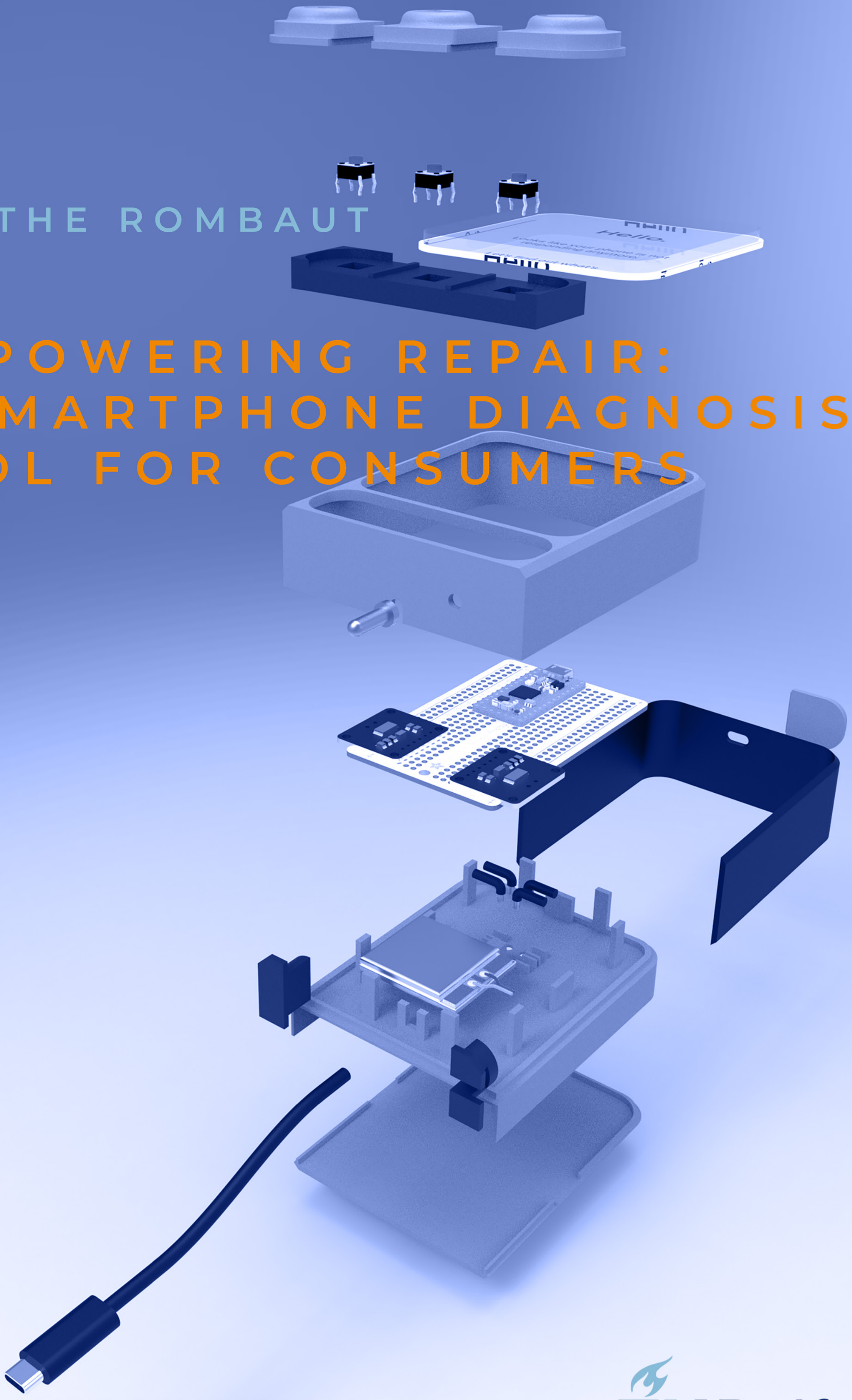
MARTHE ROMBAUT

EMPOWERING REPAIR: A SMARTPHONE DIAGNOSIS TOOL FOR CONSUMERS



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I ABSTRACT

Smartphones are the most widely used electronic devices globally, producing vast amounts of CO_2 emissions and contributing significantly to e-waste when they end up in landfills. Extending their lifespan by encouraging repairs can mitigate these environmental impacts. However, users often show resistance to repairing their devices due to a lack of knowledge about the specific issues. The barrier to diagnose a smartphone is too high. This thesis explores the design of a smartphone diagnostic tool that guides users to accurately diagnose common hardware problems in the Fairphone 3.

The four most common hardware faults in non-responsive smartphones are issues with the screen, battery, charging port, and motherboard. A testing workflow was developed to detect these faults using an elimination approach, using testing points on the phone's accessible battery and battery terminal. This method requires minimal disassembly and is integrated into a functional testing device compatible with the Fairphone 3.

The proposed design encourages repair behaviour through an interactive interface that effectively communicates diagnostic steps. It combines video and textual instructions to guide users through the process, motivating them to continue and directing them to subsequent repair actions.

Additionally, the device is designed to be shareable, available in public spaces such as libraries or maker spaces, which enhances accessibility and removes the need to purchase it for single use.

Furthermore, the potential for generalizing the diagnostic device to work with other smartphone models is discussed, broadening the design's applicability and impact.

This thesis contributes to the field by combining a simple and efficient diagnostic workflow with consumer behaviour insights in a single testing device. It enables users to diagnose their phones with minimal effort, knowledge, and time, increasing their sense of competence and safety.

Keywords: Smartphone diagnosis, Consumer behaviour, Product design, Repair

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Finally, I would like to thank everyone who helped the girl who dreamed of becoming an inventor behind her father's workbench become one. Apparently that is called an Industrial Design Engineer.

It took a city, but now I am here.

Thank you.

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FAIRPHONE
FAIRPHONE
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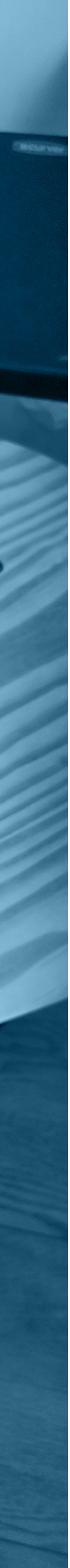


01 INTRODUCTION

In the fast-paced world we live in, electronics are one of the most wasted resources (Magnier & Mugge, 2022). Smartphones in particular contributed to 11% of worldwide ICT CO2 emissions in 2020, mainly due to their production (Fairphone, 2022). Unfortunately, all energy pumped into these devices when producing them is lost after they end up in landfills and become e-waste (Belkhir & Elmeligi, 2018; Fairphone, 2022). In 2022 alone, this caused 62 million tonnes of e-waste, an increase of 82% compared to 2010 (Cornelis P. Baldé et al., 2024). The disposal of smartphones is thus a problem on the rise.

Although smartphones have become so important in our daily lives, 70% of people do not think about repairing theirs when they break (Magnier & Mugge, 2022). Nowadays, a smartphone has an expected lifespan of only 2.7 years, during which it has a Global Warming Potential (GWP) of 57 kg of CO2 (Nilsson et al., 2016). Every year that this lifespan can be extended would mean a 31% reduction of that (Wieser & Tröger, 2018).

In the context of the circular economy, the methods of preserving the integrated value of the product by extending its lifespan are called the inner cycles (Foundation, 2019) (Figure 1). These inner cycles involve sharing, repairing, and reusing the product. They should be prioritized over refurbishing, remanufacturing, and recycling, which are the outer cycles. This prioritization ensures the time and energy spent making the product are preserved. In short, a working smartphone is worth more than its disassembled materials combined.

Unfortunately, replacing a smartphone nowadays is the user's first reflex when it breaks down. There are many reasons for this, but one of the biggest causes is the lack of knowledge about the reason for the malfunction (Dangal et al., 2021). This thesis aims to contribute to the research done to break replacing behaviour by delving deeper into smartphone diagnostics and consumer behaviour around this issue.

The first few chapters of this thesis consist of research. Consecutively, consumer behaviour towards repair and replacement (CH2), diagnosis practices (CH3) and smartphone diagnosis in particular (CH4) are covered, each resulting in respective insights for the continuation of the project. These are synthesised into design requirements in the next chapter (CH5), to be followed up by diverging and converging into concepts (CH6). In the end of that chapter, a concept is selected to continue with. The next chapter consists of elaborating on various aspects of that concept (CH7). After that, the project is concluded with a final concept proposal (CH8), a discussion (CH9) and finally a conclusion (CH10).

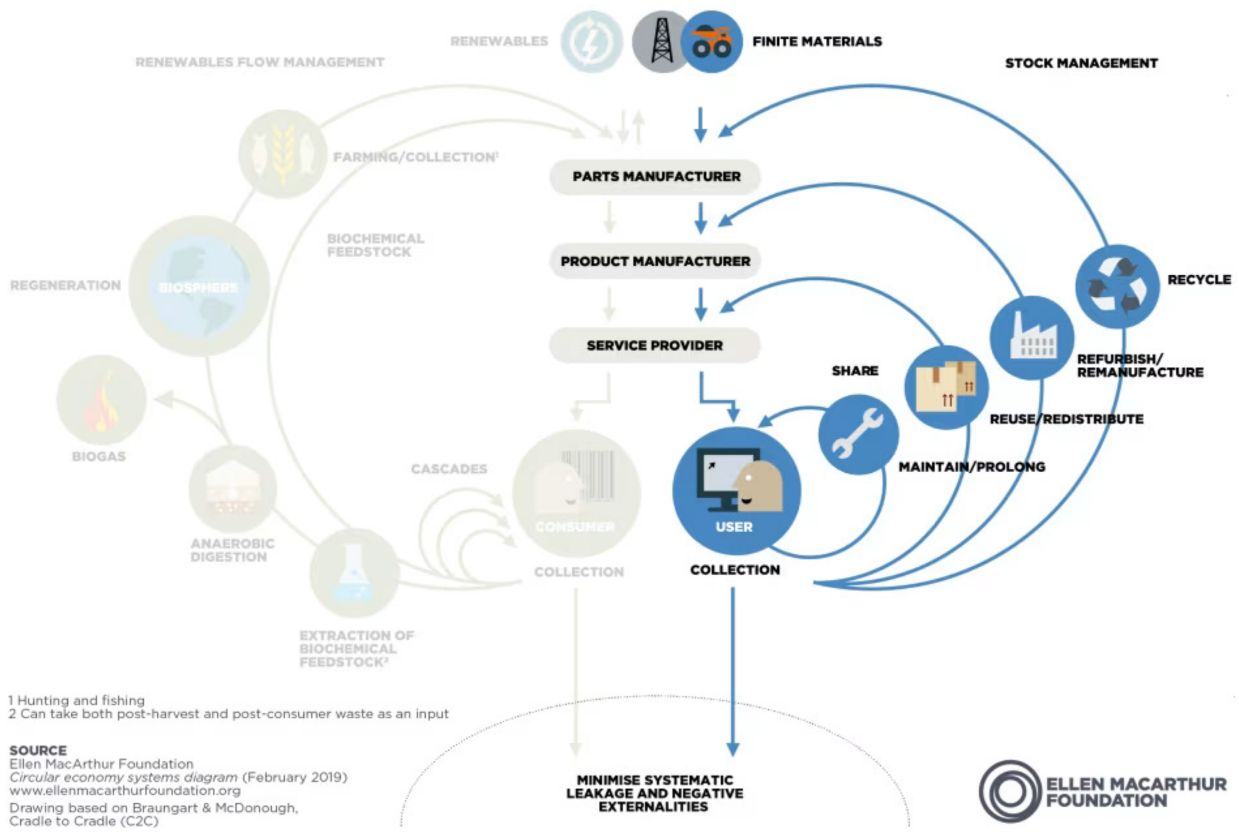


Figure 1. The technical cycle of the circular economy diagram (Ellen MacArthur Foundation, 2019)

PROBLEM STATEMENT

Smartphones are a widely used and valued electrical product. However, oftentimes they get thrown out without having tried to repair them first. It might cost too much, or require too much effort to have it fixed, people do not know what is broken and lack the knowledge to try to do it themselves. In short, there are many barriers that keep the user from repairing their phones. Diagnosing what might be the problem in their broken device is one of them. Nowadays, smartphone consumers are unable to identify and fix issues with their smartphones at home due to a lack of knowledge and guidance. Wieser and Tröger (2018) state that only 34% of the broken phones get a repair attempt.

These numbers can be increased by providing a tool for user-friendly hardware diagnosis, thereby removing a major barrier to repair behaviour. This approach will extend the lifespan of devices, reducing the amount of e-waste in landfills and the CO_2 emissions associated with the production of new models.

CARRIER DEVICE

The smartphone used as an example and subject to research and prototyping in this project was a Fairphone 3 (Figure 2). The choice for this smartphone was made out of consideration for the unique features it has considering repairability. The Fairphone is designed to open and all components are easily accessible, making it a perfect test subject. Despite this, it can be compared well with other smartphones since it generally has the same functions and components. The choice for this particular model resulted from it being available at the faculty.

Figure 2. The Fairphone 3 (Fairphone, n.d.)

RESEARCH QUESTIONS

At the beginning of this thesis, research goals need to be established. This project will focus on encouraging repair over replacement, diagnosing practices, applying these to smartphones, and influencing consumer behaviour. Therefore, the main research question will be:

"How to encourage users to repair their smartphones by diagnosing and communicating the faulty parts in them?"

To answer this, it is split up into separate topics, each tackled in their respective chapters.

RQ1: What are the main barriers for repair and how do they influence the consumer's decision-making process between replacement and repair? (CH2)
RQ1.1: How do the users make the decision between replacement and repair?
RQ1.2: What are the perceived barriers for repair and how can they be mitigated?

RQ2: How does diagnosing electrical devices work? (CH3)
RQ2.1: What are the principles and methodologies underlying fault diagnosis in devices?
RQ2.2: How do users with limited repair experience go about diagnosing a device and what are the challenges they face?
RQ2.3: What are examples of advanced diagnostic techniques used in other industries, and how can they inform smartphone diagnosis?

RQ3: How to diagnose faulty components in smartphones? (CH4, CH6)
RQ3.1: What are the most common faults in smartphones?
RQ3.2: How is the Fairphone 3 constructed?
RQ3.3: What methods can be used to diagnose faulty components in smartphones?
RQ3.4: What are the limitations of current diagnostic methodologies and how can they be addressed?

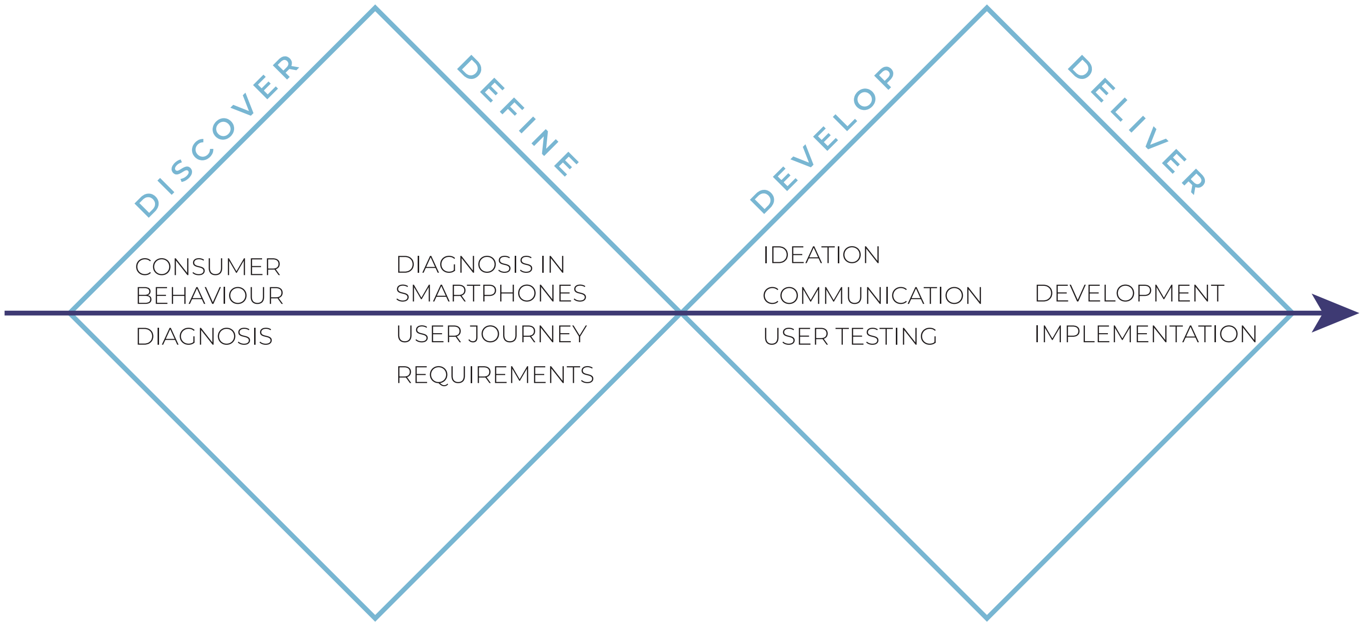
RQ4: How can diagnostic information be effectively communicated to users to stimulate repair? (CH7)
RQ4.1: What are the key factors influencing users' decisions to repair their smartphones?
RQ4.2: What types of diagnostic information are most relevant and actionable for users in the repair decision-making process?

RQ5: How can the research outcomes be integrated in the design of a smartphone diagnosis tool to empower consumers to repair their devices? (CH6, CH7, CH8)

The results of the four first four research questions will be bundled into takeaways and later a list of requirements and wishes. These will then in turn be used for the development and selection of concepts, serving as input for the fifth research question. The outcome of this last research question will be a design that will be the final result of this project.

PROJECT APPROACH

The general methodology of this project was the double diamond of (Council, 2005). This approach divides the design process into four stages: discover, define, develop and deliver. In turn, they each also consist of their respective parts.



Discover

The discover stage of the project was meant to understand the problem in depth, before delving into any solution spaces. To this purpose, a literature review was executed around consumer behaviour – especially towards repair – diagnosis and smartphone repair. Additionally, professional repairers were consulted in interviews.

Define

In the next phase, all learnings from the review and interviews were put into a list of requirements for the upcoming design. Furthermore, the user journey was also considered. The original problem was better defined.

Develop

In the development stage, possible solutions were generated by brainstorming and testing. Three different concepts were composed and the most promising one was selected for further development.

Deliver

The last phase of this project consisted of embodying, realising and user testing of – parts of – the selected concept. Design iterations made it into a product, made tangible by prototyping.

02 CONSUMER BEHAVIOUR

This research aims to design a tool with which users can diagnose their broken smartphones and thereby also stimulate them to repair their devices. To do that, firstly, the reasoning behind the replacement and repair behaviours of users need to be clarified so motivation strategies to stimulate repair behaviour can be identified, as well as design directions to stimulate it. This chapter aims to answer RQ1 and its sub-questions through a literature review of the existing consumer behaviour research to date. From this, a list of takeaways was generated.

DECIDING BETWEEN REPLACEMENT AND REPAIR

As seen in the research of van den Berge et al. (2021), the decision to replace or repair a device is the outcome of a trade-off users make between the perceived value of the old product – the mental book value – and the new product (Figure 3).

The mental book value of products for consumers is determined by several factors. Sheth et al. (1991) defined these in five categories:

1. **Functional values**: concerning the correct performance of the product.
2. **Emotional values**: concerning the emotional bond someone has with their product or what feelings get evoked by it.
3. **Social values**: concerning the pressure users experience from their environment.
4. **Epistemic values**: concerning the curiosity and feelings of novelty the product evokes.
5. **Conditional values**: concerning the particular circumstances the decision is made.

Both the old and the new products have perceived values in these categories that influence decision-making. This leads to a trade-off and a replacement of the current product if its perceived values are rated lower than the expected ones of the new product. Many reasons will make these perceived values change, mostly in favour of the new product.

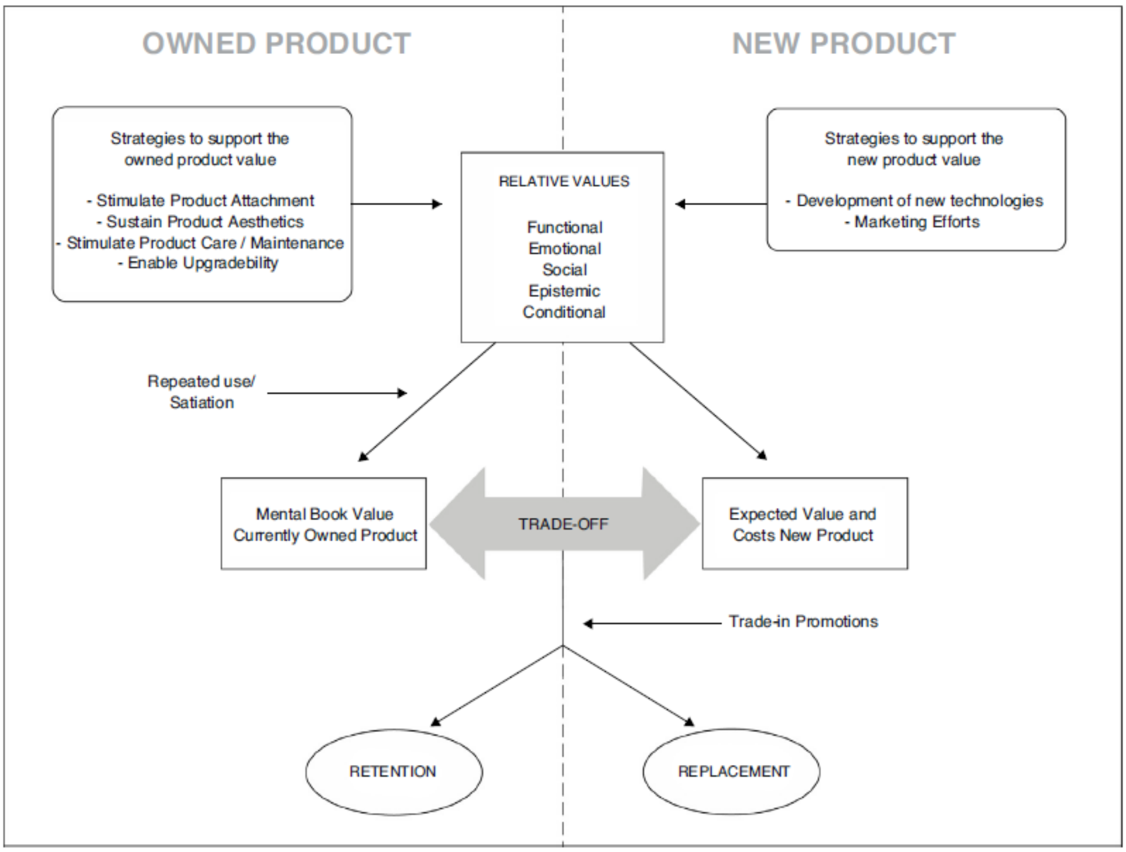


Figure 3. The decision process users go through to repair or replace their device. There is a trade-off between the mental book value of the currently owned product and the expected value of the new one, leading to either replacement or retention. (van Den Berge et al., 2021)

UNDERSTANDING THE REASONS TO REPLACE AND BARRIERS TO REPAIR

The reasons for replacing the current product are roughly divided into three categories: product-related, consumer-related and business-related.

For many consumers, the functional failure of the older product is the main reason to buy a new one. (Wieser & Tröger, 2018). If it is broken, its mental book value for the user will go down, and the majority of the time a repair is not even attempted.

In the consumer-related category, people's urge for a novel product is often suggested as the main reason for replacement. However; Wieser and Tröger (2018) state that the perceived obsolescence of the old product plays the biggest role. The old product's perceived value goes down with time, even if the functionality does not (Magnier & Mugge, 2022). This has to do with its worn-down aesthetics, the social pressure to remain up-to-date and the capability to keep up with social practices, but also with a decreased enjoyment due to the loss of novelty of the product. The mental book value also decreases when it simply has reached the lifetime users expected from it.

Business-related reasons mostly are about the low replacement prices and purchase opportunities (Jaeger-Erben et al., 2021; Magnier & Mugge, 2022) versus the high repair costs users expect.

As stated above, a product oftentimes gets replaced when it is broken or shows a loss in functionality. The fact that usually there is no attempt to repair it means that there are barriers that the user perceives as too high compared to just buying a new one. These barriers are explained on the next page.

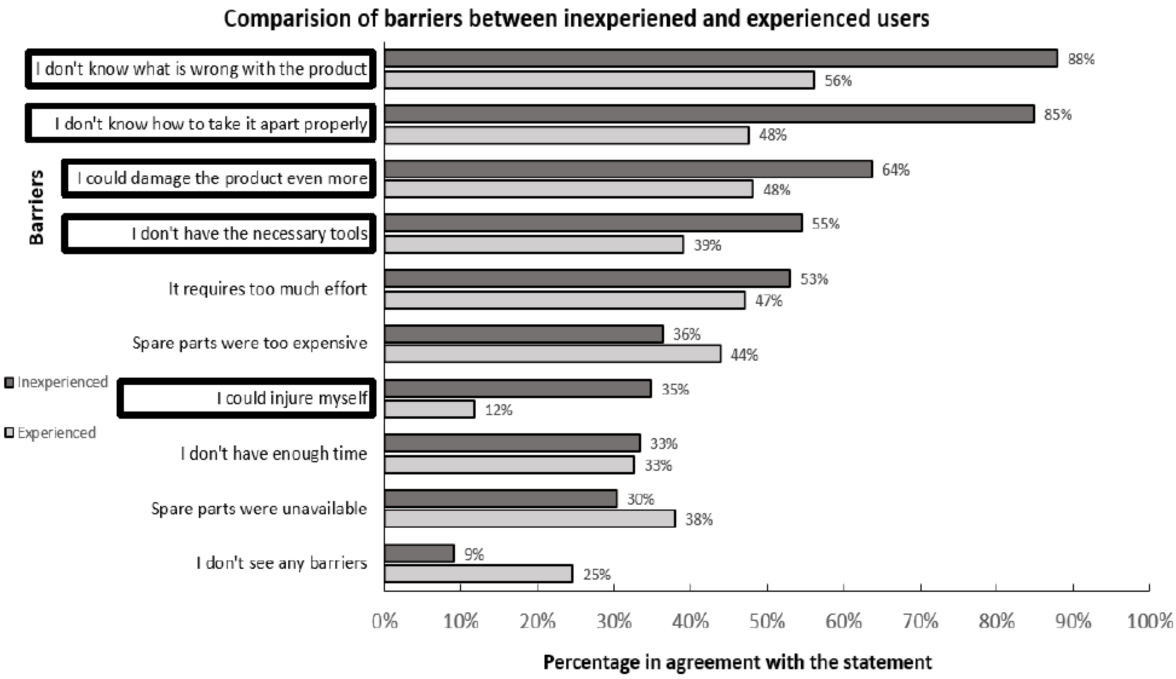


Figure 4. The most common perceived barriers to repair for inexperienced and experienced users. The top one is not knowing what is wrong with the product. (Dangal et al., 2021)

From the product design side, the general repairability of the product usually is very low (Dangal et al., 2021). This hinders disassembly and diagnosis of what is wrong with the device when it breaks (Laitala et al., 2021). Economically, the cost of repair; spare parts and diagnosing expenses are perceived as too high, as well as the required effort and time to repair (Jaeger-Erben et al., 2021; Magnier & Mugge, 2022). This pairs up with the lack of repair infrastructure and social support in this matter. As seen in initiatives like the Repair café, a social setting for repair could potentially mitigate this (Ackermann et al., 2021).

Some barriers can be linked specifically to repair by end-users (non-professionals): not knowing what is wrong with the product, not knowing how to take it apart properly and the fear of damaging the product even more come out on top (Dangal et al., 2021) (Figure 4). The users need proper repair tools, spare parts and guidance.

Additionally, inexperienced repairers are knowledgeable and confident in using basic mechanical tools, but not electrical ones like multimeters and soldering irons (Dangal et al., 2021) (Figure 5). As will be touched upon later, smartphone repairs are not doable without multimeters, making them increasingly challenging for most users.

Further from the consumer's perspective, the perceived lack of repair competence / ability is a huge burden (Dangal et al., 2021; Jaeger-Erben et al., 2021; Magnier & Mugge, 2022). Users do not have the confidence nor knowledge to attempt a repair of electrical devices, in fear of breaking the product even more or hurting themselves. All these reasons accumulate to the users not trying to repair their devices.

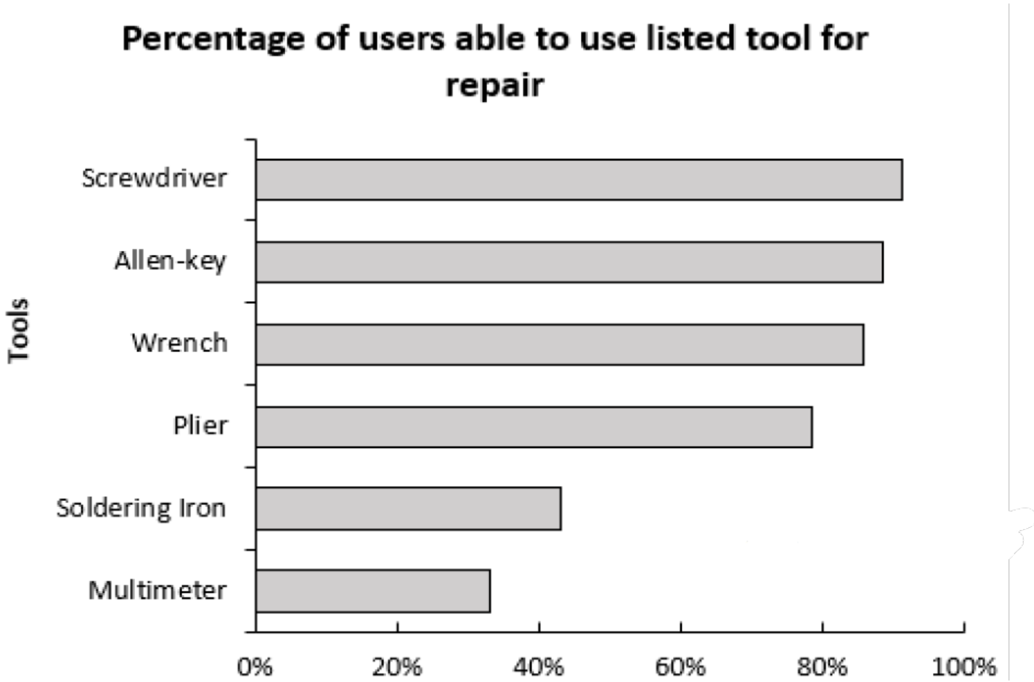


Figure 5. Stats on the number of users that can use a repair tool. The multimeter is the least known of all. (Dangal et al., 2021)

DESIGNING REPAIR BEHAVIOUR

All previously listed reasons not to repair conclude in the replacement behaviour we currently see with end-users. To change this to repair behaviour, these barriers need to be countered and a behavioural change needs to occur.

According to the behavioural model of Fogg (2009), to cause a behaviour in users three factors need to work together: there needs to be motivation, ability and a trigger. Their interaction, adapted for the topic of product care, is visible in Figure 6 from the research of Ackermann et al. (2018). In this context, product care is defined as "all activities initiated by the consumer that lead to the extension of a product's lifetime", thus also including repair practices.

In their research, it is demonstrated that the motivation of people concerning product care is higher than previously anticipated, so the focus for improvement lies on the ability and the triggers to enable the right behaviour. Based on the previous paragraph, it is clear that the ability to repair – identified as knowledge and skills, time and effort, availability of tools – leaves a lot to be desired and Ackermann et al. (2018) also state that the triggers consumers need to repair rarely are there. The different types of triggers can be listed as shown in Table 1, along with the rational decision to take them into account in this project.

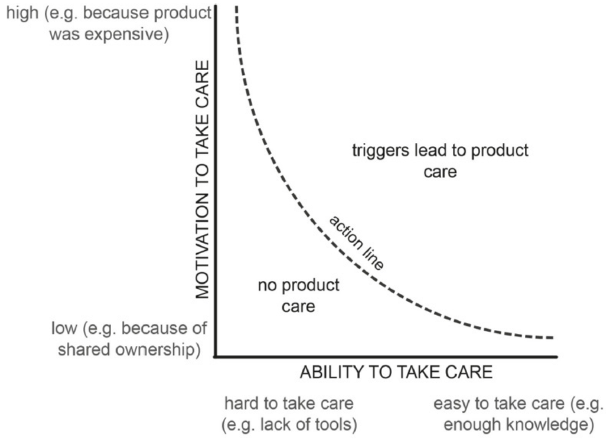


Figure 6. Specified Fogg's model based on the uncovered factors of motivation, ability and triggers for product care (Ackermann et al., 2018)

Table 1. Types of triggers contributing to behaviour. (Ackermann et al., 2018)

Trigger	Explanation	Choice	Reasoning
Appearance triggers	The product does not look nice anymore.	x	Irrelevant for a diagnosis tool.
Time triggers	Independent of the functioning of the product, after a certain amount of time an action needs to be undertaken.	x	The tool will only be used when the smartphone is malfunctioning, which usually cannot be foreseen.
Social triggers	The social surroundings exert pressure.	x	This could be included not in the way of pressuring but rewarding. The social connection could be a reward in itself.
Previous care activity experiences	When the previous experience taking care was a positive one.	v	It is desirable that this is accomplished by the correct functioning of the device and other positive experiences must be maximised while using it.
Challenge-based approach	Users want to test what their boundaries are and take on a challenge in trying.	v	This might be an interesting approach for motivating the users to keep going.

In addition to this list of triggers, as an extension of the research of Ackermann et al. (2018) also design directions were developed to stimulate product care behaviour (Ackermann et al., 2021). An overview of those is provided in Figure 7.

These were also worked out more in detail. In Table 2 a selection of the listing from the one provided by Ackermann et al. (2021) can be found consisting of the most promising factors that could be played with in this project. The reasoning of why to take these factors into account in the continuation of this project also is provided. The full list can be found in Appendix B.

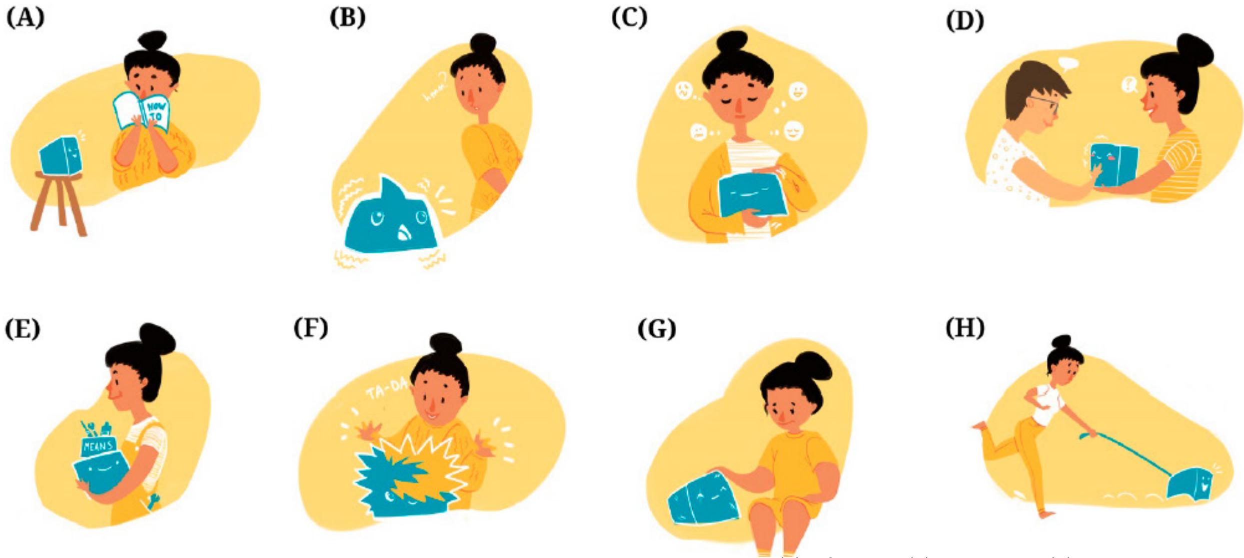


Figure 7. The design strategies developed to stimulate care behaviour. These are (A) Informing, (B) Awareness, (C) Antecedents & consequences, (D) Social connections, (E) Enabling, (F) Appropriation, (G) Reflecting and (H) Control. (Ackermann et al., 2021)

Table 2. Adapted table of design and sub-design strategies for product care to be used in this project. (Ackermann et al., 2021)

Design strategy	Sub-strategies	Explanation & examples	Reasoning
Informing	Interactive information	The consumer is informed about product care through interactive platforms, e.g., interactive websites, workshops or online tutorials	Interactivity is proven to increase motivation and might be a good trigger to keep the user going.
	Physical information	The consumer receives information or clues about product care through affordances and through the design, e.g., material, visual clues on phone cases.	The less effort the users have to put in, the easier guiding them will go.
Awareness	Product changes in appearance	The consumer's awareness about the need for product care is increased via changes in the product appearance, e.g., seeing wear indicators on electronic devices.	As this returns in Pozo Arcos (2021) (next chapter), this might be a valuable direction to continue in.
Social connections	Social connections as facilitators for product care	Product care activities are supported by other consumers or people, transforming product care into a social activity e.g., a DIY repair shop where consumers get help from other consumers or an expert.	As confirmed in interviews, a social initiative like Repair café could drive users to product care.
Social connections	Social connections as a result of product care	By making product care result in social contact with others, product care can be seen as the step to having more social interactions with other consumers or people, e.g., a community of smartphone repairers that share tips for better techniques.	As confirmed in interviews, a social initiative like Repair café could drive users to product care.
Enabling	Providing flexibility	Through the compatibility with standard tools or easy accessibility of necessary tools, consumers receive more flexibility to be able to perform product care, e.g., the use of standardized screws.	Using standard tools and easy accessibility should be maximised.
	Providing necessary means	The necessary tools and other product care means to come together with the product and thereby provide the consumer with all the necessary means for product care, e.g., a screwdriver delivered with the phone.	The lack of tools is one of the main barriers for repair talked about in the previous chapter.
Reflecting	Experience of the product care activity	Product care is made into a pleasurable care activity, e.g., repairing is made fun through gamification.	For user friendliness, it is always better if the activity is fun.
Control	Product takes initiative	The consumer is pressured into performing product care because the product initiates (the first part of) a product care activity, e.g., a coffee machine that opens up to be cleaned.	To make the threshold to initiate the activity lower, this might be interesting.

CONCLUSION

The decision to replace or repair a smartphone is not one-sided. People are continuously facing this repair / replacement dilemma but it only becomes truly inescapable when the phone they are currently using becomes unusable. They will then, instinctively and also partly subconsciously, compare the value and costs of the old and the new phone, choosing the one that comes out on top. Many barriers for repair keep users from choosing to repair their phones.

In the scope of this project, the barriers concerning time, effort, competence, safety and cost of the diagnosis are relevant to actively minimise. These are "low-hanging fruit" where a thoughtful design could make a big difference. This could be done by providing the right tools to diagnose, guidance in the process and potentially spare parts to continue the repair. Since typically users are uncomfortable using essential tools like multimeters, this could be integrated to take that barrier away.

To further stimulate repair behaviour, attention must be paid to enabling repair abilities and providing triggers to help them start or continue this behaviour. Of these triggers especially the previous care activity and challenge-based triggers are interesting to further explore for the scope of this project.

Listed below are the **takeaways** from this chapter.

- Users require guidance to diagnose common hardware issues effectively.
- Clear communication of diagnosis is essential.
- Safety during the diagnosis process is a critical concern for users.
- The tool must be user-friendly, especially for inexperienced repairers.
- Integration of necessary tools for the diagnosis process is needed, as users are uncomfortable using them on their own.
- Automation of complex diagnostic tasks is necessary.
- Interactive or physical information are effective means of communication for this project.
- Minimal effort should be required to operate the product.
- Minimal time should be required to operate the product.
- Cost-effectiveness is important to users.
- Enhancing users' feeling of competence is a goal for the tool.
- Changing product appearance could be used as a means to raise awareness of broken components.
- Social connections could be leveraged as part of the user experience.
- Creating a pleasurable experience while using the tool is desired.

03 DIAGNOSIS

Since this device will be diagnosing the broken parts in smartphones, this part of the repair process will be studied in detail. This part aims to answer the second research question and its sub-questions by a literature review of the existing – but limited – research about diagnosis of electrical devices. A framework for fault diagnosis by end users is studied and coupled to design directions to enhance this process. Afterwards, some designs are inspected that were created with diagnosis in mind or to enable it. Finally, the learnings are bundled in more takeaways for the continuation of this project.

THE DIAGNOSTIC PROCESS

The repair process can be divided into four phases: diagnosis, disassembly, repair and reassembly (Cuthbert et al., 2016). Looking more closely at the first step of diagnosis, users also run through separate steps in this phase. In Figure 8, these are envisioned for end users in household appliances (Pozo Arcos, 2021). Several interviews with professional phone repairers, users and personal experience could confirm this workflow for smartphones, as it is formulated very generally.

After the product malfunctions, the fault diagnosis process begins. This happens generally in three steps: fault detection, fault location and fault isolation. It is run through using strong or weak problem-solving strategies, depending on the level of expertise the practitioner exhibits.

Firstly, fault detection consists of observing the product for any symptoms of malfunction. This could be anything, from a flashing light to heated components, the sensation of smoke or the general dysfunction of the product.

After that, the user continues to fault location. Here there are two routes to take: the component-oriented one and the cause-oriented one. The component-oriented route is the more conventional one, this is where the users try to link the symptom to the component it might be related to and thus determine the cause. To get there, product knowledge and experience could play a big role.

From here, fault isolation is the next step. The users try to test if their hypothesis of the broken component they gained in fault location is correct, arriving at two possible endings. If the component they tested was the right one, the diagnosis is completed and they can continue to repair the device. If not, they have to restart in evaluating where else the observed symptoms

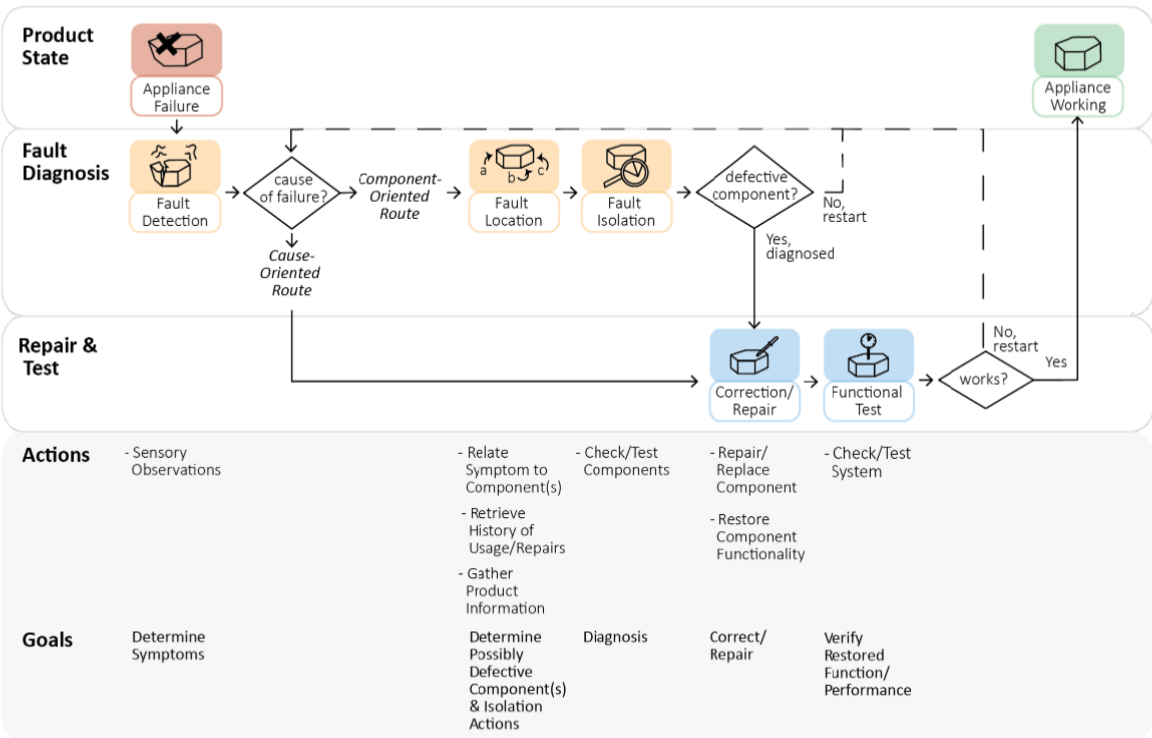


Figure 8. Framework of the process of fault diagnosis by end users. (Pozo Arcos, 2021)

could come from. The effectiveness of course is heavily influenced by the experience this particular practitioner has in diagnosis.

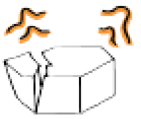
The cause-oriented route contrastingly bypasses the fault location and isolation steps altogether and tries to continue directly to repair (Pozo Arcos et al., 2022). This can be witnessed in certain manuals or error codes. It instructs an immediate correctional action that could potentially solve the problem right away, e.g. resetting the device. This approach can be very effective if the problem observed is a very common one, the symptoms are not easily traced to one component and the proposed action is quick and inexpensive to perform.

The results of this approach are not guaranteed since there is no identification of the cause of the problem. This leaves the user with a dejected feeling, not having gained any information about the product on the way. This does not benefit the repair mentality because it creates a disconnection with the product, contrary to what would be gained if the user were more involved in the process (Ackermann et al., 2021; Pozo Arcos et al., 2022). This create a connection between the user and the product, which in the end leads to better product care in the future.

DESIGN FOR DIAGNOSIS

The challenges inexperienced repairers face lie in the disassembly of a product and the connection of the symptom with the right cause of dysfunction (Pozo Arcos et al., 2021). Connected to that, the reassembly of the product is noted as the most time-consuming (Interviewee A, personal communication, 27 April 2024). To counter these difficulties, a set of design guidelines to facilitate diagnosis was formulated by Pozo Arcos et al. (2020), shown in Figure 9. The main takeaways from this research are that users need guidance for disassembly and fault location, so feedback and/or the complete elimination of the need for disassembly should be pursued. Using testing points to access crucial components for testing without disassembling the entire product is recommended. Additionally, transparent materials are suggested to allow visibility of potential defects. If the disassembly of the product is necessary, then a guided workflow approach is suggested.

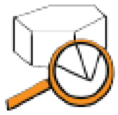
1



FACILITATE FAULT DETECTION AND SYMPTOM-TO-CAUSE DEDUCTION BY GIVING TIMELY AND UNDERSTANDABLE FEEDBACK

Designers can ease fault detection and symptom-to-cause deduction by providing audio and textual cues. For instance, designers can guide and educate end users on the sounds the appliances make during a working cycle. Moreover, text signals can communicate the process the appliance is executing, thereby providing guidance and understanding in case of a fault.

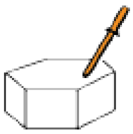
2



FACILITATE INSPECTION OF COMPONENTS WITHOUT THE NEED FOR DISASSEMBLY

Designers can avoid the need to disassemble the appliance by providing lids and doors to access the components. Including testing points in the components can also ease checking their condition. Moreover, making faults visible through the material's casing can also ease inspection without disassembly.

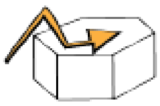
3



FACILITATE DISASSEMBLY AND REASSEMBLY IF NEEDED FOR INSPECTION

Designers can ease disassembly and reassembly by considering the fastener types and their access. For instance, fasteners would be preferable to adhesives. Fasteners prone to damage and breakage during removal should also be avoided (Pozo Arcos et al., 2018).

4



FACILITATE NAVIGATION OF THE PRODUCT'S CONSTRUCTION

Designers can help users navigate the appliance. In particular, the arrangement of components can guide users through different paths. For example, if components that are likely to fail are located on the surface, they can be quickly identified. Another possible arrangement could be one that guides the user through the input-output flow of materials. This would communicate existing relationship between components.

Figure 9. Design guidelines for fault diagnosis. (Pozo Arcos, 2021)

USE CASES IN THE INDUSTRY

As a stepping stone towards the design of a diagnosis tool, some known cases of products for diagnosis are analysed and can serve as inspiration. It is known that the error systems in household appliances usually are directed by built-in sensors in combination with software. However, this could also introduce uncertainties since these could break themselves. Next to that, it is seen in previous studies that this problem of guidance is not a new one and solutions for this have been explored.

For example, in 2013, GuideMe – a phone application – tested the use of augmented reality to let users experience home appliance manuals (Müller et al., 2013). Using the camera of the phone, they can provide an interactive manual of the appliance. Through the screen of the phone, a live image can be displayed of what the user sees combined with instructions and video animations. They concluded that even though paper manuals had a higher success rate, the perceived workload was much lower, making users choose it over the traditional manual.
Another example that takes this interaction even further is the "Immersive service guide for home appliances" from Flotyński et al. (2019), which enables one to experience the repairing of induction hobs in virtual reality.

However, they both mention that these approaches have gained little attention throughout the years due to the enormous effort and time it takes to develop them and diagnosis proves to be very difficult in real-time. Compared to the high development rate of smartphones, this would already be irrelevant at the time of release. Even though this rules AR and VR out as a short-term solution, these examples emphasize how much less effort is needed from the user to execute the action when feedback is provided and that this is preferred over static information. For the diagnosis tool this would thus be preferred to engage users more in the process.

Another remarkable example also uses the smartphone as a medium for another application. The system of Baek et al. (2020) uses its microphone to analyse the sound of a washing machine's rotor and can with that knowledge accurately diagnose what is wrong with it. This is an interesting case that uses the products users already have to help with the diagnosis, which lowers the threshold towards it. For a smartphone diagnosis tool it would not be logical to be reliant on a smartphone as a medium, since the user would then need someone else's phone to operate the device. However, a laptop which most people own themselves and have at the ready, could be used here as an interface medium or also to draw power.

Figure 10. Augmented Reality used in repair. (Arrow, 2020)

Figure 11. Virtual Reality used in the training of repair. (Transfr, n.d.)

Finally, a particularly interesting case for this project is the Tristar tester, of which the most commonly used products are from Smartmod and JC, seen in Figure 12 (JCID; smartmod, 2018). It is the only relevant hardware test device in use today for professional phone repair (Interviewee B, personal communication, 19 April 2024; full interview can be found in Appendix C). The small device is used for testing the Tristar chip of a phone. The Tristar chip is responsible for charging, it is connected to six main lines that in the end regulate the permission of the USB connection to the outside world. It can thus diagnose power related faults. Interesting parts about it are that it tests entirely without disassembly, with which also the main disadvantage arrives: when the charger port is inoperative or does not allow data transfer, the device cannot run its tests. It also requires the phone to be still able to turn on, which according to the interviewee is rare for phones with such faults. The opinions about its usefulness are thus divided. However, if it works it does its job quickly, it is mobile and unintrusive, all important features.

Figure 12. Smartmod's trisartester. (Smartmod, n.d.)

CONCLUSION

Looking at the different phases of the diagnostic process, a tool could be developed that steps in as soon as in the fault detection phase. In household appliances, the use of sensors teaches us there are interception points available from which the state of the system can be read. This also is the case for smartphones and will be explored further in the next chapter.

There is also room for improvement and guidance in the fault location phase, where inexperienced repairers are at a disadvantage in identifying the link between the symptoms and the component that might be causing it. In fact, according to van den Berge (2023), users are less likely to repair the phone without obvious symptoms. The iteration between creating a hypothesis of what component it might be and testing if indeed it is the cause seems inefficient and needs to be eliminated. It would further be beneficial to engage users in the search for the defect since it builds an attachment between them and the product, resulting in better product care in the future.

Since (re-)assembly of the product and fault location are the biggest barriers in the diagnostic process, a minimal need for disassembly should be pursued. Opening lids, testing points or transparent materials are an interesting path to explore to minimise this. Lastly, it is stated that the user lacks guidance in this process, so an interface and/or feedback would be advised. The use cases show the feedback provided should not be static, since this is perceived as a higher workload.

The **insights** deducted from this chapter are the following:

- Users require guidance for disassembly or fault location, this in the form of interactive and / or real-time feedback during the process.
- A guided elimination approach should be used to identify the broken component.
- Engaging users in the search for the broken component would strengthen the attachment between the user and the product.
- Disassembly is a major pain point in the diagnosis process and should be avoided.
- Interception points, testing points, or lids are useful to access components to test them.
- Transparent materials could be utilized to facilitate diagnosis, to make visible without disassembly what is broken.
- Incorporating other devices the consumer already owns as interfaces or extensions can lower the mental threshold for usage and potentially reduce the size of the tool.
- Using the USB-C port to read diagnostic information would eliminate disassembly.


TESTING POINTS ROADMAP
MULTIMETER TESTING
DENYS
TESTING PINS
FORESEEN TESTING SPOTS ON PCB
DENYS
TESTING SPOTS NEXT TO COMPONENTS
DENYS
DIAGNOSTICS ACCESS PORT
DENYS
QUESTIONS TO USER
FAIRPHONE
FAIRPHONE
FAIRPHONE
iFIXIT

04 DIAGNOSIS IN SMARTPHONES

This parts aims to research how the theoretical framework of the previous chapter applies to smartphones, and thus answer RQ3 and more specifically RQ3.1 and RQ3.2, before focussing on the Fairphone 3. The most common hardware defects in smartphones are identified, the insides of the Fairphone 3 examined and there is a deep delve into diagnosis practices of smartphone repairers. The information in this chapter was obtained mostly by interviews and a conducted teardown of the Fairphone 3. At the end of this chapter, the takeaways are listed.

THE MOST COMMON DEFECTS

As will be elaborated further on in the continuation of this chapter, two interviews were conducted with smartphone repair shops.

One of the main learnings from those were which parts of a normal smartphones break the easiest, this deducted from the information which parts they have to repair the most. Even though this might not be a completely accurate comparison since the users have already decided these defects are worth repairing when they get to them, it is a good indication. Both stated the following components were the most frequently (more than 80%) being repaired in this order of frequency:

1. Screen (50%)
2. Battery (20%)
3. Charger port
4. Back cover (when made from glass)

However, since a broken backside is not a problem that needs to be diagnosed, this can be excluded for the rest of the project.

Apart from these they indicated that the most difficult to repair problems were related to the motherboard or PCB, when for example there has been water damage and every single component on the board could have been affected. The then followed procedure of measuring voltages over components and looking for short circuits with thermal cameras is very time consuming and requires expensive equipment. One of the interviewees gave a price estimate of around €150 for such repairs, which according to him only covers 5% of the repairs he does on a daily basis.

Another difficulty they both mentioned is the opening of the different types of phones. They all have variable ways of being opened, glue in different places and removing that comes with challenges. Most of the times they have dedicated machines to heat up and loosen them. Fortunately, this is not the case with the Fairphone, as the back is easily removable.

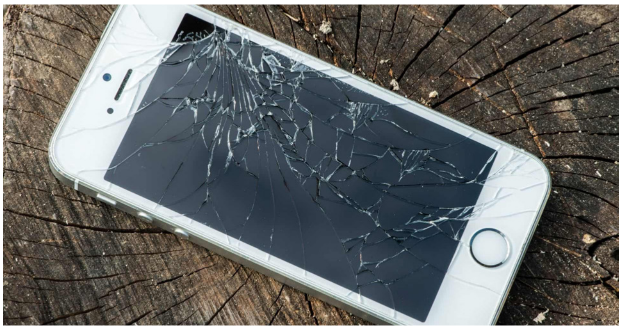


Figure 13. Screen failure, also without breakage. (SparkServices, 2021)

Figure 14. Battery failure. (Triangle cellular repair, 2019)

Figure 15. Charger port failure. (Asurion, n.d.)

Figure 16. Back cover failure. (Asurion, n.d.)

THE FAIRPHONE 3 ARCHITECTURE

The Fairphone 3, as seen torn down in Figure 17 below, is like its predecessors and successors designed to disassemble. This means almost all connections are secured by the same Philips screws and critical components like the battery, screen and charger port are easily accessible. Unlike its successors, the Fairphone 3 still has its motherboard in 1, L-shaped piece. The later models have them divided in two to fit a bigger battery. All components are connected to the motherboard with click contacts, easily detachable.

When opening the phone, the components will be encountered in the order as seen in the disassembly tree in Figure 18. Fairphone clearly made sure the two most frequently failing parts – the battery and the screen, covered in the previous paragraph – are readily accessible when opening the back cover, which in itself is not attached with screws. The battery can be pulled out as was common in older phone models and the screen needs some screws to be undone and can then be detached from the rest of the phone. A unique feature about the Fairphone 3 is that Fairphone decided to work with 'modules'. There is a top module, camera module, bottom module and speaker module. These can all separately be taken out with a minimal number of Philips screws needed to be undone, so the full module can be ordered again on their website and easily be replaced. A critical note needed to be taken: when opening the modules by themselves, the customer will lose their warranty.

Top module: selfie camera (removable), earpiece speaker (removable), headphone jack (soldered), proximity and ambient light sensors (soldered)

Camera module: Rear camera (removable)

Bottom module: vibration motor (removable), USB-C port (soldered), microphone (soldered)

Figure 17. Teardown of the Fairphone 3.

Loudspeaker module: Loudspeaker (encapsulated)

The motherboard is better tucked away. To reach it, a cover with some screws need to be removed. If wanting to open the modules, there is a need for a different type of screwdriver (T5), which is not uncommon but is not delivered with the phone. When opening the modules, the separate electronic components can be accessed. The only two less accessible critical parts are the power button and fingerprint sensor. However, according to the interviewees, issues with these were rarely seen.

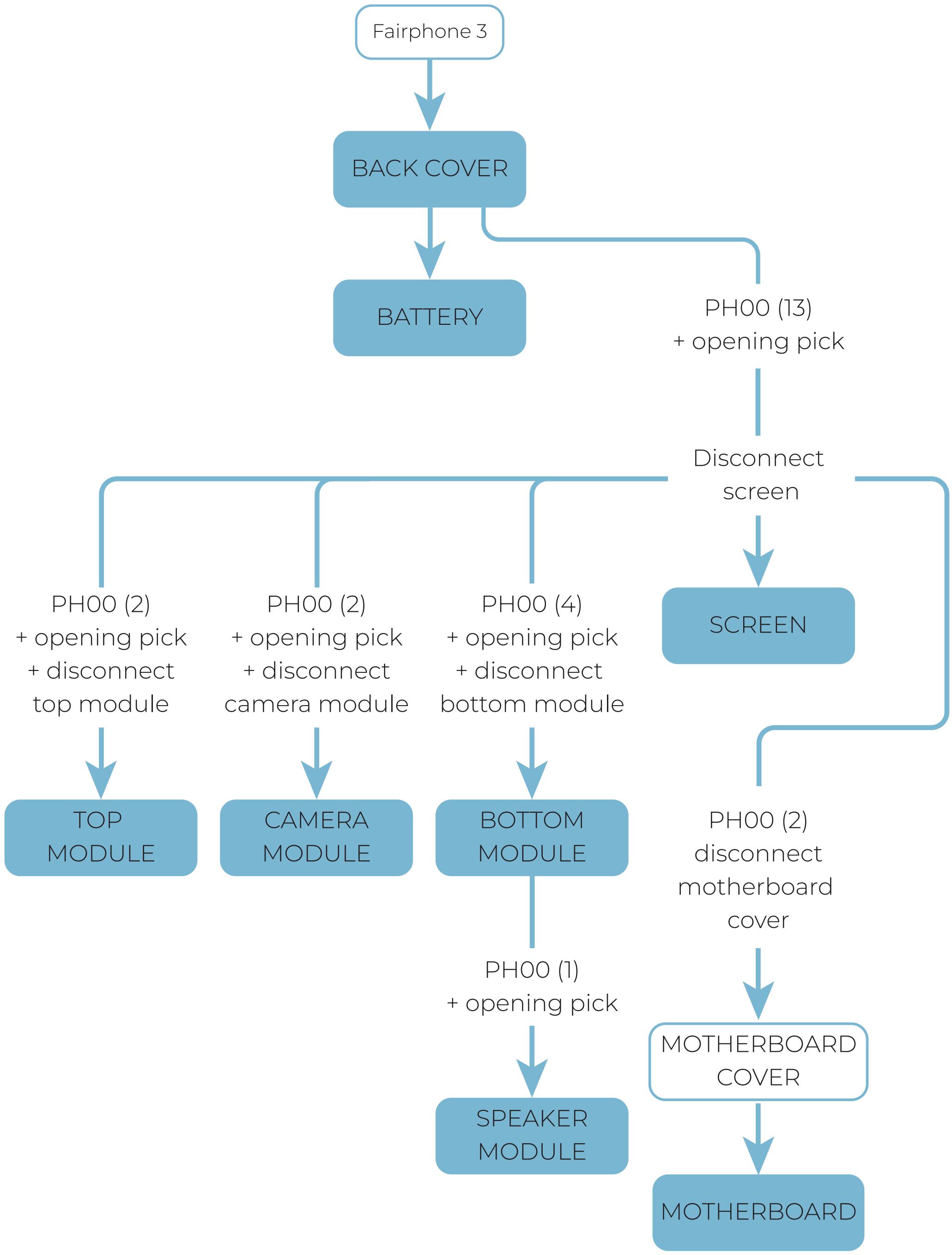


Figure 18. The disassembly tree of the Fairphone 3, for as far the user is allowed to disassemble.

THE DIAGNOSTIC PROCESS IN SMARTPHONE REPAIR

Two interviews were conducted with smartphone repair shops to understand the process of diagnosis on a professional level. The full interviews can be found in Appendix C. They both operated in a distinctly different way.

If compared to the diagnosis framework of Pozo Arcos (2021), one of them follows the component oriented route while the other follows the cause oriented route (Figure 19).

After having taken the device and questioned the customer about the problem, they both start out with general tests like trying to turn the device on and hard-rebooting it by pressing some buttons – depending on the device these differ – for a longer period of time. When this does not work, they test the device to see if there's still "life" in it. This means they connect it to a charger and monitor how much current is still drawn by the device, indicating the damage is not irreversible or of the most difficult type. This can happen while the customer is still standing right next to them. If the device still draws something, they can conclude there is life in it and they will continue the repair process. After this step their path in the diagnostic process starts to differ.

Firstly, the person going on the component-oriented route – from now on Person A – concludes they will open up the phone and go through fault location and fault isolation to diagnose exactly what is wrong. Using the problem statement provided by the customer and their own experience, they will identify all the connections and components that need to be measured. Next, they will use a multimeter to measure these components and compare the values to the nominal ones from the electrical schematics, which they obtained by purchasing from the phone's manufacturer. This way the exact problem component will be pinpointed and replaced to solve the problem. The only reason this can be a viable route to take is that because of experience, the repairer will know after having gotten the problem description from the client where they have to start looking.

Person B taking the cause-oriented route has all needed spare parts available and takes a trial-and-error approach. In an elimination method, they will replace the suspected failing component – also deducted from the client description – with a new one and only measure the before and after voltages to see if it improved. They do not use

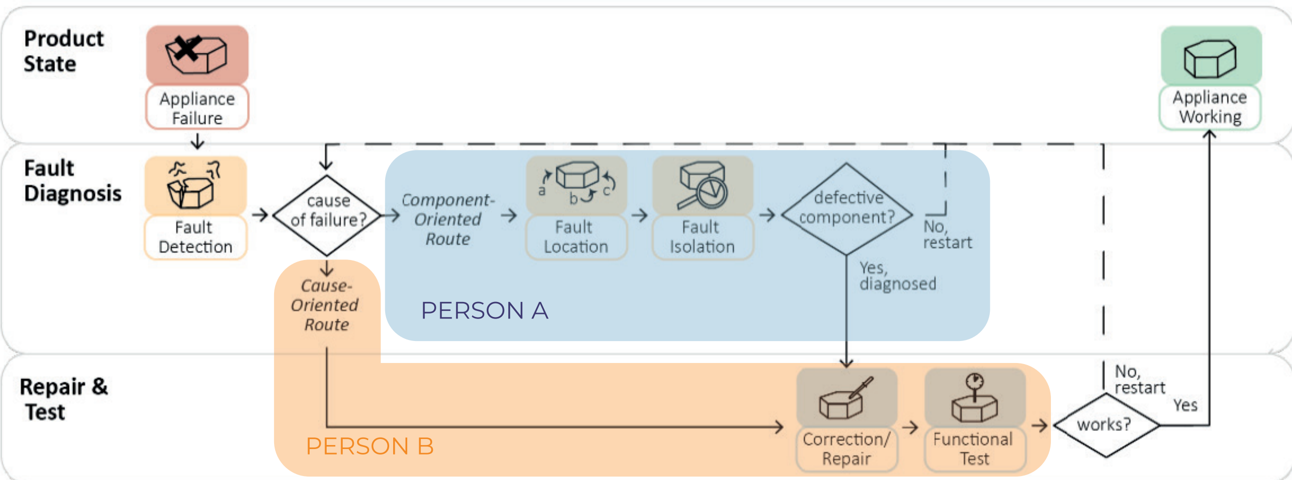


Figure 19. Adapted diagnosis process for smartphone repair (Adapted from Pozo Arcos, 2021)

schematics but know a few standard values by heart and are very effective in this manner because most of the time, the failures seen in smartphones are the same two things: screen or battery.

Person A will find the exact mistake, but person B will probably do it faster and needs less knowledge to succeed.

Even though these interviews shed light on the process of the diagnosis, the exact tests executed – except for the first "life"-test – still remained a mystery as the two interviewees were very protective about their tricks of the trade, apparently frightened I would pass on their knowledge and they would lose their professional advantage. This exact workflow thus was left to me to figure out. RQ3.3 and RQ3.4 will thus be covered in the next chapter.

The tools the repairers used range from specialised opening machines and encrypted keys to repair software, schematics, microscopes when they would repair PCB's to simple multimeters and screwdrivers. When compared to the self-made repairers on YouTube – next chapter – that are not certified, frequently only the last two are present. The next chapter will also deal with which tools are strictly necessary for the diagnosis of the most common hardware problems as defined in the previous paragraph.

In most recent years, diagnosis of smartphones has gained more attention. In response to this, many companies like Samsung, Apple, OnePlus and also Fairphone came with an app that helps the user pinpoint what is wrong with their phones from a distance, through software. Fairphone went quite far in this, as it aligns with their repairability message. In Figure 20, the flow of their app is shown.

The app provides, through a series of tests that are activated by software, a diagnosis of a hardware problem. At the end of the diagnostic process the user is directed to a contact page of Fairphone itself to take further steps if wished for. This app works quite well, is intuitive to use and covers a wide range of problems. However, it will only be of use when the phone is still functional. It is also remarkable that it does not have an option to test for the charger port or battery. To avoid crossing paths with this diagnostic tool already thoroughly developed by a company, the scope of this project will be limited to the use case where the phone is unresponsive or, in other words, to when the app is useless. The user interface flow could however be used as an example further in the project.

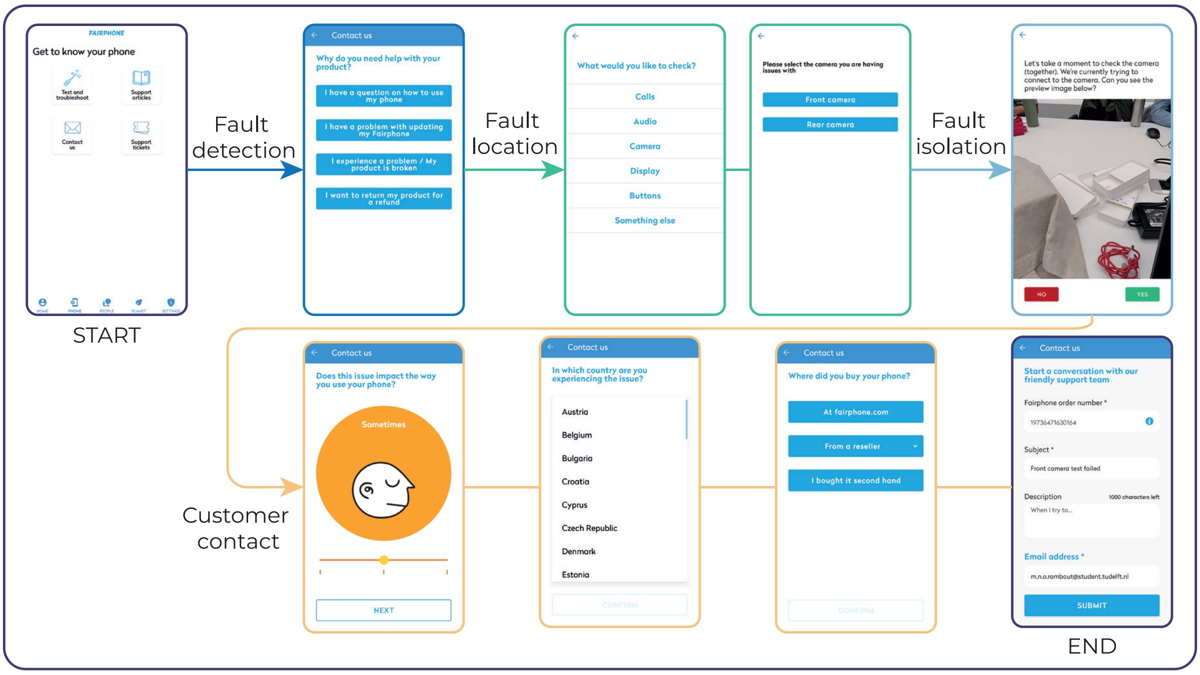


Figure 20. The Fairphone diagnostic app, here as an example for a broken rear camera. (Fairphone)

CONCLUSION

The three most common defects that need to be diagnosed in a smartphone are the screen, battery and charger port. Repairing the motherboard seems to be the most challenging as this requires the measuring of all small components on it, which is not deemed feasible for this project, neither is repairing this fault sustainable (Fairphone, 2022). However, the developed diagnosis tool should be able to diagnose which of these four options makes the phone unresponsive.

Concerning the Fairphone 3 architecture it is clear that this phone was designed with repairability in mind. The big challenge of opening up the phone and reaching the above-mentioned critical components does not require specialised tools and will be considered as a lucky advantage for this project. Further methods for disassembly of other phones will thus in this time frame not be further explored.

Further, even though the process of the component-oriented diagnosis will lead to the exact component that is broken, the three main causes of a broken phone as mentioned above will not need this kind of specific search. They can also be diagnosed through an elimination method, shown by the cause-oriented repairer, while needing less knowledge, tools (screwdriver and multimeter) and time to reach the same goal. This is considered the most feasible way to continue with. However, the workflow to reach this diagnosis is still unknown. Special attention should be given to customer contact in this process since in the previous paragraph the cause-oriented route was shown to cause less customer care due to detachment of the process.

Lastly, after researching the diagnostic app Fairphone provides with its devices the scope of this project was narrowed to when the phone does not respond anymore, and the app cannot be used. The flow of the interface however can be used as an inspiration later in the project.

Below, the additional **insights** of this chapter are listed.

- Using a guided elimination approach would be the most effective for diagnosing the most common hardware problems (screen, battery, charger port and motherboard).
- Customer contact needs to be preserved during this elimination method to make sure they do not become detached from the process.


FAIRPHONE
FAIRPHONE
Well done.
You're what progress looks like.
Model name: FP3
Designed by Fairphone BV, The Netherlands
Jollemanhof 17, 1019 GW Amsterdam, NL
Micro SD
Sim1
Sim 2
Change is in your hands

05
PROBLEM DEFINITION

Previously, the goal of this project was translated into a main research question:

"How to encourage users to repair their smartphones by diagnosing and communicating the faulty parts in them?"

With the additional insights from previous research, it can be further decomposed into three different aspects.

1. **Diagnosis of faulty parts**
   This will be further refined to the diagnosis of the most common damaged hardware: screen, battery, charger port and motherboard. This when the phone is not correctly responding anymore and built-in diagnostic tools thus are irrelevant. Software problems are outside the scope of this project due to feasibility issues.

2. **Communication to the user**
   The gap between end-users and complex technology needs to be bridged, to lower the barrier of competence and ability to repair. Therefore the communication to them needs to be clear and stimulating.

3. **Encouragement to repair**
   The users need to be stimulated to choose repair instead of replacement when their smartphone breaks. This will be done by giving them a correct diagnosis and additional information.

Additionally to these main topics, the problem space was also further defined in the sense of the target group, the current user journey when going through the diagnosis process and finally the list of requirements.

TARGET GROUP

The initially defined target group of this project consists of "end users of smartphones and third-party repairers". After having done the research and having talked to many who are part of these target groups, a critical note should be taken.

It was observed that most end-users do not want to buy a product that can diagnose what is wrong with their phones because they could only use it once in a while or it just does not seem interesting to them. This a problem. The biggest barrier they raised is that this tool can only be used once, and thus they were unwilling to pay money for it. At the time of asking, it was also still unsure how much this tool would cost. It would seem more fitting to reframe the target group to whom could use this more frequently: repairers.

However, repairers do not need to be convinced in repairing the device as it is their job. Making a functional device for them would be interesting but would completely abandon the user behaviour side of this project since their behaviour does not need to be changed, neither will they need all of the guidance or knowledge provided when using this product. Therefore, the decision was made to include the end-user as part of the target group and approach this project more as an exploration of potential possibilities and their implications, rather than viewing it as a feasible product for the market.

As seen in Chapter 2, a social setting could stimulate people to take care of their products better. To try to bypass the problem of non-frequent use rendering the product not worth buying, it is proposed as community property, for example used in Repair cafés – where non-professional repairers would use it – or as a shared device. As a community property the device could be used in libraries, makerspaces or at another governmental setting, where inexperienced users could also make use of it. This would result in the following additional **takeaways**:

- The tool must be durable to withstand frequent use and handling by multiple users.
- The tool should be designed with a shareable design in mind, facilitating easy sharing among multiple users.

USER JOURNEY MAPPING

A user journey was drawn up to get an overview of the followed process by end users while diagnosing a problem and identify problem areas. (Figure 21). The diagram is the result of input from several people who each wrote down their personal experience after being put in the imaginative scenario that their own phone had broken down. With their – then "broken" – phone in hand, they went through their scenario and wrote down simultaneously. It is notable that this process overall looks very negative.

The three main phases are again fault detection, fault location and fault isolation. After this last step, there is the possibility that the fault was not diagnosed correctly and the user needs to return to the fault location step, as previously explained in Chapter 3.

The total duration of the diagnosis process was set to 30 minutes, as Pozo Arcos et al. (2021) determined that beyond this time, the diagnosis is likely to be deemed unsuccessful since most people would not continue. This was taken as an indication, even though their research was conducted under predefined conditions.

It is notable that the user first tries to follow the cause-oriented route, trying to avoid the need for an actual diagnosis by trying some "one-fits-all" remedies like resetting the device. The hope for this to work gives a positive feeling. When this does not work a first dip in the emotional field occurs, followed by another short positive peak of hope to be able to repair it. Looking for tools is then reportedly a first deep valley when the needed tools are not found. Directly after that, there is the second one: opening up the device could come with many additional difficulties. The last dip will occur when transferring to the fault isolation step and not finding the component causing the

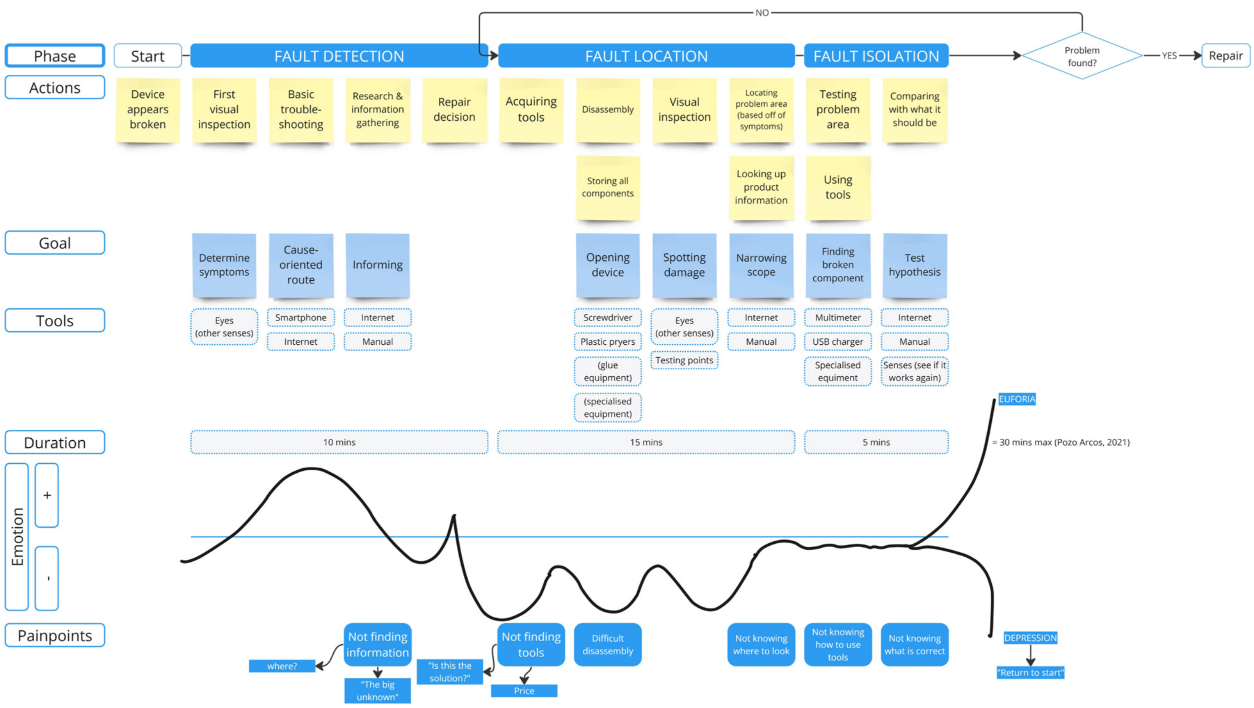


Figure 21. The user journey for diagnosing a smartphone.

problem. This step also aligns with the most tools and knowledge needed to continue.

It can be concluded that the major emotional lows are related to the lack of tools, cost and knowledge, as also seen in the previous research sections. However, an interesting observation that can be made is that there is a complete lack of knowledge on where to find repair information on the product. Since it is generally not available on the product brand's website, users do not find or trust external information. Initiatives like iFixit are not known outside the tech-savvy public, making it a priority to lower that barrier in this project. This leads to a last additional **insight**:

- Repair information should be made readily accessible for users.

LIST OF REQUIREMENTS

Derived from all gathered insights in the previous research parts, a list of requirements for the design could be composed. In addition to those, W11 and W12 were added as personal preferences.

REQUIREMENTS

R1 The tool must offer guidance to help users accurately diagnose the most common hardware issues in smartphones. (CH2, CH3, CH4)

R2 The tool must communicate that diagnosis clearly. (CH2)

R3 The tool must be safe to use at all moments of the process. (CH2)

R4 The tool must be user-friendly to operate, even for inexperienced repairers. (CH2)

R5 The tool must provide all tools needed for the diagnosis process. (CH2)

R6 The tool should do the harder parts of the diagnosis process automatically. (CH2)

R7 The tool should provide interactive and / or physical information. (CH2, CH3)

R8 The tool should use a guided elimination approach to find which component is broken. (CH2, CH3)

R9 The tool must be durable to withstand frequent use and handling by multiple users. (CH5)

R10 The tool must lower the barrier towards repair information for inexperienced repairers. (CH5)

WISHES

W1 The required effort to operate the tool must be as little as possible. (CH2)

W2 A correct diagnosis must be provided as fast as possible. (CH2)

W3 The tool should be as cheap as possible. (CH2)

W4 The tool should enhance users' feeling of competence as much as possible. (CH2)

W5 The tool should use social connections as a catalysator. (CH2)

W6 Using the tool should be as much of a pleasurable experience as possible. (CH2)

W7 The tool should involve users as much as possible in the search for the broken part, improving customer contact to maintain a high level of product care. (CH3, CH4)

W8 Diagnosing must entail as little disassembly as possible. (CH3)

W9 The tool should preferably give real-time feedback. (CH3)

W10 The tool should lend itself to the role of shareable design as much as possible. (CH5)

W11 The tool should be as innovative as possible. (Personal preference)

W12 It must be possible to prototype the tool as realistically as possible. (Personal preference)

06 IDEATION

In this chapter, the requirements and wishes defined in the previous chapter are translated into concepts, generated through brainstorming and testing. Three concepts were developed and in the end of this chapter, a selection for one of them was made.

HOW-TO'S & BRAINSTORM

Starting the ideation phase, a list of how-to's was put together to touch upon every aspect of the design vision. Afterwards, the results (found in Appendix D) of this were used as the starting point for brainstorming.

The how-to questions were generated spontaneously by brainstorming as many questions as possible while reviewing different aspects of the problem statement. Later, themes were identified to connect and group them. The questions used were the following:

Feasibility

- How to make the hardware diagnosis of the most common smartphone problems technically feasible?
- How to access the required components (screen, battery, charger port and motherboard) without disassembly?
- How to access the required components with disassembly?
- How to test the required components?

Motivation

- How to make sure the target group of less experienced repairers does not give up while diagnosing?
- How to engage users so they want to put in effort into diagnosing?
- How to make the diagnosis process more fun?
- How to make the target group want to use this diagnostic product?
- How to give encouragements during the diagnostic process?

Communication

- How to communicate diagnostic instructions clearly?
- How to tell the target group what is broken?

Usability

- How to make the diagnostic product pleasant to work with?
- How to make testing easy?
- How to make testing fast?
- How to make testing cheap?
- How to involve non-repairers?
- How to give this product an advantage?
- How to make users choose repair after diagnosing?
- How to facilitate repair after having given a diagnosis?

The first round of brainstorming that followed can be summarised in 4 directions in degrees of automation of the product, as can be seen in Figure 22 below:

1. A fully automated device that operates without disassembly of the phone.
2. A fully automated device that requires disassembly of the phone, but after that does all testing without the user having to put in effort.
3. A device that enables guided testing, as to avoid unnecessary disassembly by the user and involve them in the testing process.
4. A non-automated roadmap that guides the user as a manual through the different testing steps, letting them test everything by themselves.

In all four of these directions, feasibility was the primary concern that needed to be tackled. Firstly, the device had to be effective in diagnosing unresponsive smartphones so later there could be concentrated on the other aspects. Additionally, as making as much of a functional prototype as possible was a personal learning objective of this project, this aspect of each was prioritised as well.

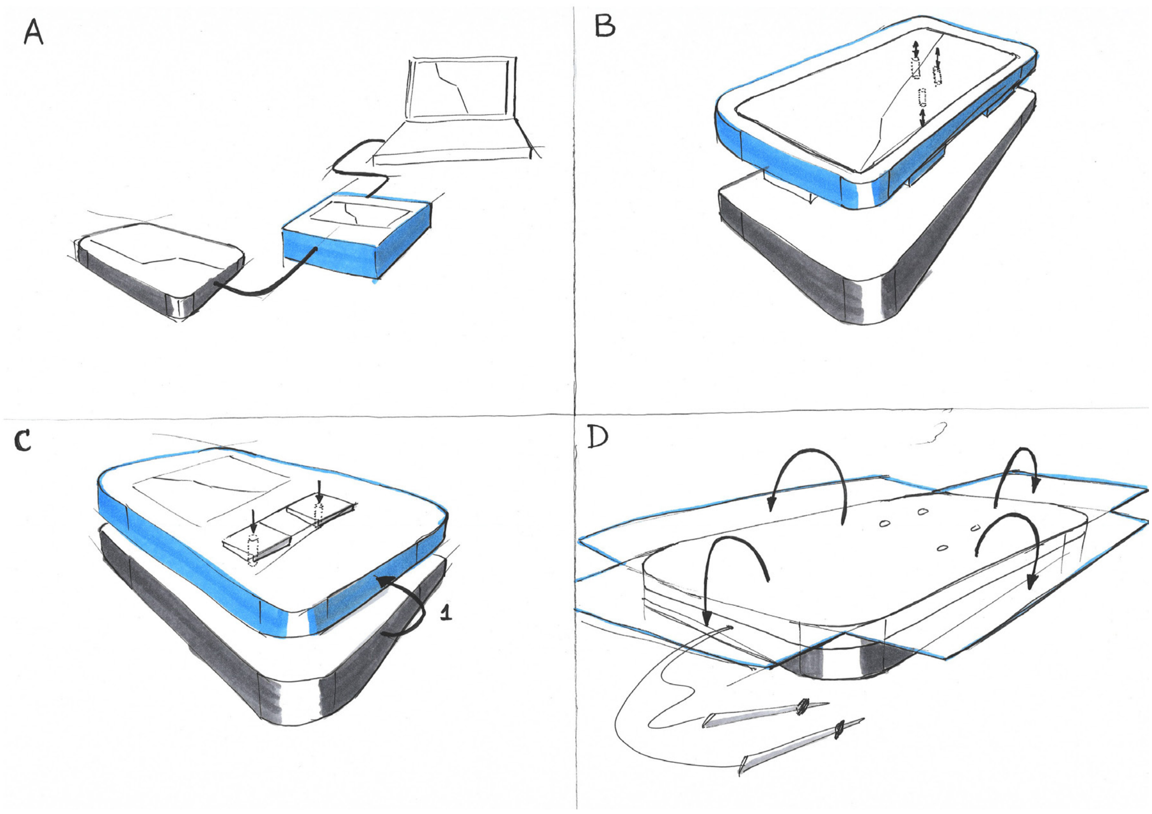


Figure 22. The four design directions after the first brainstorm.w

TESTING WORKFLOW

To succeed in hardware diagnosing a smartphone, a testing workflow had to be developed. This answers RQ3.3 and RQ3.4. Two possible directions were explored: diagnosis through testing points and through the USB-C connection.

Firstly, since the interviews of the repairers did not give precise information of how to diagnose through testing points, extensive research on the internet had to give the solution. It was found that instructional amateur YouTube videos on how to repair certain faults – with the key words power faults, screen faults etc. – also contained bits and pieces of diagnostical information. While those repairers were testing smartphones giving live commentary, their setup and working ways combined with the previous research knowledge resulted in the developed testing workflow in Figure 23.

This workflow uses an elimination method. It aims to start with as little disassembly as possible and gradually works its way down, ending with all four most common possible diagnoses. The biggest advantage here is that this eliminates the need for measuring out every single component on the phone's motherboard, which would be challenging. The tests can be explained as follows.

Test 1: Current draw

This test eliminates the screen as cause of the issue. If the phone draws the normal amount of power but does not respond, nothing on the inside is malfunctioning, but the screen is. For this test no disassembly is required.

Test 2: Batttery voltage

This test checks the health of the phone's battery. The battery voltage needs to be in the normal range for it to be functioning. For this test the battery needs to be accessed.

Test 3: Power bypass

This test checks the working of the motherboard. When bypassing the charger port and the battery (by connecting a power source to the power pins), the phone should be able to turn on if the motherboard is functioning. If it does, the only possible cause left for unresponsiveness was the charger port. If not, the problem is on the motherboard.

For this test the battery socket needs to be accessed.

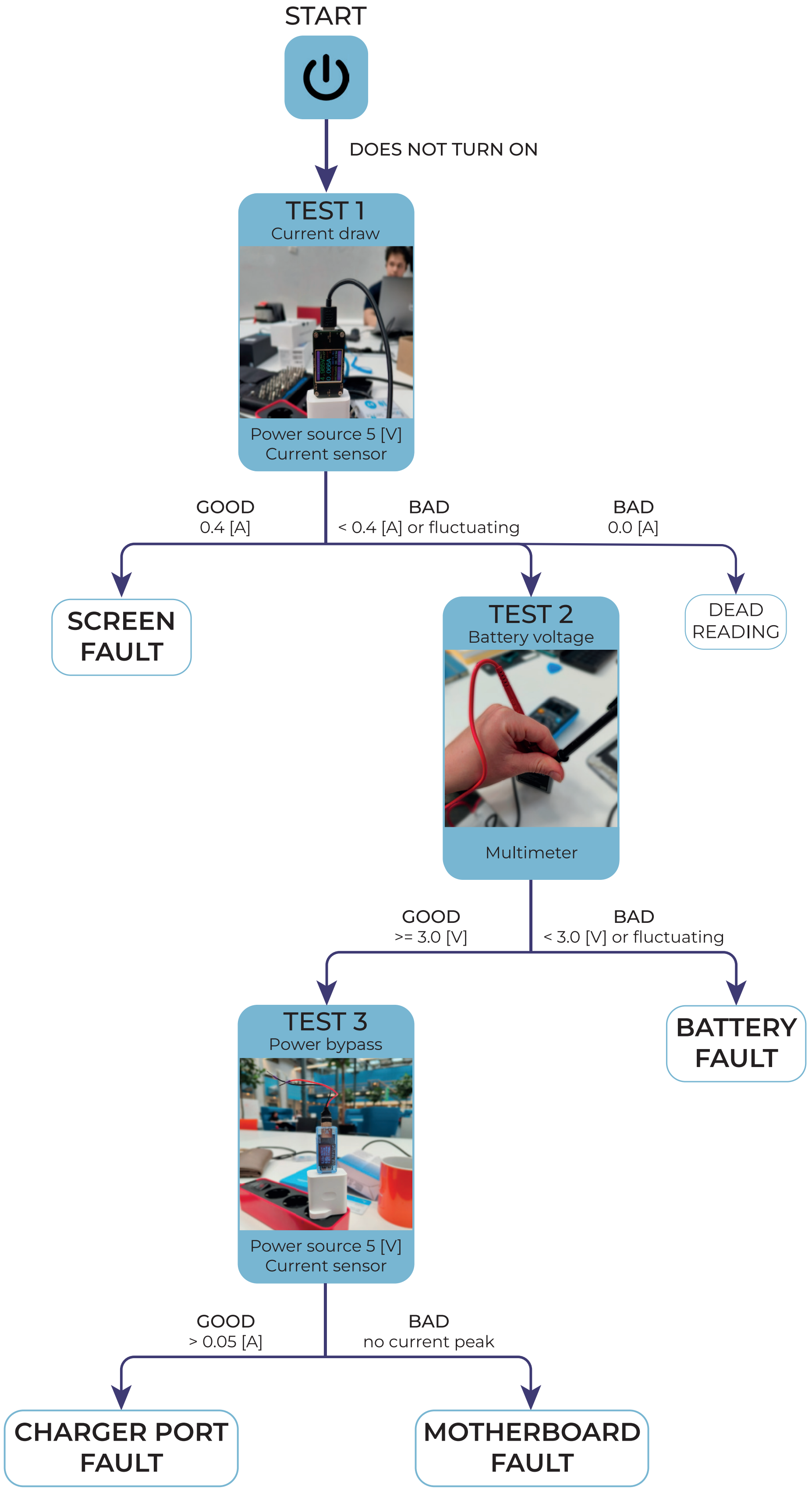


Figure 23. The developed testing workflow.

This workflow and its setup was tested and validated with 25 broken phones. All previously pried open, one by one they could be diagnosed by comparing the measured values with the default values. The results of those tests can be found in Appendix E and an overview is visible on Figure 24. It was concluded that this is a feasible, fast and reliable way of diagnosing smartphones and thus these three tests will be used as the technological diagnosis method in this project.

It may be noted that this method requires disassembly of the phone and is therefore not desirable for use in the diagnostic tool (W8). However, the disassembly required to access the necessary components is limited. The first test does not require this at all and the other two only require access to the battery connector. Since the battery is known to fail regularly, phone manufacturers usually make the battery relatively accessible compared to other components. Even if they are glued inside the housing, they usually are located to the surface and are one of the first components encountered when opening a phone. Fairphone in particular has made a point of this and made it possible to access the battery directly by only removing the back cover of their phone. Moreover, this will become even more common in the future: the EU has passed a law requiring smartphone manufacturers to make the battery easily accessible to users and make it possible to replace it (EU, 2023). This works in this method's favour and makes it a responsible choice for this project.

Testing through the USB-C port of the phone was the second option that still needed to be validated. An informal interview with Jerry de Vos, researcher at TU Delft and software/hardware specialist, gave exclusion. Testing via a USB connection is only possible if the phone's data log is accessed via an Android reboot. Not only does this require advanced software knowledge, the success of this method is also not guaranteed as it requires the phone's data connection to be intact at the time of testing. A broken USB port could thus already prevent this. In conclusion to this interview, the design direction of testing via USB connection was consequently abandoned.

Figure 24. The 25 diagnosed testing phones.

CONCEPTS

The concepts developed can be found on the next few pages. However, first a footnote needed to be taken.

Revisiting the remaining directions and trying to make concepts out of them, it was noted that the fourth one, the unautomated roadmap, could not be brought to the same level of the other two. When comparing it to the list of requirements it could be seen that it clashed with two of them:

R6 The product should do the harder parts of the diagnosis process automatically. (CH2)

This concept would not have any parts done automatically.

R7 The product should provide interactive and / or physical information. (CH2, CH3)

Seeing the concept would not be a device, enabling interaction would be difficult.

Lastly, out of personal preference this would also not be my pick due to the non-technical nature of it. Therefore, when later a more interesting concept was found – introduced later in this chapter – this direction was abandoned.

The concepts:

Concept 1 - The fully automated testing device

pg. 46 - 47

Concept 2 - The guided testing device

pg. 48 - 49

Concept 3 - The permanent back cover

pg. 50 - 51

CONCEPT 1

THE FULLY AUTOMATED TESTING DEVICE

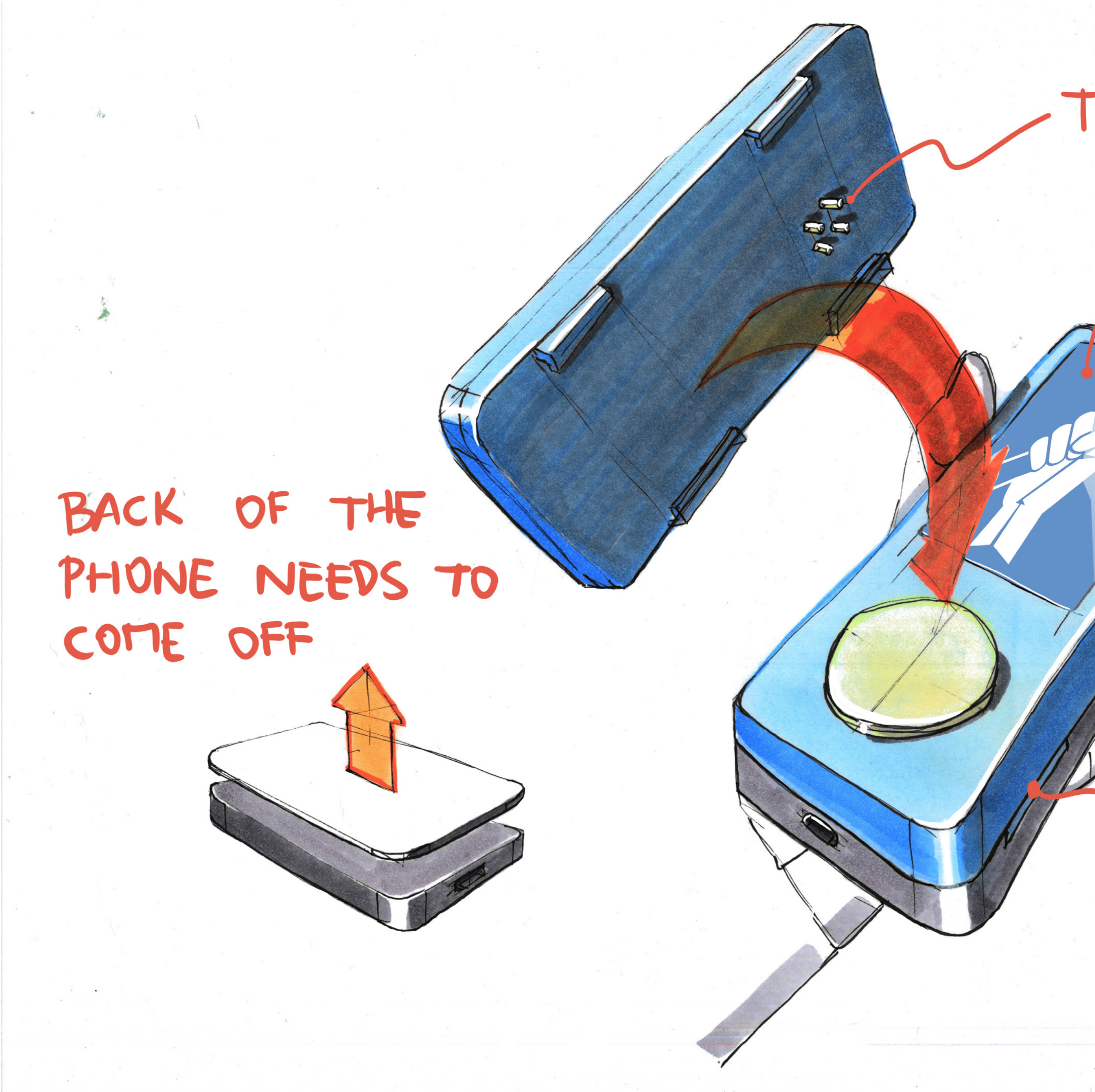
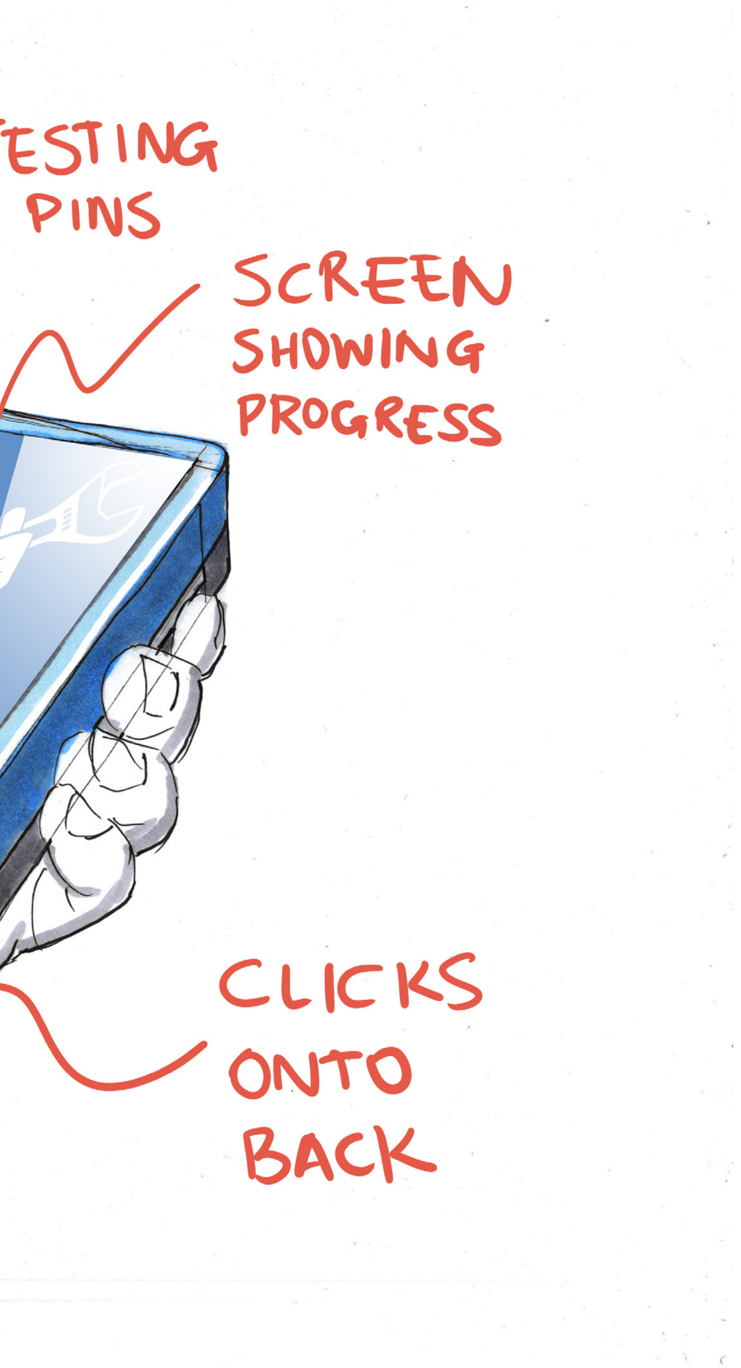


Figure 25. Concept 1 - The fully automated testing device.



The first concept is shown in Figure 25. It is the elaboration of the first design direction introduced earlier: the fully automated diagnostic tool. This tool fits on the back of the phone, where it must be installed to function. Its form-fitting – in this case to the Fairphone 3 – design ensures that everything is in the right place, as the back of the device holds the necessary test pins for the battery and power test, which then automatically fall into place. For the first test (screen), there would also be pins or an initial plug-in attachment. The user interface is on the other side of the device.

Advantages

- Diagnosis is quick and requires no user actions, making it easy to use.

Disadvantages

- The phone will always have to be disassembled to use this device.
- Diagnosis is fully automatic, ensuring that the user is not involved in the process, which will therefore not contribute to product care.

CONCEPT 2

THE GUIDED TESTING DEVICE

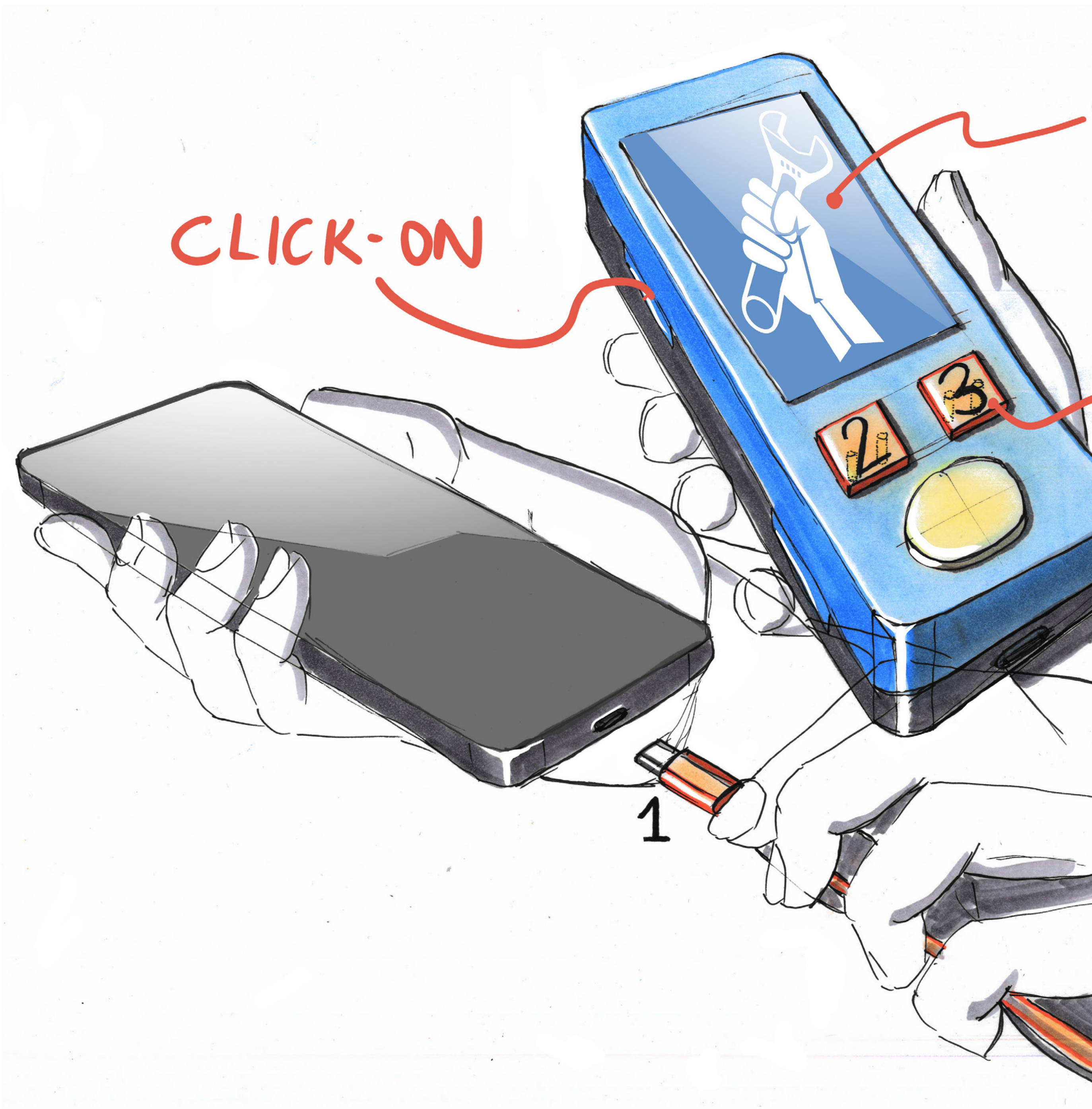
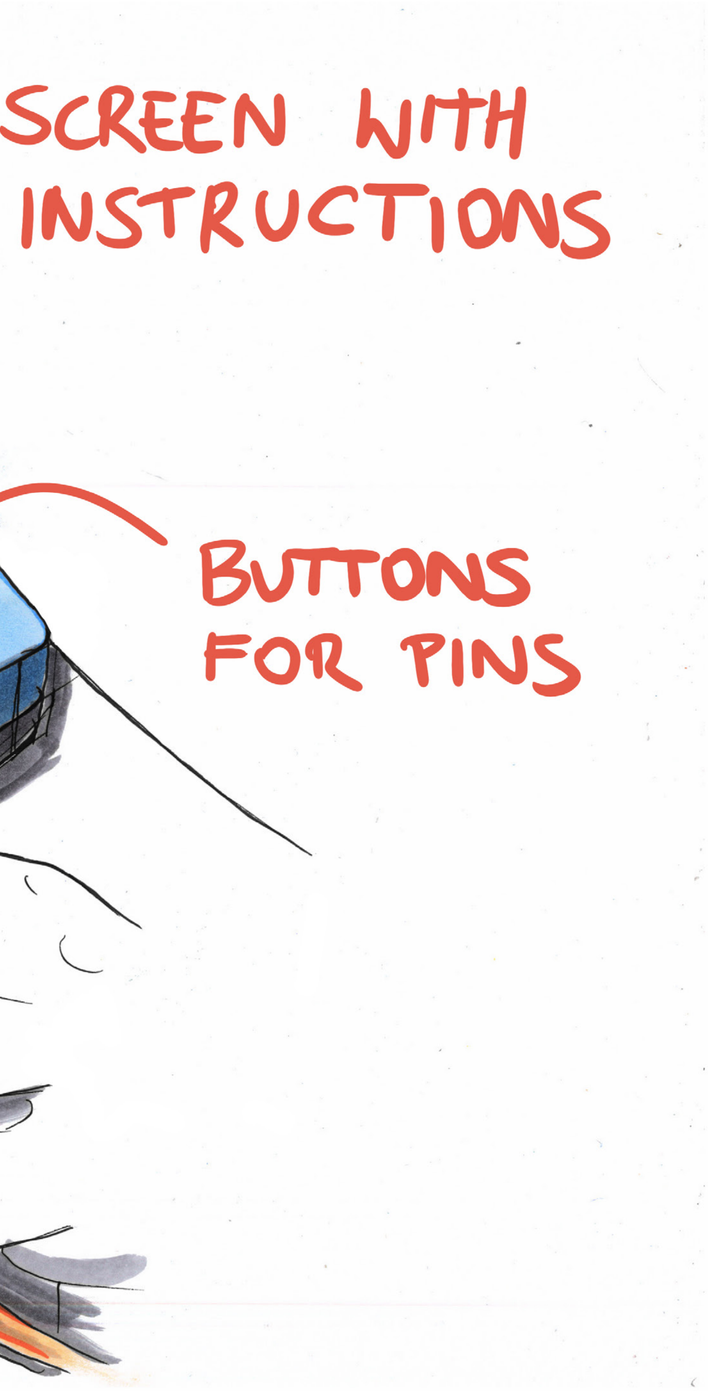


Figure 26. Concept 2 - The guided testing device.



The second concept is the continuation of the second design direction: the guided testing tool (Figure 26). It has a hybrid approach: it is not fully automatic, but neither does it let the user do everything themselves. Through a user interface on one side of the device, the user is guided through the three diagnosis tests as defined in the previous paragraph. For the first test (screen), it is not necessary to disassemble the device as it would be enough to insert an external cord when the device asks the user to. Then, the user is guided to disassemble and install the device on the back of the phone. It has the same form-fitting design as the first concept to ensure that the testing pins are in the right place for the second (battery) and third (power) tests. In these two last tests, it is the user who activates the device instead of it being automatically executed.

Advantages

- The phone does not necessarily need to be disassembled, as the diagnosis could potentially be made after the first test.
- The user gets involved in the search for what is wrong with their device, making it almost a challenge to complete. As a result, they become more engaged and attached to the device, resulting in a greater chance of product care behaviour.

Disadvantages

- The amount of effort required of the user and the time it is likely to take to diagnose the problem will increase in this concept.

CONCEPT 3

THE PERMANENT BACK COVER

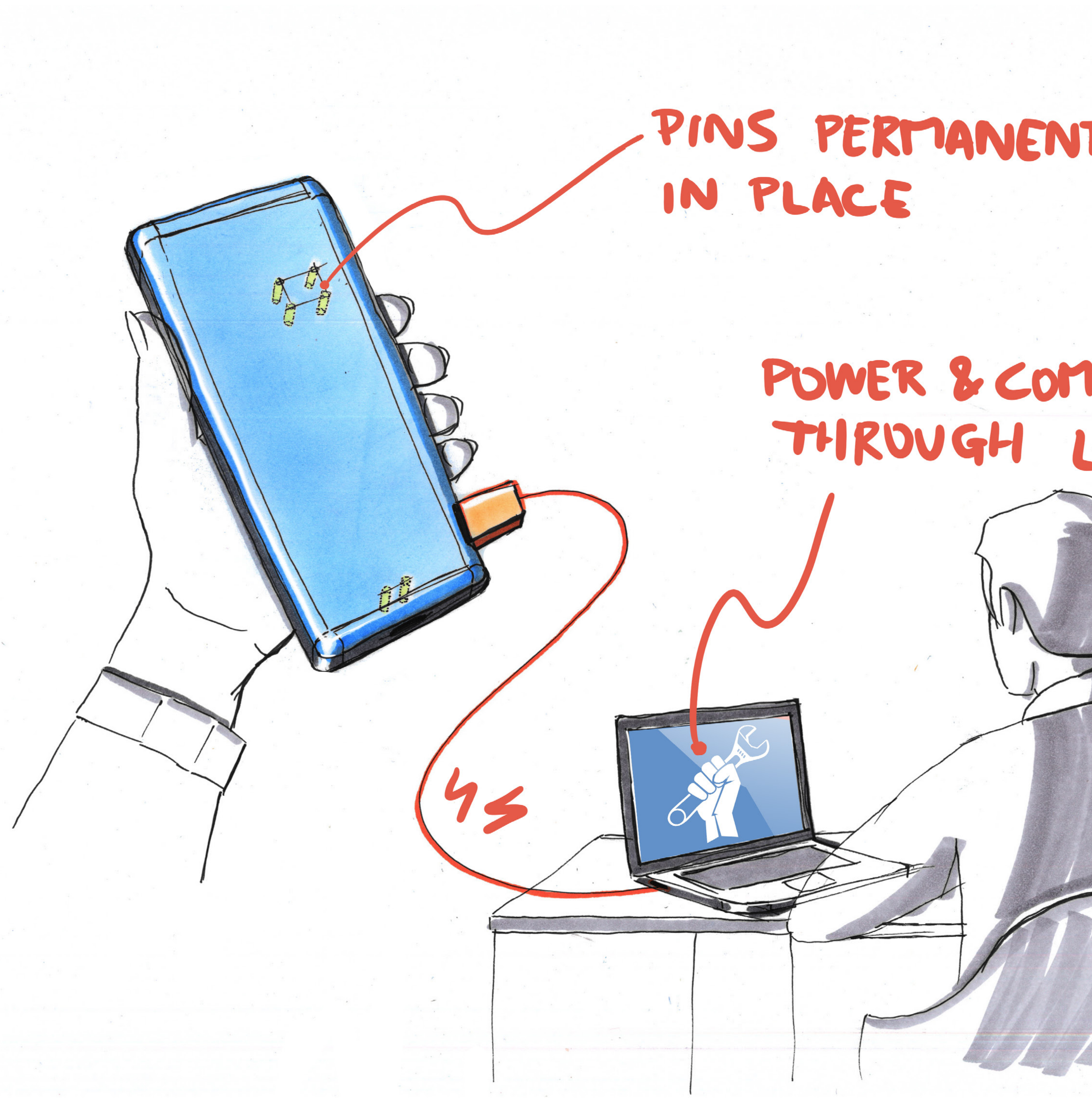


Figure 27. Concept 3 - The back cover.

The final concept is the third shown in Figure 27. This is a new concept, which goes for a more permanent approach and tries to address the problem of disassembly of the other two. It would be a back cover or case for a phone, which only needs to be installed once. In that sense, this concept would represent a redesign of the phone. This device is about an inch thick, has no interface on its surface and serves as a normal phone case.

When installing this device - which could also be done by a professional - the test pins would also be put directly in place because of its form-fitting design. When the phone eventually breaks down, the device could be connected to a laptop from where it could draw the required power and communicate with the user during the diagnostic process. For the first test (screen), more pins could be integrated or an external cord could connect the two devices.

Advantages

- Disassembly would only be necessary once.
- Aesthetics could be played with (e.g. transparency), and the user can customise it, leading to more attachment to the device.
- Less bulky than the previous two due to its power and interface connection with a laptop.

Disadvantages

- As a phone case this concept would still be quite voluminous and would permanently add to the volume of the phone.
- Installation still requires disassembly, even though that would not contribute to the user journey on the moment of diagnosis.
- The use case of the device: users would need to purchase, install and constantly walk around with a device that they might never get the chance to use, as it will only come in handy when their phone in fact becomes unresponsive.

EVALUATION OF THE CONCEPTS

For the choice between the concepts as explained above, the list of requirements and wishes was revisited. As many of the requirements as possible were already considered while coming up with these concepts, so as they would all three meet those, these could not serve as choosing criteria. However, there are some that need to be elaborated on further in the development phase as these are not yet addressed. These are the requirements listed below, they will be further elaborated on in Chapter 7.

R2 The tool must communicate that diagnosis clearly.

R3 The tool must be safe to use at all moments of the process.

R4 The tool must be user-friendly to operate, even for inexperienced users

R10 The tool must lower the barrier towards repair information for inexperienced repairers.

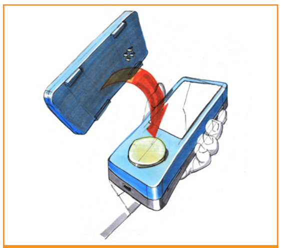
This means the selection criteria will be the list of wishes. There is one that is not considered as a selection criterion because it is included in all concepts:

W9 The tool should preferably give real-time feedback

The others were ordered in ranking of perceived importance with the most important criterion on top, according to the Delft Design Guide method (van Boeijen et al., 2013). For convenience, the wishes are abbreviated in the table. Each concept got a score ranging from ++ to --, the best concept comes out "top heavy" which means it has the most +'s for the most important criteria. The selection is shown in Table 3.

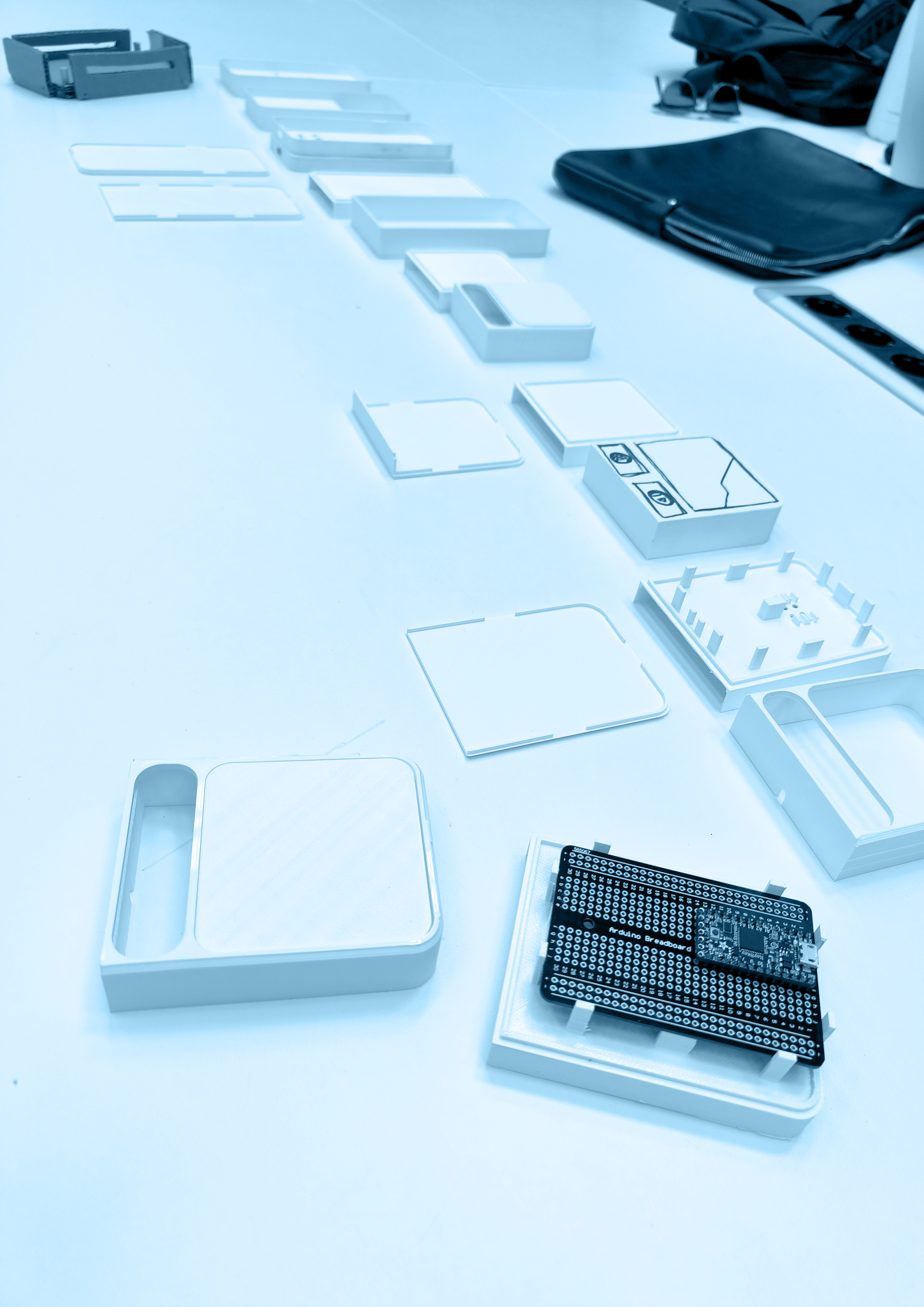
As shown in the table, the choice is really between the last two concepts, as the first one performs poorly in engagement through customer contact and disassembly due to its automatic operation. The phone case concept can generally compete well with the guided testing one. However, since the design goal of this project is 'to encourage users to repair their smartphones by diagnosing and communicating faulty parts', user engagement and stimulation are the most critical criteria. The guided testing device does better in these areas as it maintains customer contact throughout the entire process, with communication happening directly through the device rather than remotely. Furthermore, this concept is more suited to being a shareable device, unlike the case, which would then need to be installed for each use, defeating its purpose. Additionally, its strong prototyping score was also a decisive factor.

Concluding to this chapter, the concept of a guided diagnosis testing device was chosen to further develop.



WISHES	CONCEPT 1 FULLY AUTOMATED				CONCEPT 2 GUIDED TESTING				CONCEPT 3 PHONE CASE			
	--	-	+	++	--	-	+	++	--	-	+	++
W7 Engagement by customer contact	■	■					■	■	■	■		
W4 Stimulate competence		■					■	■	■	■		
W8 Disassembly	■	■					■				■	■
W10 Shareable design			■	■			■		■	■		
W6 Pleasurable experience			■	■			■	■			■	
W12 Prototyping		■					■	■		■		
W11 Innovative		■					■				■	■
W1 Effort			■			■					■	■
W2 Time			■			■					■	■
W5 Social contact			■	■			■	■	■	■		
W3 Price	■	■					■	■			■	

Table 3. The selection between the three concepts.


Arduino Breadboard

07 CONCEPT DEVELOPMENT

Exiting the ideation phase with a chosen concept, this chapter focuses on developing it into a product. All unaddressed requirements from the concept selection are now integrated. A user test was conducted to apply insights on the impact on consumer behaviour, and various aspects of the tool's embodiment are explained.

USER EXPERIENCE

A very important theme of this thesis is user behaviour, which was also the subject of most of the research and on which many conclusions were made in the form of requirements and wishes. While ideating for the concepts though, this was largely not yet considered. This part aims to make the decisions in the communication and user experience department by answering RQ4 and its sub-questions, and therefore addressing R2 for clear communication.

To make these decisions, the earlier made how-to's concerning communication, motivation and the like were revisited and reordered. The topics that had to be considered were the following:

- **Communication**
  - Through what medium will there be communicated with the user? (C1)
  - How to give the diagnosis instructions? (C2)
  - How and what to give as results information? (C3)
- **Stimulation**
  - How to motivate the user during the diagnosis process? (S1)
  - How to encourage the user to repair after diagnosis is done? (S2)

To answer these questions, as many possible solutions were arranged side by side as shown in Figure 28 and choices were made. The reasoning for them will be given per question as defined above.

C1 COMMUNICATION MEDIUM

As a communication medium, writing and video were chosen. Writing is still the fastest way to get information across to users, faster than e.g. audio. To keep the perceived workload for the user low, the written instructions should be kept short and could be accompanied by a video explaining them what to do. VR, AR and holograms were excluded because of their feasibility in the time frame of this project and the fact that developing them in general costs a lot of time, which would not be desirable in the rapidly evolving field of smartphones. If need be, writing and video are media that can be altered quickly to keep up with new evolutions, which is less the case for VR and AR.

C2 DIAGNOSIS INSTRUCTIONS

As diagnosis instructions the choice was easy to make since the diagnosis workflow developed already took the shape of a flowchart. It would only be beneficial to make this flow visible to the user. As a manner to do this, an interactive screen was chosen because it would be the ideal medium to give the interactive information talked about in R7. For prototyping this would also be the most convenient.

Figure 28. The chart with all considered communication and stimulation options listed.

C3
RESULTS INFORMATION

The result information had to be presented in a way that would be a stepping stone towards a further process of repair, it should not let them end there. Five possibilities were drawn up outside of the obvious outcome of the diagnosis process. Giving advice of what to do with the outcome is a way of guiding the users in the right direction, and additional information like the benefit for the planet, saving of money and time could convince them even further. A refreshing one was the repairability score, which would give an indication of how easy their problem was to repair (Flipsen et al., 2016).

S1
MOTIVATION

The motivation criterion was to make sure users would not stop mid-way with the diagnosis process. The best perceived chance of reaching the goal would be by constantly keeping the user involved by triggering them, showing the process and keeping the goal in mind. If there could be a chance of making it more playful and into a challenge, this would also help. The exclusion of gamification , rewards and competition was a personal choice, based on the perceived loss of professionalism and credibility that might entail.

S2
ENCOURAGEMENT TO REPAIR

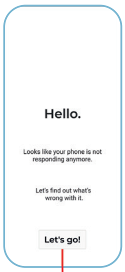
In the end, when the user has had the diagnosis, they had to be encouraged to continue the process to repair. Here it had to be made as easy as possible, with no additional effort from their side, to get to the right next steps. It was chosen not to reinvent the wheel and accept the support from already established organisations in the repair field. Therefore, directing the user to the right repair information on the iFixit website or to guiding them directly to the right repair shops seemed suitable. This solution also fulfils R10:

R10 The tool must lower the barrier towards repair information for inexperienced repairers. (CH5)

USER INTERFACE

Having decided on a communication strategy, the method to deliver this to the user had to be chosen. User input was crucial in the process, so the solution needed to be highly functional when presented to them. Therefore, an interactive user interface was developed. All panels of this version can be found in Appendix F, with a selection for the diagnosis of charger port failure shown in Figure 29.

The first part is the starting screen, followed by the first test. For test 1 and 2, both written and video instructions were provided to make them as clear as possible as well as low-effort to follow (W1). Test 3 did not need a video but an interaction with a button that would control testing pins, so this was implemented as well. Every panel was designed to trigger user interaction, the flowchart way of testing made visual by a symbolic "red thread" leading the user through the tests. The constant confirmations asked while going through the process were to keep triggering the user and keep them involved (W7). A maximum of real-time feedback was pursued, simulating the real-life testing scenario with interactive elements like buttons and



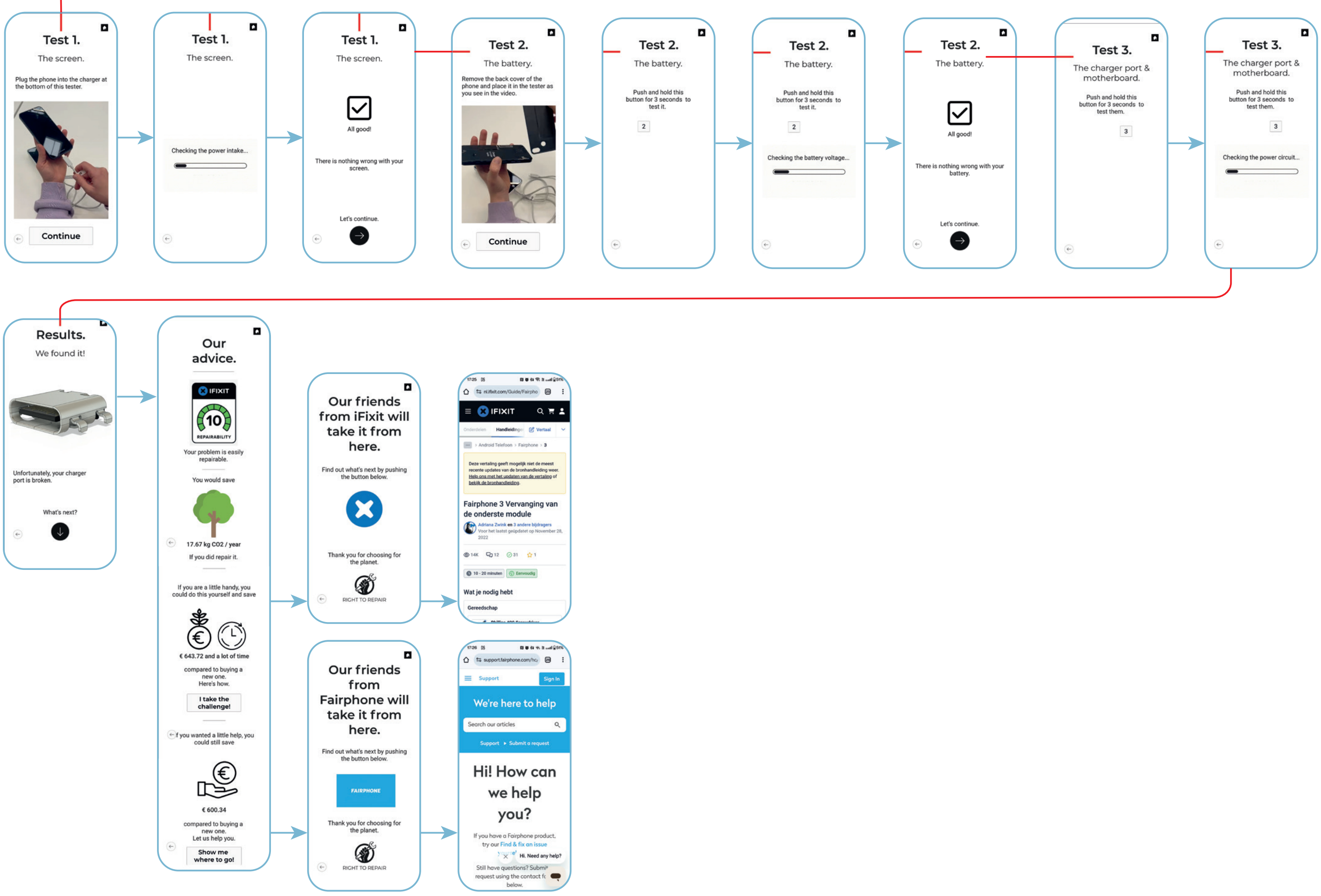


Figure 29. The first version of the user interface, here in case of a charger port failure. Full version in Appendix F.

animations shifting between the different possible testing outcomes (W9). The text provided aimed to be transparent about what was tested while being encouraging and reassuring to continue (W4). When getting to the results, the user would see a 3D render of the broken component, leading to a screen with advice.

The results screen was designed to lead the user to the next steps and be as compelling as possible. So the repairability score was the first thing shown, followed by the effect on the planet, then two options were presented. The first would be to repair the product yourself, the other to have it repaired. Both options showed the amount of money the user would save by choosing that option. When the user would then proceed, they were presented with a screen thanking them for choosing the planet and redirecting them to the correct page, namely the exact repair page for that part on iFixit's website, or Fairphone's repair intake form (Fairphone; iFixit, 2023a, 2023b, 2023c). These results were all chosen to minimise the barriers (and effort) towards repair behaviour (W1). The only exception to these results is the advice if the test shows that the motherboard is broken. In that case, it says that the planet will not benefit if the motherboard is repaired and refers to Fairphone's website for a replacement.

USER TESTING

THE MOCK-UP

Following the above development of the user interface for the diagnosis device, a user test followed to test how well the intended goals were met with potential users. As R4 states:

R4 The tool must be user-friendly to operate, even for inexperienced repairers.

To this purpose, the interface introduced in the previous paragraph was made fully functional and ready to play on another medium: my own phone. This was deemed necessary because the interface complexity required was not of the level that was feasible to remake in the allotted time with a microprocessor. This way, the full intend of it could be tested.

A simple 3D model was made and printed with FF printers so it could hold the phone as a screen, and double as the mock-up testing device. It was given the shape the device had had in the concept sketches. This meant the interactive screen would be at one side and the tested phone would have to be inserted at the other side to contact the testing pins. For the first test, a charging cable was added to the prototype, as power had to be read by connecting the test phone to a charger. There was also a cover for the test side to protect the simulated test pins when not in use. As additional help, after having done a pilot test, a visual clue ("slide in this way") was provided on the back of the device where the test phone had to be inserted. The mock-up used is shown in Figure 30 and 31.

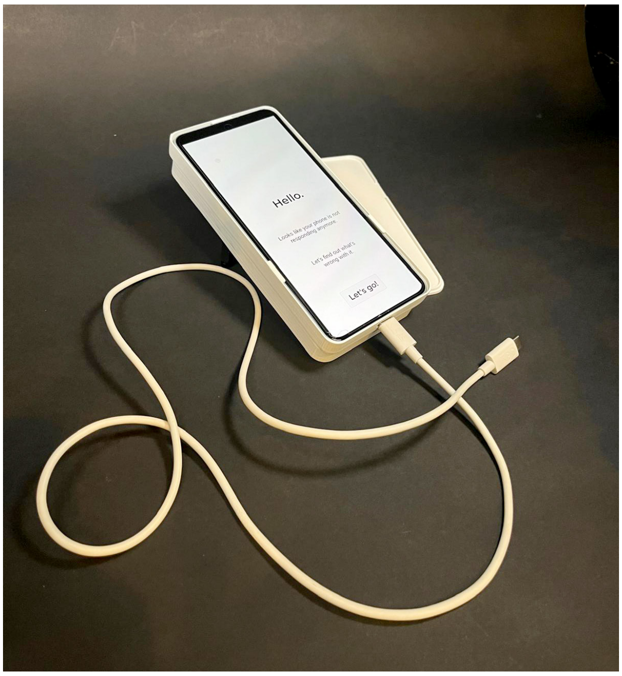


Figure 30. The prototype with user interface played on the phone.

Figure 31. The backside of the prototype where the tested phone slides in.

THE TEST

The testing method was to let the users use the product completely by themselves after having had a short introduction about the project. Their ways of handling it would be observed and a short interview was held after having finished using the product by filling out a Google Form and having a debriefing chat. The Google Form was chosen to easily visualise their responses and was filled out together with them, as keeping the dialogue lively and taking notes in the form was chosen over having the users write and think in silence. When asking for a scale, e.g. “How easy to use would you say the product was from 1 to 7?” Many questions were put on a scale from 1-5 and not 1-7, as this would be easier for them to visualise when asked about it orally. These questions were mainly used to evoke reactions and start a dialogue about the respective topic. Time-wise, this would go as follows:

- Introduction (5min)
- Observation of the user (5min)
- Debrief and first impressions (5min)
- Completing the Google Form (5min)

The questions asked after the test were to gauge whether the intended goals were met. As seen in the list of questions to the right, the main goals of this test were to see if the using of the device had gone well and without troubles, if the instructions were clear enough to follow flawlessly and if the stimulation and encouragement provided were indeed experienced as such. In order to place their behaviour and responses, they were also questioned about their technical skill and whether they had a phone repaired before. Also some targeted questions were asked addressing parts of the design that could still use some input: the results page and the shape.

1. How tech-savvy would you say you are? (1-10)
2. Have you ever had your phone repaired before?
3. Rate your overall experience using the product? (1-5)
4. How easy was it to use the product? (1-5)
5. How clear were the instructions to follow? (1-5)
6. How much did the product encourage you to repair your smartphone? (1-5)
7. What did you think about the information given in the results section? Was it enough / too much? Did you think the provided information was interesting and relevant? (1-5)
8. How confident did using the product make you feel about repairing your smartphone? (1-5)
9. How motivated did you feel to continue the diagnosis process? (1-5)
10. Was the shape of the product easy to handle?
11. Would you use this product in real life? (y/n/o)
12. Do you have any suggestions or improvements?

The test was conducted with 10 people at the Repair café in Delft. Only two repairers were tested, the others were their clients, mimicking the user target group of this product. The repairers did not give exceptionally different answers from the others and so their answers were not distinguished from the rest. Most of the participants were above 50 years old. Knowing that this age group usually has a little more difficulties with technology, this was taken as a good test to see if the interface was indeed clear enough to also guide them through the process. The participants all rated themselves from 4 to 9 on the scale of 10 for technical proficiency. The full outcome of the user test can be found in Appendix G, the demographics of the participants in Figures 32, 33 and 34.

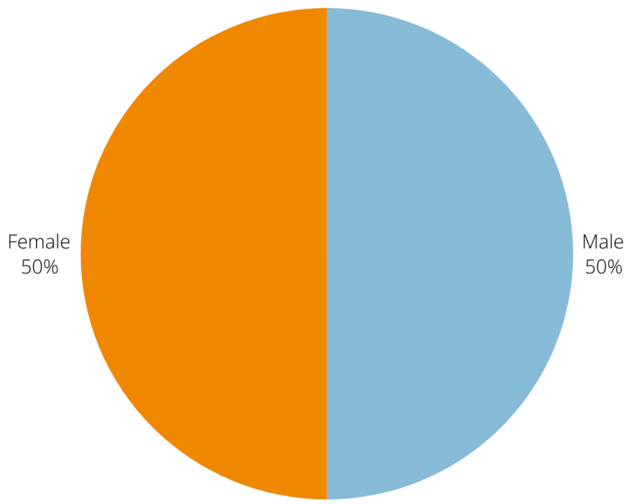


Figure 32. Gender of the participants.

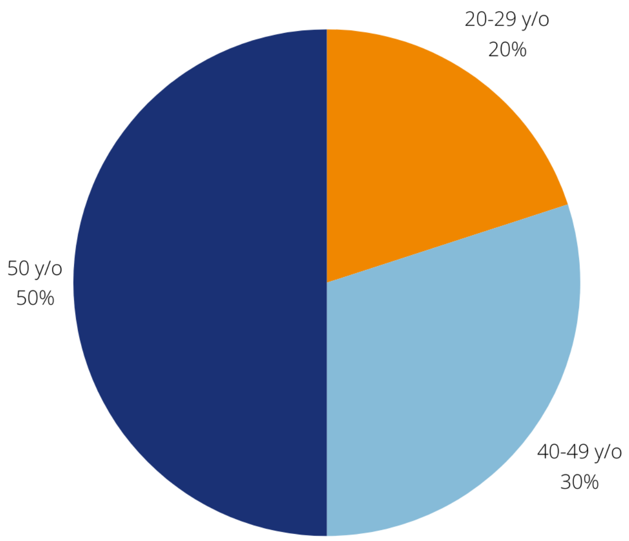


Figure 33. Age distribution of the participants.

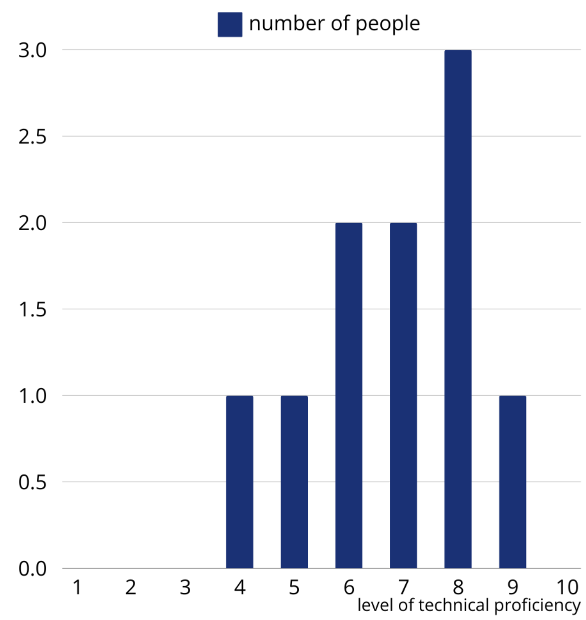


Figure 34. Self-described technical proficiency of the participants.

TAKEAWAYS

Overall, the overall experience with the product was rated highly and the instructions were perceived as very clear. The product also scored well on stimulation for repair, and users reported an increasing confidence in one's own competences and motivation during the process. The intended continuation of triggering them by asking for confirmations and step-by-step going through the process had reportedly not missed its mark. Users validated the use case for sharing the device, as they indicated that they wanted to use the device if it was available somewhere but did not want to buy it themselves. However, not everything went according to plan.

The first outcome of the test was that performing the battery check (test 2) was challenging for many, despite the video clarifying this. For example, it was noted several times that the user removed the battery from the test phone while removing the back cover, even though this was not mentioned anywhere. In general, users started mimicking the instructions in the video while it was playing. This resulted in them momentarily not paying attention and missing the next step. They then had to wait for the video to replay automatically or try to fill in the gaps themselves, which did not produce the desired results.

The results page was received surprisingly well (Figure 35). The users indicated they liked the type and amount of information provided. However, input was asked to make it better. The main problem revealed was that the numbers provided (the CO2 and money saved) did not mean anything to the users if they couldn't compare it to something.

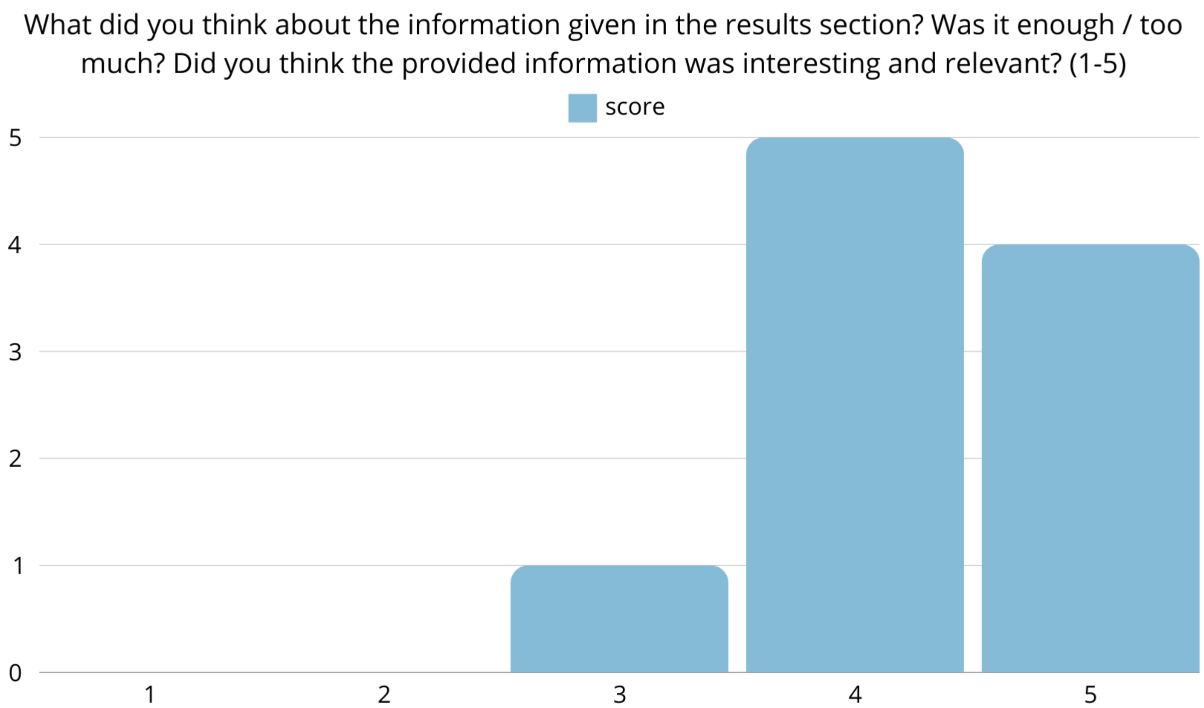


Figure 35. Scores for the results section.

Questions about the shape of the device also showed that users did not mind having the test phone back-to-back with the device, even though some usage problems were observed caused by this arrangement (Figure 36). To reduce these problems, a new setup was explored further in this chapter.

Additional takeaways resulted from the suggestions the users had to offer.

Several people mentioned difficulties with the interface being in English. To resolve this problem, there could be made a language choice menu in the beginning of the testing workflow. However, this was not implemented in the prototype because it would take too much time to make a Dutch version, which substantively would make no contribution to the project. Similarly, the suggestion of linking the repair button to a list with local phone repair shops was not implemented, however being a good idea, because this falls outside the scope of this project. Something similar has been done by Boonen (2022) in his thesis.

Finally, interesting suggestions were made about the implementation of a progress indication and real-time feedback of the buttons in tests 2 and 3. Users tended to not let go of them if nothing would tell them to.

Figure 36. Preferences about the prototype's shape. No one answered no.

IMPLEMENTATION

Concerning the user interface, some final things had to be taken into consideration. The user test had revealed some shortcomings concerning the user interface. Especially the battery check (test 2) had proven to be difficult to follow. Additionally, the results page deserved more attention and some other overall suggestions were considered.

For the battery check (test 2), the video seemed to have been playing to quickly without the possibility to pause or rewind. To counter this, play/pause and rewind buttons were added. Furthermore, as it was observed users would frequently miss the next step while executing the previous one, the test was split into four different steps with each their video, giving users the time to follow the instructions correctly. Special attention was given to the textual instructions accompanying them to make them extra clear. Finally, a mild warning not to take out the battery was also added (Figure 37).

Concerning the results page, it had to be avoided that the numbers would not mean anything to the ones reading it. Therefore, the CO2 saving was translated into the number of plastic bags – easily visualised by everyone – users would save and the prices for repair were compared to the one for buying a new phone (Corekees, 2022; Fairphone, 2024). Further, a scrolling indication was added and iFixit's and Fairphone's buttons were made clearer (Figure 38).

Following some user's suggestions, an indication of which parts had been tested and which still needed to be tested was added by displaying them at the bottom of the screen. Finally, the buttons mimicking the contact points in tests 2 and 3 were provided with real-time feedback. A red, orange and green light was therefore added to indicate when they could release them (Figure 39). The final version of the UI is shown in Chapter 8.

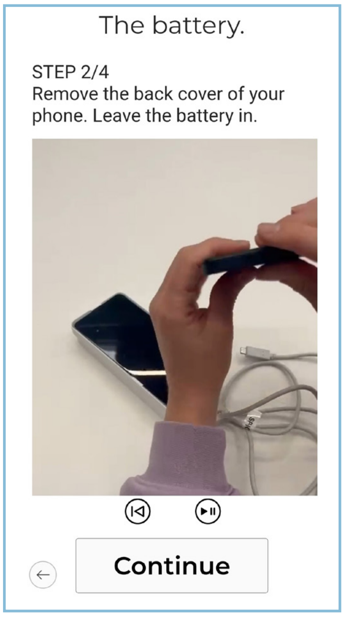


Figure 37. Screenshot of an adapted frame of the UI for test 2. The test was split up and a warning for the battery removal was added.

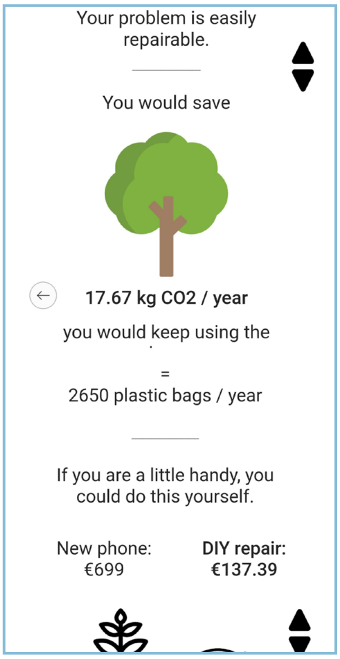


Figure 38. Screenshot of an adapted frame of the UI for the results page.

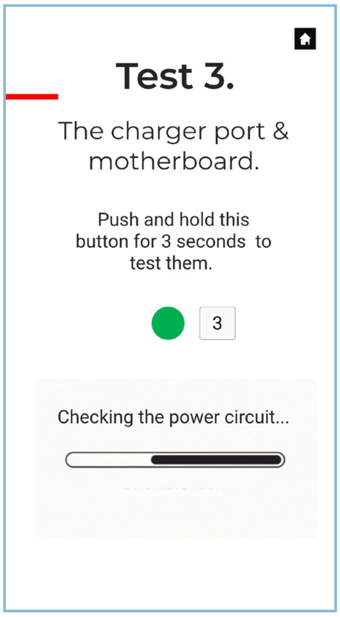


Figure 39. Screenshot of an adapted frame of the UI for tesst 3. The light indicates when to let the button go.

TECHNICAL IMPLEMENTATION

The predefined workflow had to be implemented as much as possible in a prototype. Even though it was not deemed feasible to achieve the full elaborated UI as talked about in the previous paragraphs, it still had to be possible to follow the workflow in real-life. Therefore, the tests needed to be realised with measuring devices and the process had to be coded. Additionally, the location of the required testing points was identified and safety measures were considered.

REALISING THE TESTING WORKFLOW

The testing workflow as defined in Chapter 6 was realised in a prototype, guiding the user through all three tests based on measuring results.

The different tests were implemented as follows:

- **Test 1: measuring the intake current**

The first test needs a USB-C connector feeding a 5 [V] power to the test phone. The current drawn by the phone needs to be measured and compared to the correct value, which means it needs to be above 0.04 [A] and stable.

- **Test 2: measuring the battery voltage**

The second test requires a voltmeter to measure the battery voltage. This value must be higher than 3.0 [V] to call the battery viable.

- **Test 3: bypassing the power circuit**

The final test involves bypassing the battery and charging port with a power source, connecting the minus pin of the battery connection to ground and feeding 5 [V] to the plus. After that, an attempt to power the phone on must be made while the current the phone then draws must be monitored. If the current peak the phone then draws is higher than 0.05 [A], the phone turns on, which means there is no internal problem and so the charging port is broken. If the current remains too low, the motherboard is broken.

The first step to realise these tests was to get the measuring equipment they would use working.

THE MEASURING DEVICES

To have accomplish the prototyping of the required measuring devices, an electrical circuit had to be built making it possible for a microprocessor – in this case an ItsyBitsy M4 – to read out the correct values. The two needed measuring instruments for the diagnosis process were a voltmeter and a current meter, the first needed in the battery check (test 2) and the second in both the current draw check (test 1) and the bypassing of the charging circuit (test 3).

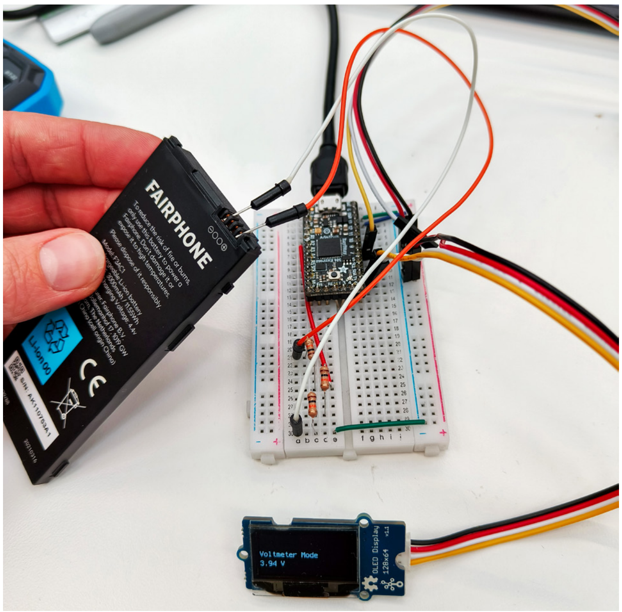


Figure 40. The voltage meter setup.

To succeed in making a voltmeter, a voltage divider needed to be designed not to overflow the maximum intake voltage the board could take. This voltage was 3.3 [V], while a full battery would measure 3.7 [V]. Therefore, resistances of 10 [kΩ] and 20 [kΩ] were used in series to create a voltage divider. This setup allows a maximum voltage of 5 [V] to be read by the analogue testing pins, which would be proportionally read by the board. With this adjustment correctly implemented into the code of the microprocessor, voltages were read correctly. The setup is shown in Figure 40.

A sensor was used to make the current meter. Using the INA219 sensor, current draw could accurately be read out when put in the middle of the respective power line, between the testing point and the power supply. When connecting the sensor to the micro controller, these values were sent to the board and ready for further processing. This setup is shown in Figure 41.

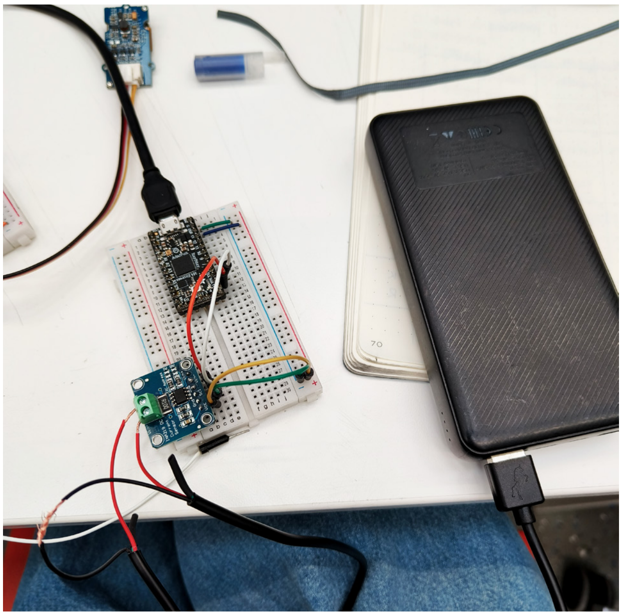


Figure 41. The current meter setup with the INA219 sensor.

WIRING AND CONTROLLING

- **Test 1: measuring the intake current**

The first test needs the input of a current measurer that is connected to the charger port of the phone, to see how much power it draws. Therefore, a USB-C cable was stripped down to the INA219 sensor in the middle of the power line, in between the USB-C ending and the 5 [V] power it would transmit from the board. The ground wire from the cable was connected to the ground of the board to close the loop. To get the INA219 sensor functional, it had to be connected to the I2C bus of the controller.

- **Test 2: measuring the battery voltage**

For the second test, the phone's battery voltage had to be read and processed. This was achieved by putting the voltage divider as introduced in the previous paragraph into the breadboard. Since a 20 [kΩ] resistor is unusual, two 10 [kΩ] resistors were put in series to arrive at that value, making a total of three resistors. One measuring pin needs to be at the end of the 20 [kΩ], the other at the end of the 10 [kΩ]. In the middle where these meet is where the voltage value can be read. This point on the breadboard is connected to an analogue input of the micro controller.

- **Test 3: bypassing the power circuit**

The last test also uses a current sensor, INA219, connected to the I2C bus of the controller. However, this time the power supply needs to be regulated to send power only when the test is initiated, as the testing pins will always make contact once the device is installed on the phone. To achieve this, the sensor is placed between a digital output of the board and the testing pin, allowing the power output to be triggered as needed.

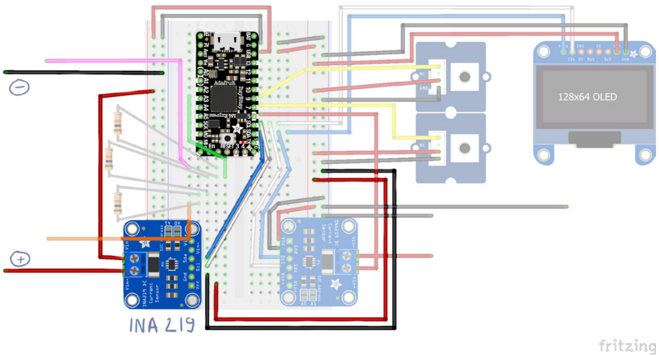


Figure 42. The schematics for the current meter setup of test 1. The test is powered by the board.

Additionally, the values read through these tests had to be processed by the micro controller, which would then determine the correct route through the workflow based on whether the values met the expected criteria. To achieve this, a programme was written in CircuitPython to control the micro controller, which can be seen in Appendix H. With the wiring setup of these components, along with the code, micro controller, and a small OLED (I2C) screen programmed to display the process, it was possible to correctly navigate through the full testing workflow. Two buttons were also implemented to move forward or back one step in the process. Figures 45 and 46 show the full setup as prototyped.

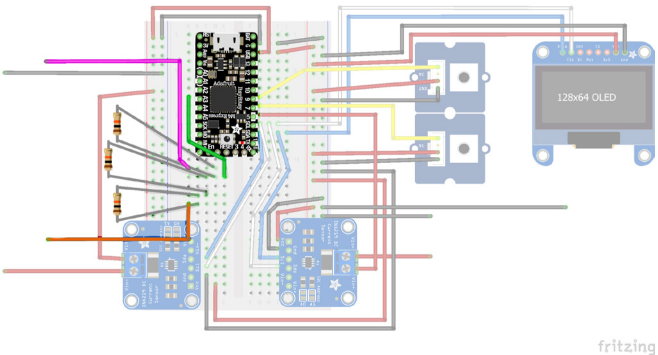


Figure 43. The schematics for the voltage meter setup of test 2. The resistors to the left make up the voltage divider.

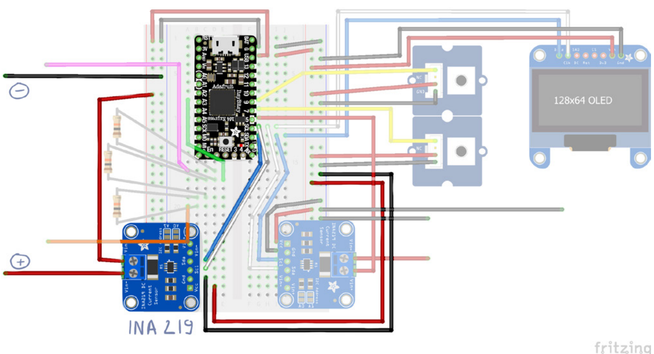


Figure 44. The schematics for the current meter setup of test 3. The test is powered by a digital output.

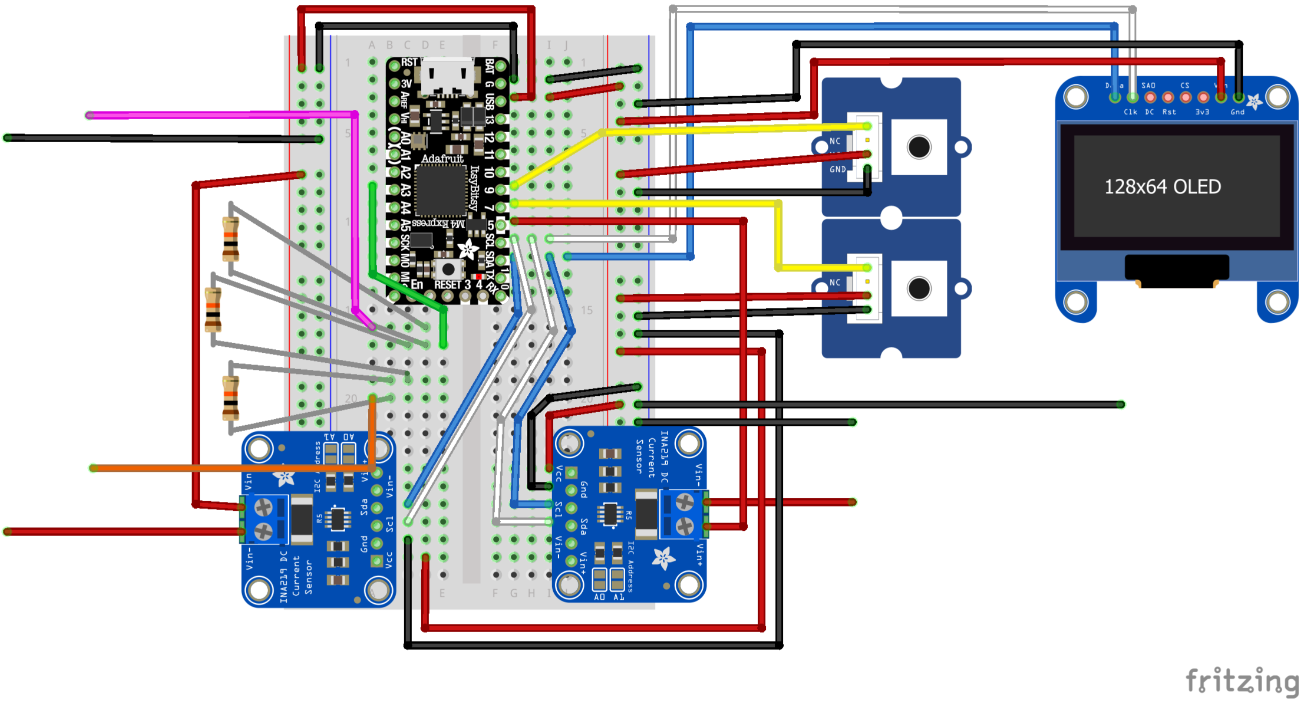


Figure 45. The full wiring in schematics, including the buttons and OLED screen.

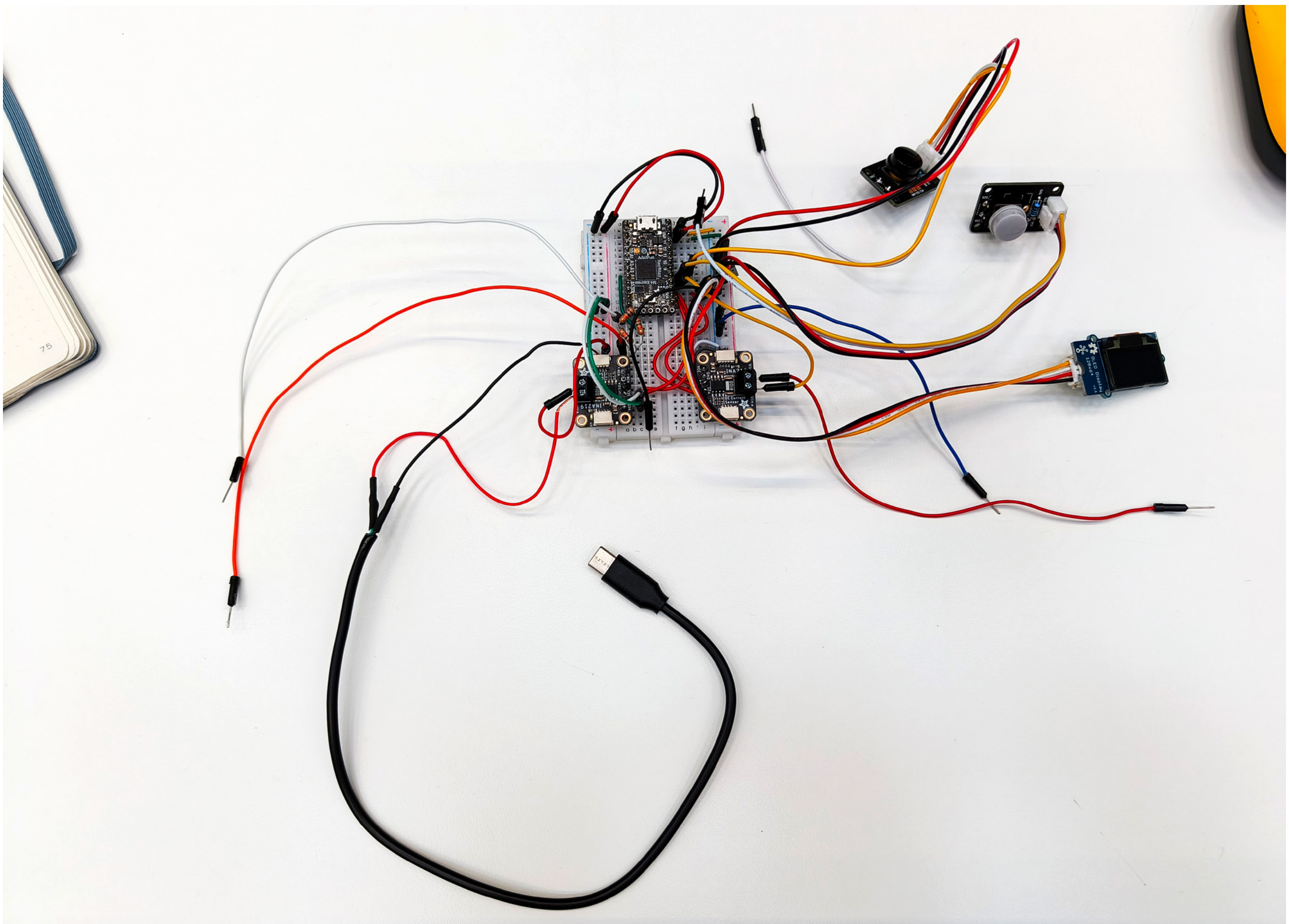


Figure 46. The wiring as executed in real-life, including the USB-C port for test 1.

THE TESTING POINTS

For both the battery check (test 2) as the power circuit check (test 3) there is the need for testing points to measure out the respective values. These are located in different places:

- **Test 2: measuring the battery voltage**

For this test, there needs to be gained access to the battery itself. One should be held against the positive pole while the other is held against the negative one. This can be done easily when taking out the battery. However, since this concept does not require more disassembly than taking off the back cover of the Fairphone 3, testing points need to be foreseen on the outside of the battery, as indicated in Figure 47 . Realising this would not only require the plastic insert that is now there to protect the connection to be modified slightly to allow for the testing pins to slide in (Figure xx).

- **Test 3: bypassing the power circuit**

Similarly, for the last test the testing points need to be brought out as well. The testing pin that will supply power must contact the positive pole, while the other pin must contact the negative pole, as shown in Figure xx. However, without disassembly, these pins are tucked away in the battery, where they connect to power the phone. To connect with the battery in place, the battery terminal, where the external pins and the motherboard connect, can serve as the testing points. To achieve this, the plastic cover over the terminal must be modified slightly to create openings for the testing pins, as seen in Figure 48.

This way, with only minor adaptions, the two tests can take place without disassembly of the rest of the phone. The shape of the testing pins could be adapted accordingly and they could be made from any conductive material, e.g. steel, brass or copper.

Figure 47. The testing points (T+ and T-) on the battery.

Figure 48. The testing points (T+ and T-) on the battery terminal.

SAFETY

Working with electronics always brings a risk. It needs to be guaranteed the user will remain safe while using the product, avoiding build-ups of Electrical Static Discharge (ESD) that can occur while establishing electrical contact between the test phone and an external device. Therefore, safety measures needed to be implemented, according to R3 regarding safety. Two were selected for this purpose.

First of all, the material of the casing had to be selected in function of safety. As this is where ESD usually builds up, it had to be made out of a safe material to the touch. Since the power used in the device is maximum 5 [V], a dissipative material that would get rid of the discharge over time is enough. A relatively cheap material that achieves this while being easily machined and printable is static dissipative ABS plastic (Acrylonitrile Butadiene Styrene) . The whole casing could be made out of this or just the parts the user would touch regularly, as a kind of handles.

For those users who would have an ESD wristband, as observed at the repair shops interviewed and in iFixit's essential repair kit, a grounding pin was provided to which they could attach their band (Figure 49). This would be a metal pin sticking out of the casing and connected to the microprocessor grounding. As most people are right-handed, this pin was foreseen to the right bottom side of the casing, as to avoid the strap from getting in the way.

Figure 49. An ESD wristband with grounding clamp.

PRODUCT APPEARANCE

The shape of the device mostly was determined by the method of testing with testing pins in the back of the phone. This meant the device would have to have direct contact with the back of the phone and that it would need a form-fitting shape to the Fairphone for the testing pins to fall into the right place immediately.

For the user testing, a setup was used with the tested phone to the back side of the interface of the device, as seen in Figure 30 and 31. However, some problems were encountered: the user would lose sight of the instructions as they would turn around the device to put the testing phone in. The first test did not require disassembly of the phone and thus this would have to happen during the process. To avoid these, it was made unnecessary to turn the device around by not having a click-on, but a slide-in insertion of the testing phone.

Another limitation was that preferably, the testing pins would be pushed down by buttons, by the users themselves. This impacted the design by having to have these right above where the testing pins needed to be located.

With these limitations in mind, a brainstorm was held to come to a suitable shape. In Figure 50 the different resulting 3D prints are shown. Iteration made clear that the targeted shape would be quite voluminous if having a shape that would not closely follow the phone's silhouette, which was not desirable and thus was avoided coming to a final shape.

Also the use case of a shareable design had an impact on the shape of the product. According to R9, the tool must be durable to withstand frequent use and handling by multiple users. This translated into a compact design with simple buttons and rounded corners on the outside of the device, protected with a rubber lining and easy to hold by the user. The final shape will be introduced in Chapter 8.

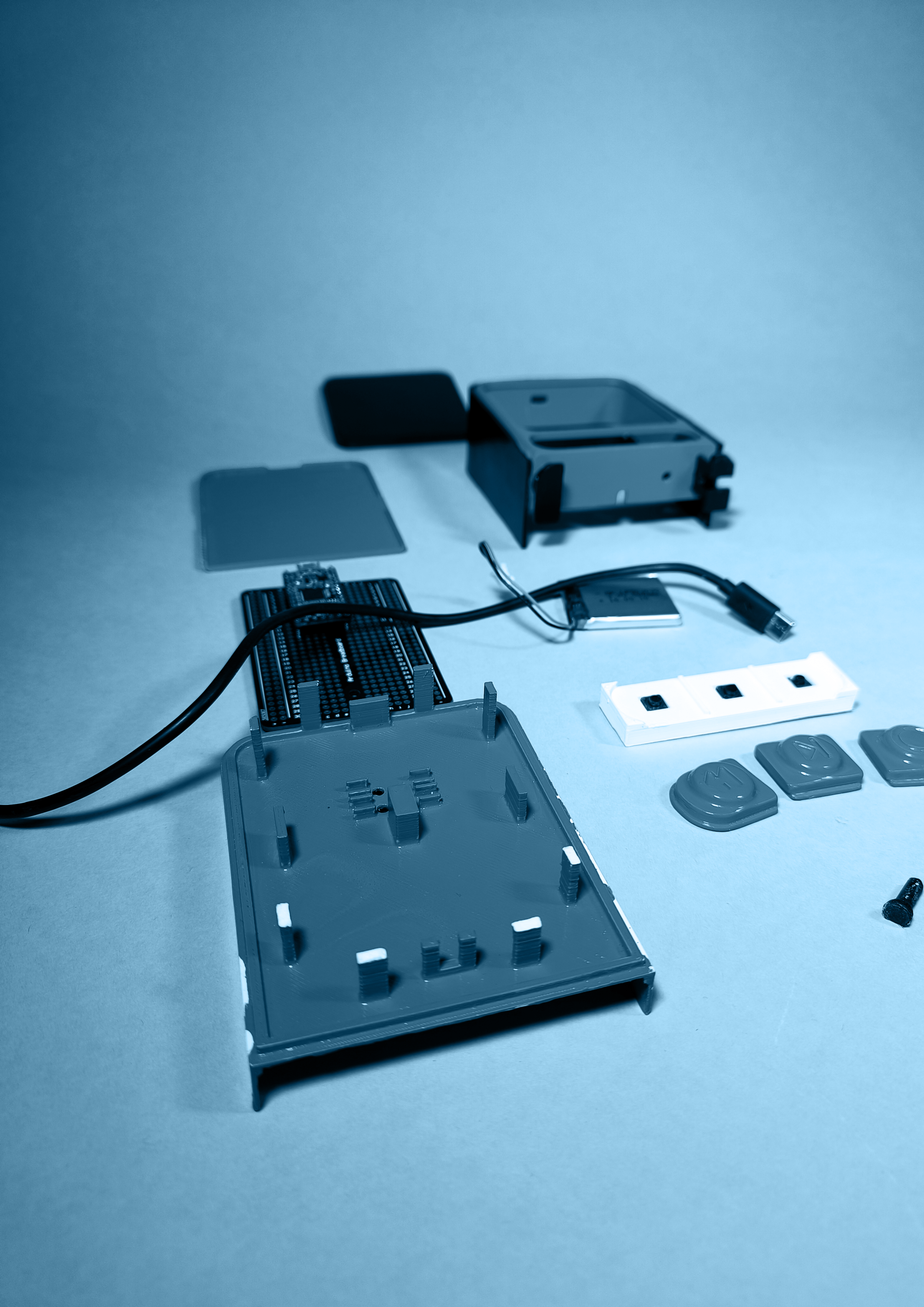
Figure 50. The different form iterations as printed.

COST-PRICE ESTIMATION

A big advantage of this design is its simplicity, which will automatically be translated into this cost-price estimation. However, since this thesis is an early exploration of such a diagnosis device, the estimation of its cost will be only a rough indication.

The tool roughly consists of a micro controller (around €20), two current sensors (each around €15), a screen (around €50) and a battery (around €10). Together with an estimated cost of the casing (dependent on the batch size this would be made) and smaller additional components, this would come together at an estimated €110. However, this does not include the working / machine hours yet even though the component costs in bulk numbers will be lower than here indicated.

Compared to the tristartester, which is sold for €129, this seems a reasonable and competitive price (tristartester, 2023). This price is low enough for public instances to see this as a worthy investment that will not break the bank.



08
FINAL DESIGN

Finally, all developments and takeaways from the previous chapters were concluded in the final design of the diagnosis tool. In this chapter, the design proposal and its different aspects will be introduced.

DESCRIPTION

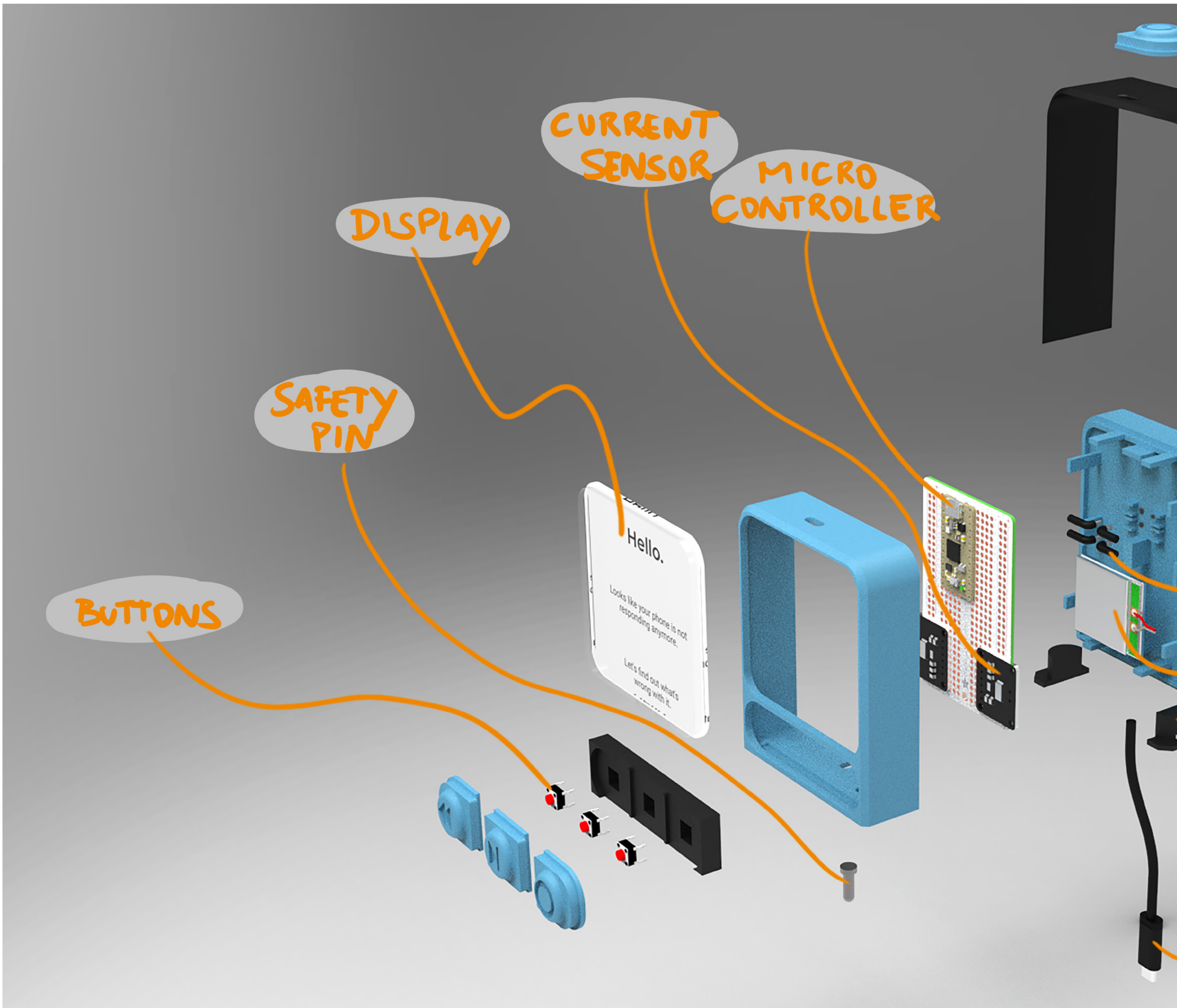
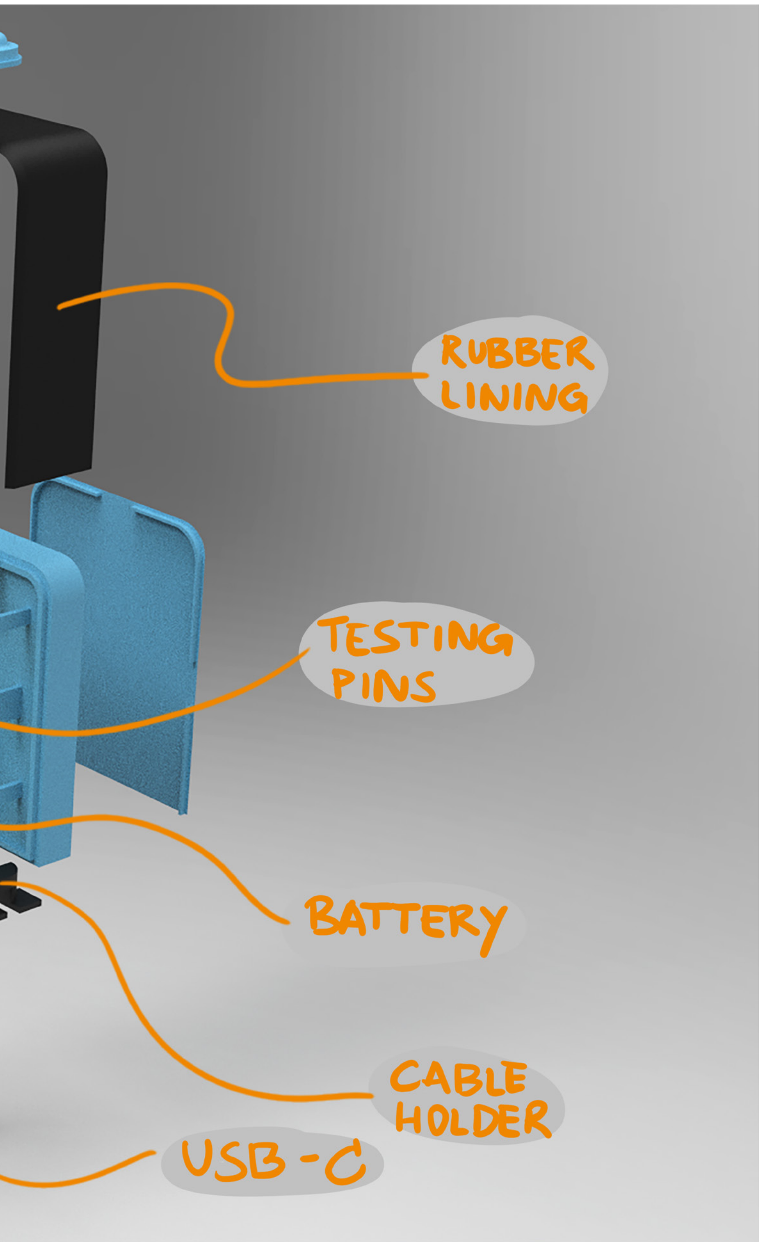


Figure 60. The final design in exploded view.

The final design is that of an electrical device that can detect the hardware faults of an unresponsive Fairphone 3. It guides the user through a unique elimination testing workflow, seamlessly designed to enhance the user's feeling of competence, resulting in a correct diagnosis. Additionally, the consumer receives advice on what to do with this information as well as next steps towards repair.

The exploded view in Figure 60 displays all the components integrated into the device. The corresponding prototype is shown in Figure 61 and 62.



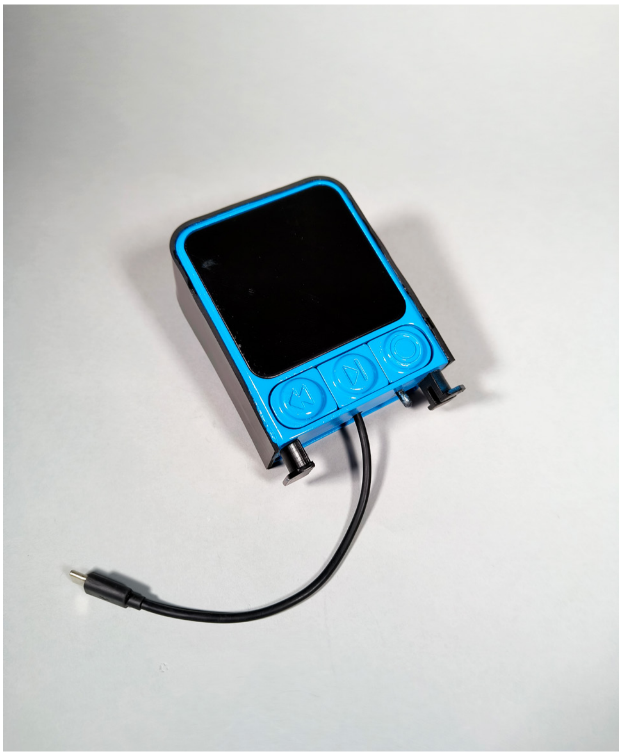


Figure 61. The prototype.

Figure 62. The Fairphone 3 inserted into the prototype.

DIAGNOSIS

This device was designed to accurately and quickly diagnose the hardware faults in an unresponsive Fairphone 3. It gets to this goal by going through a unique developed testing workflow, that allows the user to eliminate the most failing components one by one and test if they still work. The device can diagnose the four most common hardware faults occurring in smartphones with minimal disassembly of the phone. These targeted defects are:

- Screen failure
- Battery failure
- Charger port failure
- Motherboard failure

It does this by measuring out either voltage or current values in three different tests. The result of the process is shifted depending on whether the measured values meet the predefined ones that define a healthy component. The complete workflow - combined with the UI - is shown in Figure 65 .

The first test that is conducted eliminates the screen as cause of failure. By connecting the tested phone to the charger cable at the bottom of the tester, the current draw of the unresponsive phone gets monitored. If it draws normal values, the insides of the phone are functional and thus the screen is broken. Otherwise, the next test will start.

The second test decides whether the phone's battery is still in working order. By putting testing pins in the right location, the voltage of the battery is read out (Figure 63). If this does not meet the required value, the battery is faulty. Otherwise, a third test will start.

The third test is the final one that decides, after having ruled out the other components, whether the fault then lies with the charger port or the motherboard. The power circuit of the phone gets bypassed, and power is applied directly to the battery terminal through testing pins to check if this causes a current peak, indicating that the phone would turn on. If this works, it can be concluded that the motherboard is healthy and the problem was the charger port. Otherwise, the motherboard is broken.

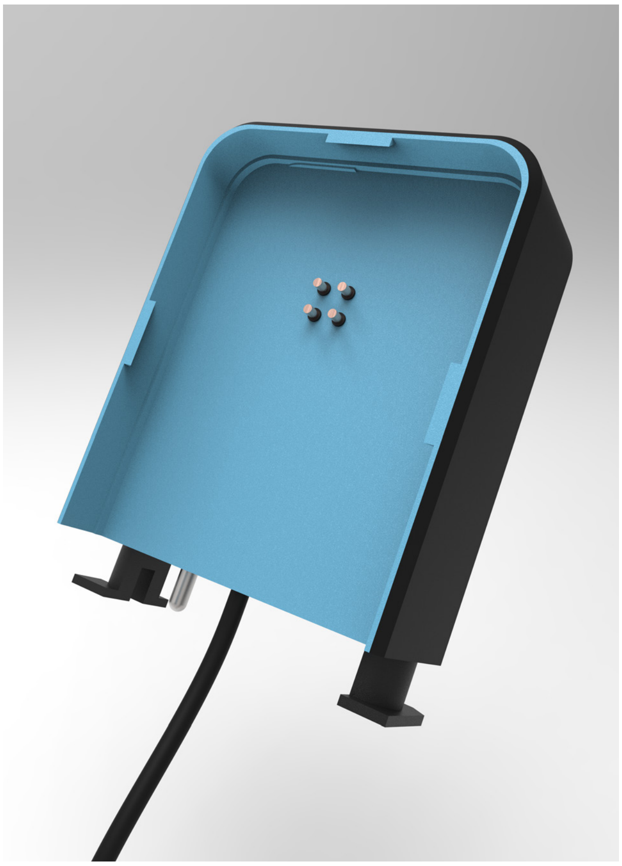


Figure 63. The testing pins at the back of the product..

COMMUNICATION AND STIMULATION

The tester was designed to guide the user flawlessly through the workflow, with several clear goals in mind. This resulted in a user interface, of which all panels and their flow are displayed in Figure 65. A rundown can be found on YouTube by clicking this **link**.

The communication media used in the interface is a combination of video and textual instructions, easy to understand with a minimal amount of effort of the user. The diagnosis instructions, visualised in their workflow with a symbolic "red thread", are displayed on a screen with which can be interacted with buttons as the flow advances. The system gives real-time feedback on the tests. As the test results appear, the user will see information encouraging them to opt for repair. This includes the repairability score for their issue, the CO2 emissions they would save (compared to the equivalent number of plastic bags), and a price comparison between buying a new phone and having it repaired.

To keep the users from giving up during the process, they are continuously triggered throughout. They have to follow simple instructions and press buttons to complete the test or move on to the next one. As a final encouragement towards repair behaviour, the barrier to taking the next step after diagnosis was lowered by providing advice based on the test outcomes and directly linking users to either repair information or the Fairphone repair service.

The interface was tested and adapted to be as user-friendly as possible.

A SHAREABLE DEVICE

Finally, a use case for this testing device was defined. This tester was designed for shared use in public spaces like libraries or Repair cafés, adapted to withstand handling by multiple users and frequent usage by its compact shape and rubber lining. This lowers the barrier for users to use the device because they do not have to purchase it for the single time they would need it, and therefore reaches a much bigger audience. Finally, the estimated price of €110 would be low enough for these public institutions to see it as a worthy investment.

Figure 64. A shareable device.

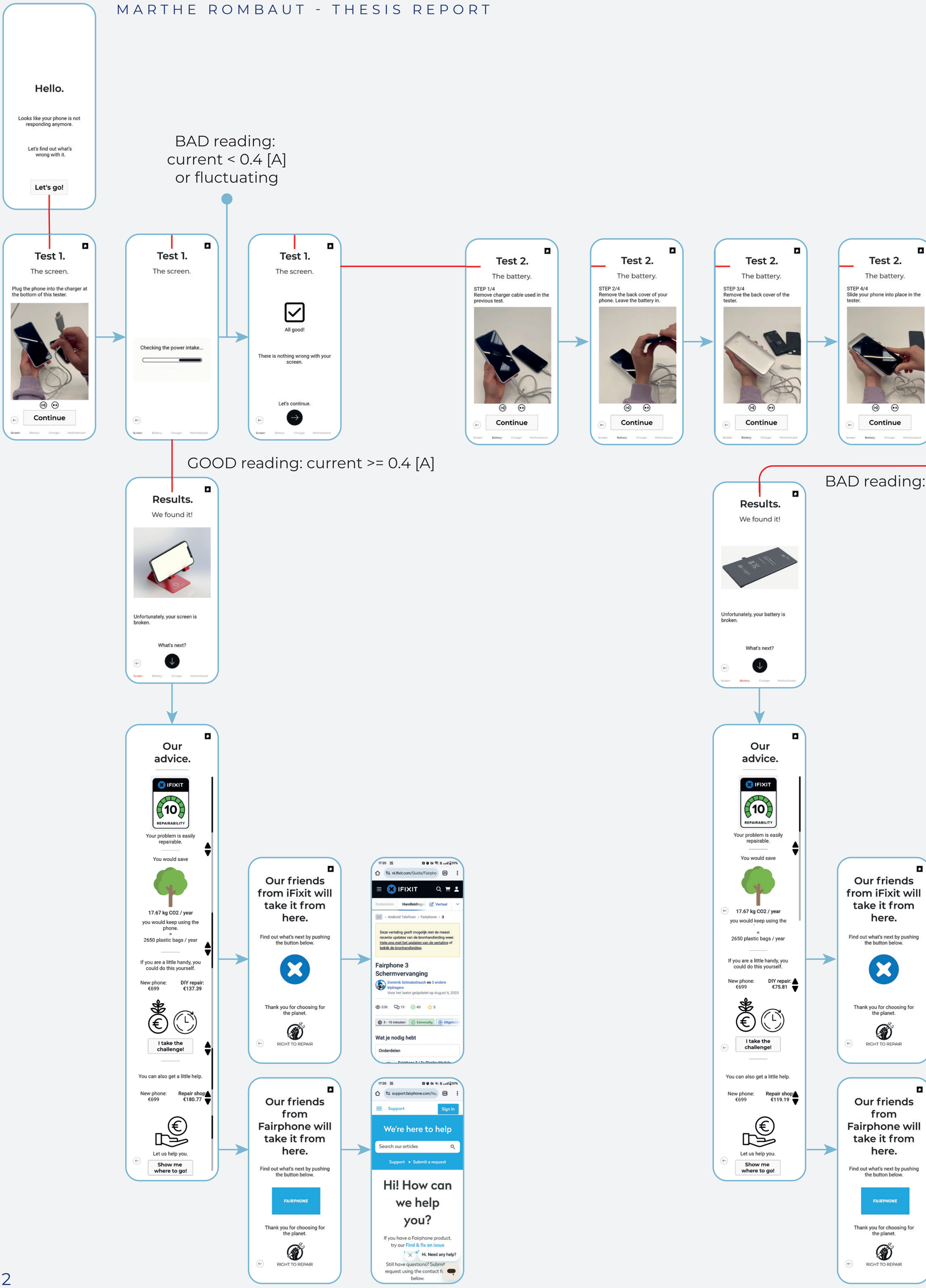
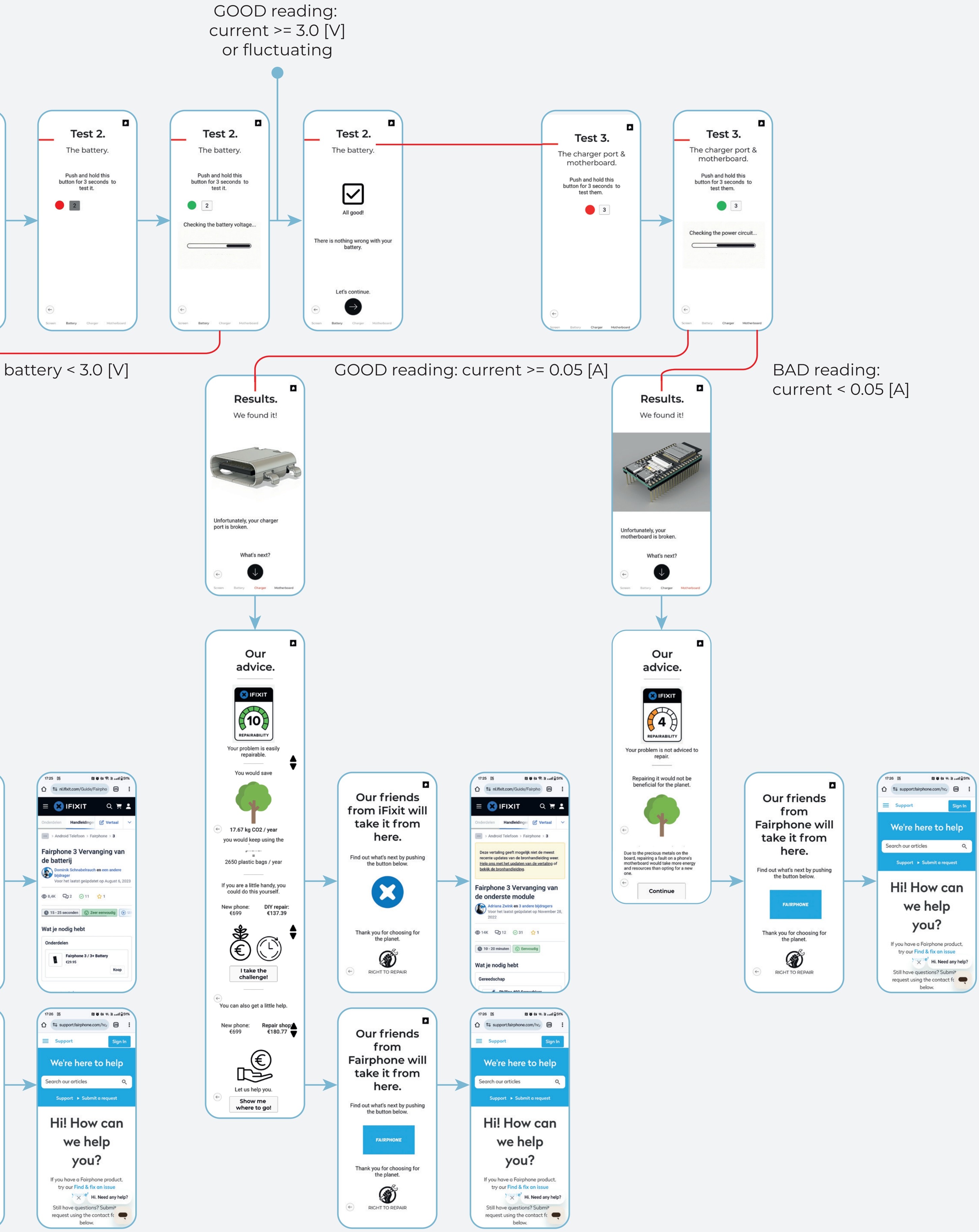


Figure 65. All panels of the final user interface.


GOOD reading:
current >= 3.0 [V]
or fluctuating
Test 2.
The battery.
Push and hold this button for 3 seconds to test it.
Checking the battery voltage...
All good!
There is nothing wrong with your battery.
Let's continue.
Test 3.
The charger port & motherboard.
Push and hold this button for 3 seconds to test them.
Checking the power circuit...
battery < 3.0 [V]
GOOD reading: current >= 0.05 [A]
BAD reading:
current < 0.05 [A]
Results.
We found it!
Unfortunately, your charger port is broken.
Unfortunately, your motherboard is broken.
What's next?
Our advice.
Your problem is easily repairable.
You would save
17.67 kg CO2 / year
you would keep using the
2650 plastic bags / year
If you are a little handy, you could do this yourself.
New phone: €699
DIY repair: €137.39
I take the challenge!
You can also get a little help.
Repair shop: €180.77
Let us help you.
Show me where to go!
Your problem is not adviced to repair.
Repairing it would not be beneficial for the planet.
Continue
Our friends from iFixit will take it from here.
Our friends from Fairphone will take it from here.
Find out what's next by pushing the button below.
FAIRPHONE
Thank you for choosing for the planet.
RIGHT TO REPAIR
Fairphone 3 Vervanging van de batterij
Fairphone 3 Vervanging van de onderste module
We're here to help
Hi! How can we help you?

09 DISCUSSION

This project started with a main research question:

"How to encourage users to repair their smartphones by diagnosing and communicating the faulty parts in them?"

Which entails three pillars: diagnosis, communication and encouragement to repair. In this thesis, a device was developed to reduce the barriers for end-users in diagnosing their own phones when they break. A straightforward testing workflow was designed to identify the four most common hardware faults in a Fairphone 3. This workflow employs an elimination approach by testing the current and voltage values of various components. Additionally, an interactive user interface was created to make the testing process accessible and comprehensible to users, guiding them from start to finish and ultimately providing advice on the next steps. This encourages users to choose repair as the next course of action. With this outcome, the three pillars of the main research question were addressed.

This chapter evaluates how well this question was answered during this project. Furthermore, the limitations of this thesis are discussed, as well as recommendations for further research.

EVALUATION

Overall, this was a first iteration in the field of diagnosis for consumers. This means both the testing and the research behind this concept should be elaborated on for further development.

The design of the tool developed a unique workflow for diagnosing the Fairphone 3, identifying the four most common hardware issues. Using an elimination approach, the tool ensures that minimal disassembly is required to achieve accurate and fast results. This method is a valuable insight that shows that smartphone diagnosis can be simpler than previously believed. Finally, the test point locations on the battery case and battery terminal are a strong positive outcome of this project as they are surprisingly accessible.

On the technical side, some specific points can be evaluated. Although the use of test points is effective, they are a working point. They are fragile and their placement must be done perfectly for the tests to work. For the third test, it was eventually realised that the digital output could not provide enough current to start up the phone. It should be diverted to 5 [V] current and controlled by a relay switch. It would also be more beneficial if users did not have to press the power button themselves to run that test. Finally, the proposed buttons to let users contact the test points themselves prove more complex than at first glance. The points are close together and special care must be taken to avoid short circuits, as this unfortunately cost the life of the Fairphone 3 used in this project. Moreover, since users already have good intentions while using the device, the buttons could cause more hassle and make the device less user-friendly. Just before the final design was made, this was realised and so they were removed, without further information.

The effectiveness of the design to guide end users to a correct diagnosis is enabled by a user interface. This interface, which is still in its infancy, shows that users can self-diagnose smartphones with simple instructions and interactions. The minimal need for disassembly in the process certainly helps in this regard. The tool bridges the gap between users and technical complexity to make the process user-friendly even for inexperienced repairers. Further elaboration, including the aesthetics of this interface would still need attention.

Encouraging the user to repair behaviour was integrated by providing advice, stimulating information and a direct link to the next steps. Increasing the user's sense of competence was also addressed by making the process as user-friendly and clear as possible. However, the effectiveness of these approaches was only tested once and is not based on hard scientific evidence. Further research and testing around this topic would be advisable to achieve the best possible results.

The choice of the use case as a shared device came from the consideration that end-users would not buy this device themselves for the occasional use. However, this is no guarantee that they would if it were offered to them in public spaces. It is also not very interesting that it can currently only be used for one type of phone if it is to be shared. This thesis serves more as an exploration of the potential for encouraging smartphone repairs among end users than as a viable business case.

Finally, this device would benefit from an extensive form study based on user testing, as there was not enough time to deeply delve into this topic.

LIMITATIONS

This thesis also had its limitations. Firstly, starting this project as an engineering graduate with a keen interest in mechanical design influenced the outcome, resulting in a focus on designing a tangible diagnostic tool rather than exploring other potential directions.

The embodiment of the design was not fully developed due to time constraints, making this project only a proof of concept rather than a validation. Moreover, the withdrawal of both Fairphone and iFixit as customers in this project resulted in limited financial resources to realise the prototype, which in turn affected the outcome.

Due to the time allocated, the thesis was made as a case study using the Fairphone 3 rather than generalising to other types of phones. This is addressed further in the recommendations and mainly affects the placement of the test pins and the form-fitting shape of the device. Furthermore, the suggested test points on the battery and battery connector have not been implemented. Access to the terminals on the components as they currently exist proves that these points would work but bringing them out had to remain as a suggestion as it could not be tested.

RECOMMENDATIONS

As specific shortcomings in the current design are already addressed in the evaluation, this paragraph will focus more on general topics.

This project opens up a promising direction for smartphone diagnostics by end users. It is an early exploration and did not end in a fully integrated product. It is therefore recommended to address the embodiment of this design in more detail and continue working on the framework established in this thesis.

Furthermore, the wider application to smartphones other than the Fairphone 3 used in this project should be explored. This would also strengthen the use case as a shareable device. In general, the shape of the device should change, as should the placement of the test points. Ideally, these test points could be moved according to the type of phone being diagnosed. It could also be made possible not to have the test points in a fixed housing but to apply them yourself, but this would come at the expense of usability and accessibility and the sense of competence for inexperienced repairers. This recommendation would be helped by the emerging EU law to make the battery more accessible in all phones, not just those intended for repair.

Another recommendation can be made about the test points proposed in this thesis. It has been proven that adding these points to the battery and battery terminal would pave the way for easy diagnosis of a phone, and so this should be implemented in the standard construction of the battery and battery terminal. This would not even be a major intervention in the design of both. This could be enforced by legislation, which, with the EU actively working on the right to repair, is a promising direction.


FAIRPHONE
Well done.
You're what progress looks like.
FAIRPHONE
Li-ion
iFIXIT
FAIRPHONE

10 CONCLUSION

This design is an early exploration of a smartphone hardware diagnosis device, one that has not been made in this way before. The purpose of this thesis was to encourage users to repair their smartphones by correctly diagnosing and clearly communicating the faults in them. Consequently, the themes of smartphone diagnosis, communication, and stimulation have been central throughout this project.

The diagnosis of the four most common hardware faults in unresponsive phones has been made possible by the design of a simple testing workflow. This workflow ensures that the screen, battery, charger port, and motherboard can be tested efficiently in an elimination manner with minimal need for disassembly. All necessary tools are integrated into the tester device.

The best way to communicate with the user was examined. A complete user interface was developed, integrating clear instructions with stimulations to further encourage repair behaviour. A combination of video and textual triggers makes the process effortless to follow, concluding with motivating advice and directing the user to the next steps.

Even though the final design in this thesis is far from finished, important milestones were achieved, showing that this direction has impact and is worth pursuing further. Especially promising are the general applicability to other smartphone models and the adaptation of battery and battery terminal designs for integration of testing points.

This thesis ends with a final design containing valuable insights, serving the purpose of encouraging end-users to repair their devices by providing them with a diagnostic tool. It contributes to minimising e-waste and promoting sustainable consumer practices. Finally, it lays a foundation for future developments in user-friendly diagnostic tools, nurturing a culture of repair and sustainability in our increasingly digital world.

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APPENDICES

APPENDIX A (PG 96)

Project brief and project planning

APPENDIX B (PG 104)

Design strategies for product care (Ackermann et al., 2021)

APPENDIX C (PG 107)

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Panels user interface (version 1)

APPENDIX G (PG 120)

User test

APPENDIX H (PG 128)

Code for the testing programme

APPENDIX A

PROJECT BRIEF AND PROJECT PLANNING

TU Delft

DESIGN FOR our future

IDE Master Graduation Project

Project team, procedural checks and Personal Project Brief

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

- Student defines the team, what the student is going to do/deliver and how that will come about
- Chair of the supervisory team signs, to formally approve the project's setup / Project brief
- SSC E&SA (Shared Service Centre, Education & Student Affairs) report on the student's registration and study progress
- IDE's Board of Examiners confirms the proposed supervisory team on their eligibility, and whether the student is allowed to start the Graduation Project

STUDENT DATA & MASTER PROGRAMME

Complete all fields and indicate which master(s) you are in

Family name	Rombaut 7071	IDE master(s)	IPD ✔ DfI ☐ SPD ☐
Initials	M. N. O.	2nd non-IDE master	-
Given name	Marthe	Individual programme *(date of approval)*	-
Student number	5841860	Medisign	☐
		HPM	☐

SUPERVISORY TEAM

Fill in he required information of supervisory team members. If applicable, company mentor is added as 2nd mentor

Chair	Prof. dr. A.R. Balkenende	dept./section	Sustainable Design Engineering
mentor	Prof. dr. ir. R. Mugge	dept./section	Design, Organisation and Strategy
2nd mentor	-		
client:	-		
city:	-	country:	-
optional comments	A client might step in at a later stage of the project.		

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

! Chair should request the IDE Board of Examiners for approval when a non-IDE mentor is proposed. Include CV and motivation letter.

! 2nd mentor only applies when a client is involved.

APPROVAL OF CHAIR on PROJECT PROPOSAL / PROJECT BRIEF -> to be filled in **by the Chair** of the supervisory team

Sign for approval (Chair)

Digitally signed by Ruud Balkenende - IO
Date: 2024.03.05 20:09:13 +01'00'

Name Ruud Balkenende Date 5 Mar 2024 Signature

CHECK ON STUDY PROGRESS

To be filled in **by SSC E&SA** (Shared Service Centre, 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 ______ EC

Of which, taking conditional requirements into account, can be part of the exam programme ______ EC

	YES	all 1st year master courses passed
★	NO	missing 1st year courses

Comments:
ID4070 IDE Academy (4,0)
ID4170 Advanced Concept Design (21,0)

Sign for approval (SSC E&SA)

Robin den Braber — Digitaal ondertekend door Robin den Braber Datum: 2024.03.12 09:39:40 +01'00'

Name Robin den Braber Date 12 mrt 2024 Signature

APPROVAL OF BOARD OF EXAMINERS IDE on SUPERVISORY TEAM -> to be checked and filled in by IDE's Board of Examiners

Does the composition of the Supervisory Team comply with regulations?

YES	★	Supervisory Team approved
NO		Supervisory Team not approved

Comments:

Based on study progress, students is ...

★	**ALLOWED** to start the graduation project
	NOT allowed to start the graduation project

Comments:
- M. Rombaut is an MVE student, so the above mentioned missing courses should be finished before the green light meeting

Sign for approval (BoEx)

Monique von Morgen — Digitally signed by Monique von Morgen Date: 2024.03.13 10:18:13 +01'00'

Name Monique von Morgen Date 13 Mar 2024 Signature

DESIGN FOR our future

TU Delft

Personal Project Brief – IDE Master Graduation Project

Name student Marthe Rombaut **Student number** 5,841,860

PROJECT TITLE, INTRODUCTION, PROBLEM DEFINITION and ASSIGNMENT
Complete all fields, keep information clear, specific and concise

Project title Empowering Smartphone Repair: Diagnosis and Consumer Communication Strategies

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

Introduction

Describe the context of your project here; What is the domain in which your project takes place? Who are the main stakeholders and what interests are at stake? Describe the opportunities (and limitations) in this domain to better serve the stakeholder interests. (max 250 words)

This thesis takes place in the context of the research project *Tackling 'Fixophobia': Improving repair practices for improving consumer electronics*, which focuses on the consumer behaviour regarding repair of consumer electronics in collaboration with several consumer electronics companies. Within this broad field of consumer electronics, I will be focusing on smartphones, and more specifically the latest Fairphone, since Fairphone is one of the companies working on this project.

The main domains of this project will be the technological diagnosis of faulty components in smartphones, consumer behaviour towards repair (awareness and willingness) and sustainable / circular engineering.

The main stakeholders of this project are the consumers / third-party repair services, who will be enabled and encouraged to lengthen the lifespan of the phone. The smartphone manufacturers (in this case Fairphone) are another big stakeholder since the outcomes of this thesis might further build upon their vision for a circular smartphone.

The opportunities of this project are to reduce the threshold for the consumers and to make it more attractive for them to attempt the repair themselves, as well as the time the whole process would take. Additionally this tool would make the work for a third-party repair service easier. For the manufacturer this comes with the opportunity to further strengthen their brand name as a sustainable company. The limitations are that if they do not decide to step in at a later stage of the project, the resources (prototypes, budget) might be limited and the outcome might be affected.

➔ *space available for images / figures on next page*

introduction (continued): space for images

image / figure 1 Repair of a smartphone (iFixit)

image / figure 2 The Fairphone 5, disassembled (Fairphone)

Personal Project Brief – IDE Master Graduation Project

Problem Definition

What problem do you want to solve in the context described in the introduction, and within the available time frame of 100 working days? (= Master Graduation Project of 30 EC). What opportunities do you see to create added value for the described stakeholders? Substantiate your choice.
(max 200 words)

Smartphones are a widely used and valued electrical product. However, oftentimes they get thrown out without having tried to repair them first. It might cost too much, or require too much effort to have it fixed, people do not know what is broken and lack the knowledge to try to do it themselves. Nowadays, smartphone consumers are unable to identify and fix issues with their smartphones at home due to a lack of knowledge and guidance.
Taking this issue away would pave the path for easier and more effective repair practices, be it at home as well as for third-party repair services. For the sake of convenience, cost-effectiveness, empowerment to take control over their own devices and of course the environment I want to enable people to repair their smartphone themselves.
The Fairphone is already designed to make the insides completely accessible to consumers for repair. However, what is missing is the diagnosis of faulty components when they break. The next step is thus to give the consumers directions to what exactly needs to be fixed and how they should tackle that task.

Assignment

This is the most important part of the project brief because it will give a clear direction of what you are heading for. Formulate an assignment to yourself regarding what you expect to deliver as result at the end of your project. (1 sentence) As you graduate as an industrial design engineer, your assignment will start with a verb (Design/Investigate/Validate/Create), and you may use the green text format:

Design a tangible solution (prototype) for smartphone users to understand what is broken in their device and encourage them to repair it themselves.

Then explain your project approach to carrying out your graduation project and what research and design methods you plan to use to generate your design solution (max 150 words)

The project will consist of 4 main phases:

1. Research: WWWWH, desktop research, context-mapping

2. Design vision: analysis of the research, persona, user journey mapping, list of requirements

3. Concept ideation: How to's, braindrawing/storming, morphological chart, rapid prototyping

4. Concept development: prototyping, sketching

Documenting: this will be an ongoing process throughout the whole project.

Project planning and key moments

To make visible how you plan to spend your time, you must make a planning for the full project. You are advised to use a Gantt chart format to show the different phases of your project, deliverables you have in mind, meetings and in-between deadlines. Keep in mind that all activities should fit within the given run time of 100 working days. Your planning should include a ***kick-off meeting, mid-term evaluation meeting, green light meeting*** *and* ***graduation ceremony****. 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 course activities).*

Make sure to attach the full plan to this project brief.
The four key moment dates must be filled in below

Kick off meeting	26 Feb 2024
Mid-term evaluation	19 Apr 2024
Green light meeting	25 Jun 2024
Graduation ceremony	23 Jul 2024

In exceptional cases (part of) the Graduation Project may need to be scheduled part-time. Indicate here if such applies to your project

Part of project scheduled part-time	
For how many project weeks	
Number of project days per week	

Comments:

Motivation and personal ambitions

Explain why you wish to start this project, what competencies you want to prove or develop (e.g. competencies acquired in your MSc programme, electives, extra-curricular activities or other).

Optionally, describe whether you have some personal learning ambitions which you explicitly want to address in this project, on top of the learning objectives of the Graduation Project itself. You might think of e.g. acquiring in depth knowledge on a specific subject, broadening your competencies or experimenting with a specific tool or methodology. Personal learning ambitions are limited to a maximum number of five.
(200 words max)

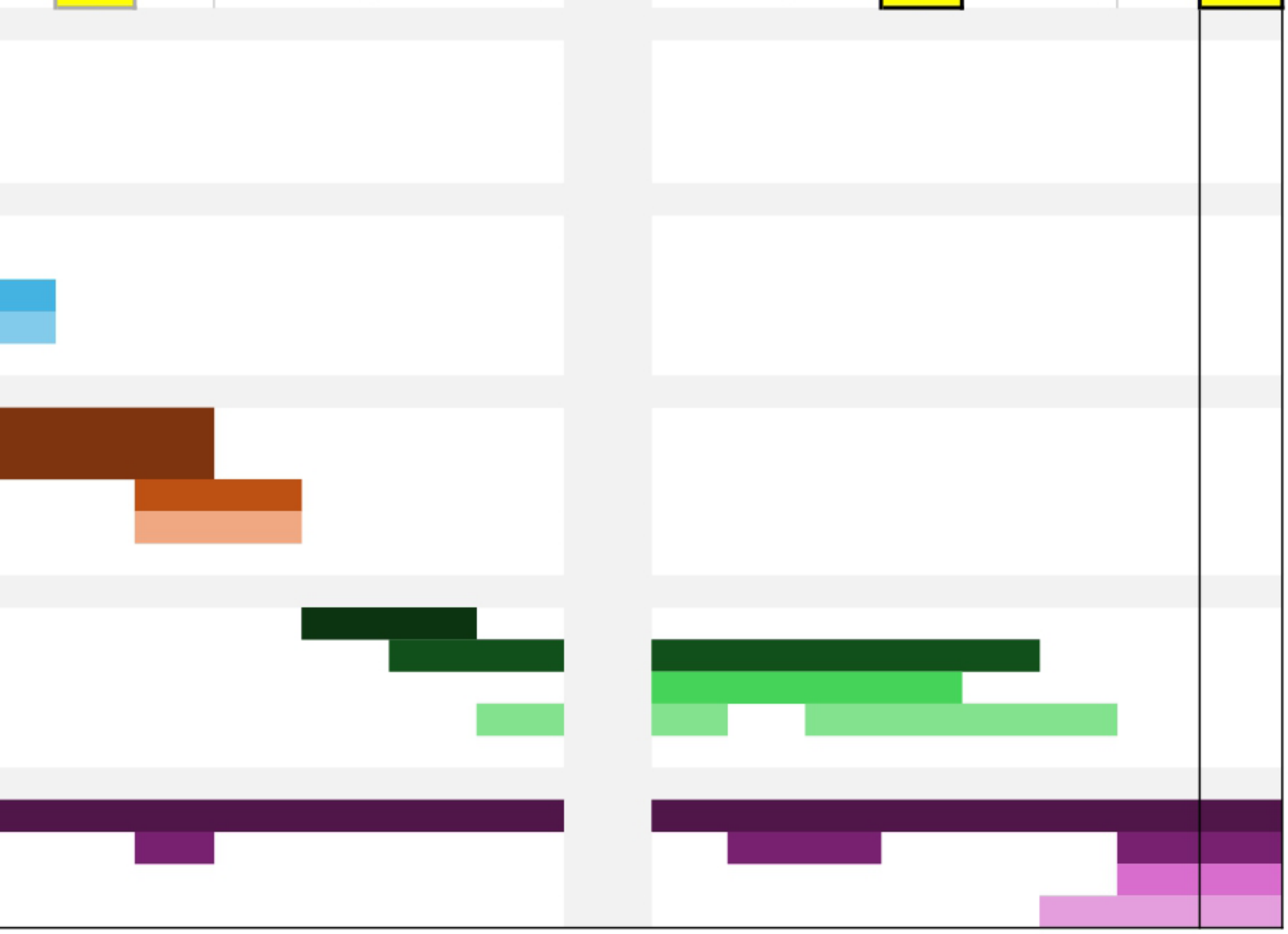
Since I have a master's degree in electromechanics, after these two years of design studies, I want to combine my knowledge and write a thesis in a field that requires both my technical skills and new creative abilities.
I have always been fascinated by consumer electronics and repair, taking apart many devices that would then perhaps never work again. Through the Advanced Embodiment Design course, I was introduced to design for repair, which piqued my interest and since I wanted to know more about the field, I decided to write my thesis in it. I also believe that with this project, we can bring sustainability to the consumer, which I think is meaningful.

It is important to me that this project's result is tangible so that I can hone my prototyping abilities and use them better in the design process. I have taken several visualisation courses and I want to use those skills. Finally, I want to overcome my fear of user input. There is little contact between the end user and an engineer, whereas there should be with a product designer. I want to gain more confidence in that, as well as further build trust in my ideation competences.

Project start date: 21/02/2024

			February		March					
		Date	21-Feb	26-Feb	04-Mar	11-Mar	18-Mar	25-Mar	01-Apr	
		Week	1	2	3	4	5	6	7	
Project Phase & Tasks	**Methods**	Days	3	8	13	18	23	28	-	
				Kick-off 19/02		Coach meeting		Team meeting	Vacation	
Research: Discover										
Desktop research on smartphone repair / consumer behaviour / ...	WWWWWH									
Current product analysis	Function analysis; context analysis									
Design Vision: Define										
Research analysis										
Persona / User journey mapping										
List of Requirements										
Design goal / vision formulation										
Concept Exploration: Develop										
Ideation	Rapid prototyping, lotus flower, braindrawing/storming, morphological chart, ...									
User input / preliminary testing										
Concept evaluation	Weighted criteria									
Concept Development: Deliver										
Further ideation	Rapid prototyping, sketching									
Concept detailing										
Final prototype										
Testing with users										
Documenting										
Report	Continual process, inDesign									
Presentation prep										
Appendix prep										
Poster or video	Renders, inDesign									

April				May				June				July			
8-Apr	15-Apr	22-Apr	29-Apr	06-May	13-May	20-May	27-May	03-Jun	10-Jun	17-Jun	24-Jun	01-Jul	08-Jul	15-Jul	22-Jul
8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
33	38	43	48	53	58	63	-	68	73	78	83	88	93	98	103
	Midterm 19/4			Coach meeting		Team meeting	Vacation		Coach meeting		Greenlight 25/06		Coach meeting		Graduation 23/07



APPENDIX B

LIST OF DESIGN STRATEGIES FOR PRODUCT CARE

Design strategy	Sub-strategies	Explanations & examples	Choice	Reasoning
Informing	Static information	The consumer is informed about product care through static manuals or tutorials, e.g. written paper manuals	x	This is a tested and approved method but requires a lot of effort from the user. Will be shown with an example in the next paragraph.
	Interactive information	The consumer is informed about product care through interactive platforms, e.g., interactive websites, workshops or online tutorials	v	Interactivity is proven to increase motivation and might be a good trigger to keep the user going.
	Physical information	The consumer receives information or clues about product care through affordances and through the design, e.g., material, visual clues on phone cases.	v	The less effort the users have to put in, the easier guiding them will go.
Awareness	Push messages	The consumer's awareness about the need for product care is increased via specific messages, e.g., notifications on the smartphone or notification lights in the car dashboard.	x	The use case of this project is for when the smartphone is non-responsive (see Chapter 4). Users are already aware it is broken.
	Product changes in appearance	The consumer's awareness about the need for product care is increased via changes in the product appearance, e.g., seeing wear indicators on electronic devices.	v	As this returns in Pozo Arcos (2021) (next paragraph), this might be a valuable direction to continue in.
	Product changes in functionality or performance	The consumer's awareness about the need for product care is increased via changes in the product's behaviour, e.g., a smartphone battery that dies quickly or a laptop that overheats.	x	The use case of this project is for when the smartphone is non-responsive. Users are already aware it is broken.

		thereby provide the consumer with all the necessary means for product care, e.g., a screwdriver delivered with the phone.		talked about in the previous paragraph.
	Providing a service	Through product care services the consumer can let a service handle product care, e.g., a laptop repair service.	x	Studying IPD, my interest and motivation to design a service are quite low.
Appropriation	Personalization	The product is adapted to the consumer's specific needs or preferences, thus heightening the chance of making the consumer feel more attached to this specific product, e.g., a custom-made phone case.	x	This might be a nice addition to the design but should not be a design direction since the tool will not be used enough to let this have a big effect.
	Ever-changeable products	By enabling the adaptation of the product during its time of usage the consumer can remodel the product according to the consumer's current needs, thus making the consumer steer away from the need for or desire of a new product, e.g., a modular phone that lets the user upgrade and adapt the same phone over and over (Phonebloks).	x	This is applicable for a smartphone (e.g. Fairphone) but less for a diagnosis tool that will have one specific purpose and will only be used once in a while.
	Creative change	By facilitating individual creative approaches, the consumer is likely to keep and upcycle the product and refrain from disposing of it, e.g., IKEA hackers guides or DIY activities.	x	This might be a nice addition to the design but should not be a design direction since the tool will not be used enough to let this have a big effect.
Reflecting	Meaningful memories	An emotional bond is created between consumer and product through shared experiences or a specific meaning, making it difficult for a consumer to neglect or throw away the product, e.g., a smartphone with a customisable back cover.	x	The diagnosis tool will not be used often enough to let memories have a meaning.
	Showing traces	The product reflects previous interaction with the consumer, thus telling a story, e.g., laptop case that shows signs of wear	x	This does not seem feasible for a diagnosis tool of smartphones.

		and develops a unique patina over time.		
	Experience of the product care activity	Product care is made into a pleasurable care activity, e.g., repairing is made fun through gamification.	v	For user friendliness, it is always better if the activity is fun.
Control	Product takes initiative	The consumer is pressured into performing product care because the product initiates (the first part of) a product care activity, e.g., a coffee machine that opens up to be cleaned.	v	To make the threshold to initiate the activity lower, this might be interesting.
	Product handles product care itself	Through products that perform product care themselves, the consumer does not have to perform product care anymore, e.g., self-healing materials.	x	This would be ideal, but not feasible.
	Unconscious takeover	Product care is made part of other routines in people's daily life, e.g., such as incorporating a charging station near a workspace or bedside table, ensuring that users remember to charge their electronics regularly as part of their daily routine.	x	For the number of times this tool will actually be necessary, having it in your routine would be irritating.
	Forcing product care	The consumer is forced to perform product care because the product stops working until it is being cared for, e.g., a coffee machine that refuses to work until it is decalcified.	x	The phone will be unresponsive, so care will be necessary (Chapter 4). This is not relevant for a tool to diagnose.

This list was adapted from the one provided by Ackermann et. al (2021).

For all strategies, the choice whether or not to continue with them in the continuation of the project and the reasoning are given.

APPENDIX C

INTERVIEWS

INTERVIEWEE A

Interviewee A is a Dutch, middle aged man of 63 y/o who frequently takes part in the Repair Café of Delft. The goal of this interview was to find out more about the diagnosis process by efficient end users, generally in electrical appliances. The interview took place in Dutch.

INLEIDING

Demographics

- *Hoe oud?* 63
- *Opleidingsniveau?* Hogere studies, elektrotechniek
- *Hoe lang al aan het repareren?* Studententijd
- *Technische achtergrond?* Ja

Hoe bent u in reparatie geïnteresseerd geraakt?

- *Hoe bent u in contact gekomen met de repair cafés en later ook betrokken?*

  Buurman, sociale contacten

Wat vindt u er zo leuk aan? Sociale contacten, voldoening, mensen tonen dat het kan, beetje competitie tussen de reparateurs “kijk, het is me gelukt

Wat is uw drijfveer achter repareren? Spullen een tweede leven geven, bewustwording van mensen

DIAGNOSE

Hoe stelt u diagnose? Welke stappen?

1. Eerst zelf kijken of het wel stuk is

- 1-inch drop test, schudden
- Knoppen indrukken en proberen laten werken

2. Openen: disassembly

- Schroefjes eruit halen, steeds op volgorde leggen
- Magnetische matjes & - schroevendraaiers

3. Visuele inspectie

- Losse contacten, brandplekken (condensatoren)
- Alles wat beweegt (knoppen, ...)

4. Testen met multimeter (contact maken = piep, weerstand testen)

- Eliminatie op volgorde van meest logische componenten
- Knop --> condensator --> zekeringen?

5. Probleem oplossen (niet vaak solderen)

6. Reassembly

- Volgorde
- Usecues!

Welke tools gebruikt u hiervoor?

- Schroevendraaiers (heel veel verschillende koppen)
- Plastieken klemmetjes (pry tool)
- Multimeter (!!)
- Soldeerbout (niet vaak, 1/10 keer)
- Aardingsklemmen (bij kleinere elektrische producten)

Hoe gebruikt u deze tools? Multimeter: uitmeten van weerstanden, controleren van connectie (piep = goede verbinding), uitmeten van spanning en vergelijken met schema's of die hetzelfde is

Hoe ziet u wat er kapot is? Losse contacten, brandplekken, multimeter die geen verbinding geeft

Wat is de belangrijkste tool? Multimeter!

Zijn er variaties in diagnose aanpak voor verschillende soorten problemen? Niet per se, gewoon blijven afgaan en elimineren

Waar let u op tijdens het proces?

Doet u eerder visuele inspectie of gebruikt u meer tools? Of nog andere dingen? Visuele inspectie is de eerste stap!

Welke symptomen wijzen vaak op een kapot onderdeel?

Kan u voorbeelden geven van welke symptomen op wat wijzen?

Waar vertrouwt u het meeste op? Multimeter

Hoe ervaart u dit proces? Is het over het algemeen moeilijk? Hoe kleiner hoe moeilijker

Waar zitten de pijnpunten?

Wat maakt dit proces moeilijk? Disassembly steeds moeilijker

Wat kost het meeste tijd? Reassembly! Véél schroeven, maar ook nodig voor bv waterdichtheid etc

Wat (in teken van product design) verhindert u om het goed te doen?

- Klikcontacten, niet meer open te krijgen
- Miniaturisatie
- Alles zit ingebouwd

Kunt u een voorbeeld geven van een situatie waarin het diagnosticeren van een kapot onderdeel uitdagend was en hoe u het heeft opgelost? 1950 radio, volledig doorgemeten met koppelingsschema ernaast (welke V is niet zoals het moet zijn?) en toen gevonden welk onderdeel er vervangen moest worden

Wat voor onderdelen gaan er het meeste stuk? Zekeringen (maar met reden), condensatoren

Welke informatie deelt u meestal met klanten over de staat van hun smartphone en de benodigde reparaties?

MENING OVER TOOL

Wat ziet u als de grote hindernissen voor reparatie? Tijd, moeite, reparatieonderdelen duur

Wat zijn momenteel de grootste pijnpunten in het reparatieproces?

Wat denkt u dat mensen zou kunnen stimuleren om meer hun toestellen te repareren? Gamification in tool ("loop deze stappen door"), benadrukken dat ze geld sparen en dat ze een verschil maken voor de planeet

Zou u het nuttig vinden om een tool te hebben voor diagnose? Ja, foutcodes geven niet genoeg informatie, realtime info is handig!

Moet deze tool eerder tastbaar zijn of een software? Foutcodes met verdere stappen zouden goed zijn maar moeilijk

Wat zou u belangrijk vinden dat deze tool moet hebben?

INTERVIEWEE B

Interviewee B is a Dutch man in his 30s who runs his own phone repair shop in the city centre of Delft. The goal of this interview was to find out more about the diagnosis process by professional repairers. This person was very protective about the information he wanted to give, so that explains why quite some questions remained unanswered. The interview took place in Dutch.

INLEIDING

Demographics

- *Hoe oud?* 35
- *Opleidingsniveau?* Hogere studies, elektrotechniek
- *Hoe lang al aan het repareren?* 12j
- *Technische achtergrond?* Ja

DIAGNOSE

Kunt u ons door uw algemene diagnoseproces leiden wanneer een klant een kapotte smartphone bij u brengt?

- *Is hier een bepaalde volgorde bij?*

Klant weet vaak wat er stuk is als ze ze komen brengen, helemaal unresponsive komt maar weinig voor.

Eerst checken of het wel stuk is (want klanten hebben soms geen idee), openen en doormeten met multimeter

- *Waar let u op tijdens het proces?*
    - *Doet u eerder visuele inspectie of gebruikt u meer tools? Of nog andere dingen?*

Visueel kan, maar dan moet het wel heel duidelijk zijn (bv opgeblazen batterij, kapot scherm) verbranding op PCB komt bijna niet voor.

ERVARING is de belangrijkste tool om te weten waar het probleem zit.

- *Welke symptomen wijzen vaak op een kapot onderdeel?*
    - *Kan u voorbeelden geven van welke symptomen op wat wijzen?*

Opgeblazen batterij, waterschade heeft indicatoren

- *Welke gespecialiseerde tools of apparatuur gebruikt u tijdens het diagnose- en reparatieproces? (bv. microscoopcamera's voor het controleren van connectorpennen of multimeters voor het meten van spanningen)*

Gespecialiseerde apparatuur om batterij / scherm erin te drukken (press) en om toestel te openen (suction cups, pryers, heat guns voor lijm)

Multimeter om door te meten

Microscoop bij heel gedetailleerde herstellingen

Schroevendraaiers

Schema's

- *Hoe gebruikt u die?*
- *Welke tool vindt u het belangrijkste of waar vertrouwt u het meeste op?*

Multimeter is onmisbaar, alle componenten worden ermee doorgemeten

- *Maakt u gebruik van softwaretools om problemen met de software of het besturingssysteem van smartphones te diagnosticeren?*
    - *Welke software gebruikt u en hoe helpt het u bij het stellen van een*

diagnose?

- *Welke componenten ziet u het meeste stukgaan / binnengebracht worden voor reparatie?*

Batterij en scherm

- *Zijn er bepaalde tests die u specifiek gebruikt voor een bepaald type component?*

Batterij : zwellen, gewoon slecht werken, direct leeg etc

- *Kunt u mij enkele voorbeelden geven van complexe problemen die u hebt opgelost en hoe u deze hebt aangepakt?*

CPU was stuk en niemand zag het, is erachter gekomen door heel veel door te meten (tijd, geld!) en ervaring

- *Hoe ervaart u het diagnose proces? Is het over het algemeen moeilijk?*
- *Waar zitten de pijnpunten?*

Voor en achterkant is nu vaak van glas, is breekbaar (tools en ervaring nodig), heel sterke lijm onder batterijen

- Wat maakt dit proces moeilijk?

IPX is moeilijk

- *Wat kost het meeste tijd?*

Waterschade. De mensen zeggen het ook vaak niet en kost heel veel tijd om schoon te maken en door te meten, je weet niet welk component aangetast is en hoeveel.

Het doormeten en vergelijken met schema's.

REPARATIE IN HET ALGEMEEN

Hoe zorgt u ervoor dat de reparaties die u uitvoert van hoge kwaliteit zijn?

Welke stappen onderneemt u om te voorkomen dat er tijdens het reparatieproces verdere schade aan de smartphone ontstaat?

Hoe hebben recente technologische ontwikkelingen, zoals nieuwe smartphone-modellen of software-updates, uw werk beïnvloed?

Apple geeft een error wanneer er een niet-origineel scherm wordt in gezet, en voor een origineel scherm heb je een licentie en gelicencieerde tools nodig (duur). Dit zorgt voor wantrouwen! De right to repair van de EU zou hier verandering in kunnen brengen.

Welke trends ziet u in de soorten problemen die u tegenkomt bij het repareren van smartphones?

Wat ziet u als de grote hindernissen voor reparatie?

- *Wat zijn momenteel de grootste pijnpunten in het reparatieproces?*

MENING OVER TOOL

Wat denkt u dat mensen zou kunnen stimuleren om meer hun toestellen te repareren?

Zou u het nuttig vinden om een tool te hebben voor diagnose?

- *Moet deze tool eerder tastbaar zijn of een software?*
- *Wat zou u belangrijk vinden dat deze tool moet hebben?*
- *Zou u bezwaren hebben bij het gebruiken van zo'n tool? Zou u bijvoorbeeld denken dat het de kwaliteit van de reparatie zou beïnvloeden?*

TRISTARTESTER

Interviewee: only gives 3 possible diagnoses (battery, pcb and…) and could be confusing (a diagnosed battery could also be the pcb that doesn't respond) but it is nice to have when there is no response from the device as an additional support.

CONCLUSIES

Process: eerst checken of het wel stuk is, openen en doormeten op de plekken waar het zou kunnen zitten (weten door ervaring en beschrijving klant), vergelijken met schema's

Tools:

Gespecialiseerde apparatuur om batterij / scherm erin te drukken (press) en om toestel te openen (suction cups, pryers, heat guns voor lijm)

Multimeter om door te meten

Microscoop bij heel gedetailleerde herstellingen

Schroevendraaiers

Schema's

Meeste stuk: scherm en batterij

Pijnpunten: (dis)assembly met glazen achterkanten, helemaal doormeten met multimeter, heel sterke lijm onder batterijen

Notes: hardware hulp voor diagnose (tristar), Apple geeft error bij niet-originele onderdelen, zorgt voor wantrouwen!

INTERVIEWEE C

Interviewee B is another Dutch man in his 30s who runs his own phone repair shop in the city centre of Delft. The goal of this interview was to find out more about the diagnosis process by professional repairers. The interview took place in Dutch.

INLEIDING

Demographics

- *Hoe oud?* 38
- *Opleidingsniveau?*
- *Hoe lang al aan het repareren?* 10j, nu manager dus niet echt meer
- *Technische achtergrond?* Nee, heeft met een vriend de winkel opgericht en een reparateur in dienst genomen waarvan hij het geleerd heeft.

Hoe bent u in reparatie geïnteresseerd geraakt? Business

DIAGNOSE

Kunt u ons door uw algemene diagnoseproces leiden wanneer een klant een kapotte smartphone bij u brengt?

- *Is hier een bepaalde volgorde bij?*

Klant komt bij hen, hangt het direct aan meetstation om te kijken of er leven is (trekt stroom, ligt aan IC of batterij)

Aanname, overleg met klant voor waarschijnlijke prijs.

Openen, doormeten verschillende componenten

Methode 1: gewoon voor en na meten, telkens componenten vervangen! GEEN SCHEMA, gewoon eliminatie, snelste oplossing. Doormeten is lastig want alles is apart verpakt.

Methode 2 (boven de €150): microscoop, ICs ontkoppeld, thermisch naar kortsluiting zoeken, doormeten bijna nooit (info bij resellers of producent)

Waar let u op tijdens het proces?

- *Doet u eerder visuele inspectie of gebruikt u meer tools? Of nog andere dingen?*
- *Welke symptomen wijzen vaak op een kapot onderdeel?*

Schema's worden niet gebruikt, weet bepaalde standaardwaarden uit zijn hoofd en gaat daarop af. Verder gewoon elimineren of vergelijken met gezond toestel.

- *Kan u voorbeelden geven van welke symptomen op wat wijzen?*

Welke gespecialiseerde tools of apparatuur gebruikt u tijdens het diagnose- en reparatieproces? (bv. microscoopcamera's voor het controleren van connectorpennen of multimeters voor het meten van spanningen)

Disassembly machines, multimeters bijna nooit!

Meetstation is KEY

- *Hoe gebruikt u die?*
- *Welke tool vindt u het belangrijkste of waar vertrouwt u het meeste op?* Meetstation
- *Maakt u gebruik van softwaretools om problemen met de software of het besturingssysteem van smartphones te diagnosticeren?* Ja, om software te herstellen
    - *Welke software gebruikt u en hoe helpt het u bij het stellen van een diagnose?*

Welke componenten ziet u het meeste stukgaan / binnengebracht worden voor reparatie?

50% zijn schermreparaties

Batterij

Oplaadpoort

Gebroken achterkant

- *Zijn er bepaalde tests die u specifiek gebruikt voor een bepaald type component?*

Camera niet vaak

Batterij: meetstation

Kunt u mij enkele voorbeelden geven van complexe problemen die u hebt opgelost en hoe u deze hebt aangepakt?

Moederbord en vocht zijn heel lastig

Hoe ervaart u het diagnose proces? Is het over het algemeen moeilijk?

Waar zitten de pijnpunten?

Verschillende methodes om verschillende telefoons te openen

Software goed zetten, soms cryptisch gecodeerd (geven errors als niet origineel, geeft geen betrouwbare indruk)

- *Wat maakt dit proces moeilijk?*
- *Wat kost het meeste tijd?*

Diagnose, assembly is wel oké

REPARATIE IN HET ALGEMEEN

Hoe zorgt u ervoor dat de reparaties die u uitvoert van hoge kwaliteit zijn?

Soms gaan dingen stuk, waterdicht kan niet meer hersteld worden (of kost te veel tijd en moeite)

Welke stappen onderneemt u om te voorkomen dat er tijdens het reparatieproces verdere schade aan de smartphone ontstaat?

Hoe hebben recente technologische ontwikkelingen, zoals nieuwe smartphone-modellen of software-updates, uw werk beïnvloed?

Welke trends ziet u in de soorten problemen die u tegenkomt bij het repareren van smartphones?

Dunne schermen, niet de juiste tools, veel lijm

Wat ziet u als de grote hindernissen voor reparatie?

- *Wat zijn momenteel de grootste pijnpunten in het reparatieproces?*

CONCLUSIE

Deze man doet het op de snelle manier: snel checken waar het mogelijk zit door meetstation, open doen en gewoon vervangen, kijken of het daarmee opgelost is.

Proces:

Klant komt bij hen, hangt het direct aan meetstation om te kijken of er leven is (trekt stroom, ligt aan IC of batterij)

Aanname, overleg met klant voor waarschijnlijke prijs.

Openen, doormeten verschillende componenten

Methode 1: gewoon voor en na meten, telkens componenten vervangen! GEEN SCHEMA, gewoon eliminatie, snelste oplossing. Doormeten is lastig want alles is apart verpakt.

Methode 2 (boven de €150): microscoop, ICs ontkoppeld, thermisch naar kortsluiting zoeken, doormeten bijna nooit (info bij resellers of producent)

Schema's worden niet gebruikt, weet bepaalde standaardwaarden uit zijn hoofd en gaat daarop af. Verder gewoon elimineren of vergelijken met gezond toestel.

Tools: MEETSTATION, gespecialiseerde openingsmachines

Meeste stuk:

50% zijn schermreparaties

Batterij

Oplaadpoort

Gebroken achterkant

Pijnpunten: Software

Notes: zegt ook iets over error meldingen die het onbetrouwbaar maken, zweert bij het "meetstation"

APPENDIX D

HOW-TO'S FOR BRAINSTORM

The following questions and answers were generated to answer the design challenge. These were afterwards used as a starting point for ideation.


H2 MAKE SURE THEY DON'T GIVE UP?
SHOW PROGRESS
KEEP TRIGGERING
H2 ENGAGE USERS (SO THEY PUT IN EFFORT)
COMPETITION
REWARDS
KEEP THE OUTCOME IN MIND
MAKE IT A CHALLENGE
GAMIFICATION
H2 MAKE THIS FUN?
H2 MAKE PPL WANT TO USE THIS?
H2 GIVE ENCOURAGEMENTS
H2 GIVE THIS PRODUCT AN ADVANTAGE
MAKE IT PORTABLE
SHOW THE BENEFIT FOR THE PLANET
MAKE IT CONNECTED
H2 MAKE THEM CHOOSE REPAIR
SOCIAL CONTACT
MAKE IT CHEAP
MAKE IT QUICK
LET IT SHOW HOW MUCH YOU SAVE
USE OTHER DEVICES (FOR COMMUNICATION, POWER...)
H2 MAKE THIS CHEAP?
H2 INVOLVE NON-REPAIRERS
SHARING SYSTEM (E.G. REPAIR CAFÉ)
TELL THEM WHAT TO DO AFTERWARDS
USE BASIC MATERIALS & COMPONENTS
SMALLER

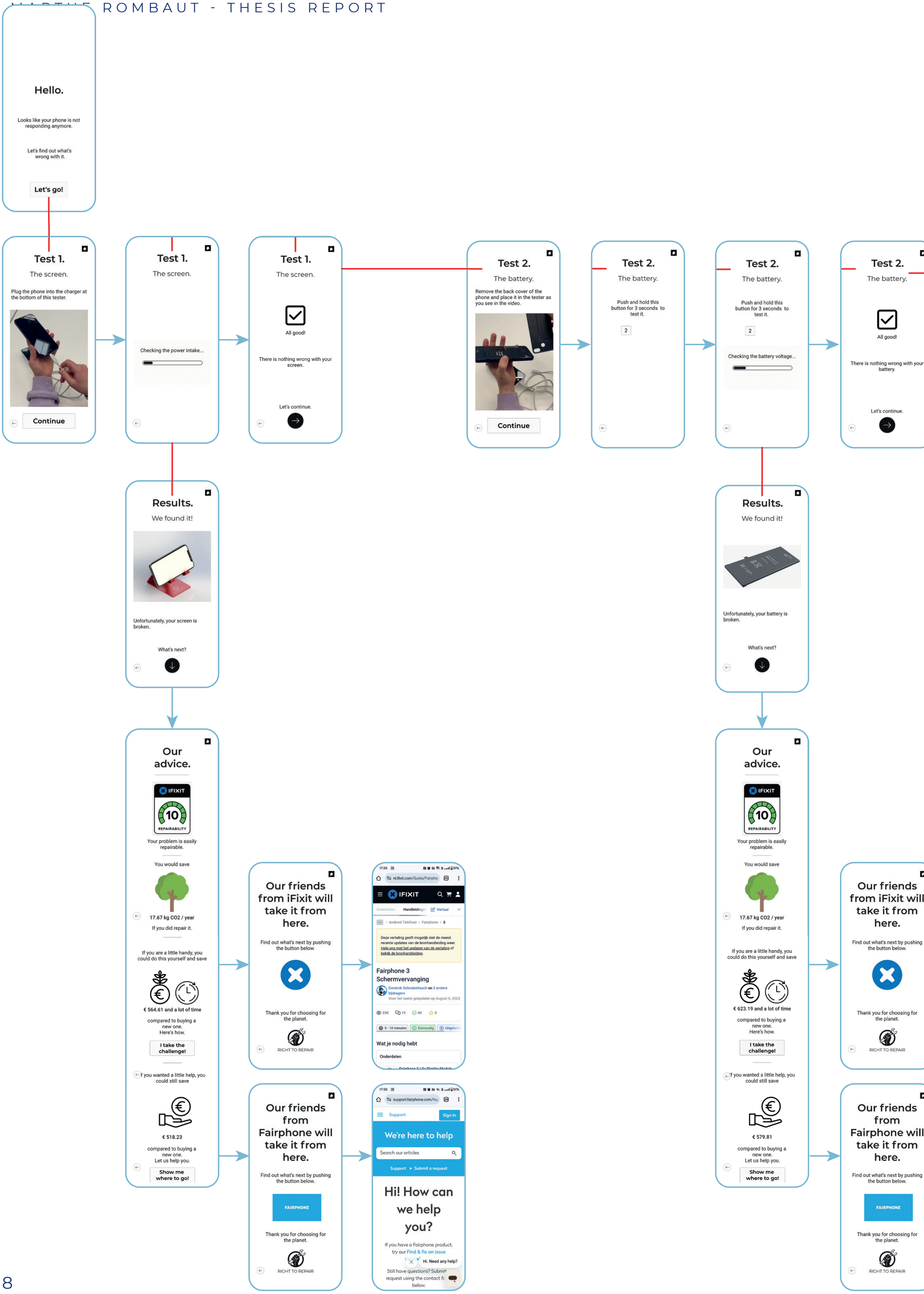

H2
MAKE THIS FEASIBLE?
H2
ACCESS THE COMPONENTS
MAP OUT TESTS
SCANNER
THROUGH ANOTHER PHONE
DIAGNOSTICS ACCESS PORT
TAKE BACKCOVER OFF
FORESEEN
TESTING SPOTS ON PCB
MULTIMETER TESTING
VISUAL CONTROL SPOTS
LED TESTING
WIRELESS
H2
ACCESS WITHOUT DISASSEMBLY
TEST WITH DISASSEMBLY
USB C
BATTERY TESTER
USB-C TESTER
BACK CASE WITH TESTING EQUIPMENT
PLACEHOLDER "BATTERY"
TESTING SPOTS NEXT TO COMPONENTS
H2
MAKE THIS PLEASANT TO WORK WITH
H2
MAKE TESTING EASY
GIVE AUDIO FEEDBACK
FREE UP SENSES (NOT 1 SENSE AT 2 TASKS)
GAMIFICATION
TREAT
FAST
MAKE IT PRETTY
ONE-HANDED OPERATION
CHEAP
MAKE IT SMALL

APPENDIX E

DIAGNOSIS OF TESTING PHONES

This table is the result of the testing and diagnosing of 25 phones that were given to me. Most had problems with the battery, which can be explained by them having been out of use for quite a while. The third test only was validated for one phone, which can be accurate because most were ICC dead when given to me, meaning that the motherboard would not respond anymore. The one case where it did work shows the method is valid.

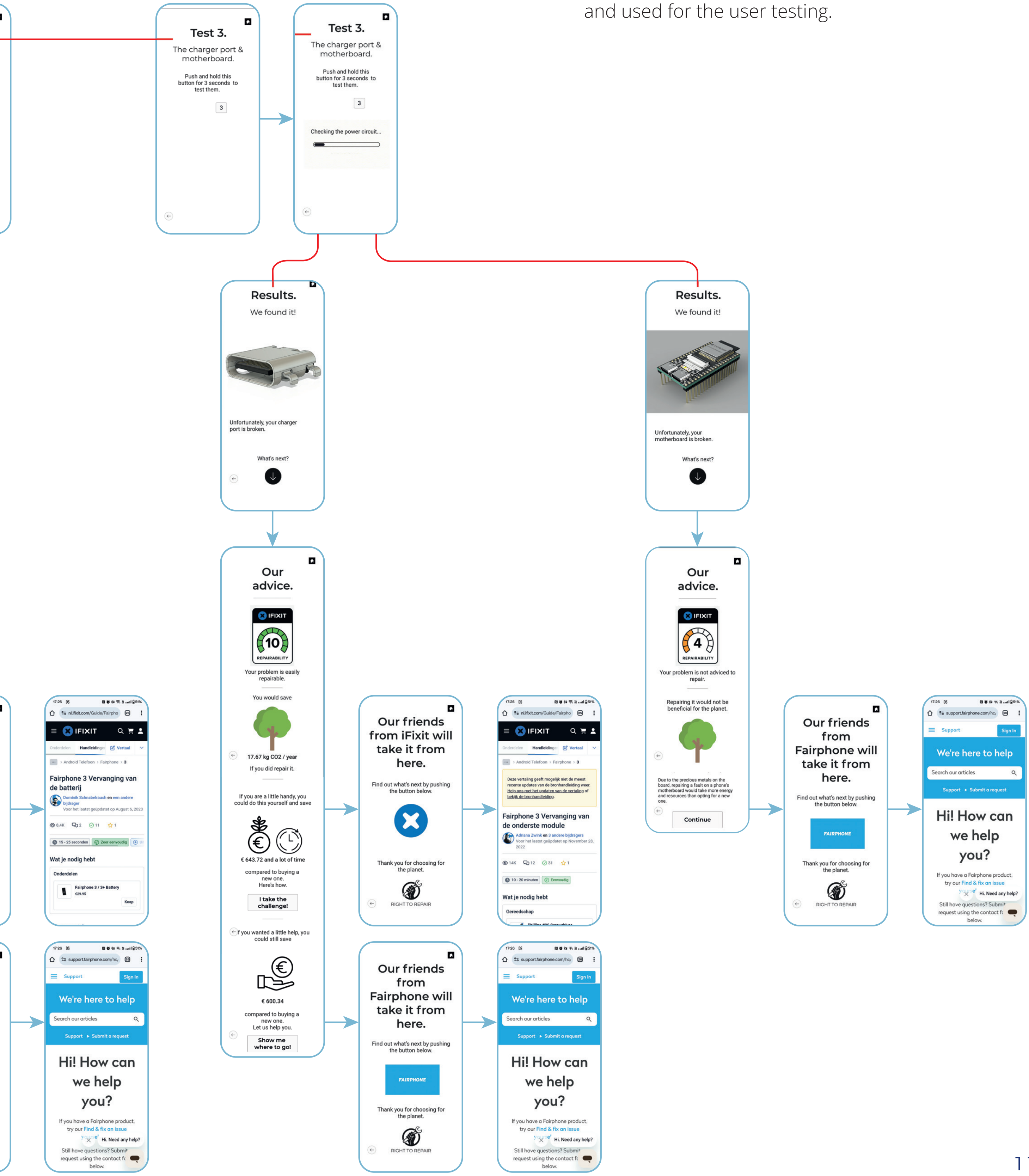
Number	Phone	Test 1 [A]	Test 1 res	Test 2 [V]	Test 2 res	Test 3 [y/n]	Test 3 res	Diagnosis	Notes	
03 D	Oneplus Nord N100 (grey/blue)	max 0.2, fluctuates	x	0	x			Battery		
04 C	Redmi 9T (carbon gray)	max 1.5, fluctuates	x	-	-			Screen + battery	Couldn't open for test2	Not sure
02 D	Samsung S20 (grey/blue)	0.316	x	-	-			Battery	Bloated battery, couldn't open	Further testing needed
x	Samsung Flip (all screen)	0.52	v	0	x			Screen	Started, screen lit up partly	
64	Huawei ALE-L02 (black)	0.087	x	0	x	/		Battery	no access for test3	
93	Sony Xperia (blue) (number 93)	0.4, fluctuates	x	3.077	v	n	x	Board / charger		
58	HTC	0	x	3.193	v	/		Board / charger		
62	Huawei	0.101	x	0.004	x	/		Battery	missing 2 screws	
19	LG nexus white	0.46	v	2.7	x	/		Battery	no access for test3	
33	Sony Xperia matte black	0.09	x	0	x	/		Battery	no access for test3	
10	Samsung leather black	0.05 max, goes to 0 a	x	0	x	n	x	Battery + motherboard	pulles 0.05 A in test 3	
x	Huawei turquoise	0.066	x	0.004	x	n	x	Battery + motherboard		
16	Sony Xperia	0.179	x	0.308	x	/		Battery	no access for test3	
61	Huawei	0.092	x	2.6	x	n	x	Battery + motherboard		
x	LG with retractable battery	1.7	v	3.4	v	/		NONE	Turns on, no issues	
15	Sony Xperia	0.133	x	2.429	x	/		Battery		
x	LG leather red	0.341 fluctuates to 0	x	2.7	x	n	x	Battery + motherboard	Battery does not jumpstart (thermal safety)	
67	LG gold	0.32	x	2.68	x	n	x	Battery + motherboard	did pull 0.15A in test 3	
1	Samsung note	0.45	v	2.6	x	n	x	Battery + motherboard	did pull 0.25A in test 3	
13	Sony Xperia	0.064	x	0.003	x	/		Battery		
x	Samsung metallic dark grey	0.46	v	3.3	v	y	v	Screen	good test for test 3! Worked	
x	Nokia white	0.045	x	0.0028	v	/		Battery	no access for test3	
12	Sony Xperia yellow	0.136	x	0.34	x	/		Battery	Battery disconnected, connector broken	
2	Samsung purple dark blue	0.162 to 0	x	0	x	n	x	Battery + motherboard	did pull 0.16A in test 3	
9	Samsung shiny dotted	0.06	x	-	-	n	x	Motherboard	No battery	


Hello.
Looks like your phone is not responding anymore.
Let's find out what's wrong with it.
Let's go!
Test 1.
The screen.
Plug the phone into the charger at the bottom of this tester.
Continue
Checking the power intake...
All good!
There is nothing wrong with your screen.
Let's continue.
Test 2.
The battery.
Remove the back cover of the phone and place it in the tester as you see in the video.
Push and hold this button for 3 seconds to test it.
Checking the battery voltage...
There is nothing wrong with your battery.
Results.
We found it!
Unfortunately, your screen is broken.
Unfortunately, your battery is broken.
What's next?
Our advice.
IFIXIT
10
REPAIRABILITY
Your problem is easily repairable.
You would save
17.67 kg CO2 / year
If you did repair it.
If you are a little handy, you could do this yourself and save
€ 564.61 and a lot of time
€ 623.19 and a lot of time
compared to buying a new one.
Here's how.
I take the challenge!
If you wanted a little help, you could still save
€ 518.23
€ 579.81
compared to buying a new one.
Let us help you.
Show me where to go!
Our friends from iFixit will take it from here.
Our friends from Fairphone will take it from here.
Find out what's next by pushing the button below.
FAIRPHONE
Thank you for choosing for the planet.
RIGHT TO REPAIR
IFIXIT
Fairphone 3
Schermvervanging
Wat je nodig hebt
Onderdelen
Support
Sign In
We're here to help
Search our articles
Hi! How can we help you?
If you have a Fairphone product, try our Find & fix an issue
Hi. Need any help?

APPENDIX F

PANELS USER INTERFACE (VERSION 1)

This is the first version of the user interface, made and used for the user testing.



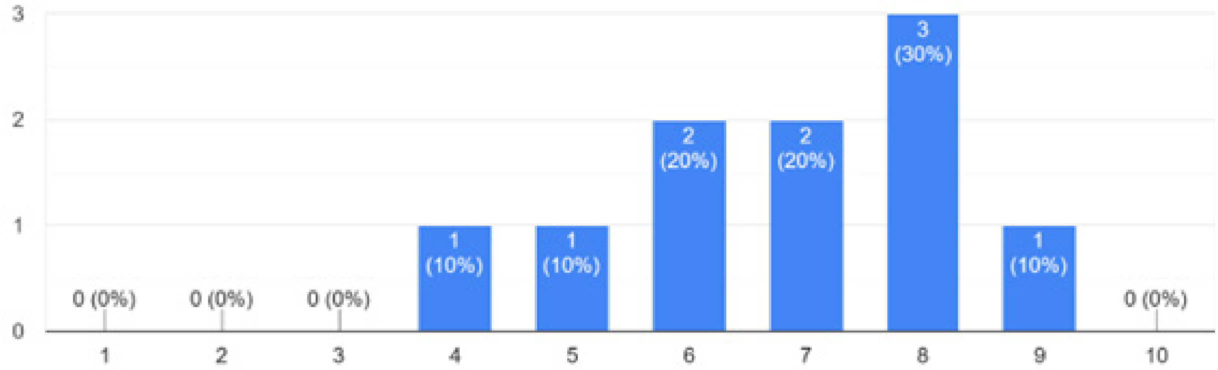
APPENDIX G

USER TESTING RESULTS

These are the results of the Google Form used in the user test, as well as the notes and conclusions drawn from it.

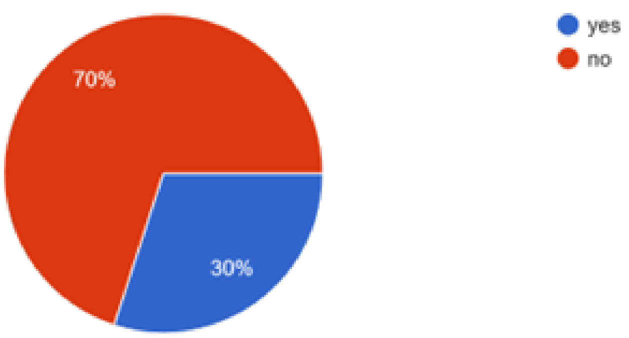
Hoe technisch handig zou u zelf zeggen dat u bent? How tech-savvy would you say you are?

10 antwoorden

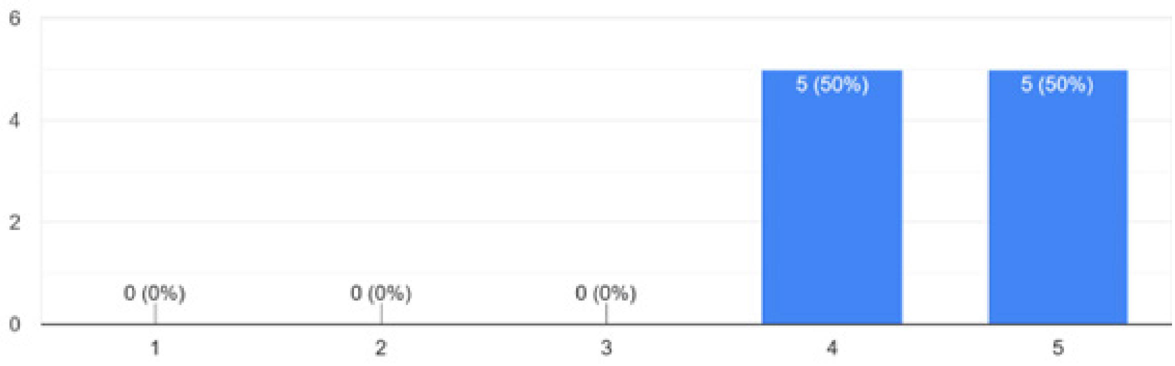


Heeft u wel eens eerder uw telefoon laten repareren? Have you ever had your phone repaired before?

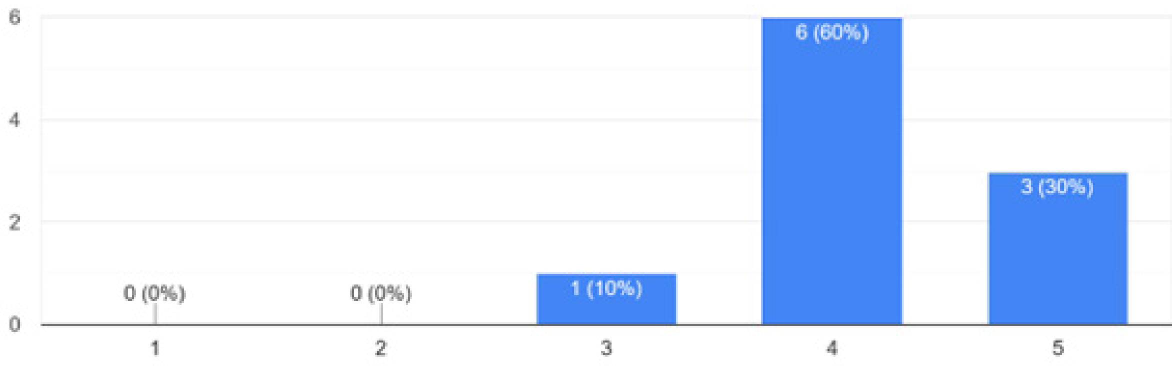
10 antwoorden



Hoe zou u uw algemene ervaring met het product beoordelen? (1-5) Rate your overall experience using the product? (1-5)
10 antwoorden



Hoe gemakkelijk was het product te gebruiken? (1-5) How easy was it to use the product? (1-5)
10 antwoorden

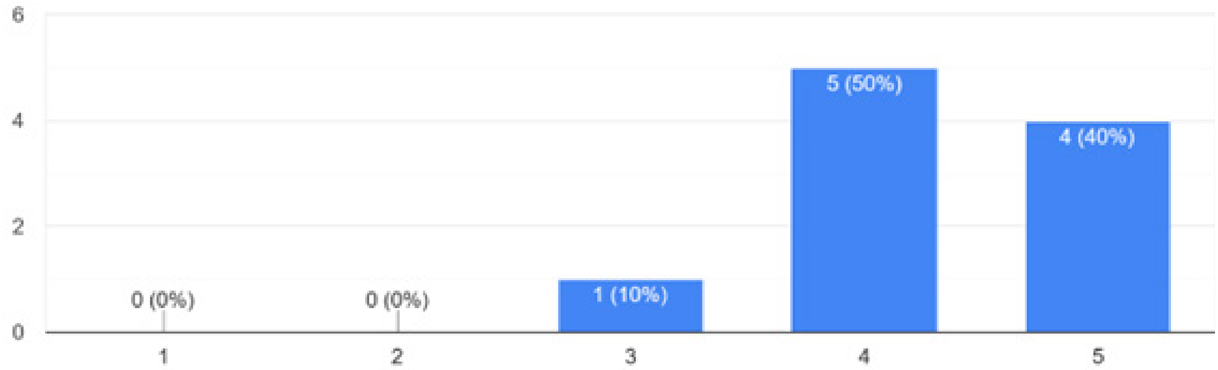


Notes
2 antwoorden

Mockup choice results was a little confusing

Makkelijker in het nederlands, kies taal in het begin

Hoe duidelijk waren de instructies te volgen? (1-5) How clear were the instructions to follow? (1-5)
10 antwoorden



Notes
6 antwoorden

Especially the videos

Took the battery out as well because she was too quick

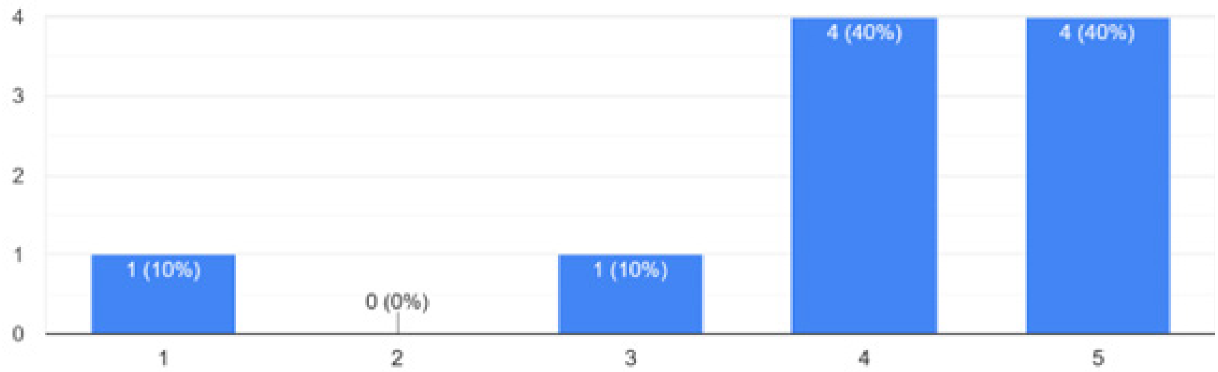
Hij haalde de batterij uit, video is heel handig Amar wil meer duidelijke tekst

Engels!

Test 2 video te snel, pauzeknop en terugspelen is handig

Filmpje bleef maar door lopen, geen begin en einde, gaat te snel met de stappen want doet tegelijkertijd

Hoeveel heeft het product u aangemoedigd om je telefoon te laten repareren? (1-5) How much did the product encourage you to repair your smartphone? (1-5)
10 antwoorden



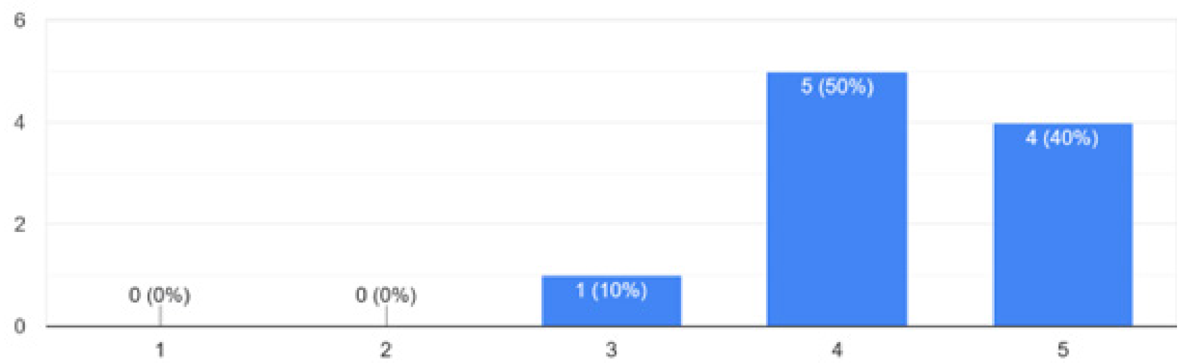
Notes

1 antwoord

Zou het toch laten repareren

Wat vond u van de informatie gegeven bij het resultaat? Was het te genoeg / te veel? Vond u de informatie interessant en relevant? (1-5) What did y...the information was interesting and relevant? (1-5)

10 antwoorden



Notes

4 antwoorden

Repairability was interesting but not visible because too much info at once. Could be in a drop-down menu for each of them.

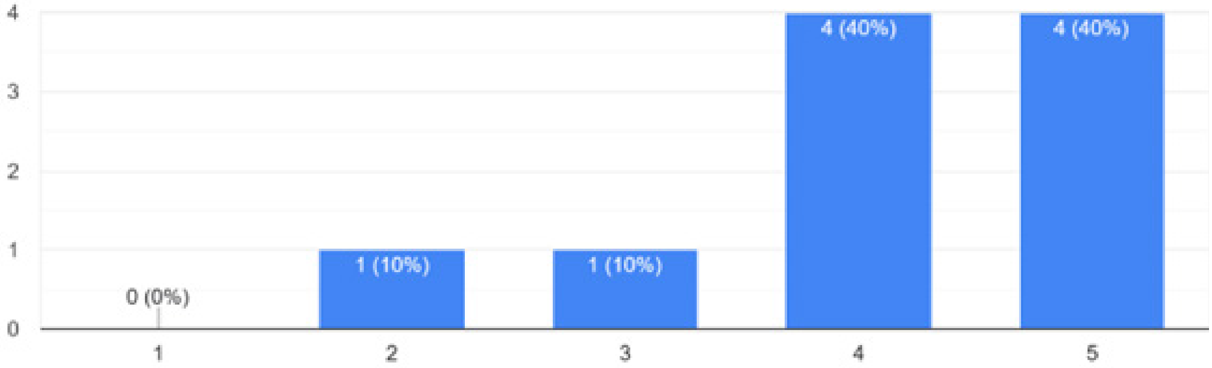
Misschien meer repairability score vergelijken?

Te weinig opties, winkel in de binnenstad mag ook optie zijn, idealiter lokaal

Eerst als je het zelf doet kost het dit, nog makkelijker maken om reparateur in de buurt te vinden

Hoe zelfzeker liet het gebruiken van het product u voelen over het repareren van je smartphone? (1-5) How confident did using the product make you feel about repairing your smartphone? (1-5)

10 antwoorden



Notes

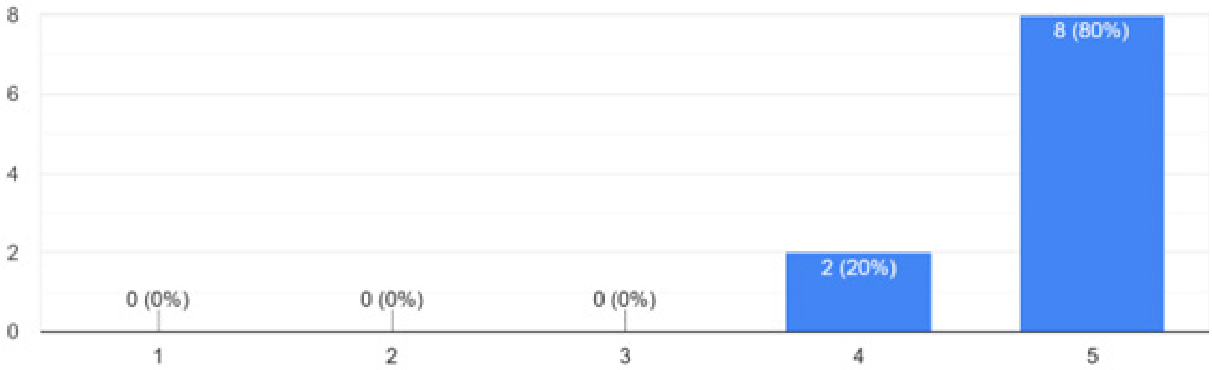
2 antwoorden

Wegstrepen welke componenten er al getest zijn, "en dit is goed dus batterij is oké)

Is zelf 'niet heel zeker met tech

Hoe gemotiveerd voelde u u om het diagnoseproces verder te zetten? (1-5) How motivated did you feel to continue the diagnosis process? (1-5)

10 antwoorden



Notes

1 antwoord

Achterkant was moeilijk ervan af te krijgen

Was de vorm van het product makkelijk in gebruik? Was the shape of the product easy to handle?

10 antwoorden

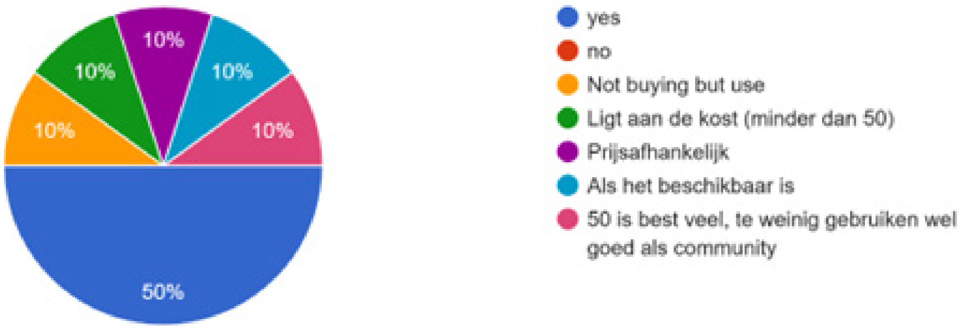
Notes

1 antwoord

Back to back is maybe not as nice as seeing everything at once

Zou u dit product in het echte leven gebruiken? Would you use this product in real life?

10 antwoorden



Notes

2 antwoorden

Would not buy it but use it if it were available (library, ...)

Als het niet te duur is

Heeft u nog suggesties of verbeteringen?
Do you have any suggestions or improvements?

4 antwoorden

Can't be too expensive, or a loaning device

Public property, not enough use cases otherwise

Scrollen was niet duidelijk, alle andere schermen waren statisch

Communicatie

NOTES

- People take the battery out in test 2?
- Test buttons: show when they can release the buttons (vibration? Licht? Just something on the screen?)
- Modularity for other phone models: maybe foresee manual mode to make this possible
- Show what the measured target is (e.g. 3.7V) and what has been measured
- Show repair cost instead of saved costs, they're too high to mean anything
- Or just be able to compare: a new one costs €699, a repair costs €30
- It's not clear the results are scrollable
- Fairphone / iFixit buttons are unclear
- Prototype: hole for USB in tester makes it unclear whether it should be connected or not when inserted
- Video of test 2 goes too quickly
- Rewording of CO2 result, it's complicated to understand (yearly saving? What does it mean?)
- Give confirmations about whether instructions have been followed up well
- Will there be a time saving if I repair?

CONCLUSIONS

GOOD SUGGESTIONS

Language choice in the beginning

- Leave as a suggestion due to time – does not change anything content-wise

Progress: strike out what components have been tested

Show when buttons can be released

Compare testing results with what it should be (comparison bar?)

- Other participants said this would confuse them

TEST 2

Split the video into different steps so they have time to follow the instructions

- Give confirmation when steps have been completed correctly?
    - Not necessary when the steps are so short

Implement pause and rewind buttons, let them push play when they're ready

Better text instructions with the steps

Prevent them from taking battery out

RESULTS

Drop-down menu for each aspect

- Leave as suggestion, don't know how to make that + more effort for user

Compare costs instead of showing saved costs

Scrolling graphics need to be made clear

Fairphone / iFixit buttons need to be made clear

CO2 results need to be made clear (yearly? Meaning?)

Time saving?

More generally give local repairers instead of link to Fairphone

- Leave as a suggestion, no idea how to accomplish that right now

SHAPE

Not have them lose sight of the screen while following the orders: no back-to-back (even though not very dramatic)

Slide in vertically at the bottom?

Let them leave USB in after test 1, make it possible to insert it with it

APPENDIX H

CODE FOR THE TESTING PROGRAMME

This was the programme written to execute the full workflow on the ItsyBitsy M4. It is fully functional and guides the user through all three tests. When using the wiring schematics provided in Chapter 7 this code can just be copied in a code editor and used. The one used in this project was Mu Editor. Make sure the micro controller runs on CircuitPython.

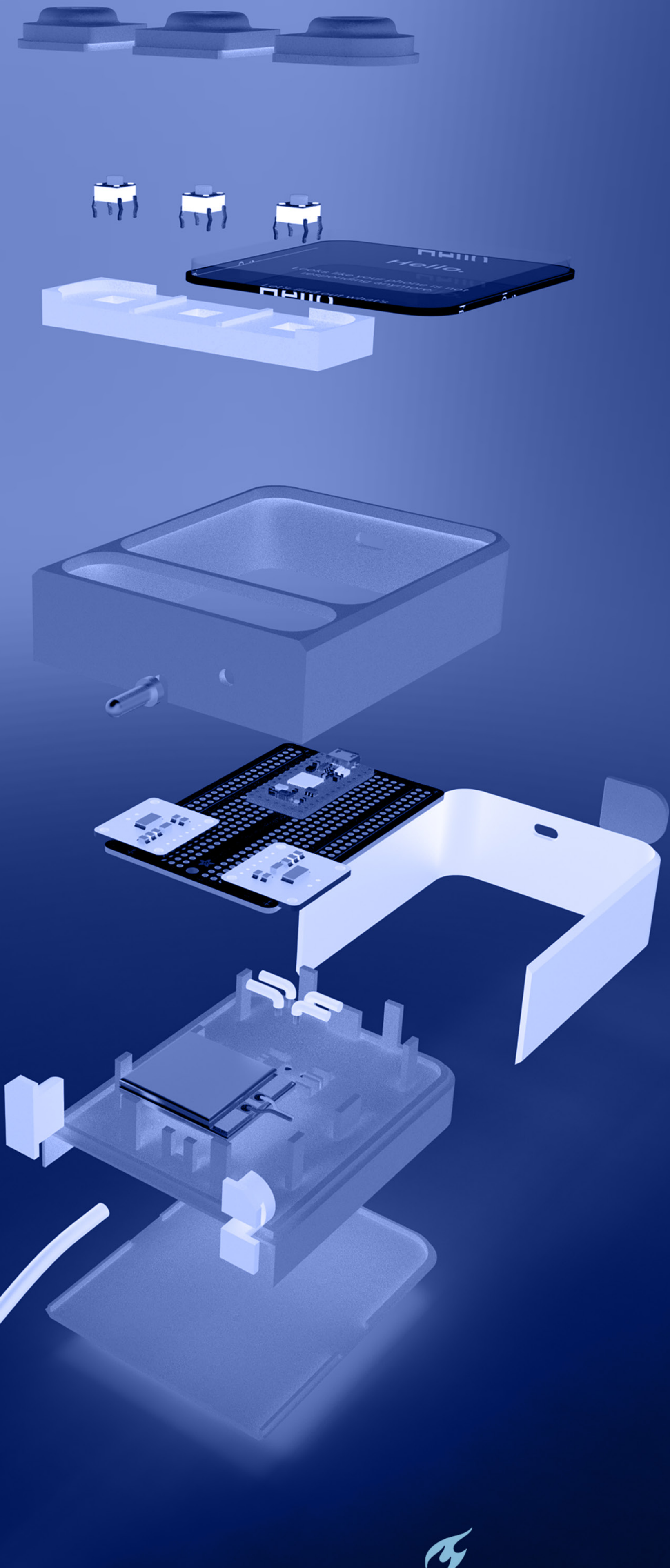
```
#  Workflow COMPLETE


import board
import time
import digitalio
import analogio
import displayio
import terminalio
from adafruit_display_text import label
import adafruit_displayio_ssd1306
import adafruit_ina219  # Use INA219 library for current measurement


# Compatibility with both CircuitPython 8.x.x and 9.x.x.
try:
    from i2cdisplaybus import I2CDisplayBus
except ImportError:
    from displayio import I2CDisplay as I2CDisplayBus


# Release any resources currently in use for the displays
displayio.release_displays()
oled_reset = board.D2

# Initialize I2C interface
i2c = board.I2C()  # uses board.SCL and board.SDA
display_bus = I2CDisplayBus(i2c, device_address=0x3C, reset=oled_reset)


# Initialize INA219 sensors for current measurement
ina219_1 = adafruit_ina219.INA219(i2c)  # First INA219 for initial current measurement
ina219_2 = adafruit_ina219.INA219(i2c, addr=0x41)  # Second INA219 for output current measurement


# Initialize OLED display
WIDTH = 128
HEIGHT = 64
oled = adafruit_displayio_ssd1306.SSD1306(display_bus, width=WIDTH, height=HEIGHT)


# Create a display context
splash = displayio.Group()
oled.root_group = splash


color_bitmap = displayio.Bitmap(WIDTH, HEIGHT, 1)
color_palette = displayio.Palette(1)
color_palette[0] = 0xFFFFFF  # White
```

```
bg_sprite = displayio.TileGrid(color_bitmap, pixel_
shader=color_palette, x=0, y=0)

splash.append(bg_sprite)


# Initialize analog pin for voltage measurement

vpins = analogio.AnalogIn(board.A3)


# Initialize button to toggle modes

button = digitalio.DigitalInOut(board.D9)

button.direction = digitalio.Direction.INPUT

button.pull = digitalio.Pull.DOWN


# Initialize return button

return_button = digitalio.DigitalInOut(board.D7)

return_button.direction = digitalio.Direction.INPUT

return_button.pull = digitalio.Pull.DOWN


# Initialize output pin for test 3

output_pin_1 = digitalio.DigitalInOut(board.D5)

output_pin_1.direction = digitalio.Direction.OUTPUT


# Voltage divider resistors

R1 = 10000.0  # resistance of R1 (10K ohm)

R2 = 20000.0   # resistance of R2 (20K ohm, series
of 2 times 10K)


# Other variables

mode = -1  # Start with mode -1 for waiting state

interval = 0.3  # 300 milliseconds

result_display_delay = 5.0  # Delay after displaying
test result messages (adjust as needed)

waiting_state_interval = 0.1  # Interval in waiting
state for responsiveness


previous_time = time.monotonic()


# Countdown variables

countdown_duration = 5  # Countdown duration in
seconds

countdown_start_time = 0

countdown_active = False


# Last mode to track which test was completed
before entering waiting state

last_mode = -1


# Function to read voltage (using external voltage
divider)

def read_voltage():

    value = vpins.value

    vout = (value * 3.3) / 65536.0

    vin = vout / (R2 / (R1 + R2))

    if vin < 0.09:

        vin = 0.0

    return vin


# Function to read current (using INA219)

def read_current(ina):

    return ina.current / 1000.0  # Convert current
from mA to A


# Function to start countdown

def start_countdown(duration):

    global countdown_start_time, countdown_active

    countdown_start_time = time.monotonic()

    countdown_active = True


# Function to check if countdown is complete

def countdown_complete():

    global countdown_start_time, countdown_active

    if countdown_active and time.monotonic() -
countdown_start_time >= countdown_duration:

        countdown_active = False

        return True

    return False


# Main loop
```

```
while True:
    current_time = time.monotonic()

    if mode == -1:  # Waiting for button press to start tests
        text = "Press button to start tests"
        if button.value:  # Button pressed, start tests
            time.sleep(0.15)  # Debounce
            mode = 0  # Move to first test (current meter)
            start_countdown(countdown_duration)  # Start countdown for the first test
            print("Starting tests...")

    elif mode == 0:  # Test 1: Current Meter
        if countdown_complete():
            current = read_current(ina219_1)
            if current >= 0.4:
                text = "Test 1 Passed\nYour screen is broken."
            else:
                text = "Test 1 Failed\nCurrent: {:.2f} A".format(current)
            text += "\nPress button to continue to Test 2."
            last_mode = mode
            mode = 3  # Move to waiting state
            previous_time = current_time  # Reset time to ensure immediate display of waiting state
        else:
            remaining_time = int(countdown_duration - (current_time - countdown_start_time))
            text = "Test 1 in progress...\nCountdown: {} s".format(remaining_time)

    elif mode == 1:  # Test 2: Voltage Meter
        if countdown_complete():
            vin = read_voltage()
            if vin >= 3.0:
                text = "Test 2 Passed\nVoltage: {:.2f} V".format(vin)
                text += "\nPress button to continue to Test 3."
            else:
                text = "Test 2 Failed\nBattery is broken."
                text += "\nPress button to reset."
            last_mode = mode
            mode = 3  # Move to waiting state
            previous_time = current_time  # Reset time to ensure immediate display of waiting state
        else:
            remaining_time = int(countdown_duration - (current_time - countdown_start_time))
            text = "Test 2 in progress...\nCountdown: {} s".format(remaining_time)

    elif mode == 2:  # Test 3: Output Current Measurement
        # Supply power to output pin
        output_pin_1.value = True  # Provide power
        if countdown_complete():
            current = read_current(ina219_2)
            if current >= 0.05:
                text = "Test 3 Passed\nCharger port is broken."
            else:
                text = "Test 3 Failed\nMotherboard is broken."
            text += "\nPress button to end tests."
            last_mode = mode
            mode = 3  # Move to waiting state
            # Turn off the output pin after the test
            output_pin_1.value = False
            previous_time = current_time  # Reset time to ensure immediate display of waiting state
        else:
            remaining_time = int(countdown_duration - (current_time - countdown_start_time))
            text = "Test 3 in progress...\nCountdown: {} s".format(remaining_time)

    elif mode == 3:  # Waiting state
```

```
        if last_mode == 0:
            text = "Test 1 Waiting mode\nPress button to proceed to Test 2."
        elif last_mode == 1:
            text = "Test 2 Waiting mode\nPress button to proceed to Test 3."
        elif last_mode == 2:
            text = "Tests completed.\nPress button to reset."

        # Handle button press in waiting state
        if button.value:
            time.sleep(0.15)  # Debounce
            if last_mode == 0:
                mode = 1  # Move to the next test (voltage meter)
                start_countdown(countdown_duration)
            elif last_mode == 1:
                mode = 2  # Move to the next test (output current measurement)
                start_countdown(countdown_duration)
            elif last_mode == 2:
                mode = -1  # Reset to initial waiting state
            print("Continuing to next test...")

        # Handle return button press
        if return_button.value:
            time.sleep(0.15)  # Debounce
            mode -= 1  # Move back one test
            if mode < 0:
                mode = 0  # Ensure mode does not go below 0
            print("Returning to previous test...")

    # Display the text on OLED
    splash.pop()  # Clear previous text
    text_area = label.Label(terminalio.FONT, text=text, color=0xFFFFFF, x=0, y=HEIGHT//2)
    splash.append(text_area)

    # Ensure text remains displayed for a specified delay before moving to waiting state
    if mode in {0, 1, 2} and current_time - previous_time >= result_display_delay:
        previous_time = current_time  # Update time for next display delay

    if mode == 3:
        time.sleep(waiting_state_interval)  # Adjust to ensure responsiveness in waiting state
```

MARTHE ROMBAUT



MSC INTEGRATED PRODUCT DESIGN
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