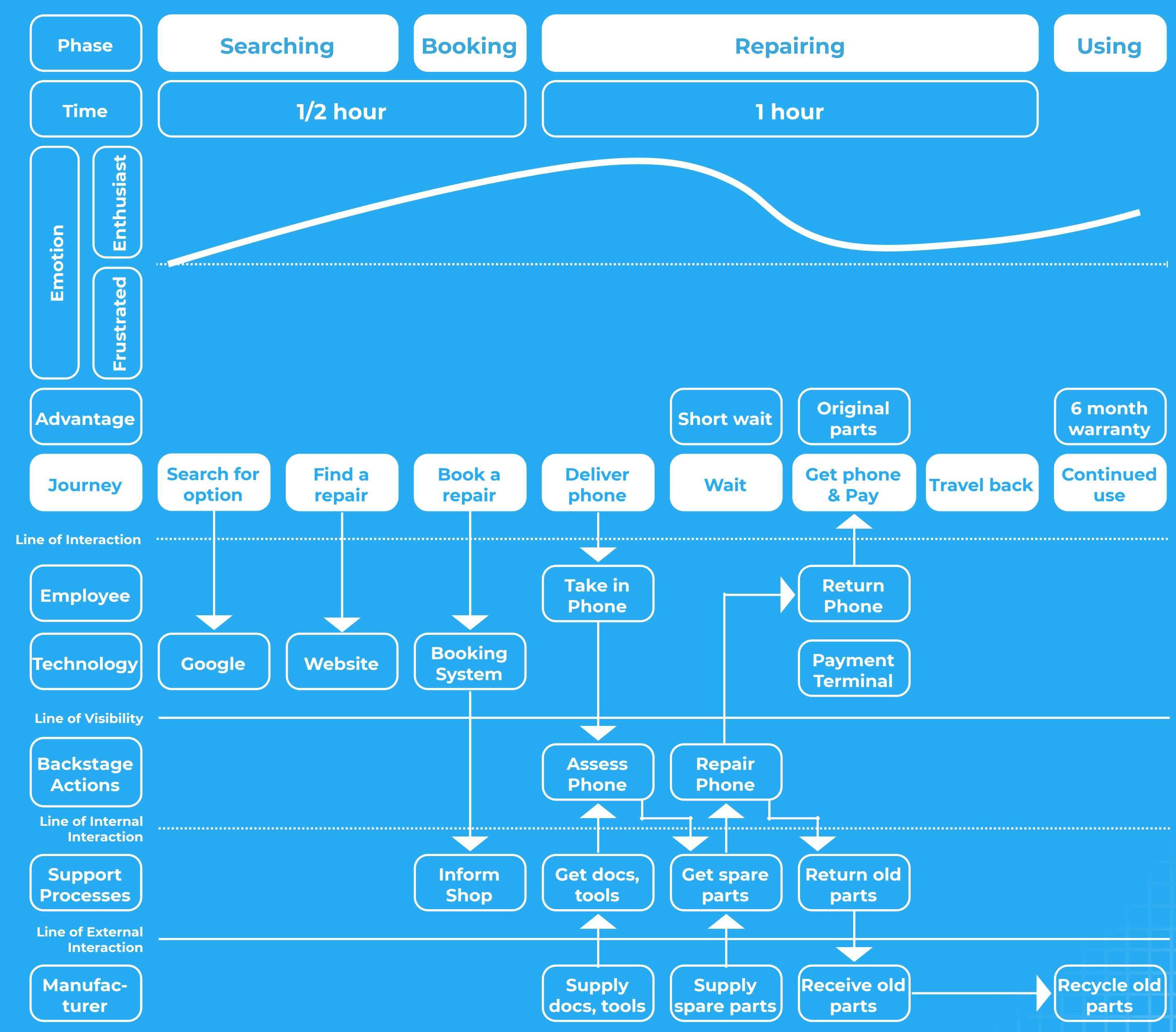



*Figure 50 - Journey map & Service Blueprint Fiksall*

## 9.2 Functionalities

To make these journey possible, multiple functionalities are included in the Fiksall platform. A concept website is built for this, which is tested with users. It aims at fulfilling three main user needs (Desmet & Fokkinga, 2020): autonomy, comfort, and impact.

The homepage of the website portrays the main advantages to this platform; guaranteed quality, ease of repairing, and changing the world. These play into three key user needs: autonomy, comfort, and impact (Desmet & Fokkinga, 2020). The quality is accomplished by providing repair shops with the original spare parts and making sure they know what to do with the right documentation and the correct tools. Six months of warranty is provided on the repair, and the shops are checked for quality. This links to the autonomy since the user is provided with more options to get a reliable repair and find freedom of decision in this. If they want, they can go to the manufacturer or a repair partner, yet the repair shops are also capable of handling the repair with the original parts. The ease of repairing is accomplished through the website of the platform and the widespread network attached. Because of the widespread network, comfort is achieved by offering convenience to the user. The need for impact is achieved by changing the world. By making clear what the user's part is by repairing instead of replacing, the user can feel their contribution towards a better planet. This is done by showing the user what impact they are making by repairing when using it for another year.

During the repair, the user first specifies what smartphone they have, and what the defects are. They are then directed to the page to schedule their repair. They can pick any of the repair shops shown in their vicinity, while on the right they get an overview of the repair and the associated costs, along what is saved. What is saved is divided into three different categories: e-waste, GHG emissions, and money in relation to buying a new device. The e-waste saved is the weight of the specified smartphone, the GHG emissions come from the calculations in chapter 4.2. The comparison to a new device is in relation to buying the same device new at that moment.

*Table 32 - User needs (Desmet & Fokkinga, 2020) typology Fiksall*

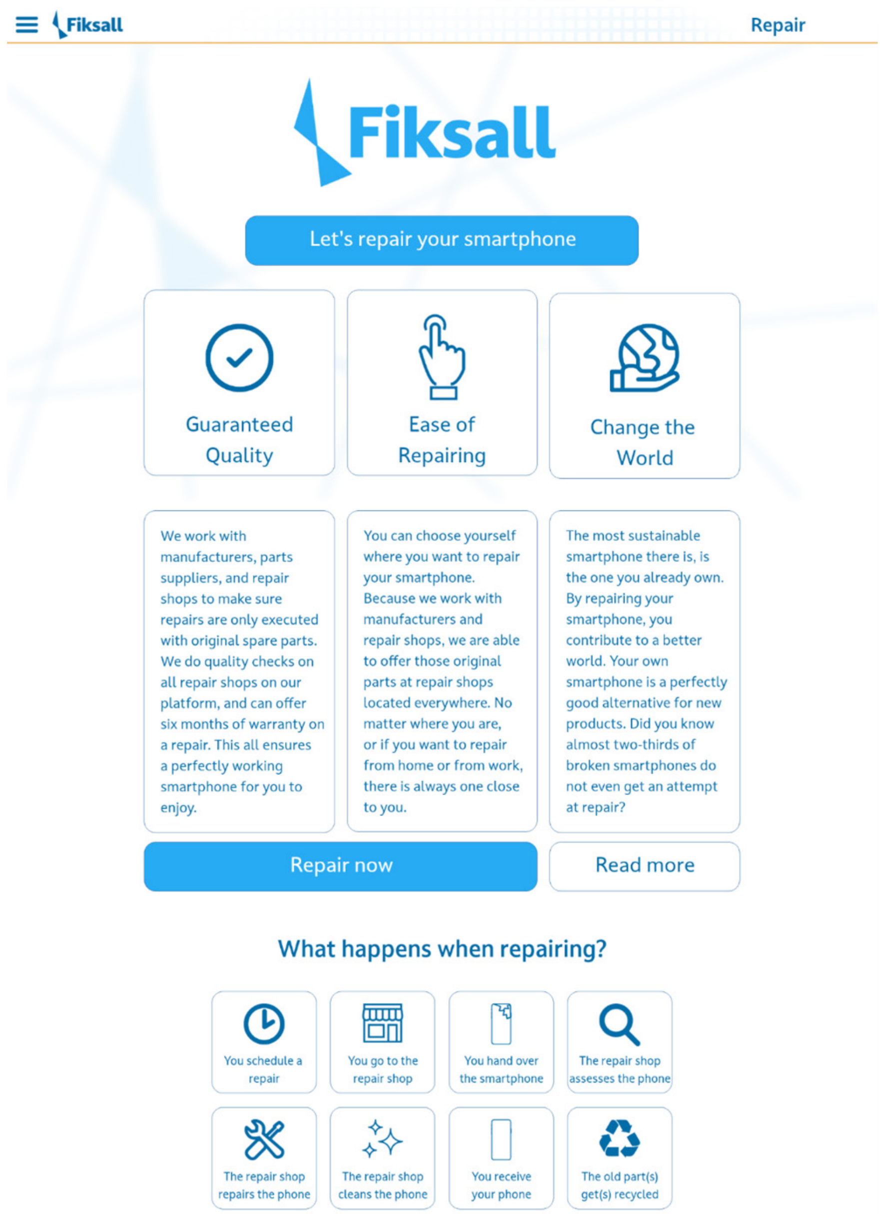




*Figure 51 - Homepage Fiksall*

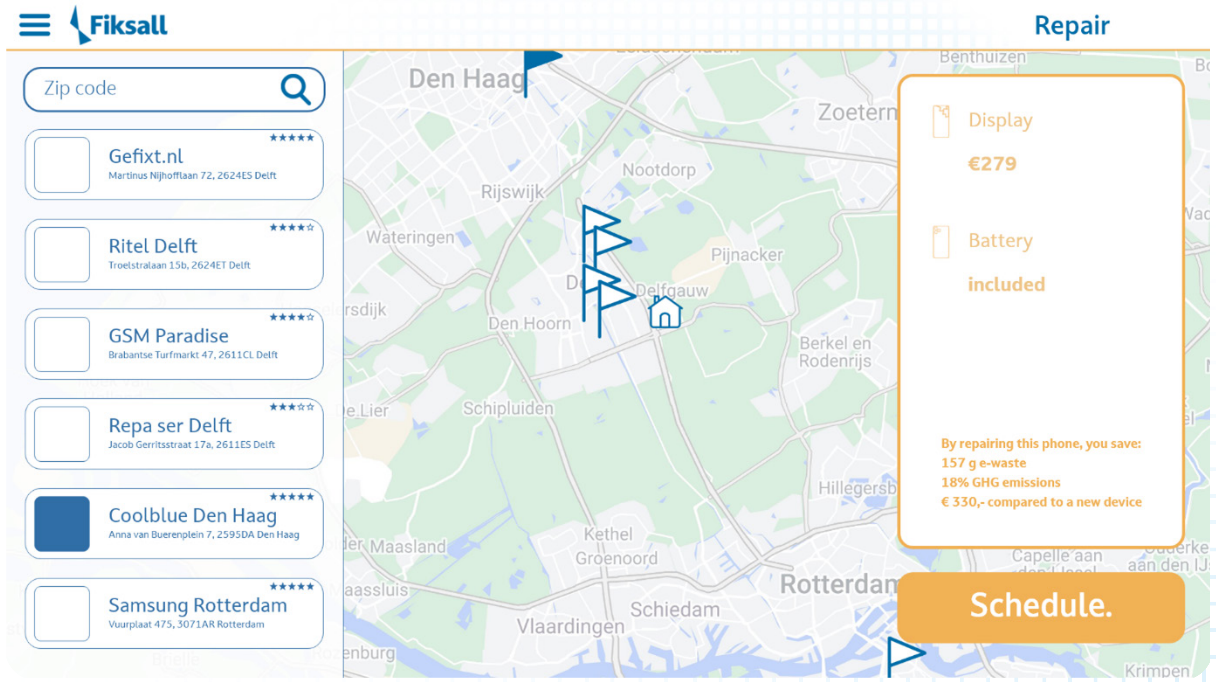



*Figure 52 - Schedule page Fiksall*

## 9.3 Concept Smartphone

A smartphone optimised for repair makes the core of the platform perform better, as it decreases the repair time and thus the time the user has to put in. This concept smartphone is developed by looking at contemporary smartphone architecture and looking at where changes can be made to benefit the repairability of the device. This model, and the process, are described in Appendix D. The model is followed by an isometric visualisation of the different components. These components are then modelled for volumetric design, after which detail is added to the model, and it is 3d-printed and tested. After updating the 3d model, the following renders are created to show the design.

As stated in chapter 5.2, there are a few things a high-end repairable smartphone needs to be considered competitive (Requirement 20-37). All these requirements will have to be met. Designing the smartphone is executed in three different steps:

1. Surface area
2. Repairability measures
3. Volumetric design

The surface area was determined by specifying the display size of the smartphone. With a display size of 6 inches, the smartphone will be 148.7x71.1mm with a display aspect ratio of 19:9, which is what Samsung uses for their smartphones (Samsung, n.d.). This will have effect on the thickness of the smartphone later, as well as the placement of the components in the volumetric design step.

The repairability measures are the next thing to look at. Since the display needs to be easily repairable, and the other components' repairability should not be hindered, the design opts for an inner chassis configuration (chapter 6). This enables the display to be accessed from one side of the smartphone, while the other components can be accessed through opening the smartphone from the rear. Since the display needs to be removable from the front of the smartphone, the connector is placed on this side of the smartphone as well. To assure the rear cover does not have to be removed for the display to come off, the display is adhered into place, with a foam adhesive (chapter 6).

Following was the volumetric design, where besides the surface area of the smartphone as determined by the display size, there is one more constraint in the form of requirement 27, being that it cannot be thicker than 10mm. Also from the requirements, there are two more things to consider when determining the volumes; the battery size needs to be 4000 mAh at least and the smartphone should feature 2, preferably 3 cameras on the rear.

The battery is not spanning the entire width of the smartphone, since that would mean having to connect the motherboard and the daughterboard with a flexwire, which is not preferred for two reasons; it adds thickness (even though a flexwire is only 0.1mm thick) and more importantly, it then must be removed first before the battery can be accessed. To maximise the area available for the battery and the motherboard then, the cameras have been placed in the top corner. The motherboard stretches down to the bottom of the battery and is then connected by flexwire to the daughterboard containing the USB port and sim card reader. A shield is placed on top of that to secure the daughterboard into place, and it contains the speaker and a vibration motor.

*Figure 53 - Smartphone design with display removed*


*Figure 54 - Smartphone design with rear cover removed*

## 9.4 User Testing

The digital prototype conveying the proposed offer is tested with users to figure out whether it matches with the user needs for repair. A questionnaire was sent out to nine selected respondents from the target group young adults. They were asked questions about in what situations they would repair, the full questions can be found in appendix E. The questions were in terms of the following dimensions:

- Cost
- Travel time
- Repair time
- Original parts
- Warranty
- GHG emission savings

After this, the proposed offer was analysed. The users were provided with a scenario, having a smartphone with a shattered display and a battery that has seen better days. It cost them €899 2.5 years ago. And they were show Figure 53 and Figure 54 to get a sense of the service. They are shown that the repair costs €279 for the display, while the battery is included in the repair. 157g e-waste is saved, 18% of GHG emissions, and €330 compared to buying the same device new. They were asked whether they think the offer is fair, whether they would take it, what stands out, what they think could be improved, and if anything is still unclear about the offer.

Q1. Do you think this offer is fair, and why?
Q2. Would you take this offer, and why?

*Table 33 - Responses Q1 and Q2*

| ***Respondent*** | **#1** | **#2** | **#3** | **#4** | **#5** | **#6** | **#7** | **#8** | **#9** |
|---|---|---|---|---|---|---|---|---|---|
| *Q1* | Y | M | N | M | Y | Y | M | N | Y |
| *Q2* | M | N | N | N | Y | Y | M | N | M |

Respondents indicated whether they thought the offer was fair or not in yes, no, or maybe, with an explanation. There are four users that think it is a fair deal, two that find it too expensive, and three that need some more consideration. Users noted that “the pricing is often way too high in general, given how long you can move forwards with a new phone” (#3), and “I’m unsure if I’m going to get another year or 2 of use out of this phone, so I would find it a risk” (#7). Respondents did note that the warranty and quick service are advantages, but overall, the price is high for a device over 2 years old.
After that, they answered whether they would take the offer. Two of the respondents would take it mainly out of their belief in longevity. Three of them indicated they were unsure since it depends on what is on the market at the time and because of expectations for future software updates. One stated “normally I buy a new phone every 3 years, so if the new features are interesting, I maybe want the newest one instead of repairing a 2.5-year-old phone” (#1), another stated “the screen and battery replacement could increase the lifetime of the phone, you will still have the same performance for half the price of a new one” (#6).

Q3. What stands out for you about this offer, and why?
Q4. What could be improved about the offer?
Q5. Is there anything unclear?

Respondents indicated that on the positive side the fast repair, verified original parts, and the repaired battery are valued. On the negative side, the price stands out (#8: “the price is more than one-third of the original price”) and that is what could be improved about the offer. There are also things that could be made clearer. The warranty that is offered on the repair is unclear now, so that should be highlighted more on the homepage. The feedback for the comparison to a new phone is that it is more plausible users want to replace with a similar but newer device instead of the same device as is now indicated. They do see the advantages of saving GHG emissions, yet some find the percentages to be a little abstract. This means that the display of the GHG emission savings should be further examined.
Concluding, this means that there are improvements to be made to the offer by being clearer about the advantages such as warranty and the environmental benefits. The main concern users have with repairing is the cost, which should be addressed in part by creating a more repairable smartphone.

# Deliver

# 10 Final Design

After evaluating the prototype, the concept was further developed while keeping the user feedback in mind: providing more clarity on the warranty and on the emission savings, and change the price comparison to a newer model smartphone. This chapter will elaborate further on the concept, by looking at the business model, the implementation strategy, the user flow, and the further development of the concept smartphone.

## 10.1 Description

The Fiksall platform must compete with the current repair offers, as well as the attraction of new smartphones. Therefore, it needs to be closer to the user than current offers from the manufacturer and repair partners, offer more reliable repairs than independent repair shops, and aim at reducing costs for the user. By combining the widespread network of independent shops with the reliability and warranty manufacturers can offer, a desirable service can be created.

To create the best functioning system, the smartphone design and the repair network need to reinforce each other; a large repair network that is not utilised does not make sense, as does a repairable smartphone that you cannot repair within a reasonable amount of time. Therefore, users need to be motivated to repair, and a repairable smartphone needs to decrease the repair time to increase motivation even more.

## 10.2 Business Model

This requires creating value for all involved stakeholders to have them participate: the user, the repair shops, and the manufacturer. The user needs to be motivated to repair, thus the affordability, accessibility and attractiveness of the repair offer need to be improved. The repair shop needs a better ability to repair to increase the accessibility for users, they need to be provided with the right manuals, tools, and spare parts, and through the platform they can generate more customers. The manufacturers need to enable this and value needs to be added in the form of a strengthened competitive position.

In Figure 55, on the following pages, a circular business canvas is shown, where the business aspects of the service are addressed. The value propositions for the different stakeholders are included, as well as the revenue and cost streams for Fiksall. The mission is to organise a collaboration between repair shops and manufacturers that makes repairing smartphone displays affordable, accessible, and attractive to users. The service is aimed at repair candidates, users who have a smartphone with a broken display.
For the user, original parts are combined with a quick, accessible service at a reduced cost. Users get a more reliable repair at more locations closer to them. They are attracted to repair by reducing the time and effort it costs to have a smartphone repaired, and by playing into their intrinsic motivation. The user will feel their contribution to the environment by means of an impact calculator, as will later be described in more detail.

*Table 34 – Environmental break-even points display repair*

| Scenario | Impact per year of use (kgCO2e/year) | Use (months) | Added time to break-even (months) |
|---|---|---|---|
| *Shorter use (1.7 years)* | 39.5 | 20.4 | |
| *Break-even display replacement* | 39.5 | 21.8 | 1.4 |
| ***Baseline (2.7 years)*** | 25.9 | 32.4 | - |
| ***Break-even display replacement*** | 25.9 | 34.7 | 2.3 |
| *Longer use (3.7 years)* | 19.7 | 44.4 | |
| *Break-even display replacement* | 19.7 | 47.5 | 3.1 |

The repair shops gains a better ability to repair smartphones, through having access to documentation, tools, and available spare parts. Customers are referred to them through the platform, increasing their online presence and having users trust their repairs more. The repair shops will have to return the broken parts they take off devices to the manufacturers. Overall, with more repairable smartphones and available repair documentation they will be able to gain a quicker turnaround.
The manufacturer opens up access to the documentation, tools, and spare parts to the participating repair shops. They gain a repair network for their smartphones, and the return of broken parts to be recycled and enter their supply chain again, which cuts costs. Having a larger repair network has advantages for manufacturers, as (Sabbaghi, Esmaeilian, Cade, Wiens, & Behdad, 2016) and (Lemke & Luzio, 2014) have shown that a better repairability results in returning customers and recommendations of the manufacturer to others, and (Zomerdijk & Voss, 2010) argue that upgrading the user experience leads to higher satisfaction and loyalty. The customer satisfaction is also increased because their smartphones do not have to be replaced when breaking, as they can instead be repaired, resulting in customers that stay with them for longer and are more loyal. More loyal customers also results in being able to sell users more products and services and gain a stronger competitive position. Furthermore, sustainably conscious companies have been shown to outperform their competition in terms of profitability metrics (EY, 2021).
Revenue for Fiksall as a platform to continue to exist is generated by charging manufacturers with a commission on returned parts. This way, the fee is performance-based and the more repairs Fiksall can outsource for a manufacturer, the more it is rewarded. From these revenues, the office and staff needs to be paid, as well as marketing campaigns that targets users and motivates them to repair.

This has a general positive effect on the environment, since more repairs can be carried out, prolonging the lifetime of smartphones, and recycling broken parts for the materials to enter the supply chain again. A possible downside is the rebound effect, users could start repairing earlier than they used to. Yet, if this means that the user is more satisfied with the device and it therefore lasts longer, it does no harm. A user that has been using the smartphone for 2.7 years would have to continue to use it for a little over two months extra to break-even environmentally speaking when the display is replaced (Table 34). These calculations are derived from chapter 4.2.

The environmental break-even points are calculated by setting the yearly impact to equal the impact of the baseline situation, where the smartphone is used for 2.7 years without repairs. The corresponding use needed in months to reach the same yearly impact is then calculated. The added use-time needed in months is then derived from the use-time needed compared to the use-time of the baseline scenario. The break-even takes shorter when the device has been in use for a shorter period, and longer the other way around. This is due to the lower yearly impact a longer use-time has, and thus the larger fraction the new part has in it.

# Business Model Canvas

| | | | | |
|---|---|---|---|---|
| Positive Impacts | | | Prolonging Smartphone Lifetime<br>Lower Environmental Impact | Recycling of Broken Parts |
| Negative Impacts | | $CO_2$ of Web Servers | Rebound Effect | |

**Mission:**
Organise a collaboration between repair shops and manufacturers that makes repairing smartphone displays affordable, accessible and attractive to users

## Key Activities

Design Platform
Marketing
Platform Development
Partnership Management

## Partners

Company:
Web Hosting

Users:
Manufacturers
Repair shops

## Natural Resources

## Technical Resources

Computers
Software
Web Hosting
Offices

## Energy Resources

Electricity

## Value Proposition

User:
Affordable, Accessible, Attractive Repair

Repair shop:
Documentation, Tools, Spare Parts
Customers
Quicker Turnaround

Manufacturer:
Repair Network
Customer Loyalty
Supply Chain Optimisation
Strengthening of Market Position

## Users & Contexts

Repair Candidates

## Next Use

Return Broken Parts to Manufacturer

## Distribution

Website
Web advertisements
Online Partnerships

| | | | | |
|---|---|---|---|---|
| Revenues | Partnerships | | | Commission on Returned Parts |
| Costs | Wages<br>Service Provides | Office Rent<br>Equipment<br>Energy | | Advertisements |

*Figure 55 - Circular Canvas*

## 10.3 Implementation Strategy

Since the service cannot materialise immediately, a strategy for implementation is necessary. The goal is to get the repair market ready for repairable smartphones. For that, a few things need to happen. Firstly, a repair network needs to be in place to support the smartphone. The users need to be motivated to repair in the first place, and find their way to repair shops. Secondly, the manufacturers need to be attracted to cooperate, which enables repair shops to perform more reliable repairs. This will attract more users. Thirdly, when all this is in place, repairable smartphones can be introduced. The user will have locations where the device can be repaired, and the repair will become more favourable as turnaround times can be significantly shortened. For this implementation strategy, a roadmap is created, which can be found on the following pages (Figure 56).

**Horizon 1 - 2022**

To start, there are three elements needed: money, repair shops, and customers. The platform should be developed to convince repair shops to join the program. Therefore, money is necessary, and it can be brought in by investments, loans, and funding. The European Union has digitalisation and environmental allocations within the Multiannual Financial Framework and NextGenerationEU programmes (European Commission, n.d.), where applications for funding can be submitted (European Commission, n.d.). Repair shops will be brought in by making them part of a network and supplying them with customers, with the perspective of access to documentation, tools and spare parts enabling them to repair more smartphones. Customers will be attracted by extensive (online) marketing campaigns.

This marketing strategy will aim at users' environmental consciousness and intrinsic motivation, and the advantages of repairing a smartphone over replacing it: reducing e-waste, saving GHG emissions, and being less expensive than a brand-new smartphone. The message needs to be simple, clean, and professional to portray a trustworthy image. In the campaign, free battery replacements with a display repair as a promotion and the benefit of having a warranty should be emphasized. Warranty should be included to convey reliability and a battery replacement offered to attract users and motivate them to use the smartphone for longer. Battery replacements on current smartphones are not expensive, since the part is affordable and while repairing the display it can be accessed. They also have a short break-even point (Table 35).

**Horizon 2 - 2023**

For the second horizon, the key is to involve manufacturers and have them provide documentation and tools to increase the repair shops' ability to repair. Furthermore, repair shops need to be provided with spare parts that they can order any time they need to. For the manufacturers, this means providing them with incentives to make these accessible. The first advantage is they gain a larger repair network than they themselves can accomplish. Besides that, the broken parts are returned to them, to get recycled and enter the supply chain again. This reduces the cost in the supply chain massively, since the materials come in at no added cost, albeit that it needs investments in distribution to get the parts to the factory. It also makes manufacturers more prepared for the future, with changing regulations and the upcoming right to repair.

**Horizon 3 - 2025**

For horizon 3, the smartphone designs must be optimised for repairability. Considering the repair shops and the manufacturers are attracted in the preceding horizons, there is a final improvement to be made in the efficiency and the user experience. That is aiming for shorter waiting times and lower repair costs. This can be accomplished by designing the smartphone with the professional repairability in mind, for which a concept is elaborated on in the section 10.5.

*Table 35 – Environmental break-even points display repair*

| Scenario | Impact per year of use (kgCO2e/year) | Use (months) | Added time to break-even (months) |
|---|---|---|---|
| *Shorter use (1.7 years)* | 39.5 | 20.4 | |
| *Break-even battery replacement* | 39.5 | 21.0 | 0.6 |
| ***Baseline (2.7 years)*** | 25.9 | 32.4 | - |
| ***Break-even battery replacement*** | 25.9 | 33.3 | 0.9 |
| *Longer use (3.7 years)* | 19.7 | 44.4 | |
| *Break-even battery replacement* | 19.7 | 45.7 | 1.3 |

# Implementation Roadmap

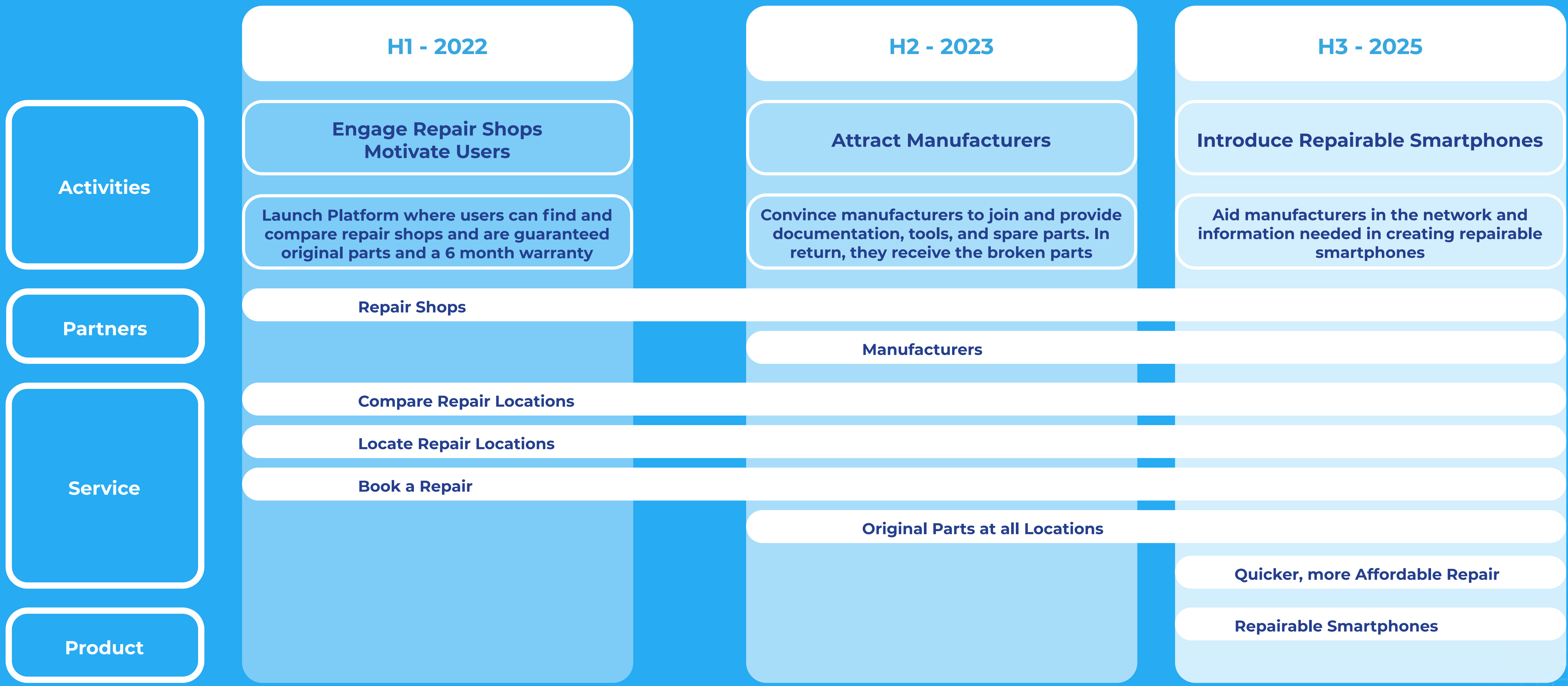



*Figure 56 - Roadmap for implementation*

## 10.4 Website Flow

The user flow for the Fiksall website aims at motivating users to repair, and explores the stage set for horizons 1 and 2, and thus what needs to happen to get the market ready for repairable smartphones. Through marketing campaigns they will be drawn to the website, where they will be guided in booking a repair at a repair shop in the vicinity.

Compared to the concept, the warranty is portrayed more explicitly on the homepage, while it continues to put emphasis on the ease of repairing accomplished through the platform and the contribution to a better world.

The user then specifies what smartphone they want to repair, where it is compared to the costs of buying a similar device new. The defect needs to be indicated next, and the user puts in the rough date of acquisition of the to be repaired smartphone. The environmental savings in the form of GHG emissions are then calculated on the basis of the numbers of months the user indicates to use the smartphone after the repair. The environmental savings are then displayed, alongside the monetary savings.

The next step is to find a repair shop in the vicinity. All repair shops are displayed, while the ones that do not have the expected parts in stock, are greyed out to show their current unavailability. Booking would be possible, yet it is indicated that a repair will take longer or they will have to plan the repair for a later date. What rests, is actually booking the repair, for which the user is directed to a planning page. The options for that particular repair shop are displayed and an overview of the repair is given.

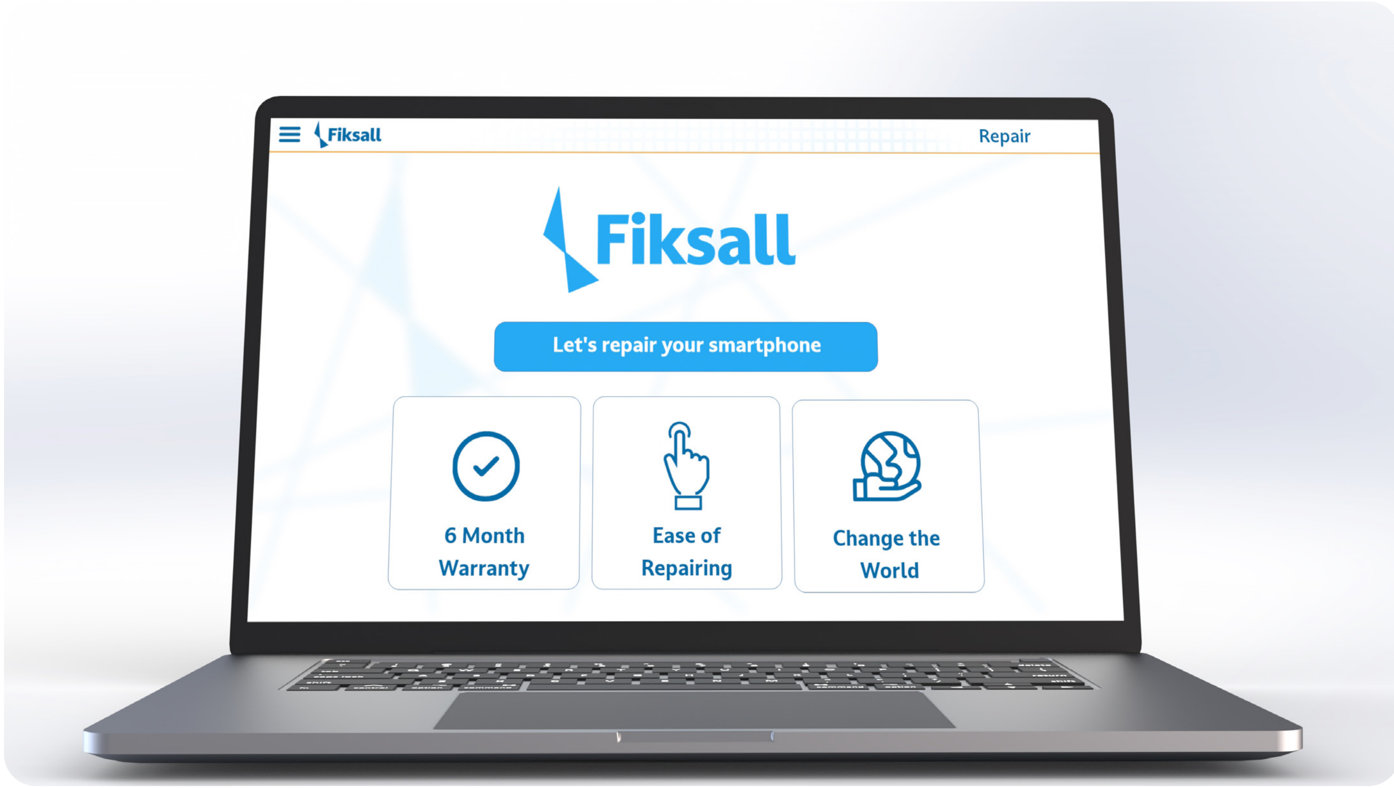



*Figure 57 - Homepage Fiksall*


*Figure 58 - Schedule page Fiksall*

# Website Flow


*Figure 59 - Step 1 Homepage*

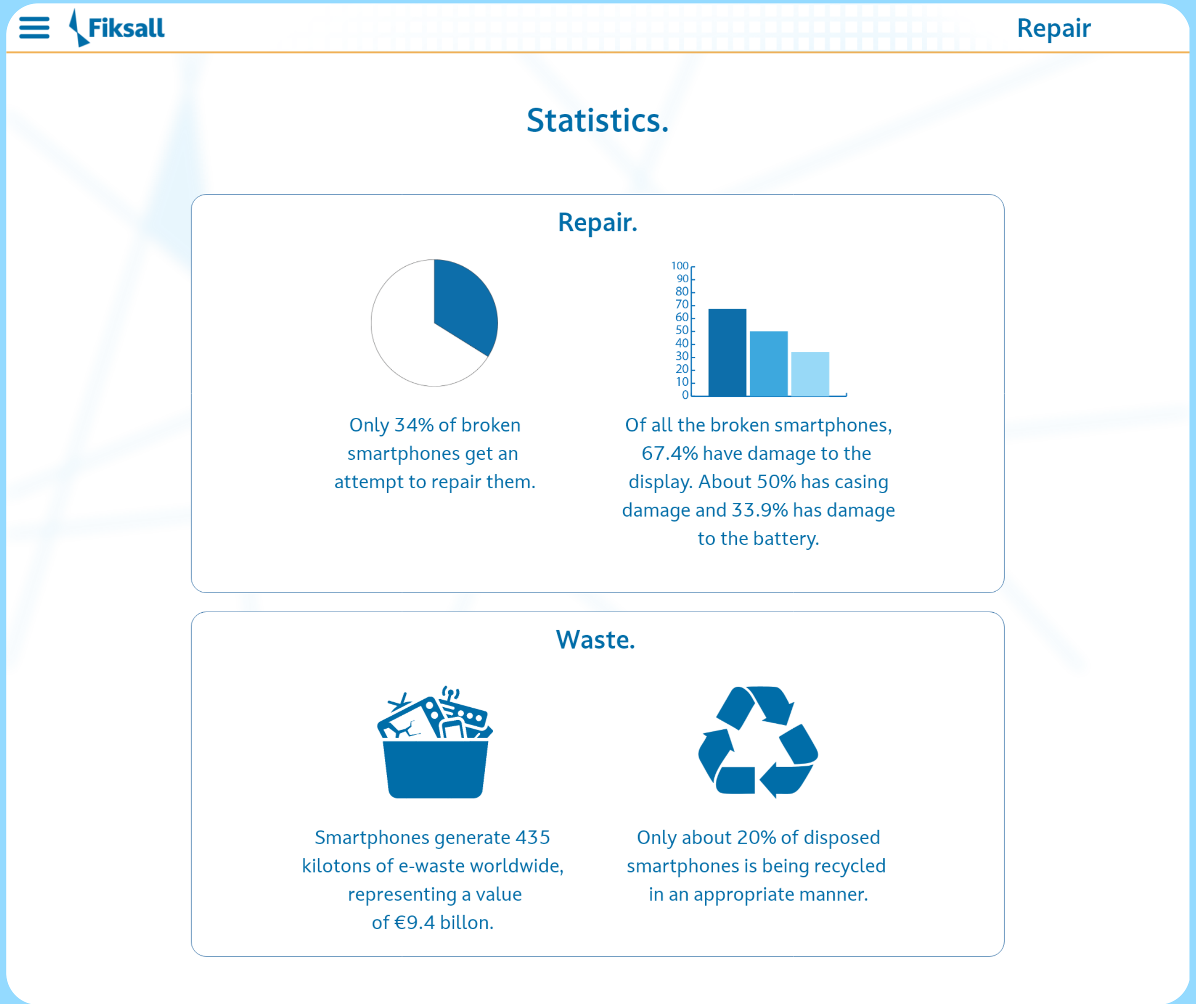



*Figure 60 - Side-step Read more*

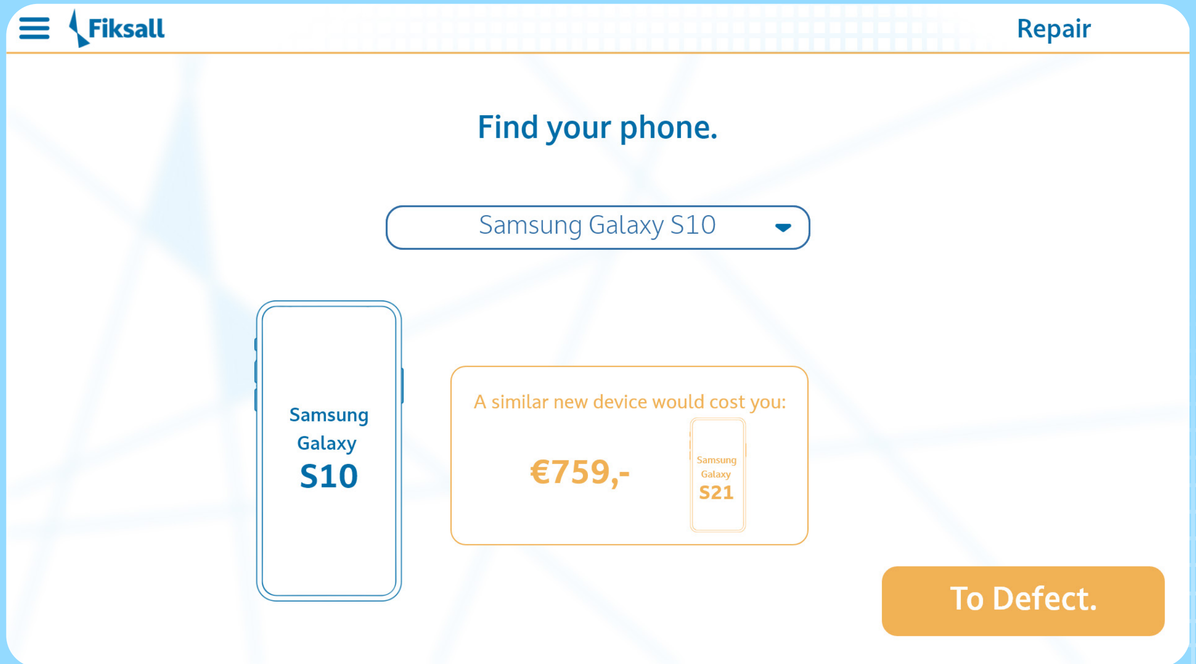



*Figure 61 - Step 2 Specify your smartphone*

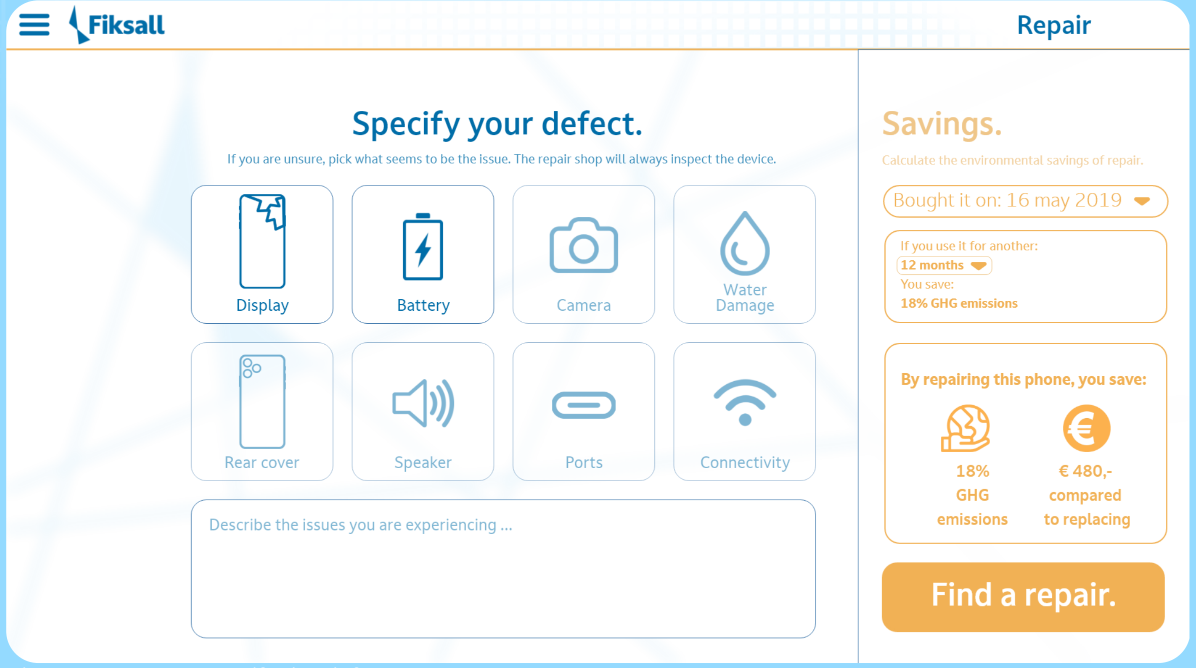



Figure 62 - Step 3 Specify the defect

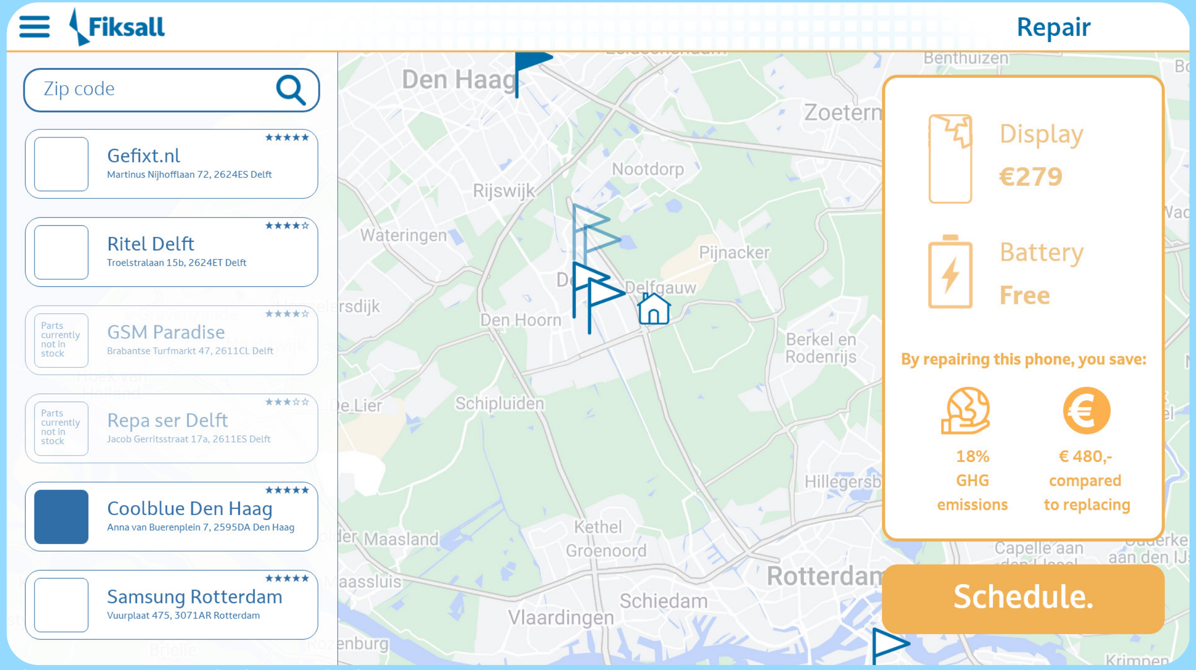



Figure 63 - Step 4 Find a repair shop

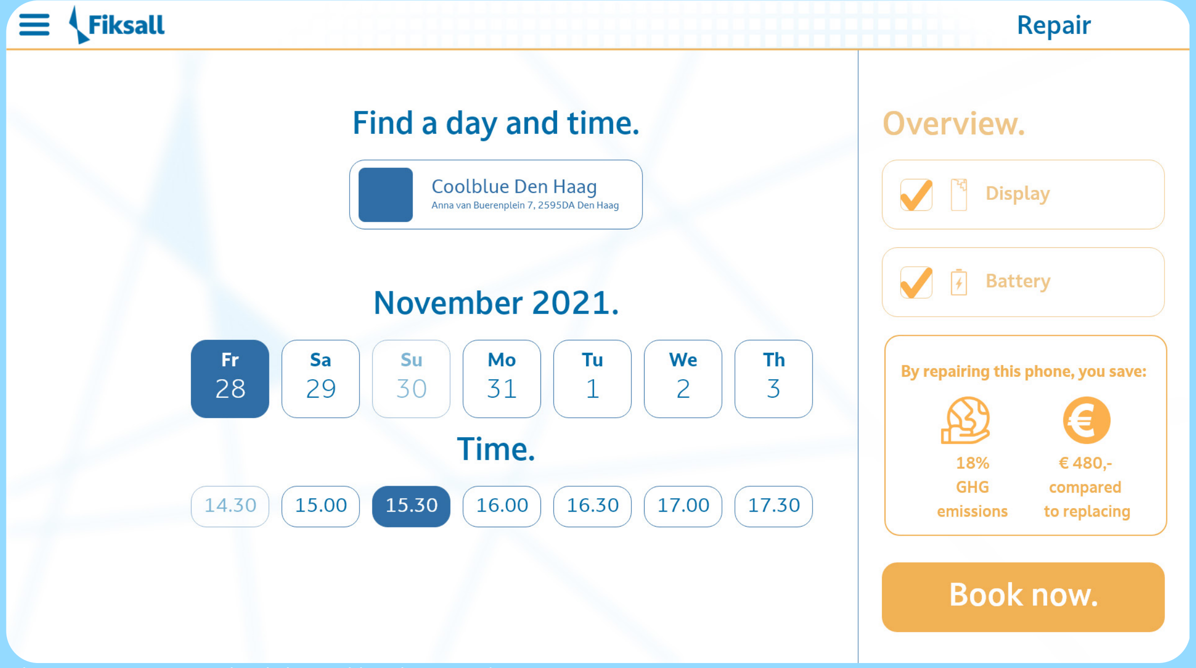



Figure 64 – Step 5 Schedule and book a repair

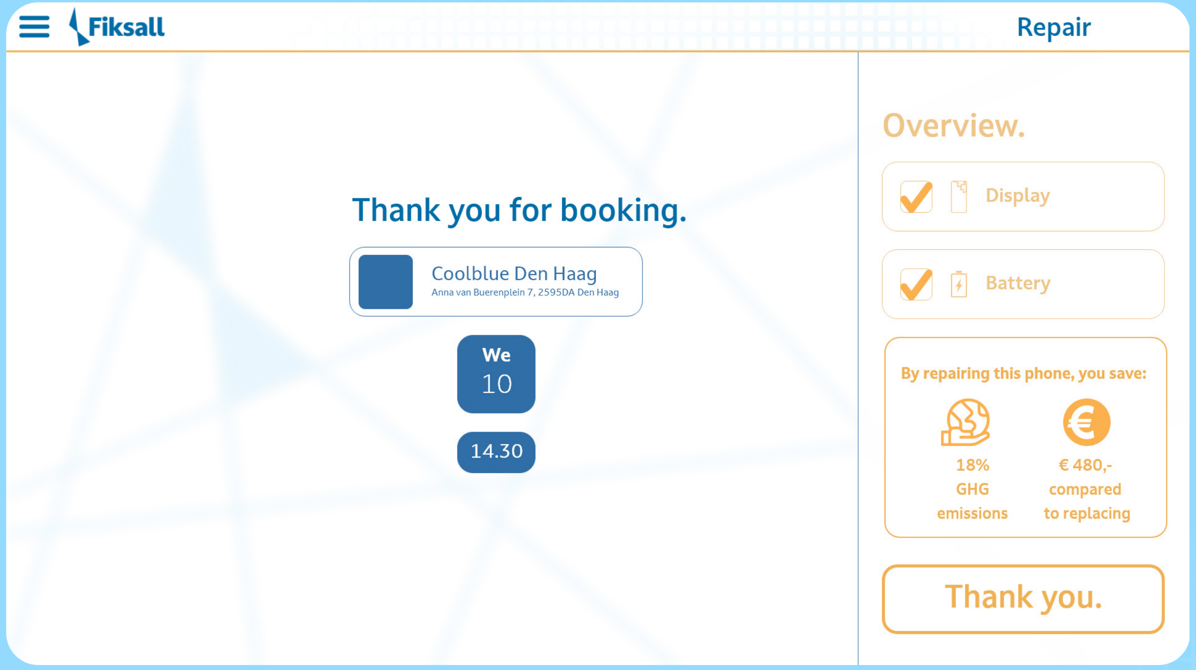



Figure 65 – Step 6 Thank you screen

## 10.5 Smartphone Embodiment

*Figure 66 - Concept smartphone*

Building upon the concept smartphone of chapter 9, the model is developed in three more steps:

4. Construction
5. Connectors
6. Estimation of the specifications

First, the construction of the components was addressed. Both the display and the rear cover are adhered into place using a foam adhesive, to ensure an IP68 rating while still being sufficiently replaceable. Inside the smartphone, the motherboard is screwed into place with a total of seven screws, one in each corner of the L-shaped motherboard and one halfway along the longest side against rattling. The rear cameras, the top speaker and the front camera are all pressed into a specific slot in the chassis, while attaching to the motherboard by a flexwire. The battery is adhered into place using pulltabs, to prevent it from moving around when dropped, yet to be able to remove it when it is needed. The daughterboard is pressed into place by the shield covering it (Figure 68), which is attached to the chassis with four screws of the same type as those for the motherboard. The rear cover is made from plastic, to prevent it from making repair difficult by having broken glass in the way or having it break during the repair.

*Figure 67 - Exploded view smartphone design*

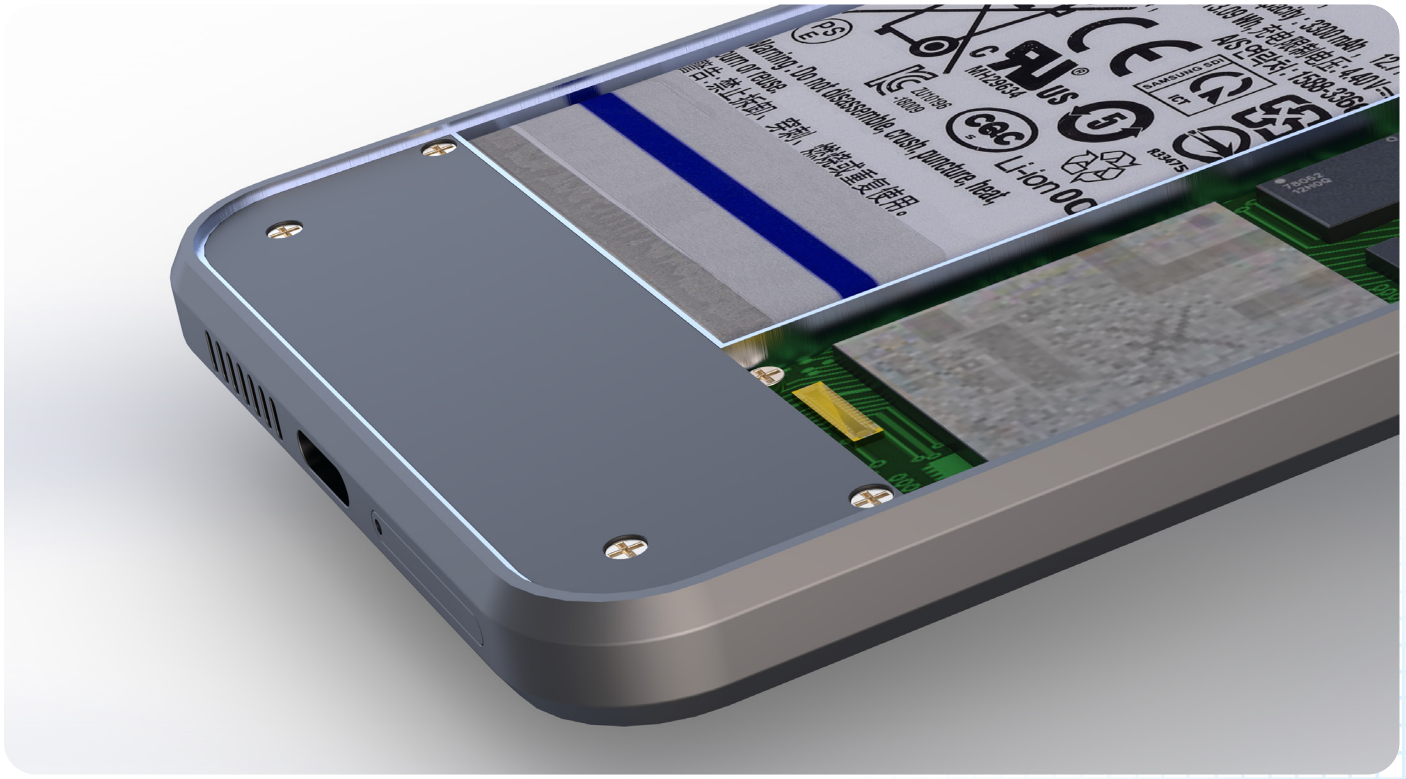


*Figure 68 - Shield daughterboard*

*Figure 69 - Display connection through the chassis*

Considering the way the different components communicate with one another, most of them are attached to the motherboard by press-fit sockets with flexwires. This is done for the display (through the chassis, as shown in Figure 69), rear cameras, top speaker, front cameras, and the daughterboard. The battery is connected to the motherboard with pogo pins (Figure 70), while contact pads are used for the remaining components (Figure 71 and Figure 72): the bottom speaker, the vibration motor, and the buttons. Antennae are included in the chassis and connect through contact pads with the motherboard.


*Figure 70 - Pogo pin connector battery*

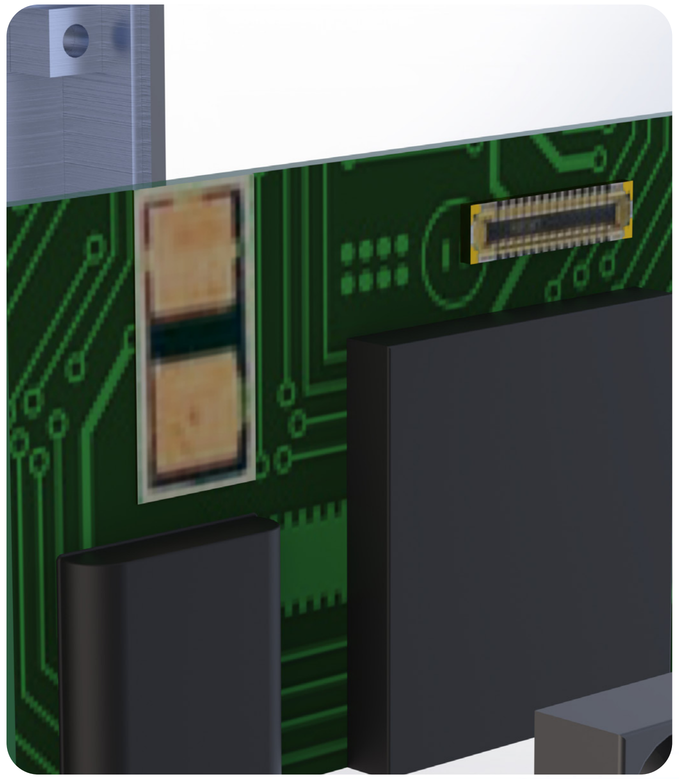


*Figure 71 - Contact pads on daughterboard*

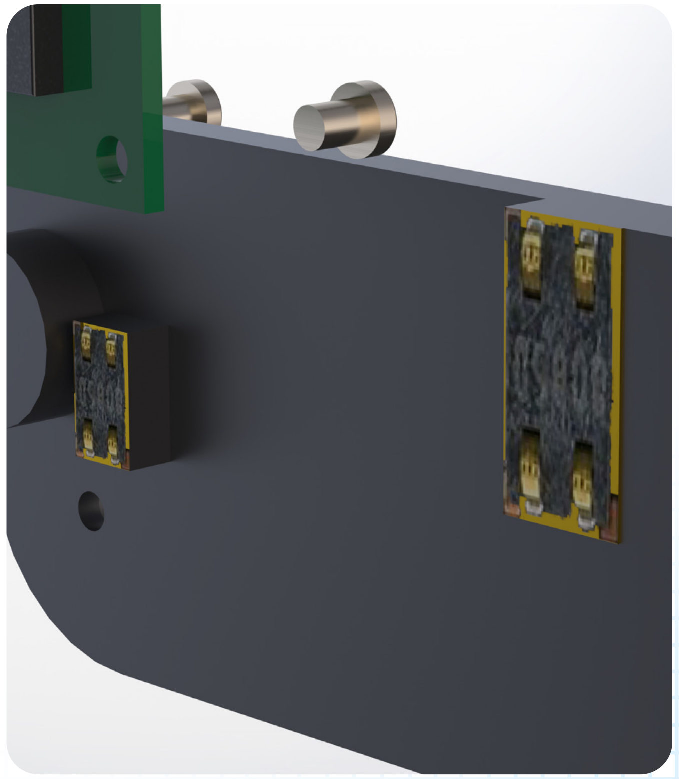


*Figure 72 - Contact pads on the shield*

Looking at the specifications that can be accomplished through this design, it follows the same lines as the high-end smartphones in chapter 3 (Table 36). The dimensions and display are similar, and it features three rear cameras and a front-facing one, while IP68 can be achieved. The storage and RAM options would be dependent of how the motherboard is designed, as well as the specific specifications of the CPU, yet there is enough space in the device to make it possible.

The size of the battery is estimated through comparing its volume to the volume of a battery from a high-end smartphone (Table 37). The physical battery size from the smartphones from chapter 3 are unknown, so the S21 ultra was used, which is a larger model smartphone than those analysed in chapter 3, yet data on the physical size of the battery is available.

*Table 37 - Battery capacity estimation*

| | **S21 ultra** | **Concept Smartphone** |
|---|---|---|
| *Height (mm)* | 66 | 95 |
| *Width (mm)* | 66 | 42 |
| *Thickness (mm)* | 5.5 | 4.81 |
| *Volume (mm3)* | 23958 | 19191.9 |
| *Capacity (mAh)* | 5000 | **4005** |
| *Capacity density (mAh/mm3)* | 0.21 | |



*Table 36 - Estimated specifications versus high-end smartphones (chapter 5.2)*

| | **Concept** | **Samsung Galaxy S21** | **Apple iPhone 13** | **Huawei P40 Pro** | **Xiaomi Mi 11** | **Motorola Edge 20 Pro** | **OPPO Find X3 Neo** | **Oneplus 9** | **Sony Xperia 5 III** |
|---|---|---|---|---|---|---|---|---|---|
| |  |  |  |  |  |  |  |  |  |
| | | *(Samsung, n.d.)* | *(Apple, n.d.)* | *(Huawei, n.d.)* | *(Xiaomi, n.d.)* | *(Motorola, n.d.)* | *(Oppo, n.d.)* | *(Oneplus, n.d.)* | *(Sony, n.d.)* |
| *Price* | - | €779 | €909 | €679.99 | €749 | €699 | €699 | €689 | €999 |
| *Dimensions* | 148.7x71.1x8.21 mm | 151.7 x 71.2 x 7.9 mm | 146.7 x 71.5 x 7.7 mm | 158.2 x 72.6 x 8.95 mm | 164.3 x 74.6 x 8.06 mm | 163.4 x 76.1 x 7.99 mm | 159.9 x 72.5 x 7.99 mm | 160.2 x 74.2 x 8.7 mm | 157 x 68 x 8.2 mm |
| *Weight* | - | 171 g | 173 g | 209 g | 196 g | 189 g | 184 g | 192 g | 168 g |
| *Display* | 6.0" full HD | 6.2" Full HD AMOLED | 6.1" Super Retina XDR | 6.58" OLED | 6.81" AMOLED | 6.67" OLED | 6.55" AMOLED | 6.55" Full HD AMOLED | 6.1" HDR OLED |
| *Battery* | 4005 mAh | 4000 mAh | 3095 mAh | 4200 mAh | 4600 mAh | 4500 mAh | 4500 mAh | 4500 mAh | 4500 mAh |
| *Cameras* | 12 MP<br>12 MP wide<br>12 MP tele | 12 MP<br>12 MP wide<br>64 MP tele | 12 MP<br>12 MP wide | 50 MP wide<br>40 MP ultra-wide<br>12MP tele | 108 MP wide<br>13 MP ultra-wide<br>5MP tele | 108 MP<br>16MP wide<br>8MP tele | 50MP<br>16MP wide<br>13MP tele | 48 MP<br>50 MP wide | 12 MP<br>12 MP tele<br>12 MP wide |
| *Storage* | 128GB | 128GB | 128GB | 256GB | 128GB | 256GB | 256GB | 128GB | 128GB |
| *RAM* | 8GB | 8GB | 4GB | 8GB | 8GB | 12GB | 12GB | 8GB | 8GB |
| *CPU* | 2.9 GHz Octa core | 2.9 GHz Octa core | Hexacore | Octa core | 2.9 GHz Octa core | 3.2 GHz Octa core | 2.8 GHz Octa core | 2.9 GHz Octa core | 2.9 GHz Octa core |
| *Connectivity* | 5G, eSIM | 5G, eSIM | 5G, eSIM | 5G, eSIM | 5G | 5G | 5G | 5G | 5G |
| *IP rating* | IP68 | IP68 | IP68 | IP68 | ≈IP68* | IP52 | IP68 | IP68 | IP68 |

** Xiaomi Mi11 does not have an official rating, yet manufacturer claims are similar to IP68*

# 11 Discussion

To examine whether the objectives have been achieved, the main research question is brought in:

***How to prolong the use-time of smartphones through stimulating repair actions?***

This chapter will dive into how use-times are prolonged by evaluating the different measures taken to stimulate repair actions. Furthermore, limitations of the thesis and the concept are listed, as well as recommendations for further research.

## 11.1 Evaluation

Repair actions are stimulated in different amounts by improving upon the affordability, accessibility, and attractiveness of repair offers. Therefore, the concept is evaluated on these three pillars.

**Affordability**
The affordability is in part addressed by redesigning the smartphone to make quicker repairs possible, that reduce the costs of wages per repair for repair shops and reduces risks of unnecessary breaking of other components. The price of the spare parts, and the distribution, are not addressed and could still be an issue holding users back from repair.

**Accessibility**
The accessibility of repair options is improved by bringing reliable repairs, with original spare parts and sufficient warranty, closer to the user. The repair network enables this and works by connecting different stakeholders; the user, the repair shops, and the manufacturers. For that reason, a platform has been created that is tasked with attracting users and managing the collaboration between stakeholders. The awareness will be improved by providing the user with an overview on the Fiksall website. Users should be drawn to the website by extensive marketing campaigns. Since the campaign is not yet mapped out, this effect cannot be estimated adequately.

The repairability of the smartphone is improved by the concept smartphone. The moving of the display connector to the same side as the display itself makes this repair quicker and easier. The placement of all other components on the opposite side, with only the rear cover to remove prevents breaking the display upon entry of the smartphone, further improving the repairability.

**Attractiveness**
The attractiveness of the repair offer is improved by stimulating the intrinsic motivation of users and reducing the time and effort a repair takes. The intrinsic motivation is stimulated in the form of cooperation and recognition. The user can see their attribution to a lower environmental impact and is acknowledged for their repair action during the journey through the website when booking a repair. The attractiveness of the repair is stimulated by offering warranty on repairs for all shops and offering a battery replacement with repairs for horizon 1 and 2. This adds a benefit to repairing, and the extra environmental impact it poses is compensated by less than one month of prolonged use. The time and effort are reduced through a larger repair network and a more repairable smartphone. The pleasure and functionality a smartphone delivers to the user, is not improved. Yet, what can be seen in repairable or reliable smartphones is that they tend to be thicker and therefore less desirable to users (chapter 5). This effect is minimised in the design, at least aiming to keep a comparable amount of pleasure and functionality, and keeping the competitiveness of the smartphone.

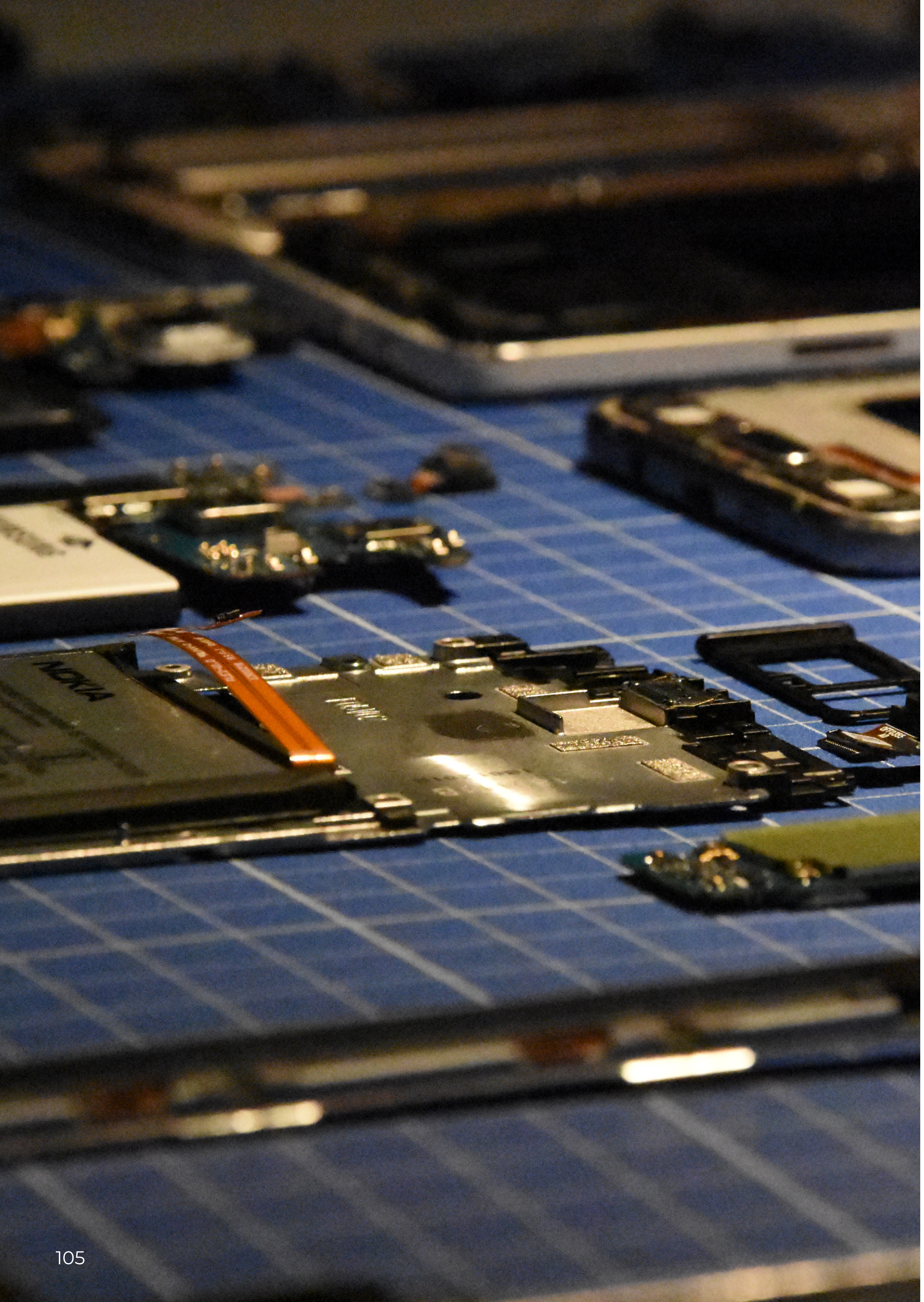


## 11.2 Limitations

Overall, the repair offers are stimulated though making them more accessible and attractive, while the affordability of repair remains to be further improved. The financial motivation is a key factor in the user's decision to repair or replace and it should thus be further explored. Other factors that need more research are the pleasure and functionality the smartphone provides. This concept aims to be competitive in this field and have users choose the smartphone over others, while with prolonged use-times these factors need to be increased to ensure a favourable mental book value over a longer period of time, which makes repair more likely.
Furthermore, this thesis assessed the environmental impact mostly by looking at the yearly impact (kgCO2e/year), while the issue of e-waste generation is not addressed in-depth. Further research should dive into the weights of individual components and the materials that are scrapped. What components contain the scarcest materials, and thus need to be recycled most should be a measure to determine what repairs to further prioritise.
It also needs to address the collection of devices after the use-times. Since repairs should be popularised, smartphones are used for longer, meaning they are closer to the end of their potential maximal use-time and become technologically obsolete when users are done with them. This reduces the need to keep them, and incentives and means to collect them need to be introduced for further improvements in recycling and implementation of circularity.

*Table 38 - Affordability - Accessibility - Attractiveness of the designed solution*

| | Needs | Factor | | Accomplishments |
|---|---|---|---|---|
| ***Affordability*** | *Motivation* | Financial | – | In part addressed by shorter repair times |
| ***Accessibility*** | *Motivation* | Trust | ↑ | Trust is increased by more reliable repairs with original parts and a warranty |
| | *Ability* | Awareness | – | Addressed by marketing campaign |
| | | Network | ↑ | Network for reliable repair is created |
| | | Repairability | ↑ | Repairability is improved by the concept smartphone |
| ***Attractiveness*** | *Motivation* | Intrinsic | ↑ | Motivation is increased by impact calculator |
| | | Pleasure | – | Pleasure of the device is not improved |
| | | Functionality | – | Functionality of the device is not improved |
| | *Ability* | Time and Effort | ↓ | Time and effort a repair takes are decreased by reliable repairs in the vicinity (large network) and improved repairability of the smartphone |
| | *Triggers* | Previous repairs | ↑ | Repair is stimulated, which increases the amount of previous repair experiences |
| | | Social | – | In part addressed by easier repairs |





# 12 Conclusion

The purpose of this thesis has been to improve the user's repair journey to stimulate repairs, and therefore prolonging smartphone use-times. Three pillars of importance have been introduced; affordability, accessibility, and attractiveness of the repair offers. The accessibility and attractiveness of the offer have been extensively addressed, and improvements have been made. The affordability of the offer, though, has not been adequately improved through this design.

The accessibility of reliable repair options is improved through generating a large repair network of independent repair shops that get support from manufacturers. The general repairability is increased by the concept smartphone, and thus quicker repairs are possible. This means, compared to independent repair shops, that the travel time is similar as it makes use of those same shops, yet the repair time can be cut in half by differently designed smartphones. This means repair costs less time and effort for the user, and the repair shops gain quicker turnaround times.

Furthermore, the attractiveness of repair offers is improved by increasing the user trust with guaranteed original parts and warranty for participating repair shops. The time and effort a repair takes are decreased by a large repair network and shorter repair times. Intrinsic motivation is stimulated through showing the user what impact their decision has on the environment, and what can possibly be saved by repairing the smartphone and using it for longer. Manufacturers can gain a stronger competitive position by being early to stimulating repair, and should open up their repair knowledge and develop smartphones that are easier to repair.

The synergy between the network and the smartphone is key to stimulating repairs. A network that is not being used to its full potential, as is currently the situation, does not make sense. Neither does a repairable smartphone that can only be repaired at limited locations, as manufacturers currently organise it. This concept aims at combining these into a system that favours repair over replacement. While many more steps are needed before this can be implemented, this is a first step in combining efforts of the repair network and repairable smartphones to prolong the use-times of smartphones.

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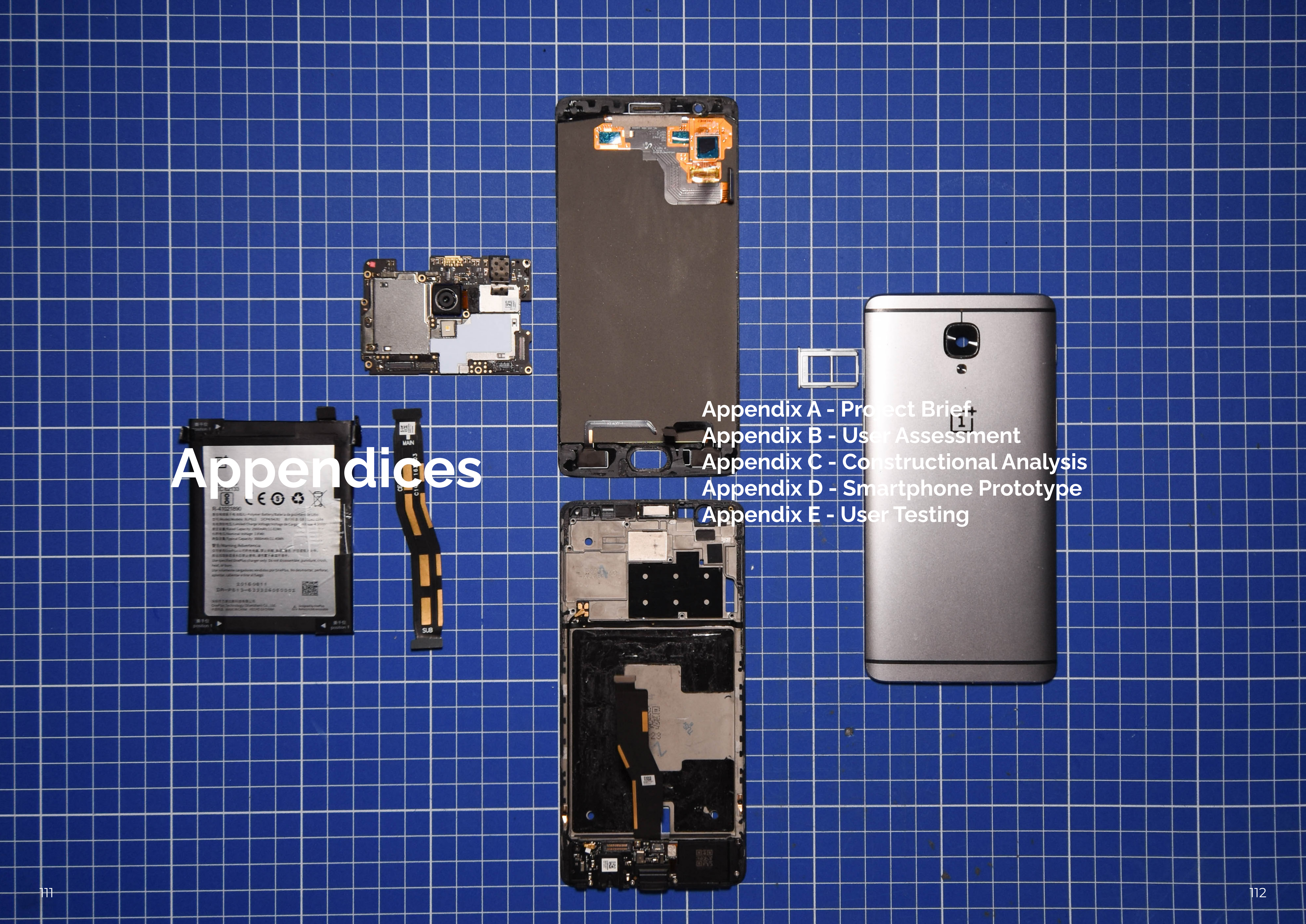


# Appendices

Appendix A - Project Brief
Appendix B - User Assessment
Appendix C - Constructional Analysis
Appendix D - Smartphone Prototype
Appendix E - User Testing

# Appendix A - Project Brief

DESIGN FOR our future

TU Delft

## IDE Master Graduation

Project team, Procedural checks and personal Project brief

This document contains the agreements made between student and supervisory team about the student's IDE Master Graduation Project. This document can also include the involvement of an external organisation, however, it does not cover any legal employment relationship that the student and the client (might) agree upon. Next to that, this document facilitates the required procedural checks. In this document:

- The student defines the team, what he/she is going to do/deliver and how that will come about.
- SSC E&SA (Shared Service Center, Education & Student Affairs) reports on the student's registration and study progress.
- IDE's Board of Examiners confirms if the student is allowed to start the Graduation Project.

**USE ADOBE ACROBAT READER TO OPEN, EDIT AND SAVE THIS DOCUMENT**

Download again and reopen in case you tried other software, such as Preview (Mac) or a webbrowser.

### STUDENT DATA & MASTER PROGRAMME

Save this form according the format "IDE Master Graduation Project Brief_familyname_firstname_studentnumber_dd-mm-yyyy". Complete all blue parts of the form and include the approved Project Brief in your Graduation Report as Appendix 1 !

family name: Boonen 4792
initials: M given name: Marijn
student number: 4365488
street & no.:
zipcode & city:
country:
phone:
email:

Your master programme (only select the options that apply to you):
IDE master(s): (★) IPD ( ) Dfl (★) SPD
2nd non-IDE master:
individual programme: - - (give date of approval)
honours programme: Honours Programme Master
specialisation / annotation: Medisign
Tech. in Sustainable Design
Entrepeneurship

### SUPERVISORY TEAM **

Fill in the required data for the supervisory team members. Please check the instructions on the right !

** chair: Ruud Balkenende dept. / section: SDE
** mentor: Ruth Mugge dept. / section: DOS
2nd mentor:
organisation:
city: country:

comments (optional)

Chair should request the IDE Board of Examiners for approval of a non-IDE mentor, including a motivation letter and c.v..

Second mentor only applies in case the assignment is hosted by an external organisation.

Ensure a heterogeneous team. In case you wish to include two team members from the same section, please explain why.



TU Delft

**Procedural Checks** - IDE Master Graduation

### APPROVAL PROJECT BRIEF

To be filled in by the chair of the supervisory team.

chair: Ruud Balkenende date: 05 - 03 - 2021 signature: [signature]

### CHECK STUDY PROGRESS

To be filled in by the SSC E&SA (Shared Service Center, Education & Student Affairs), after approval of the project brief by the Chair. The study progress will be checked for a 2nd time just before the green light meeting.

Master electives no. of EC accumulated in total: 27 EC
Of which, taking the conditional requirements into account, can be part of the exam programme: 27 EC
List of electives obtained before the third semester without approval of the BoE

(★) YES all 1st year master courses passed
( ) NO missing 1st year master courses are:

name: C. van der Bunt date: 08 - 03 - 2021 signature: C. van der Bunt Digitally signed by C. van der Bunt Date: 2021.03.08 10:51:38 +01'00'

### FORMAL APPROVAL GRADUATION PROJECT

To be filled in by the Board of Examiners of IDE TU Delft. Please check the supervisory team and study the parts of the brief marked **. Next, please assess, (dis)approve and sign this Project Brief, by using the criteria below.

- Does the project fit within the (MSc)-programme of the student (taking into account, if described, the activities done next to the obligatory MSc specific courses)?
- Is the level of the project challenging enough for a MSc IDE graduating student?
- Is the project expected to be doable within 100 working days/20 weeks ?
- Does the composition of the supervisory team comply with the regulations and fit the assignment ?

Content: (★) APPROVED ( ) NOT APPROVED
Procedure: (★) APPROVED ( ) NOT APPROVED

- remark: problem definition not clear/generic

comments

name: Monique von Morgen date: 16 - 03 - 2021 signature:

Design Guidelines for Repairable and Upgradeable Smartphones project title

Please state the title of your graduation project (above) and the start date and end date (below). Keep the title compact and simple. Do not use abbreviations. The remainder of this document allows you to define and clarify your graduation project.

start date 15 - 02 - 2021 04 - 10 - 2021 end date

**INTRODUCTION ****

Please describe, the context of your project, and address the main stakeholders (interests) within this context in a concise yet complete manner. Who are involved, what do they value and how do they currently operate within the given context? What are the main opportunities and limitations you are currently aware of (cultural- and social norms, resources (time, money,...), technology, ...).

My graduation project is set within the research project PROMPT, Premature Obsolescence Multi-Stakeholder Product Testing Program, which looks at different aspects regarding the premature obsolescence of four types of consumer goods: washing machines, vacuum cleaners, (smart-)TV's and mobile phones. Premature obsolescence regards the early disposal of a product, meaning it is being discarded while still physically functioning or demanding a, be it minor, repair (van den Berge & Thysen, 2020). There are many factors that relate to it, among which the functional aspects as well as the user-business aspects. These can be divided in the absolute obsolescence, referring to the physical wear of the product, and the relative obsolescence, depending on the users' view on the product.

This project will focus on smartphones in the European market and their relative obsolescence, with in particular the repairability/upgradeability and user-business aspects of the designs. This means balancing the technological aspects, meaning the physical features that make a smartphone repairable or upgradeable, with the psychological aspects, meaning the awareness and the willingness of consumers to repair or upgrade.

The main stakeholder here is the consumer, as the strongest interaction is between the user and the technology. There is a need for a change in behavior of consumers in relation to smartphone repairs and upgrades. On the other hand there are the manufacturers, who need to enable the possibilities for repairing and upgrading and encourage consumer to do that. For repairing, there are two options, doing it yourself or going to a repair company. Repair companies are therefore also a stakeholder, and they can make clear that repairing or upgrading is worth the effort and communicate that the behavioral and financial costs of repair are not high.

The opportunities within this project are making consumers more attracted to repairing or upgrading their smartphones and inspire manufacturers into new business models that enable more repairing and upgrading. The limitations of this project are that there is little focus on the absolute obsolescence, the physical wear and tear of smartphones.

The project fits IDE and both my Master programmes, because it combines the three pillars of people, technology and business by looking at the interaction between consumers and their technology, in this case smartphones, through a business perspective, looking at how this interaction can be altered in favor of repairing and upgrading. It fits 'Design for our future' because it aims to create a more sustainable way of dealing with smartphones. Both the SPD as the IPD aspects come forward here, as there is a need to figure out why consumers behave the way they do in this market, and what strategies can be applied to make people more prone to repairing their smartphones. There is then a call for combining the needs of the different stakeholders across different product aspects and use integrative approaches into the development of a concept design.

van den Berge, R., & Thysen, T. (2020). State-of-the-art knowledge on user, market and legal issues related to premature obsolescence

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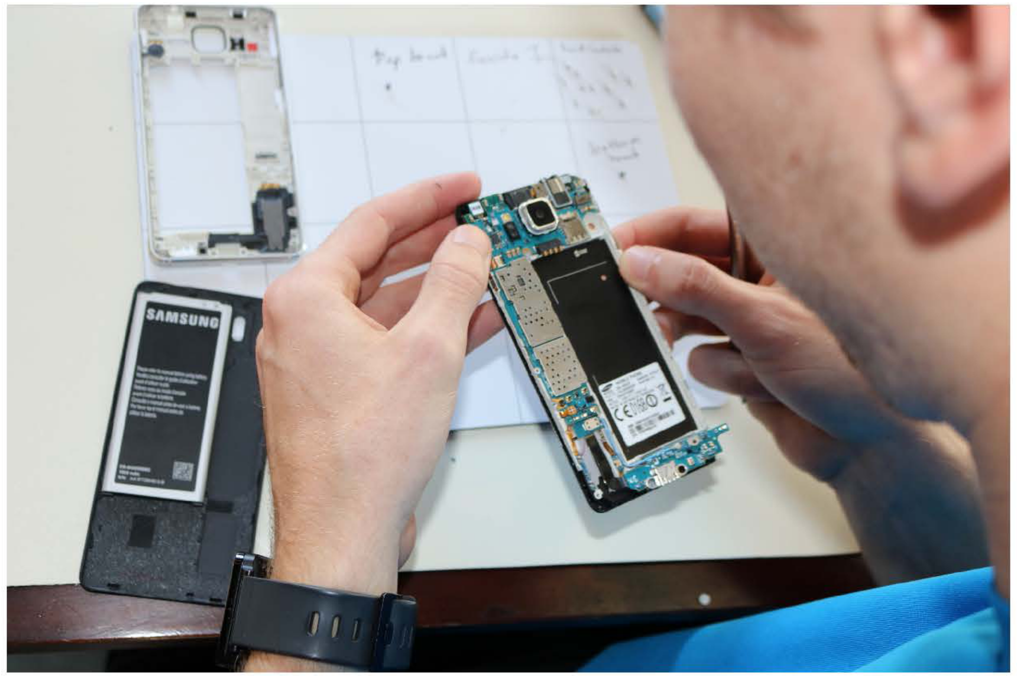



image / figure 1: Repairing a smartphone (iFixit)

TO PLACE YOUR IMAGE IN THIS AREA:

- SAVE THIS DOCUMENT TO YOUR COMPUTER AND OPEN IT IN ADOBE READER
- CLICK AREA TO PLACE IMAGE / FIGURE

PLEASE NOTE:

- IMAGE WILL SCALE TO FIT AUTOMATICALLY
- NATIVE IMAGE RATIO IS 16:10
- IF YOU EXPERIENCE PROBLEMS IN UPLOADING, COVERT IMAGE TO PDF AND TRY AGAIN

image / figure 2:

## PROBLEM DEFINITION **

Limit and define the scope and solution space of your project to one that is manageable within one Master Graduation Project of 30 EC (= 20 full time weeks or 100 working days) and clearly indicate what issue(s) should be addressed in this project.

Smartphones are often discarded before the actual end of their lifetime. There is a discrepancy between the expected lifetime of mobile phones, about 5.2 years, and the actual lifetime, about 2.7 years (Wieser et al, 2015). The two most common reasons for getting a new phone are that the old phone is defective or has a restricted functionality and that the new phone is a better one (Wieser & Troger, 2018). Next to this, it is currently in most phones not possible to upgrade anywhere in its lifetime. There are opportunities in repairing, as in Germany only 23% of inhabitants have had their phone repaired (Greenpeace, 2016), and as Jaeger-Erben et al (2020) indicate, there is a need for a strategy favoring repair over replacement.

Wieser, H., Tröger, N., & Hübner, R. (2015). The Consumers' Desired and Expected Product Lifetimes.
Wieser, H., & Tröger, N. (2018). Exploring the inner loops of circular economy: Replacement, repair, and reuse of mobile phones in Austria.
Greenpeace, 2016. Greenpeace Global Mobile Survey 2016.
Jaeger-Erben, M., Frick, V., & Hipp, T. (2020). Why do users (not) repair their devices? A study of the predictors of repair practices.

## ASSIGNMENT **

State in 2 or 3 sentences what you are going to research, design, create and / or generate, that will solve (part of) the issue(s) pointed out in "problem definition". Then illustrate this assignment by indicating what kind of solution you expect and / or aim to deliver, for instance: a product, a product-service combination, a strategy illustrated through product or product-service combination ideas, ... . In case of a Specialisation and/or Annotation, make sure the assignment reflects this/these.

Creating a set of design guidelines to enable more smartphone repairs and upgrades, these guidelines will be exemplified by a design concept. To get there, the current circumstances around smartphone repairs and upgrades will be researched.

For this project, the outcome will be a set of design guidelines, exemplified by a concept that will be worked out to near embodiment. The following deliverables will be expected:

- End-Term Presentation (Public)

- Video presenting the concept

- Graduation report (thesis) - target audience TU Delft

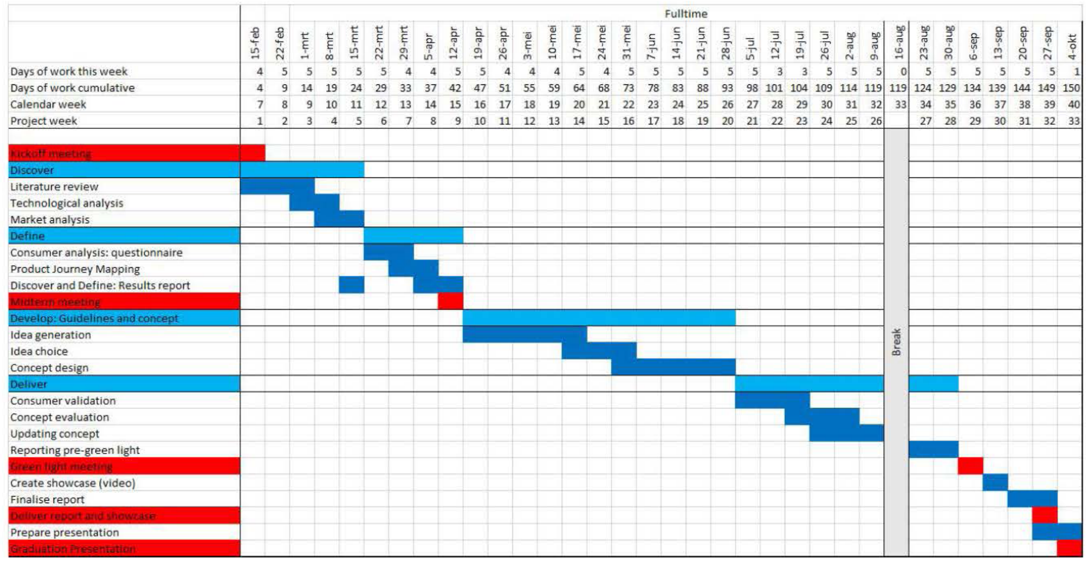




## PLANNING AND APPROACH **

Include a Gantt Chart (replace the example below - more examples can be found in Manual 2) that shows the different phases of your project, deliverables you have in mind, meetings, and how you plan to spend your time. Please note that all activities should fit within the given net time of 30 EC = 20 full time weeks or 100 working days, and your planning should include a kick-off meeting, mid-term meeting, green light meeting and graduation ceremony. Illustrate your Gantt Chart by, for instance, explaining your approach, and please indicate periods of part-time activities and/or periods of not spending time on your graduation project, if any, for instance because of holidays or parallel activities.

start date 15 - 2 - 2021 4 - 10 - 2021 end date




For my project, the double diamond structure will be used as an overall method. It will start with thorough analysis into the existing literature, the current technology inside smartphones and a market analysis. This will provide insights into the problem, along with the current solutions. It will be followed by an analysis on what consumers think of repairing and mainly upgrading their smartphones. The product journey will be mapped and finally there will be a report of the discover and define phases, which ends on a clear problem definition as a start for finding solutions.

After that, the guidelines and the concept will be developed, starting with idea generation, choosing and elaborating on the concept. This will then be validated with consumers and evaluated on other points. The concept will be altered along this and finalized, after which it is a matter of finishing the deliverables and working towards the graduation presentation.

During the project, there are a few days off planned. First, there are the national holidays in march, april and may. In july, there is a long weekend away, and I will be gone the week of 16th of august. Taking these days into account the planning amounts to 150 days.

## MOTIVATION AND PERSONAL AMBITIONS

Explain why you set up this project, what competences you want to prove and learn. For example: acquired competences from your MSc programme, the elective semester, extra-curricular activities (etc.) and point out the competences you have yet developed. Optionally, describe which personal learning ambitions you explicitly want to address in this project, on top of the learning objectives of the Graduation Project, such as: in depth knowledge a on specific subject, broadening your competences or experimenting with a specific tool and/or methodology, ... . Stick to no more than five ambitions.

Over the last three years, I have learned a lot in both my masters. From developing concepts and embodiment design to understanding consumers and creating strategies. The graduation is where it needs to come together. This project can allow for that, because one of the interesting questions here is how to take the reasoning and behavior of consumers into account in designing physical features in smartphones. This combination of factors, and mainly the balance between the two, is where the two masters come together. I wanted to take on a project that touches upon larger issues in the world, and sustainability is such a theme. It is becoming more and more important and this is not yet apparent in all of our behavior. I have always had an interest in taking things apart, seeing how they work and trying to repair them and I believe this is something that needs to be done more, as it can prolong the lifetime of products and therefore reducing environmental impact.

Last semester, I had the elective sustainable design strategies and I want to learn more on sustainability throughout this project, as it is something that I have not touched upon enough during my education I believe. During the project, I also want to work more on communication, and mainly communicating my line of thought to others, as this is an aspect I believe there is room for improvement in.

## FINAL COMMENTS

In case your project brief needs final comments, please add any information you think is relevant.

# Appendix B - User Assessment

A questionnaire was sent out to obtain data from a group of 25 respondents, to find out whether they are willing to repair and what options they do consider when they want to. If they have repaired before, they were asked why they have done it and if they are not willing to repair, they were asked for their reasoning. The goal of the analysis is to find out whether users are willing to repair and what options they consider when they would want to repair.

***Method***
A questionnaire, asking questions about smartphone repair experience, was created, and sent out to find answers to the questions above.

*Respondents*
The target group consists of young adults, ranging from 20-31 years. These are the heaviest smartphone users (Deloitte, 2019), and they also replace their smartphones earlier than other age groups (Nolsoe, 2020). In total, there were 25 respondents from this age group, and they all have the Dutch nationality.

*Questions*
The questions were about the current and previous smartphone, asking for how long they owned it and why they replaced or repaired it. A final section provided a scenario to the respondents what they would do if the display of their current smartphone would suddenly break, so that it doesn't function properly anymore.

1. Age

Current smartphone

2. What smartphone do you currently have? (Brand and model)
3. How long have you had this one for?
4. Is something on it broken? If yes, what, and are you planning to fix it?
5. Have you ever repaired this one? If yes, what was broken, en why did you have it fixed?

Previous smartphone

6. What smartphone did you have? (Brand and model)
7. How long have you had that one for?
8. Why did you replace it?
9. If it was broken, why did you choose to replace and not for repair?

Scenarios

10. Imagine that your display cracks tomorrow, would you get it fixed and why?
11. What would you pay for it maximum?
12. What options would you consider to have it fixed?
    a. Manufacturer
    b. Authorised reseller/repair shop
    c. Independent repair shop
    d. A friend
    e. Self-repair
    f. Other, ...
13. Why?
14. Could you rate the pros and cons of every option?
    a. Manufacturer?
    b. Authorised reseller/repair shop?
    c. Independent repair shop?
    d. A friend?
    e. Self-repair?



***Results***
Table 39 below shows the different smartphone models of the respondents, alongside how long they have had it for and how much they are willing to pay if the display would break, impacting the usability of the device, like in Figure 73, which was shown in the questionnaire. The actual repair cost has been looked up on the manufacturer websites, or that of official repair partners. For respondent 1 the model of smartphone is unknown, so a repair cost for it could not be found.

*Figure 73 - Display break*

*Table 39 - Respondents willing to pay vs the repair cost*

| Respondent # | Smartphone | Phone age (years) | Willing to pay (euros) | Actual cost (euros) | Percentage |
|---|---|---|---|---|---|
| *1* | Xiaomi | 2 | 100 | | |
| *2* | Onuplus 5T | 3,5 | 50 | 82,3 | 61% |
| *3* | Nokia 7.1 | 1,5 | 80 | 109,99 | 73% |
| *4* | Samsung Galaxy S10 | 1 | 100 | 279 | 36% |
| *5* | Samsung Galaxy A70 | 2 | 150 | 145 | 103% |
| *6* | Samsung Galaxy S20 | 0,5 | 50 | 259 | 19% |
| *7* | Samsung Galaxy A50 | 2 | 100 | 129 | 78% |
| *8* | Apple iPhone 6 | 3 | 30 | 151,1 | 20% |
| *9* | Samsung Galaxy A40 | 2 | 60 | 129 | 47% |
| *10* | Samsung Galaxy A50 | 1,5 | 40 | 129 | 31% |
| *11* | Huawei P10 Light | 4 | 80 | 99 | 81% |
| *12* | Apple iPhone 8 | 2 | 100 | 171,1 | 58% |
| *13* | Apple iPhone 7 | 5 | 100 | 171,1 | 58% |
| *14* | Apple iPhone 6 | 2,5 | 50 | 151,1 | 33% |
| *15* | Samsung Galaxy S10e | 1 | 100 | 199 | 50% |
| *16* | Umidigi S2 Pro | 3 | 100 | 175 | 57% |
| *17* | Samsung Galaxy A5s 2017 | 4 | 20 | 139 | 14% |
| *18* | Oppo Reno 2 | 1,5 | 20 | 195 | 10% |
| *19* | Samsung Galaxy S21 | 1 | 150 | 225 | 67% |
| *20* | Samsung Galaxy M31 | 1 | 40 | 129 | 31% |
| *21* | LG G8s ThingQ | 2 | 100 | 139,99 | 71% |
| *22* | Samsung Galaxy A70 | 2 | 120 | 145 | 83% |
| *23* | Oneplus Nord 2 | 0,1 | 80 | 117 | 68% |
| *24* | iPhone SE 2 | 2 | 100 | 151,1 | 66% |
| *25* | Samsung Galaxy A72 5G | 0 | 100 | 155 | 65% |

Next to that, the respondents were asked which repair options they would consider and why. Those results can be found in the Table 40.

Besides the considerations, respondents have indicated why they opted to replace their last smartphone, and if it was broken why they have not chosen for a repair. Respondent 1 noted that the phone had been repaired twice before, so the choice became to replace because of the cost. Respondent 24 stated something similar, that the device had been repaired before and he was not satisfied with the cost of repair and the quality of the one performed earlier. Respondent 3 stated that the costs of repair were not in balance with the value of the phone and that the phone was replaced because he was not entirely happy with the device as well. Respondent 6 brought up another issue and indicated that he did not know where to repair. Respondent 8 stated that he would not repair if he was planning on replacing in the next six months anyway. Respondent 21 stated that a display repair is often expensive and thought that a new smartphone would add more value, as well as noting that ordering a new smartphone is less complicated than getting one repaired. Respondent 23 stated that he wanted to buy a new phone for a while, and the repair cost were high in comparison to the value of the device.

*Table 40 – Respondents' considerations and perceptions of the different repair options*

| | Manufacturer | Official repair partner | Independent repair shop | Friend | DIY |
|---|---|---|---|---|---|
| *Considered by* | 17 | 19 | 17 | 9 | 7 |
| *Pros* | Quality | Quality | Quick | Low price | Low price |
| | Official parts | Quicker than manufacturer | Good price | Proximity | Challenge |
| | Warranty | | | | |
| | | Proximity | | | |
| *Cons* | Takes long | Takes long | No warranty | High risk | High risk |
| | High price | High price | No original parts | | Effort |

***Conclusions***

Overall, the respondents are willing to repair, yet there is careful consideration in place weighing multiple aspects of repair or replacement. The respondents indicated that they would not repair if it were redeemed as not worth it in relation to the value of the device. A hard conclusion on what users a willing to pay cannot be concluded from this analysis, but the amount of money they state they are willing to pay is way less than the actual cost for most of the respondents. Besides comparing the costs of repair and the value of the phone, there are other considerations in choosing whether to repair or to replace. Among the reasons are getting a new one with a new provider subscription or from someone else, having a very old phone that is getting outdated or wanting a better smartphone.

According to the user, there is no real margin between manufacturer, partner, or independent shop, they just each have their different advantages and disadvantages according to the respondents. Where the manufacturer and the repair partner have the best service in terms of quality and warranty, they both lack in that they are perceived as expensive and taking a lot of time for a repair. The independent repair shop is perceived as a quicker, cheaper alternative, yet the respondents stated that they fear that they repair with non-original parts. Repairing themselves or having it done by a friend that would be capable of it is sometimes perceived as an option, but it is stated that there is a high risk involved here.

# Appendix C - Constructional Analysis

A technological analysis was performed to figure out how smartphones are constructed. The goal has mainly been to see in what ways the construction of the display influences the repairability and the reliability of the device  (Cordella, Alfieri, Clemm, & Berwald, 2020b). The analysis is a combination of two parts, one self-performed teardown analysis to figure out the different elements in a smartphone. The second part is complementing to this, by looking at analyses performed by iFixit, and linking that to the repairability and reliability of the device.

***Teardown Analysis***

The first part consisted of tearing down smartphones that were collected in and around Delft. These eleven different smartphones were then taken apart to get an understanding of the different parts of a smartphone and the method of construction. The teardown analysis consisted of the following phones:

- Samsung Galaxy A5 2016
- Samsung Galaxy A5 2017
- Samsung Galaxy A7 2015
- Samsung Galaxy S6
- Apple iPhone 5s
- Apple iPhone 6
- Huawei P20 Lite
- LG Nexus 5
- LG Nexus 5X
- Oneplus 3
- Nokia 6

*Method*

The setup consisted of a workspace, which also functioned as the background for the photos, with two cameras above it attached to a tripod. The workspace was lighted by an LED light. One camera, a Nikon DSLR, above the workspace took photos, which were directly sent to the laptop and processed, while the second one, a GoPro, recorded the entire procedure of tearing the smartphone apart and putting it back together. These recordings were later used to check the procedure and investigate the assembly methods used in the smartphone. The laptop was running Adobe Photoshop Lightroom with the DLSR connected in tethering mode. The smartphone was put on the workspace and a wide range of tools was used to tear down different smartphones. The tools used were the iFixit pro tech toolkit and next to that, a heat gun was used for some smartphones with tough adhesive.

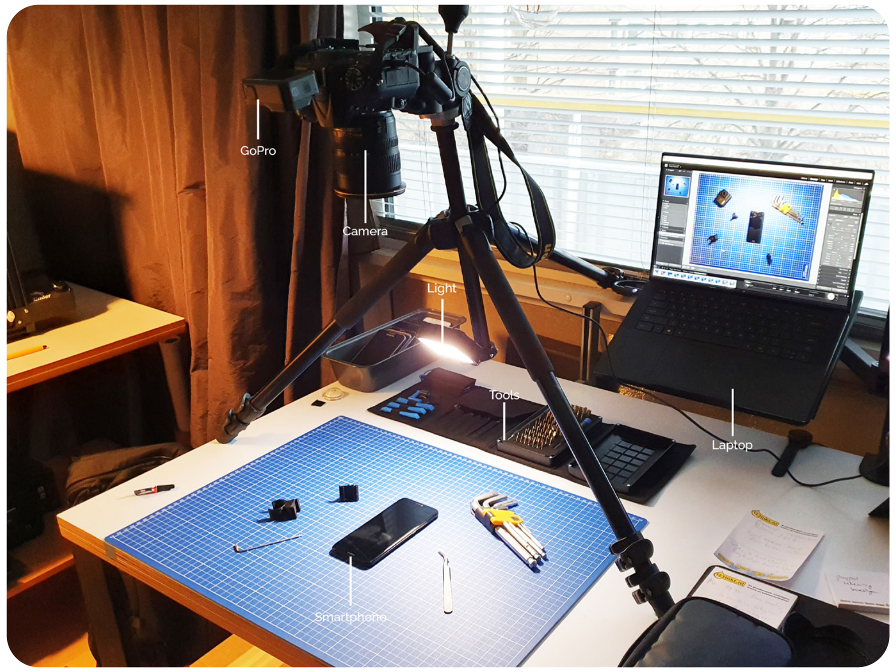



*Figure 74 - Setup used for teardown analysis*

The procedure used was roughly the same for every smartphone and consisted of the following steps:

1. Position cameras
   a. Lens at 15mm
2. Lights in the room off
3. LED light on
4. Test shooting/calibrating
   a. Empty workspace
   b. Open Lightroom Classic
   c. Set up tethered shooting
   d. Test photo of the workspace
   e. Cut to the right size in Lightroom (4:3)
   f. Add lens corrections in Lightroom
   g. Transform vertically, if necessary, in Lightroom
5. Turn on GoPro recording
6. Clean phone
7. Take photos of the smartphone (front and back)
8. Remove the rear/front, this differs for every smartphone
   a. Shoot photos for every step
9. Tear down rest of the phone into smallest possible bits, yet still possible to re-assemble
   a. Take photos of every step
10. Put phone back together
    a. Photo when a problem arises
    b. Photo at the end (front and back)
11. Turn off GoPro recording
12. Put tools back
13. Process photos
14. Upload videos to pc
15. Edit videos and save

For every smartphone, a set of parts was listed alongside the used method of construction. The parts listed are the display, the rear cover/ chassis, motherboard, battery, cameras, and the ports. From that, and from the experience of the teardown, a list of pros and cons was drafted in terms of what made a repair easy or hard to perform.

*Results*

The results of the analysis were processed in smartphone repairability cards. These do not aim to give a definitive score on repairability but give an overview of the construction used and a short description of the advantages and disadvantages for repairability of that. They were used to determine construction options.

*Discussion*

From the teardown analysis, there are two things that became useful for the following analysis. The first thing is the parts of which a smartphone mainly consists of:

- Chassis
- Display
- Rear cover
- Motherboard
- Battery
- Cameras
- Ports

And these parts were thus the basis for the smartphone repairability cards. The advantages and disadvantages for repair will be combined with those found in the iFixit analysis and discussed in the general discussion afterwards.

## *iFixit Analysis*

The analysis was complemented by teardowns from the iFixit website. The smartphones selected are from the 10 largest manufacturers, as can also be found in Section 0. The phones selected are from the last ten years, there was no teardown performed by iFixit for Nokia and Lenovo on a phone from this era, so they have not been included. Next to this, repairable smartphones from both Fairphone and Shift were analysed to compare what makes them different. There were a total of 63 smartphones compliant to the criteria and the full list of smartphones analysed can be found in Table 41.

*Method*

The process consisted of looking up the teardowns on the iFixit website, reading them fully and analysing what makes them hard or easy to repair. From the teardowns, the list of parts from the self-performed teardown analysis was used and the method of construction was listed, in agreement with the analysis above. The advantages and disadvantages are derived from the iFixit website.

*Results*

The results are processed on smartphone repairability cards, derived from the ones found in the teardown analysis above. They were used to create table 34.

*Table 41 - Smartphones selected for the iFixit Analysis*

| Year | Samsung | Apple | Huawei | Xiaomi | Motorola | LG | Oneplus | Sony | Google | Fairphone | Shift |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *2011* | S II | iPhone4s | | | Droid RAZR<br>Droid Bionic<br>Droid 3 | | | | | | |
| *2012* | S III | iPhone5 | | | Droid 4 | Nexus4 | | | | | |
| *2013* | S4 | iPhone5s | | | Moto X | Nexus5 | | | | Fairphone1 | |
| *2014* | S5<br>Alpha | iPhone 6 | | | Nexus 6 | | Oneplus One | | | | |
| *2015* | S6 | iPhone6s | Mate 8 | Remi Note3 | | Nexus5X<br>G4 | Oneplus2 | | | Fairphone2 | Shift 5.1 |
| *2016* | S7 | iPhone7 | P9<br>Mate 9 | Mi 5 | Moto Z | G5 | | Xperia X Compact | Pixel XL | | |
| *2017* | S8 | iPhone8<br>iPhone X | Mate 10Pro | | | G6 | | | Pixel2 XL | | |
| *2018* | S9 | iPhone XS | P20 Pro<br>Mate 20Pro | | | | Oneplus6 | | Pixel3 XL | | Shift 6m |
| *2019* | S10 | iPhone11 | Mate 20X<br>Mate 30Pro | | | | | | Pixel3a<br>Pixel4 XL | Fairphone3 | |
| *2020* | S20 Ultra<br>A51 | iPhone12 | Mate 40Pro | | | | | | Pixel4a | | |
| *2021* | S21 Ultra | | | | | | | | | | |



*Discussion*

From the iFixit analysis, different methods of construction came to light, which can be found in Table 42.

## *General Discussion*

From this analysis, advantages and disadvantages for repair become apparent. The characteristics for repair from the teardown analysis and iFixit analysis are combined and they are compared to the construction that was used in the smartphone. A few things that are repetitive in the analysed smartphones are:

- Same type of screws makes for an easier workflow
- A rear chassis ensures that the display is the first to remove, making that repair quicker
- Lots of or strong adhesive make removing parts difficult
- A tough battery adhesive can mean the battery breaks when removing it
- An inner chassis that needs to be opened from the rear cover means having to tear the entire phone apart to remove the display
- A display chassis, where all the components are attached to the display, makes getting to the display a Xlot of work

*Table 42 – Construction method per part*

| | ***Part*** | | | | | | |
|---|---|---|---|---|---|---|---|
| | **Chassis** | **Display** | **Rear cover** | **Mother-board** | **Battery** | **Cameras** | **Ports** |
| *Construction* | Inner chassis | Screws | Screws | Screws | Adhesive | (Soldered to) Motherboard | (Soldered to) Motherboard |
| | Rear chassis | Adhesive | Adhesive | Midframe | Pulltabs | Connector | (Soldered to) Daughterboard |
| | Display chassis | Clips | Snapfit | Adhesive | Separate | Flexwire | Flexwire |
| | | Chassis | Chassis | | Midframe | Screws (module) | Screws (module) |
| | | | | | | | Separate |
| | | | | | | | Module |

# Appendix D - Smartphone Prototype

The prototype for the smartphone was generated by following different steps. The first was grabbing actual smartphone components and fitting them together in a way that should make the smartphone more repairable. These components were then compared to the latest high-end smartphones and notable volume differences were taken to the next steps. After the model, an isometric visualisation was made to show what goes where, after which the volumes were taken to create a 3d model of the concept smartphone. This model was then further developed and 3d-printed to evaluate it for repairability steps, after which it was adjusted, and renders were created.

A prototype model was built using real smartphone components, trying to fit them together, resulting in the non-functioning FrankenPhone. The model shows how different components could be fitted inside the chassis to ensure easy disassembly. It can also estimate how thick the smartphone would be with components of this size.

To start with the display, which is the focus point, that will be placed on the front of an inner chassis configuration. It will be adhered to the front with foam adhesive, which provides an IP-rating while also being reasonably removable, especially by a professional repairer. The display will be connected to a press-fit socket on the motherboard that sticks through the chassis.

The isometric visual representation shows where the different components are placed in relation to each other. After this, it was time to check the volumes and define the components sizes by volumetric design.

This volumetric model was developed in more detail, then it was 3d-printed for testing.

The model is functional in the sense that the components are attached in the same manner as it would be in an actual smartphone. The different steps of removing the components have been tested, and adjustments have been made to the 3d model.

After updating the design, a final 3d model was created and renders were created, it can be found in the main report, in chapter 9 and 10.


*Figure 75 - Smartphone model 1*


*Figure 76 - Smartphone model 2*

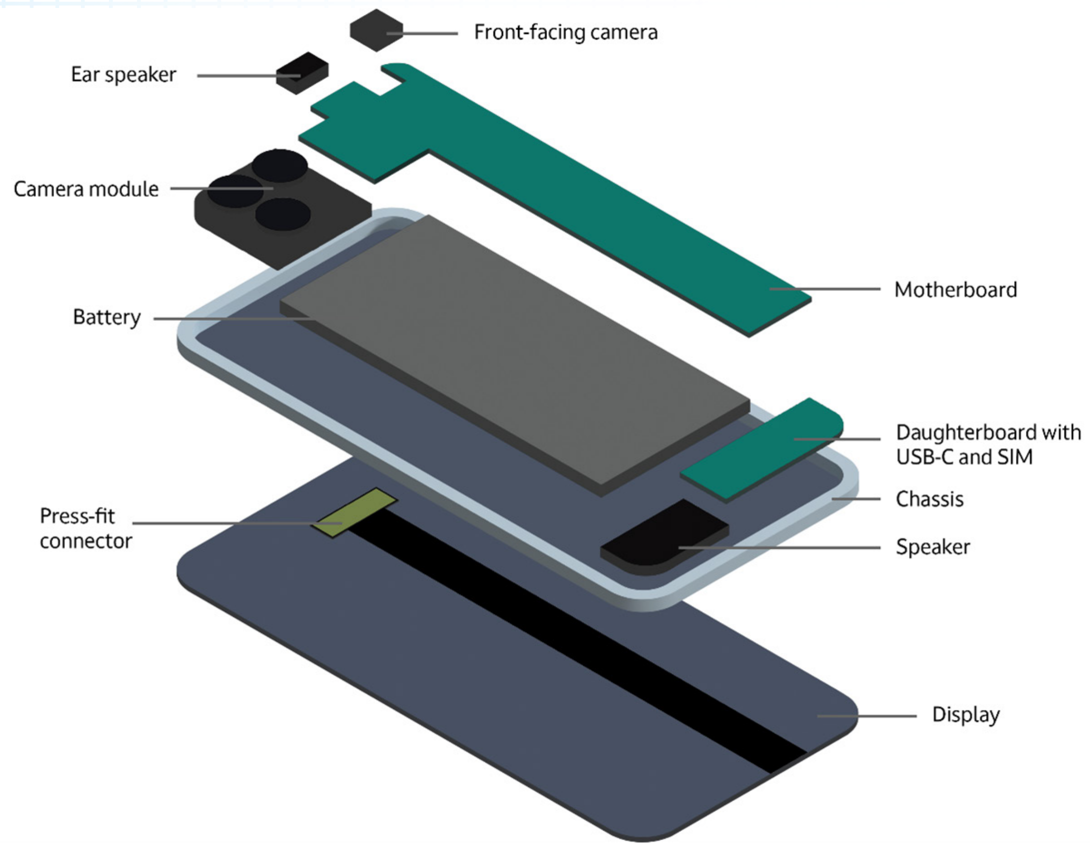



*Figure 77 - Isometric visualisation*

*Figure 78 - Volumetric design step 1*

*Figure 79 - Volumetric Design step 2*

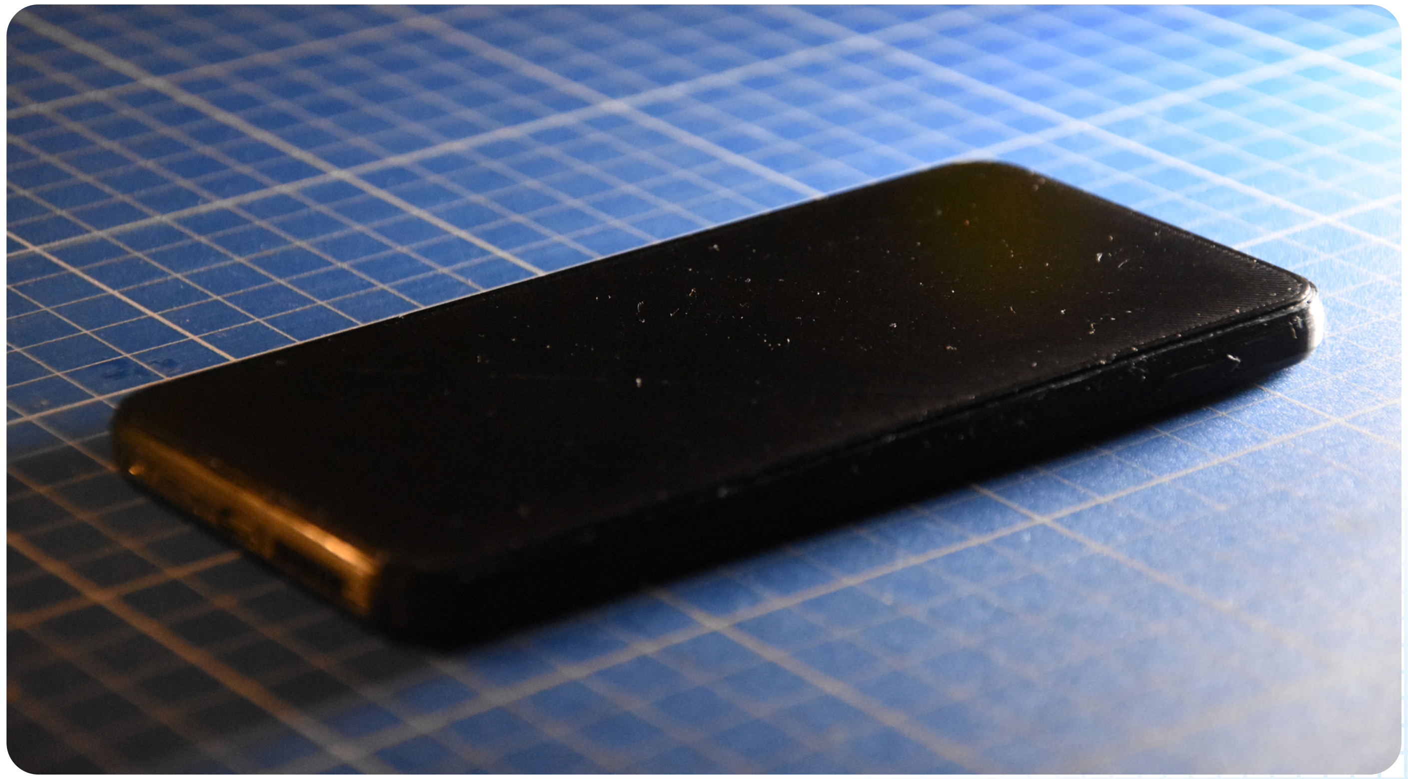


*Figure 80 - 3dprinted model 1*

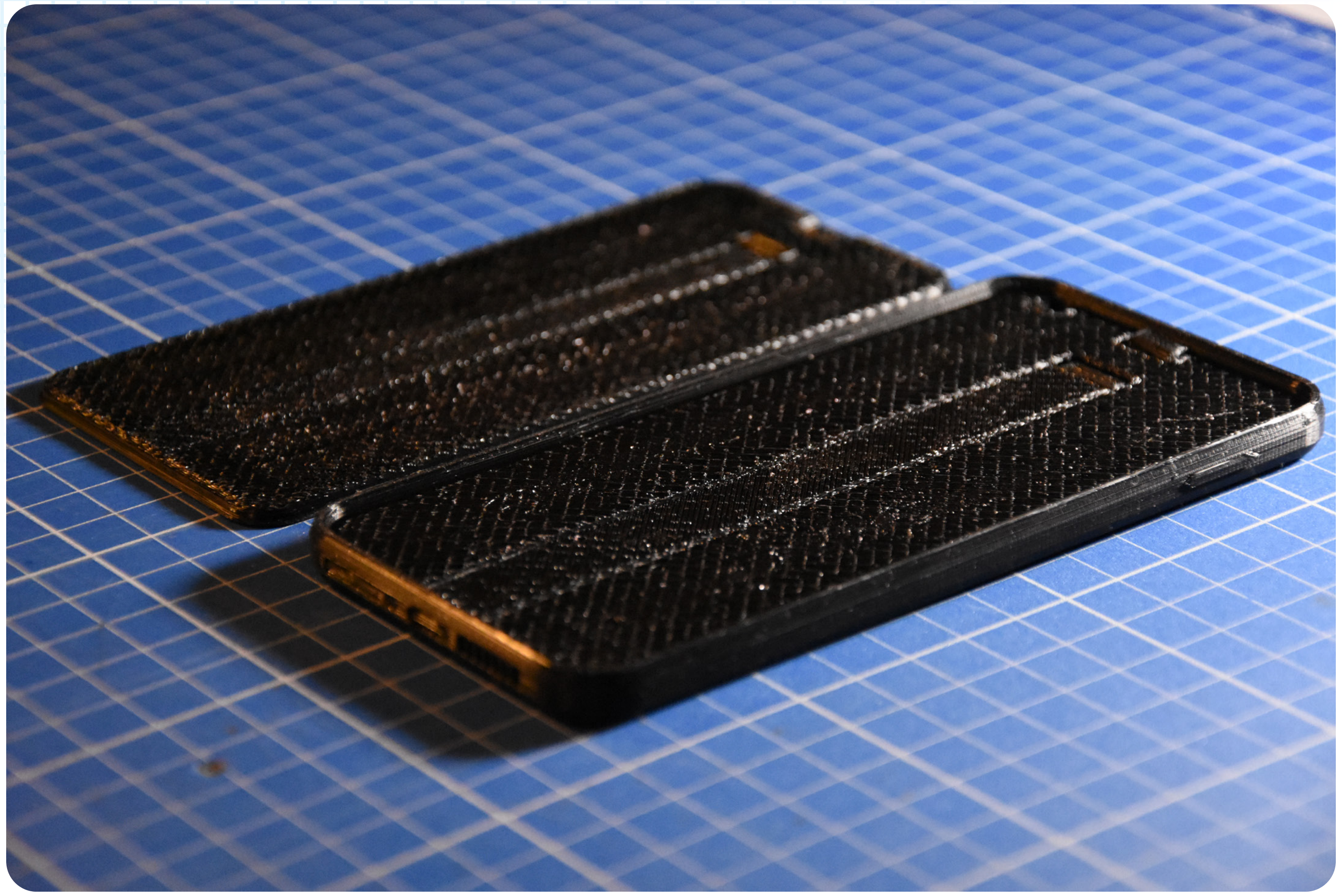


*Figure 81 - 3dprinted model 2*

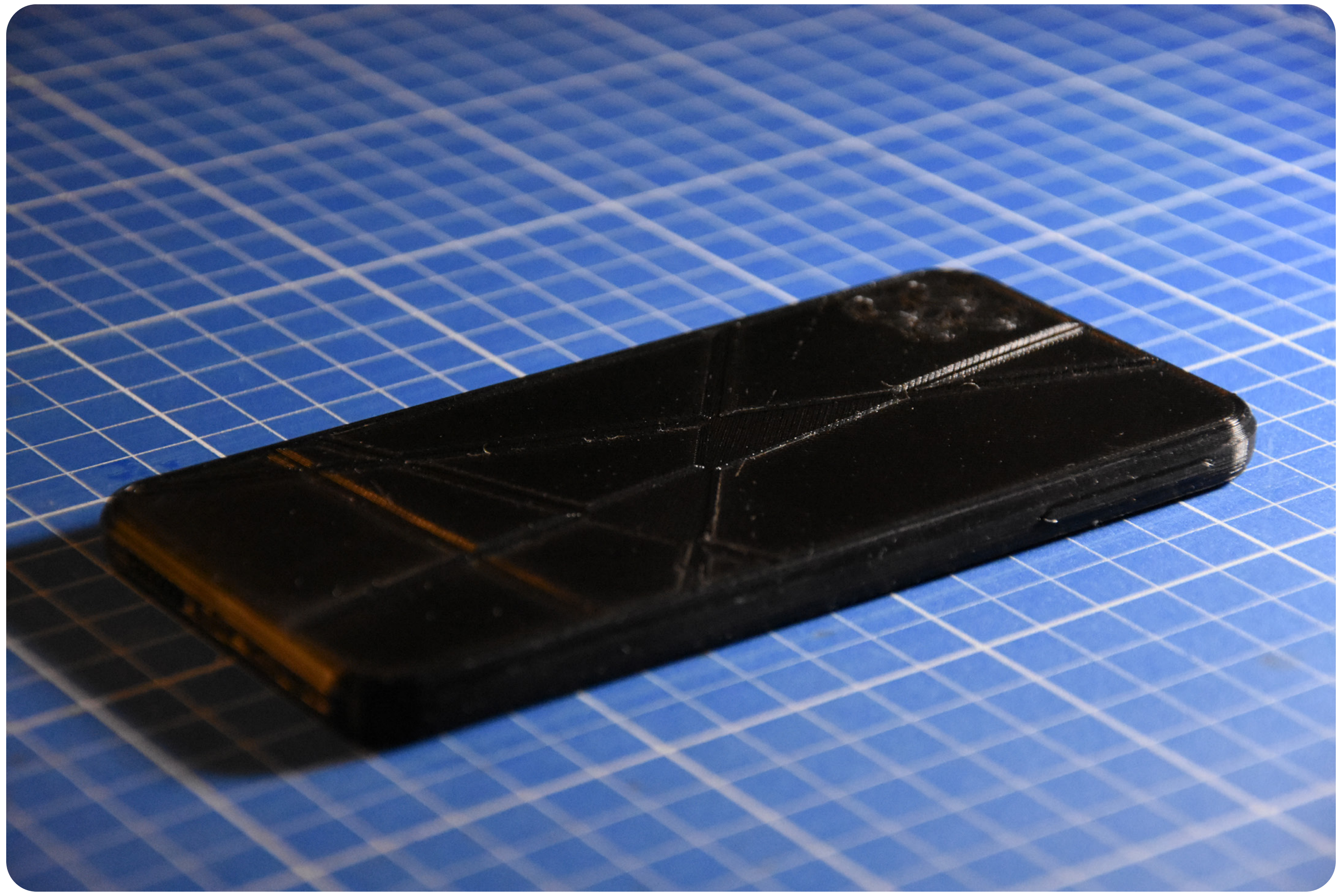


*Figure 82 - 3dprinted model 3*



*Figure 83 - 3dprinted model 4*

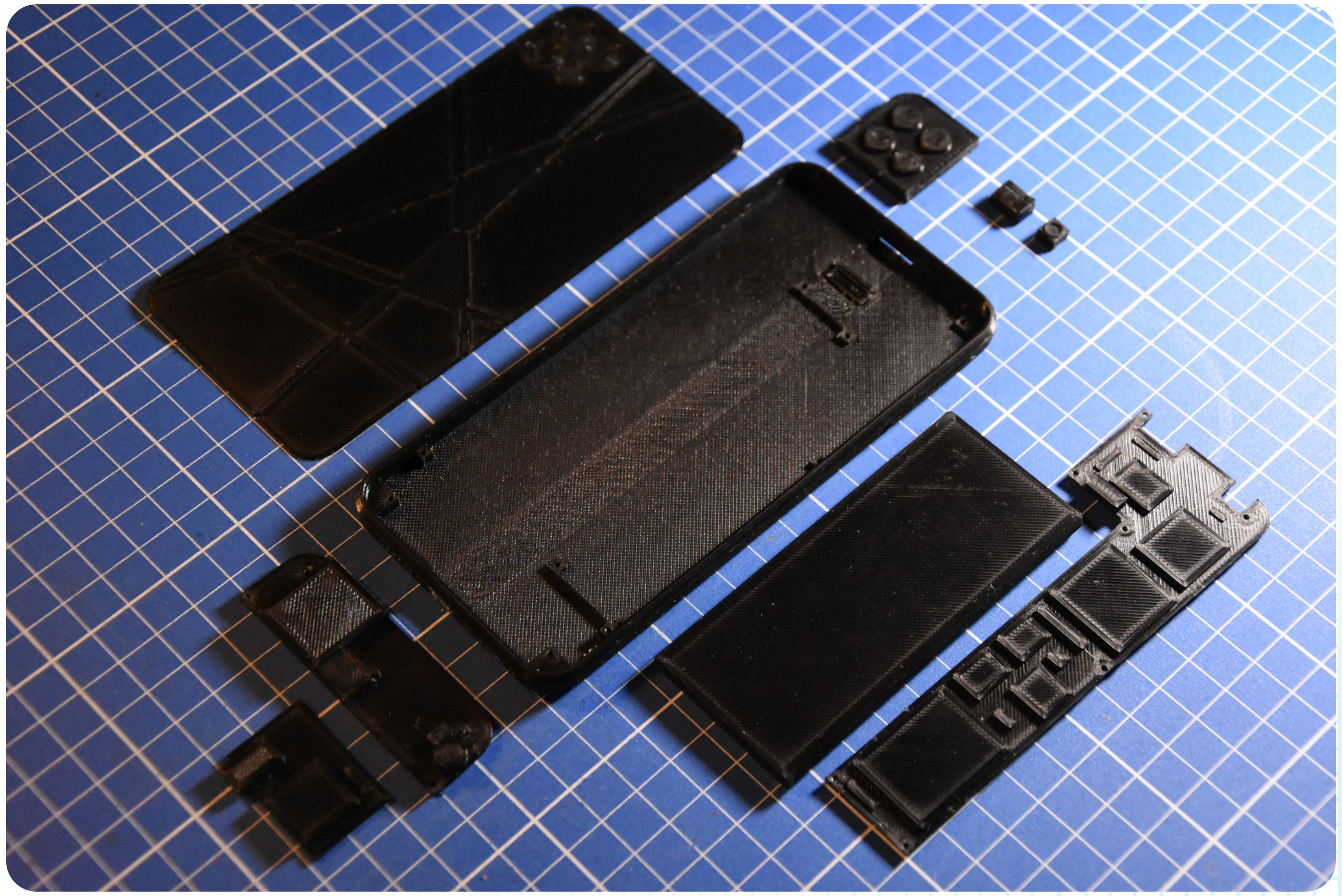


*Figure 84 - 3dprinted model 5*

# Appendix E - User Testing

Section 1: Smartphone display repair
The following questions are aimed at whether you would repair your smartphone.
Suppose you have a smartphone that once cost you €899, and you have had it for 2.5 years. The front glass is shattered, and the battery has seen better days, repair is needed, which is possible.
Would you repair if it costs:
Q6. I would not repair it
Q7. <€100
Q8. €100-150
Q9. €150-200
Q10. €200-250
Q11. €250-300
Q12. €300-350
Q13. €350-400
Q14. >€400
Suppose you want to repair it, would you travel:
Q15. >15 mins
Q16. 15-30 mins
Q17. 30-45 mins
Q18. 45-60 mins
Q19. >60 mins
Having it repaired takes some time, are you willing to wait:
Q20. >15 mins
Q21. 15-30 mins
Q22. 30-45 mins
Q23. 45-60 mins
Q24. >60 mins
Would you repair with:
Q25. Non-original parts
Q26. Not sure
Q27. Only verified original parts
Considering warranty, would you repair:
Q28. Without warranty
Q29. With 1 month warranty
Q30. With 3 months warranty
Q31. With 6 months warranty
Q32. With 12 months warranty
Q33. Needs to be more
Repairing your smartphone saves greenhouse gas emissions in comparison with buying a new device, would you repair when it saves:
Q34. <5%
Q35. 5-10%
Q36. 10-15%
Q37. 15-20%
Q38. 20-25%
Q39. 25-30%
Q40. >30%
Do you have anything to add?

Section 2: Repair platform
The following questions are about a specific scenario, where you would book a repair through a platform that ensures repairs with original parts, while having repair shops at locations near you.


*Figure 85 - Screen shown in user test 1*

The scenario
You have a Samsung Galaxy S10 with a shattered display and a battery that could be better. It cost you €899 2.5 years ago. After selecting 'repair now' on the screen above, you specify what device you have, and what the defects are. You can then locate a repair shop to handle your repair, as shown on the screen below.

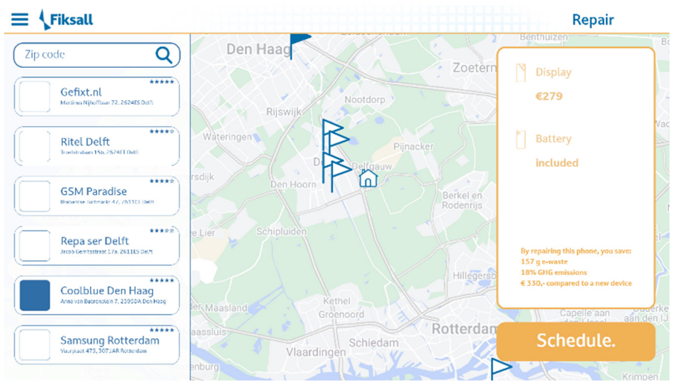



*Figure 86 - Screen shown in user test 2*

If you were to replace the smartphone by the same model, it would cost you €609, while a repair costs you €279, which replaces the display, the battery, and the edges of the smartphone.
It would cost you about 15 minutes of travel time to get to the repair shop, and 30 minutes of waiting in or around the repair shop. The parts will be verified original parts.
Because you repair the smartphone, you will save 18% of greenhouse gas emissions if you use it for another year.
Q41. Do you think this offer is fair, and why?
Q42. Would you take this offer, and why?
Q43. What stands out for you about this offer, and why?
Q44. What could be improved about the offer?
Q45. Is there anything unclear?
Thank you!

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