Repair Friendly Headphones

Leveraging intuitive design and artificial intelligence to encourage consumer repair willingness

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Abstract

This report explores the barriers consumers face when attempting to repair personal electronics, focusing specifically on wireless Active Noise Cancellation (ANC) headphones. While these devices have become increasingly common, repair is often overlooked in favour of replacement due to psychological resistance, economic factors, and practical limitations. Through research into user attitudes and product architectures, this project identifies the main hurdles to repair, such as lack of knowledge, intimidating product design, and insufficient support materials.

Based on these findings, this project proposes a solution that addresses the main challenges preventing user-led repair. The final concept introduces a diagnosis-to-repair system supported by an intuitive physical headphone design and an AI-powered digital assistant. The design focuses specifically on the four most common malfunction scenarios reported by users: cushion wear and tear, hinge breakage, charging issues, and audio malfunctions.

The experience is designed to lower the perceived complexity of diagnosis and repair by actively engaging users directly in the troubleshooting process. The proposed headphone design enables users to simply switch cables between ports to help quickly isolate issues without the need for tools or full disassembly, encouraging active learning through doing while keeping stress and confusion to a minimum. At the heart of the headphone concept is a tiered repair model: common, high-frequency issues such as ear cushion replacement or battery swaps are tool-free and quick, while higher complexity tasks remain accessible with minimal guidance. This avoids overwhelming users while still granting them meaningful control over their device. The process is supported by a digital repair assistant, hosted on common messaging platforms like WhatsApp and Telegram, ensuring familiarity and universal accessibility to repair information when users need it the most. It guides users in identifying the problem, then adapts to their input and repair confidence level, modifying its instructions accordingly, while using helpful visuals, and offering alternative repair pathways, all in a single, accessible and unified platform.

This project aims to support the broader goals of sustainability and circularity by making repair more approachable and attractive by reducing friction and enabling users to make confident, informed decisions at the point of device failure. The end goal is to extend headphone lifespans and reduce electronic waste by re-framing headphone repair from a burden into an empowered, user-driven experience.

Contents

01

Introduction
Problem Statements, Research Objectives and
Process Methodologies

1.1 Introduction

Facilitating product repair is a complex challenge that requires attention across multiple domains, including design, business models, consumer behaviour, and policy frameworks. This project will specifically focus on the dimension of consumer behaviour.

The Ellen MacArthur Foundation's Butterfly Diagram (Fig.1) illustrates the continuous flow of materials within a circular economy, depicting two cycles: the biological cycle and the technical cycle. The technical cycle is particularly relevant here, as it concerns products that are used rather than consumed, such as electronics and involves strategies like maintenance, reuse, refurbishment, and recycling to keep materials in use and minimise waste. From an environmental perspective, extending the lifespan of commonly used electronic devices such as headphones is important. Electronic waste (e-waste) is one of the fastest growing waste streams globally, with an estimated 53.6 million metric tonnes generated in 2019 alone and projected to increase further (Herrmann et al., 2023). Improper disposal of e-waste results in severe ecological damage, including soil and water contamination from toxic substances like heavy metals and hazardous chemicals, which disrupt ecosystems and harm biodiversity. Furthermore, the disposal and manufacturing of electronics greatly contribute to carbon emissions - over 50 million tonnes of CO_2 equivalents annually (Herrmann et al., 2023). This highlights the importance of extending product lifetimes to reduce environmental harm. Within the circular economy framework, encouraging end-user involvement in product repair is therefore a major component of sustainability (Bovea et al., 2021; Russell et al., 2022).
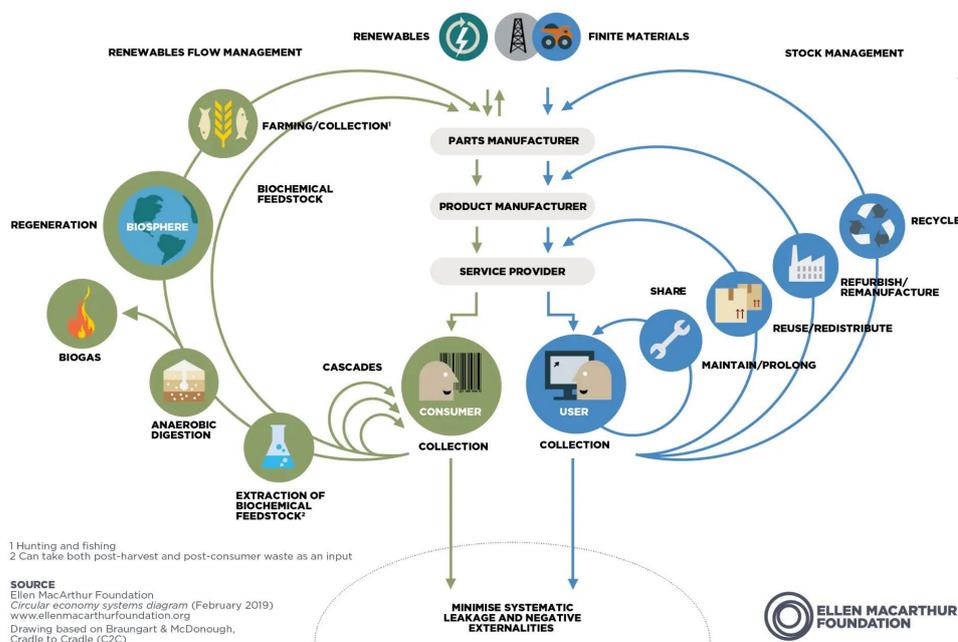
Fig 1: Butterfly diagram for a circular economy (Ellen MacArthur Foundation, 2019)

1.2 Understanding Fixophobia

"Tackling Fixophobia: Improving repair practices for consumer electronics" is a research proposal granted by the NWO (the Dutch Research Council). Fixophobia, a phenomenon where users portray reluctance, distrust, or negative emotions toward repair practices stands as a barrier to repair participation (Research on Consumer Electronics Repair Commissioned by NWO, n.d.). This resistance is evident especially in the personal electronics domains, such as laptops, smartphones, tablets and headphones, where issues like rapid innovation cycles, limited repair knowledge, task complexity, high repair costs and perceived inconvenience discourage users from attempting repairs (Scharff & Plepys, 2020).

Several factors contribute to Fixophobia among consumers. A lack of awareness about repair processes and inadequate access to tools and resources serve as major barriers (Terzioglu, 2020). Time and effort required to be invested for repairs, combined with manufacturer-imposed restrictions such as proprietary components and software locks further adds to the list of reasons consumers refrain from attempting fixes (Proske et al., 2023). Emotional attachments to items, especially those with sentimental value or in good basic condition, can motivate repairs. However, these motivations are often overshadowed by the barriers to accessibility and convenience (Bovea et al., 2021).

Fig 2: Tackling Fixophobia (Het Groene Brein; n.d.)

Research also suggests that individual repair decisions are shaped by personal skill and competence levels, social influences, and availability of repair-friendly infrastructure (Svensson-Hoglund et al., 2022). Aligning with the objectives of organisations such as the Netherlands Organisation for Scientific Research (NWO) and the Knowledge and Innovation Communities (KIC), focusing on user-centric design and effective support materials can help create a positive shift in societal attitudes toward repair practices, ultimately contributing to a more sustainable and circular economy (Fig 2). Using headphones as the product focus, this project seeks to understand the factors contributing to Fixophobia and develop solutions that encourage consumers to choose repair over replacement.

1.3 Why Headphones?

The decision to focus on wireless Active Noise Cancellation (ANC) headphones was based on 2 main reasons -

1.3.1 From Elective to Exploration

From an individual perspective, I worked on a project during my first year elective, where the objective was to analyse and redesign a pair of headphones for better repairability (Fig 3). My research during the course led me to realise that merely improving the hardware repairability of a product, although important, is not enough to support the decision to repair (Makov & Fitzpatrick,2021). The issue of repair must be addressed through two main avenues. Firstly, designing products to be easily repairable, and secondly, ensuring that users have convenient access to the resources and materials needed to carry out repairs confidently. This realisation motivated me to delve deeper into this topic. For more information about the work done during this elective, refer Appendix B.

Fig 3: Initial headphone repairability analysis during first-year elective (2023)

1.3.2 Industry Relevance

On an industry/product specific level, the headphone domain presented both opportunities and challenges for designing products that are competitive in the market as well as repairable. Wireless ANC headphones represent a rapidly growing segment of the consumer electronics market. In 2020, the global wireless headphones market was valued at $11 billion and is projected to grow by 20% annually, making it one of the most popular consumer electronics products (D'Souza, 2024). However, these categories of products are one of the biggest victims to premature disposal, due to few components like cushions, batteries or cables that have shorter lifespans than the entire product itself and contribute heavily towards the generation of E-waste (Herrmann et al., 2023).

One of the main challenges with recycling headphones is that they are typically composed of mixed materials such as fabrics, critical metals, and polymers (Fig 4). Polymers, being the majority material (61.7%), likely contribute a substantial portion of the environmental impact, considering the energy intensive processes like injection moulding. Although metals and magnets make up only 20.9% of the material composition, they have a disproportionately high carbon footprint due to the intensive processes involved in their extraction, processing, and casting (Nuss & Eckelman, 2014). These materials are often glued together to prevent vibration and protect sound quality. This design choice, while beneficial for performance, makes disassembly for repair or recycling purposes more difficult and costly (AR Balkenende. & CA Bakker, 2015a). Although the end-of-life phase of headphones accounts for just 3.6% of their total climate impact, the manufacturing stage contributes approximately 81%, largely due to energy and resource intensive production processes (Herrmann et al., 2023). This shows that focusing solely on disposal yields limited environmental gains, whereas extending product life span by avoiding new manufacturing is far more impactful. While repairs do require spare parts, their material and energy demands are minimal compared to producing an entirely new device. For example, battery replacement can nearly halve the headphone's global warming potential per use hour from 4.7 to 2.4 g CO-eq/h (Herrmann et al., 2023). By keeping devices in use longer, repair spreads the high initial emissions of production over a longer period, thereby lowering emissions per use.
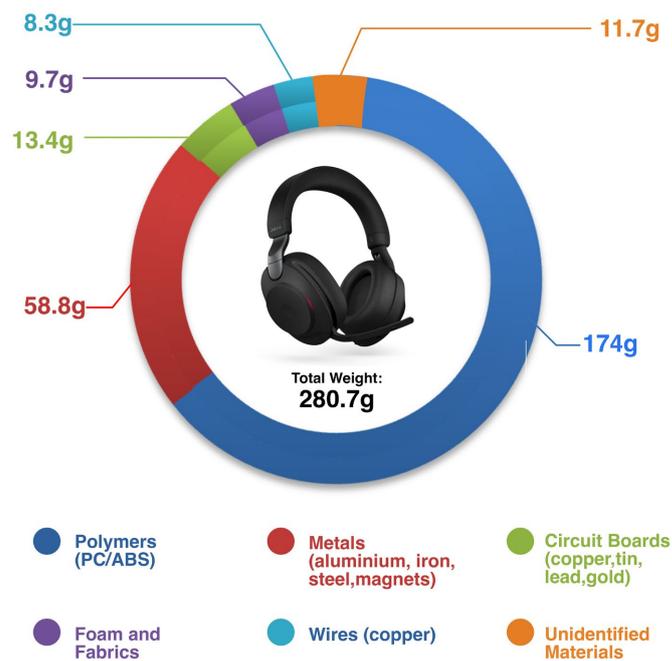
Fig 4: Material distribution across the Jabra Evolve 2 85 Headphones (in grams) (Herrmann et al., 2023)

1.4 Research Objectives

The overall goal of this project is to develop interventions that are based on understanding current consumer interactions with repair and the subsequent barriers that prevent users from engaging in repair behaviours. By focusing on user-centric solutions, this project aims to create practical and accessible strategies that not only stimulate interest in repair but also encourage actual repair actions, distinguishing it from purely technical solutions available today. To achieve this, the following research objectives were formulated -

RO1 **Understanding consumer preference for replacement over repair.**

Q1.1 What psychological, economic, and practical factors contribute to consumers' preference for replacement over repair?

Q1.2 Are headphone companies supporting this preference through design and product lifecycle strategies?

RO2 **Evaluate existing solutions for user-driven repair**

Q2.1 What role do support tools (e.g., Repair manuals, repair tutorial videos,) play in improving the self-repair experience?

Q2.2 How have modular, repairable designs and spare part availability impacted self- repair experiences?

Q2.3 Where have these solutions succeeded and where have they fallen short?

RO3 **Understand ways to trigger and sustain user engagement with repair**

Q3.1 How can we incentivise repair for the average headphone user?

Q3.2 How can we make repair information easily accessible for confident decision making?

Q3.3 How can we make the process of repair non - intimidating and engaging?

1.5 Methodology and Approach

Since the project focus is on improving how consumers interact with the repair process, the user journey will serve as a framework guiding the research through the following four chapters. Each research chapter delves into different stages of this journey, contributing to answering the first two research objectives by delving into user experiences, decisions and challenges encountered during repair of headphones (Fig 5). Building on the insights from the following four chapters, the following ideation and development phases aim to answer research objective 3 by exploring tangible solutions to user needs identified during the research phase.

Literature Research + Expert and user interviews

RO1

Market Research + Product case studies

RO1

Technical Study + Product Disassemblies

RO2

Project Guidelines + Co-creation Sessions

RO2

RO3

01 Consumer Attitudes to Repair

- Map user journey: purchase to repair
- Identify key phases and factors for further research

02 Repair Interest

- Explore factors influencing repair interest.
- Analysis of current headphone market

03 Repair Decision

- Identify most frequent headphone malfunction scenarios
- Explore availability and content of current repair support resources

04 Repair Action

- Explore hands-on aspects of headphone repair (disassembly, access, replacement)

05 Ideation

- Setting up an ideation framework
- Explore potential technologies and brainstorming solutions

RO3

Iterative physical and digital prototyping

RO3

Integrating and realizing solutions

RO3

06 Concept Development

- Narrowing down the project scope
- Explore solutions within the scope

07 Concept Refinement

- Design Detailing
- Concept Testing

08 Final Concept

- Concept Delivery
- Identification of shortcomings and scope for future work

Fig 5: Research and Design Methodology

02

Consumer attitudes toward repair
Understanding repair decisions in phases

Questions explored in this chapter

RO1: Understanding Consumer Preference for Replacement Over Repair

Q1.1: What psychological, economic, and practical factors contribute to consumers' preference for replacement over repair?

This chapter will provide a preliminary overview of Q.1.1, by listing out the most relevant factors that influence consumers' preference for replacement over repair.

2.1 Introduction

In this chapter, the objective is to establish an overview of the factors influencing consumer decisions regarding repair. Understanding the user relationship with headphones from the point of purchase to malfunction and repair action may seem like a broad approach, but seems relevant to make sure no factors are left out.

While repair decisions are usually considered only after a product malfunctions, a broader view of the user journey can explore whether consumer decisions affect repair decisions even before issues arise. By mapping out the macro view of the user relationship with headphones, this chapter also identifies which phases of the user journey require more focus in later chapters.

To support this analysis, the repair process flowchart conceptualised by Russell et al. (Fig 6) was used as a foundation to build a structured view of repair engagement, which will be further built upon in the following section to include a macro view of consumer headphone engagement in order to better understand the decision-making process surrounding repair.
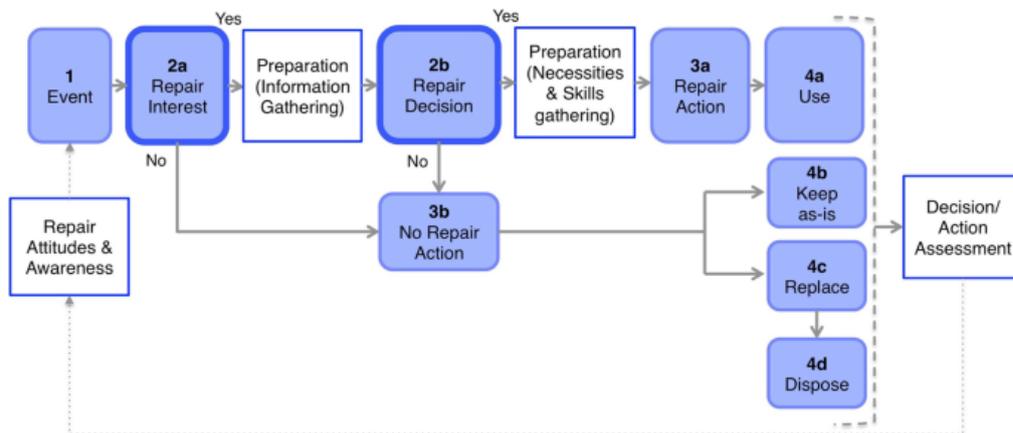
Fig 6: The Repair Process (Russell et al.)

2.2 From Purchase to Repair

The following flowchart is a macro view of the interaction that consumers have with their headphones from the point of purchase to the point of malfunction and eventually, repair.

This journey can be divided into 2 stages -

Stage 1 - Product ownership and engagement

2.2.1 Headphone Purchase

Initial purchase of headphones directly influences later repair behaviour. When the design is perceived as valuable and justifies the higher cost, consumers are more likely to invest in repairs, as they associate the product's worth with its longevity and reliability. Thus, a combination of cost and appealing design can be major factors in encouraging repair decisions (Bovea et al., 2021).

2.2.2 Headphone Engagement and Maintenance

Positive product engagement can lead to emotional attachment, which may increase the likelihood of repair in the event of a malfunction (Jaeger-Erben et al., 2020b). While both engagement and maintenance are important factors of the ownership experience, they fall outside the scope of this study, which will focus on direct user experiences and motivations post- malfunction.

2.2.3 Headphone Wear and Tear

Gradual deterioration of physical components such as ear and headband cushions can affect user comfort and overall experience, even if the headphones remain functionally intact in terms of audio or charging. This stage represents the starting juncture where users begin to weigh the option of repair or replacement. While some may continue using the product despite the decline in comfort, others may choose to replace the unit entirely, especially if the wear compromises perceived product value (Terzioglu, 2020b).

2.2.4 Headphone Malfunction

In a malfunction scenario like audio issues or charging issues, the core functional values of the headphone are affected. In this scenario, users will make a range of cognitive and practical decisions to determine whether they will repair or replace their headphones.

Stage 2 - Repair engagement and decision making

2.2.5 Repair Interest

The initial tendency to repair is influenced not only by the headphone's initial cost but also by how well its design, both functional and aesthetic, justifies that cost. Users are more likely to consider repair when the product has delivered reliable performance over an extended period, thereby increasing its perceived value. This makes repair feel like a justified and meaningful choice (Russell et al., 2022). This is especially true for higher-end headphones, where the original cost is justified by the product's sustained quality, while lower-cost models are more often regarded as disposable (Proske et al., 2023).

2.2.6 Repair Decision

Once the interest in repair exists, users decide whether repairing the headphones is feasible. Four factors influence this decision: repair warranty, financial cost, diagnosis result and resource availability. Financial costs and warranty coverage are important factors influencing repair decisions; however, they fall outside the scope of this study. This research instead focuses on diagnosis and the availability of repair support such as accurate access to diagnostic support materials and clear repair guidance as these are the major practical barriers that discourage users to successfully carry out repairs (Svensson-Hoglund et al., 2021).

2.2.7 Repair Action

Finally, if users decide to repair their headphones, their success is dependent on ease of disassembly, task complexity and support material effectiveness. Many headphones are designed with adhesives and compact assemblies with hidden components that make disassembly difficult (Fakhredin,2018). This makes user-led repair attempts to often result in failure. The complexity of the repair process ranging from simple cushion replacements to soldering wires influences whether users will proceed independently or seek professional help. The most common form of support available to users are repair manuals and video tutorials. The effectiveness of these resources plays an important role in facilitating smooth repair experiences. If these resources are unclear or insufficient, repair attempts may fail (Eversberg & Lambrecht, 2023).

2.3 Chapter 2 Takeaways

RO1 Understanding Consumer Preference for Replacement Over Repair

Q1.1 What psychological, economic, and practical factors contribute to consumers' preference for replacement over repair?

- The decision to repair a product is not a single decision, but a series of decisions. The end user goes through multiple stages and phases before successfully repairing a product. The true challenge is not to just trigger interest in repair but sustain that interest till the product is repaired.

- Factors in stage 1 such as the positive engagement and maintenance can improve product longevity. However, this study will focus on how investment price and physical product condition can impact later repair decisions as these factors are more directly correlated to the repair phases in stage 2.

Main Takeaways

The factors mentioned in Stage 2 (**Repair Interest, Repair Decision and Repair Action**) of the user journey will be studied and discussed in depth in the following chapters, as it presents the most direct and immediate insights into overcoming barriers to repair.

03
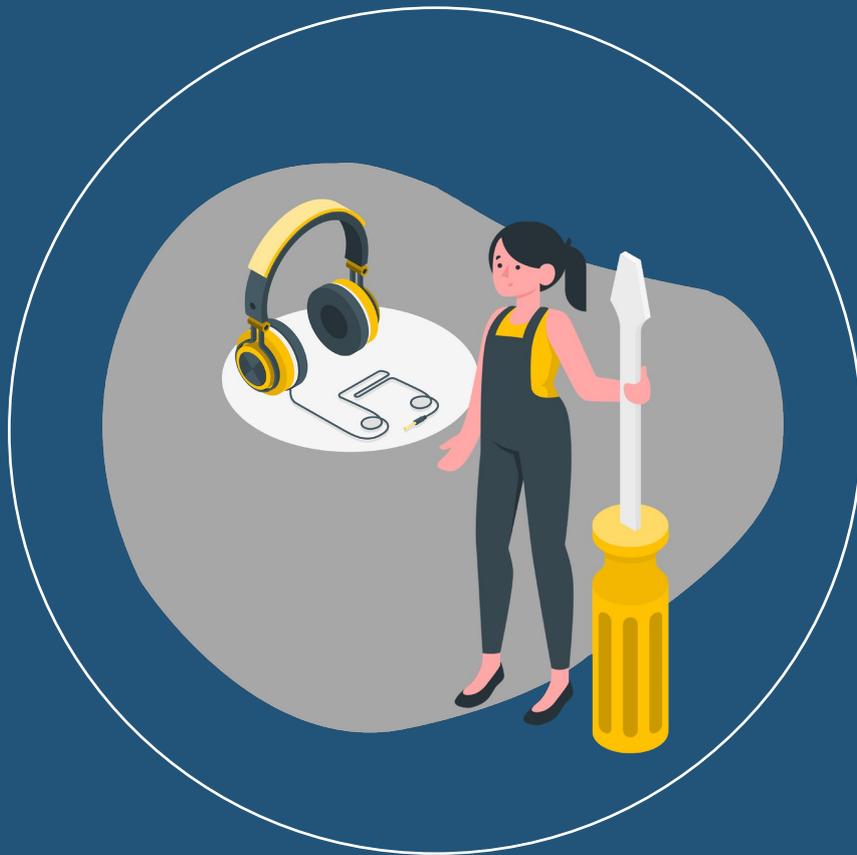
Repair Interest
Initial Investment Price, Emotional and
Functional Values

3.1 Introduction

The repair interest phase is an important juncture where users decide whether to repair, replace, or discard a malfunctioning product. This phase sets the path for the rest of the repair journey and is influenced by various psychological, economic, and practical factors. While repairability is often considered only after a product malfunctions, prior interactions with the product give rise to the following influential factors - Initial Investment, Perceived Value (functional value and aesthetic value) and Emotional Attachment. The following section will explore how these factors interact.

3.2 Factors Influencing Repair Interest

3.2.1 Initial Investment and Perceived Value]

The initial purchase price of a product influences its perceived value, which includes both functional and aesthetic aspects (Fig 7). Generally, higher-priced items are seen as more valuable, which strengthens users' emotional attachment to the product.

Consumers often associate these products with greater reliability, performance, and design quality, justifying the investment. This perceived value increases the likelihood of users choosing repair over replacement, as the products' functional benefits and visual appeal sustain its worth over time (Terzioglu, 2020b; Russell et al., 2022).

3.2.2 Perceived Value and Emotional Attachment

Perceived value and emotional attachment are closely interconnected (Fig 7). Products that fulfil practical needs such as headphones are used daily and naturally tend to form a high emotional attachment with the user. This emotional connection motivates users to maintain and repair the product to preserve it's functionality and the positive experiences associated with it (Terzioglu, 2020b). Conversely, emotional attachment can improve the perceived value through the product's ongoing utility and the satisfaction derived from its use. This reciprocal relationship increases the user's willingness to invest effort and resources into repairing the product rather than replacing it (Terzioglu, 2020b).
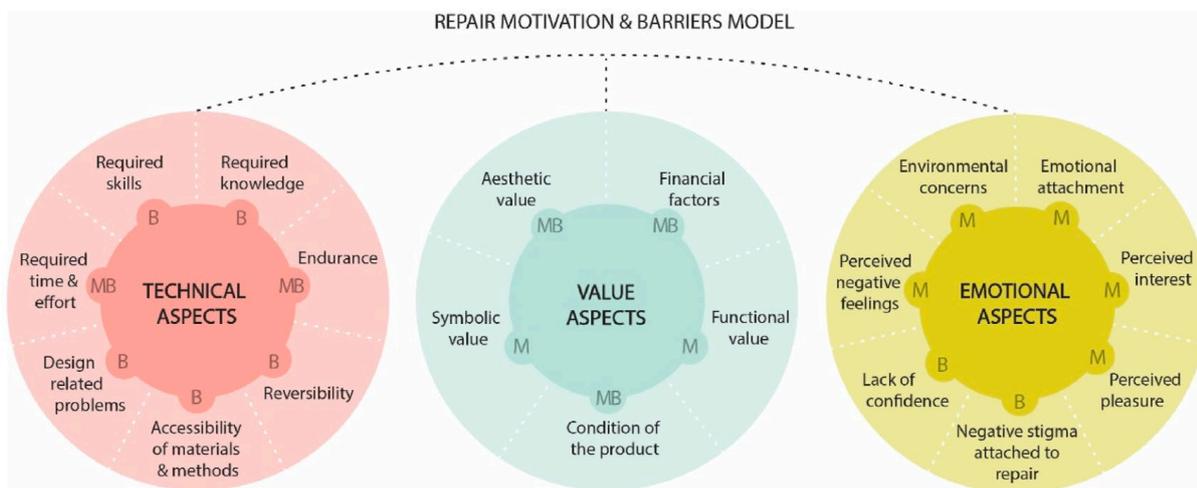
Fig 7: Repair motivation and barriers model diagram, illustrating the factors that affect people's repair behaviour. (Terzioglu, 2020b)

3.3 The Current Market

Now that the most influential factors within repair interest have been established, an in-depth understanding of Q1.1 has been achieved. To answer Q1.2, these factors will be explored in the context of the current headphone market and lifespans to better understand how manufacturer decisions support or reduce user interest in repair. A mainstream market perspective will provide a different lens to examine design decisions and the balance between functionality and repairability, when making design decisions. Case studies of repair- focused brands will further provide insights into current approaches taken to supporting repair interest, while maintaining competitiveness in the market. This will help in identifying gaps in the market where repair interest factors could be better implemented into the mainstream headphone market.

Since the repair interest is higher when the initial purchase price is high and consumers are more likely to consider repair over replacement for higher value products (Terzioglu,2020b), the research will specifically focus on wireless ANC headphones in the 200 Euro and above price range (Fig 8), as these premium category products tend to offer a higher incentive to repair.

Sony WH1000XM5 (399 Euros)
(Sony Corporation, n.d)

Bose QuietComfort 35 II (299 Euros)
(Bose, n.d)

Apple Airpods Max (549 Euros)
(Apple, n.d)

Fairbuds XL (250 Euros)
(Fairphone ,n.d)

AIAIAI TMA 2 (300 Euros)
(AIAIAI.audio ,n.d)

Fig 8: Popular Headphones models within the 200 - 400 Euro Price range

3.4 Mainstream Headphone Market

3.4.1 Headphone Lifecycles

Wireless Active Noise Cancelling (ANC) headphones, have an average lifespan of 3.3 years (Herrmann et al., 2023). However, their performance generally, begins to degrade around the second year of use (cushion wear and tear, battery degradation, broken hinges), which coincides with rapid innovation cycles in the industry (Fig 9), averaging 2 years or less (Herrmann et al., 2023). By the time a product begins to show signs of deterioration, such as decline in performance after about two years, a new model, offering newer features or improved performance, is often already available, leaving users feeling that repair may not be worth the investment (For more information about headphone innovation cycles, refer Appendix C).

Since functional deterioration has a negative influence on user experience, it can be stated that in some cases, emotional attachment to the product is also reduced.

Fig 9: Average innovation cycles of Sony's WH1000 line of headphones

3.4.2 Manufacturer's Perspective

An interview with a large headphone manufacturer provided insights into how the headphone industry approaches repairability. Major manufacturers prioritise design decisions in the following order - Aesthetics, Durability, Performance and lastly, Repairability.

This priority list suggests that manufacturers focus on creating products that cater to consumers' immediate needs at the time of purchase rather than on repairability. Generally, companies consider the best approach to repair is to not have to repair at all. As a result, durability and robustness takes a higher stand in the design decision list. Repairability becomes a secondary concern, often only considered when competitor companies decide to place it as a higher priority in their design decisions. Companies like Fairphone, whose repair-first approach is not seen as a direct competitor by larger brands due to Fairphone's focus on the niche market of eco-conscious consumers, primarily in Europe, while larger brands cater to a wider audience across the world.

3.5 Repairability First Companies

While large mainstream headphone brands prioritise performance, aesthetics, and market competitiveness over repairability, some brands are challenging this approach by placing repair at the core of their design philosophy. These repairability-first companies offer an alternative model where modularity and longevity are given priority in the design decision process. By doing so, they aim to counteract the growing trend of disposable electronics, encouraging users to maintain their devices for longer.

To better understand the current scenario and potential of repairability-driven design, two prominent industry players in the repairability space were analysed - Fairbuds XL by Fairphone and TMA-2 by AIAIAI. These products cater to niche markets, but demonstrate how repairability can coexist with consumer value.

3.5.1 Fairbuds XL – Sustainability-Driven Repairability

Fairbuds XL (Fig 10) developed by Fairphone, takes a sustainability-first approach to headphone design. Fairbuds XL offers longevity through modular construction and user-repairability. Almost all components, including the battery, ear cushions, and headband assembly, can be easily replaced, reducing electronic waste, and extending the product's lifespan.

Pros:

- Fully modular and repairable design, promoting long-term sustainability.

- Appeals to environmentally conscious consumers who prioritise ethical production.

Cons:

- Design, build, and performance is underwhelming compared to competitors in the same price range.

- Due to mid-range noise cancellation and mostly plastic and clunky build, the Fairbuds cost do not offer a premium feel that justifies the 250 Euro price tag.

Fig 10: Fairbuds XL (Fairphone, n.d)

3.5.2 AIAIAI TMA-2 – Customisation for Professionals

The AIAIAI TMA-2 (Fig 11) presents a different approach to repairability by offering an added value of customisation-driven novelty with modular design. The company offers several compatible components like cushions, headbands and audio drivers, each with their own specifications and can be mixed and matched to meet specific audio preferences. The headphones are sold in a disassembled state. This enables users to assemble them manually. This process not only increases emotional attachment to the product through means of the "Ikea Effect" (Norton et al., 2011b), but also familiarises users with its components and how they are put together, making future repairs less intimidating.

Pros:

- Combines customisation and repairability, making it appealing to professionals and audio enthusiasts.

- The disassembled setup promotes emotional attachment and technical familiarity, reducing barriers to self-repair. (Norton et al., 2011b).

Cons:

- The level of customisation can be overwhelming for casual users who prefer a ready-to-use solution.

Fig 11: AIAIAI TMA 2 (AIAIAI audio, n.d)

19.

3.6 Chapter 3 Takeaways

RO1: Understanding Consumer Preference for Replacement Over Repair

Q1.1: What psychological, economic, and practical factors contribute to consumers' preference for replacement over repair?

- Initial Investment: Consumers are more likely to consider repair if the product's initial purchase price is high.

- Perceived Value (Functional and Aesthetic): It's not enough for a product to be expensive; its design quality, build, and performance must justify the cost. High perceived value strengthens emotional attachment.

- Emotional Attachment: Emotional value forms when users perceive that the product's design and functionality are worth the investment, building pride and ownership, which motivates repair over replacement.

Q1.2: Are headphone companies supporting this preference through Design and product lifecycle strategies?

Mainstream Manufacturers:

- Prioritise design, robustness, and performance, which increases perceived value and justifies higher costs to consumers.

- This approach builds user attachment through product quality and aesthetics but neglects repairability.

- When a malfunction occurs, users feel frustrated by limited repair options despite strong emotional attachment to the product.

Repairability-first brands:

- AIAIAI offers self-assembly and modular customisation through which users can achieve technical familiarity, which lowers barriers to self-repair.

- Fairbuds prioritise modularity and ease of repair, promoting sustainability and product longevity. However, these products often lack the premium design, build quality, or advanced features that mainstream users expect, leading to a mismatch between perceived value and initial investment.

Main Takeaways -

- Repair Interest requires balancing premium design, choice of materials, and build quality with genuine repairability. Products must justify their cost while also being easy to fix, making sure that consumers feel both value and confidence in repairing rather than replacing.

- Headphones requiring self-assembly (like in the case of the AIAIAI TMA 2), may help with improving technical familiarity as well as instilling a sense of pride, ownership, and agency in the user, making them more likely to repair their headphones.

04

Repair Decision
Availability of Resources and
Fault Diagnosis

Questions explored in this chapter

RO2: Evaluating Existing Solutions for User-Driven Repair

Q2.1: What role do support tools (e.g., repair manuals, repair tutorial videos) play in improving the self-repair experience?

Q2.3: Where have these solutions succeeded, and where have have they fallen short?

This chapter provides a preliminary answer to Q2.1 in the context of availability and information coverage of support tools such as manuals and repair tutorials. Based on the answer to Q2.1, a preliminary answer to 2.3 can be gained. A complete answer to Q2.3 will be developed in the next chapter where product repairability and repair support material effectiveness will be assessed through analysis of Q2.2 and Q2.1, respectively.

4.1 Introduction

In chapter 1 and 2, it was established that repair willingness is dependent on consumer intrinsic factors like emotional attachment and perceived value as well as extrinsic factors like initial investment price. Assuming that these factors are influential enough for the consumer to consider a repair, the next set of factors to be considered are in the repair decision phase. This phase involves the financial and contextual factors that influence user-driven repair. Financial factors involve the cost of replacing parts, whereas contextual factors include warranties, the availability and access to spare parts (refer Appendix D) as well as repair support tools available to consumers such as manuals or tutorials.

This chapter will analyse most probable malfunction scenarios for headphones, which will form the basis for examining whether the information covered in manuals provided by brands like Fairphone, AIAIAI and Sony effectively address these scenarios. Accessibility of these manuals will also be considered while assessing their effectiveness. Understanding the external conditions that support or discourage repair is important to supporting informed repair decisions. Insights gathered in this chapter will help understand the barriers users phase that leads them to choose (or decline) to repair their devices despite being inclined to repair and can help identify areas that need improvement.

4.2 Malfunction Scenarios

Understanding malfunction scenarios is an important first step in evaluating the effectiveness of repair support and the feasibility of user-driven repair. By identifying what typically goes wrong with headphones, designers and manufacturers can better assess which issues are realistically addressable by users and which require professional intervention. This analysis not only helps prioritise which components should be designed for easy replacement, but also informs the development of targeted, practical repair support materials. Without a clear understanding of the types and frequency of malfunctions, repair guides and support tools risk being misaligned with real-world user needs, ultimately reducing their effectiveness, and discouraging repair behaviour. Publicly available statistics and data on headphone issues is limited due to the relatively low number of headphones brought in for repair at Repair Cafés. Interviews with Repair Café volunteers suggest that this is due to the lack of readily available spare parts and the relative complexity involved in repairing headphones. Therefore, data collected from various online resources (V-Trust, 2020; Wicked Cushions, n.d.; Shokz UK, 2024) and insights from interviews with repair café volunteers were used to formulate the most common headphone malfunction scenarios, presented in table 1.

Malfunction Scenario	Components Involved	Probability of Component Malfunction
Worn out Head/Ear Cushions	Ear Cushions	High
	Headband Cushions	High
Not Charging	Battery	High
	Charging Cable	High
	Charging Port	Medium-High
	Hinges	High
Mechanical Damage	Headband	Low
Audio Issues (Muffled audio, audio only from one side,etc.)	Connecting Cable	High
	Plug Connectors/Solder Joints	Medium - High
	Loose Screws/Components	Low - Medium
	Audio Driver	Low
Connectivity Issues (Bluetooth)	Pairing Software	High
	Bluetooth Module	Low
Buttons/ Touch pad not working	Button PCB	High
ANC (Active Noise Cancellation) Not working	Software Issue	High
	Bluetooth Module	Low
	Microphone Cables	Low

Table 1: An overview of the most probable malfunction scenarios for headphones in decreasing order of frequency (Top to bottom)

This study will focus on the top four malfunction scenarios identified based on frequency of user-reported issues:

• Worn-out ear and head cushions
• Charging issues
• Mechanical damage (e.g., broken hinges)
• Audio issues (e.g., Sound only from one side, no sound, muffled audio)

From Table 1, it becomes clear that while some of these issues, such as mechanical damage and worn-out cushions, are visually apparent and relatively easy for users to identify and diagnose, others are more complex. Charging and audio-related issues may arise from multiple underlying causes. For example, charging problems could result from battery degradation, faulty charging ports, or damaged charging cables. Similarly, audio issues could be caused by problems with the audio cable, internal connection points, or in rare cases, driver malfunction.

4.3 Repair Support Availability

To assess how well headphone brands support users in addressing these common malfunctions, this section presents a comparative study of selected headphone models (Sony WH1000XM5, Fairbuds XL by Fairphone and the AIAIAI TMA 2) and analyses the availability and information coverage of their repair materials (Table 2). This includes an evaluation of the type, depth, and accessibility of repair documentation such as manuals, visual guides and video tutorials. The aim is to determine how effectively each brands' support ecosystem equips users to repair the top four malfunctions examined in Table 1. Generally, physical manuals provided by companies upon the purchase of the product are discarded as users find no immediate use for them. In that respect, Table 2 showcases how companies like Fairbuds and AIAIAI have made major strides in making the repair process more accessible through comprehensible resource availability in the form of digital manuals and short form videos. In addition to this, they cover the replacement of most of the critical components mentioned in table 1. However, they fall short when it comes to one factor - Fault diagnosis, which will be explored in the next section.

Headphone Model	Availability	Includes	Components Covered	Excludes
Sony WH1000XM5 *Sony WH1000XM5s Professional repair manual (encompass, n.d)*	• Only available to licensed repair professionals	• Servicing notes (e.g., unleaded solder, battery caution) • Repair/replacement procedures for battery and main circuit board • Limited troubleshooting (reset, Bluetooth checks) • Basic specifications and accessory list • Model identification and serial checking	• Ear pads • Circuit boards • Cable connector • Batteries	• No circuit diagrams/ schematic • Specialised tool list • Spare parts catalog with part numbers • Disassembly guidance for headband components • Comprehensive troubleshooting or diagnostic guide
Fairbuds by Fairphone *Fairbuds XL Headband repair tutorial (Fairphone support, n.d)*	• Publicly available on iFixit and Fairphone's official website	• Step-by-step repair instructions with video tutorials • List of tools required • Handling and care • Limited troubleshooting via FAQs	• Ear and Head Cushions • Battery • Connector Cables • Headband • Headband Hinges • Driver Enclosure	• Offers a diagnostic application but falls short in offering advanced customisation and a seamless user experience.
AIAIAI TMA 2 *AIAIAI repair manual (AIAIAI.audio, n.d)*	• Publicly available on AIAIAI's official support page	• Visual guides and Usage instructions for modular components (e.g., H10 headband, S10 speakers) • Spare parts sourcing info • Tools required	• Ear Cushions • Battery • Connector Cables and Headband (Integrated) • Driver Enclosure	• Offers an online FAQ, but covers only a narrow range of topics (bluetooth problems, component compatibility, etc.)
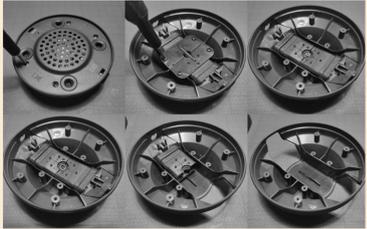
Table 2: Overview of repair support material availability and information coverage

4.4 Diagnosis: The Missing Piece

The process and results of a comprehensive diagnosis plays a major role in the repair decision process, particularly when consumers are considering user-driven repairs. Both Fairbuds XL and AIAIAI TMA-2 have made efforts to support users through most of the repair process through modular designs, making it easy to replace malfunctioning parts. They also provide resources such as repair manuals and video tutorials to assist users in making repairs. The question that remains unanswered by these support tools is - How do I know which part is causing the issue? Or Which part should I replace? Fault diagnosis is often the most time consuming and difficult part of the repair process (refer Appendix E), yet it remains relatively unsupported in the current repair support ecosystem. Simply understanding a product's failure can support the consumer's repair intentions (Van Den Berge et al., 2023b). Many users may face difficulties in identifying the exact cause of the issue, and this uncertainty can lead to frustration and in some cases, abandonment of the repair process altogether.

4.5 Current Solutions to Diagnosis

4.5.1 Diagnostic Applications

While AAIAI and Sony do not provide diagnostic applications, Fairphone provides a dedicated diagnostic app for its Fairbuds XL model. This app is designed to help users troubleshoot certain issues, such as connectivity problems or device malfunctions. The diagnostic app offers basic functionality but is not comprehensive in identifying faults. It mainly performs a limited set of functions, like checking the connection status or battery health, but struggles to accurately assess the condition of the battery or provide actionable insights on more specific faults (e.g., faulty audio or damaged ports). The application scores a 2.7/5 on the Application store (refer Appendix F) and users have reported that the app's diagnostic features are rudimentary (App Store Review, 2024). Furthermore, requiring users to download dedicated applications for infrequent tasks like repair or diagnosis can hinder accessibility. Most users are unlikely to install and retain an app they might only need once a year, making vital repair information less readily available when it's needed.

4.5.2 Community Forums

Platforms like iFixit and various online forums offer user-generated solutions and repair guides. These resources can be helpful in diagnosing issues, especially when users share their experiences and troubleshooting steps (refer Appendix F). However, as with most community-driven platforms, the accuracy of these guides varies, and response times can be slow. Users often must wait for other community members to respond, which can be frustrating if the issue is urgent. Since these solutions are not officially endorsed by manufacturers, there can be trust issues regarding their reliability.

4.5.3 Customer Service

Generally, headphone companies provide customer service for diagnosis, but users need to ship the product to an authorised service centre for official evaluation. In case of warranty expiry, repair service fees generally include diagnostic costs, materials, and repair charges. A successful diagnosis is not guaranteed to result in repair, but in cases where the product is not covered by warranty, users must pay for the diagnostic service even if the product is not repaired (Fairphone, Support. 2024). The customer service process also includes costs for shipping (both ways), which can deter some users from seeking official repairs.

4.6 Chapter 4 Takeaways

RO2: Evaluating Existing Solutions for User-Driven Repair

Q2.1: What role do support tools (e.g., repair manuals, repair tutorial videos) play in improving the self-repair experience?

- Support tools are important enablers for users attempting self-repair.

Q2.3: Where have these solutions succeeded, and where have they fallen short?

Successes:

- Fairbuds XL and AIAIAI TMA-2 have publicly available instructions and guides for replacing common malfunctioning parts (e.g., Battery, hinges, etc.). They also provide tool lists and sourcing guidance, making it easier for users to prepare before a repair attempt.

Shortcomings:

- Users struggle to determine which part needs replacement due to unsupported diagnosis solutions, leading to repair abandonment.

- Requiring users to download dedicated apps for diagnosis and repair (e.g., Fairphone's diagnostic app) discourages access, especially since most users are unlikely to install an app they will only use once a year.

- Support materials for diagnosis and repair lack integration. Resources are scattered across manuals, apps and websites rather than centralised in a single, user-friendly platform.

Main Takeaway:

- For support tools to be most effective, they must be readily accessible in a centralised platform and effectively cover the most relevant information (e.g., fault diagnosis for most common issues, comprehensive repair guides for these issues and guides to access tools and parts needed for the repair).

05

Repair Action
Ease of Disassembly, Task Complexity
and Support Material Effectiveness

Questions explored in this chapter

RO2: Evaluating Existing Solutions for User-Driven Repair

Q2.1: What role do support tools (e.g., repair manuals and repair tutorial videos) play in improving the self-repair experience?

2.2: How have modular and repairable designs impacted self-repair experiences?

2.3: Where have these solutions succeeded, and where have they fallen short?

This chapter will fully answer the questions under RO2. Disassembly maps and task specific studies will help answer Q2.2 with respect to how modular designs affect repairability. Q2.1 will be answered through studying the cognitive experience that users engage with during a repair process, using standard repair support tools discussed in earlier chapters. These studies will ultimately be used to identify shortcomings and opportunities under each of these topics, thus providing an answer to Q2.3.

5.1 Introduction

Once a user decides to repair a product, they encounter the technical challenges of disassembly, task complexity, and comprehension challenges related to the effectiveness of support materials. This phase will analyse technical factors through disassembly case studies on three headphone models: Fairbuds XL, Sony WH-1000XM5, and Sony MDR-RF820R. Each model presents unique challenges in repairability due to their year of make, design intentions and assembly techniques. This chapter also connects to the last chapter in terms of the repair support resources and will explore more user cognitive factors in the context of repair support tools discussed in chapter 4 and how it influences the user's tendency to successfully complete or abandon the repair process.

5.2 What are Priority Components?

Premium active noise-cancelling (ANC) headphones in the 200–400 Euro price range are generally expected to last beyond four years with proper care (Bhatia et al., 2024). However, their realistic average lifespan tends to fall between two to four years, mainly due to limitations in battery technology and the complexity of internal electronics. Considering this, we can assess each component's expected lifespan relative to this 2–4-year product lifespan to identify which parts are most critical for maintenance or replacement.

A priority component is defined by two criteria:

1. **High Functional criticality** — important to the core operation and user experience of the device

2. **Low - Medium Lifespan** — expected to degrade or fail before 4 years.

Components meeting both conditions are more likely to affect the long-term usability of the product and are therefore classified as priority components. Priority components can further be classified into Class A and B (Table 3) to establish a hierarchy of priority, based on differing lifespans.

Label	Function Criticality	Lifespan
A	High/Very High	Low (1 - 2 Years)
B	High/Very High	Medium (2 - 3 Years)

Table 3: Classification of priority components

Understanding common failure modes is important for focusing repair efforts on the components most likely to cause issues. Therefore, building on the top 4 malfunction scenarios identified in table 1, we analyse the lifespan and functional criticality of headphone components, illustrated in Fig 12. Table 4 summarises priority component identification and classification to guide repairability improvements.

Fig 12: (Dismantled View of the Sony WH1000XM3, eBay, n.d.)

Ref.	Component	Function	Function Criticality	Lifespan (vs 2-4 Years)	Priority Component Label
1	Ear and Head Cushions	• Comfort, seal for sound and noise isolation. • Provides comfort across the head.	High	Low (1 - 1.5 years)	A
9	Battery	• Powers electronics in wireless mode.	Very High	Low (1.5- 2 years)	A
7	Audio Connector Cable (left to right ear cup)	• Transfers audio and electrical signals between ear cups	Very High	Low (1.5- 2 years)	A
3	Headband Hinges	• Connect the headband to the ear cups. • Allows for foldability for portability • Adjustment to account comfort.	Very High	Low (1 - 2 Years)	A
8	Charging and Audio Ports	• Enables charging and wired listening.	High	Medium (2 - 3 Years)	B
10	Audio Connector Connection points	• Solder/plug points connecting audio cables to the PCB.	Very High	Medium (2 - 3 Years)	B
2	Headband	• *Connects the two ear cups and distributes weight across the user's head.*	High	High (3 + Years)	Not a priority component
4	Audio Driver	• Converts electrical signals into sound.	Very High	Very High (5+ Years)	Not a priority component
5	Microphones + Cables	• Carry audio for calls/ ANC features.	Medium	High (4+ Years)	Not a priority component
6	Bluetooth Module	• Enables wireless audio connectivity.	Medium	Medium (2 - 3 Years)	Not a priority component

Table 4: *Headphone component priority assessment table*

5.3 Disassembly and Task Complexities

Improving access to the priority components mentioned in the previous section can help increase the user's willingness to follow through with the repair process they had started. To achieve this, headphone designs must be analysed in terms of two factors -

5.3.1 Ease of Disassembly

This is an objective factor that refers to the sub-assemblies, layers and fasteners that must be removed to access specific components. For example, in the Sony WH-1000XM5, accessing the hinges requires full ear cup disassembly and headband disassembly. The disassembly maps framework (De Fazio et al., 2021) is a tool that will be used to visualise and analyse this aspect (Appendix G). The location and accessibility of priority components within the headphone architecture can help identify shortcomings in headphone design frameworks in the context of repairability.

5.3.2 Task Complexity

This is a subjective factor based on the repairer's technical knowledge and experience. This factor provides a qualitative view of disassembly that is not offered by disassembly maps. For example, removing a battery connector cable seems simple in the context of a disassembly map as it is stated as a single step process. However, the information about the delicate nature of removing the connector in a single direction is left out and needs to be considered for a low to medium tech-savvy user, who might not have experience with performing these tasks.

The following pages will cover the disassembly and task complexities for the Sony WH1000 XM5s, the Sony MDR RF820Rs and the Fairbuds XL.

5.3.3 Sony WH-1000XM5

The most recent headphone release in Sony's most popular headphone product line will provide insights into the most recent design practices in the repairability context. The repair complexity is covered in table 5. The disassembly map for this model can be found in Appendix G.

Fig 13: Sony WH1000XM5 dismantled view

Component No	Component	Task Description	Tools Required	Task Complexity
0 & 28	Ear cushions	• Held by 6 snap fits, requires careful prying	Prying tool	Easy - Medium
52	Headband Cushion	• Requires full dismantle of headband through cutting wires, removing hinges from earcup removing hidden screws.	Ph#0 and Ph#00 Screwdriver, Spudger, Tweezers Soldering Iron, Cutting Pliers	Difficult
57 & 28	Headband Hinges	• Requires disassembly of ear cup and removal of cushions, through removal of multiple hidden screws and adhesive layers • Wires were channeled through the hinges and had to be cut for full access	Ph#0 and Ph#00 Screwdriver, Spudger, Tweezers, Cutting Pliers	Difficult
9 & 36	Connector Cables	• Embedded within the hinge and headband. Has to be cut and resoldered	Ph#0 and Ph#00 Screwdriver, Spudger, Prying tool, Tweezers, Cutting Pliers, Soldering Iron	Difficult
35	Battery	• Adhesive-sealed, requires spudger to pry out safely, but was not a safe option • Battery connector had to be removed delicately	Ph#0 and Ph#00 Screwdriver, Spudger, Prying Tool, Tweezers	Medium - Difficult
20 & 45	Ports	• Hidden beneath gasket layers • Ribbon connectors require delicate removal	Ph#0 and Ph#00, Prying Tool Screwdriver, Tweezers	Medium - Difficult

Table 5: *An overview of task complexities in disassembling the Sony WH1000XM5s*

5.3.4 Sony MDR-RF820R

The Sony MDR-RF820R has a simpler design, which allows us to assess if fewer components lead to easier repairs compared to newer, more complex models like the XM5s. The repair complexity is covered in table 6. The disassembly map for this model can be found in Appendix G.
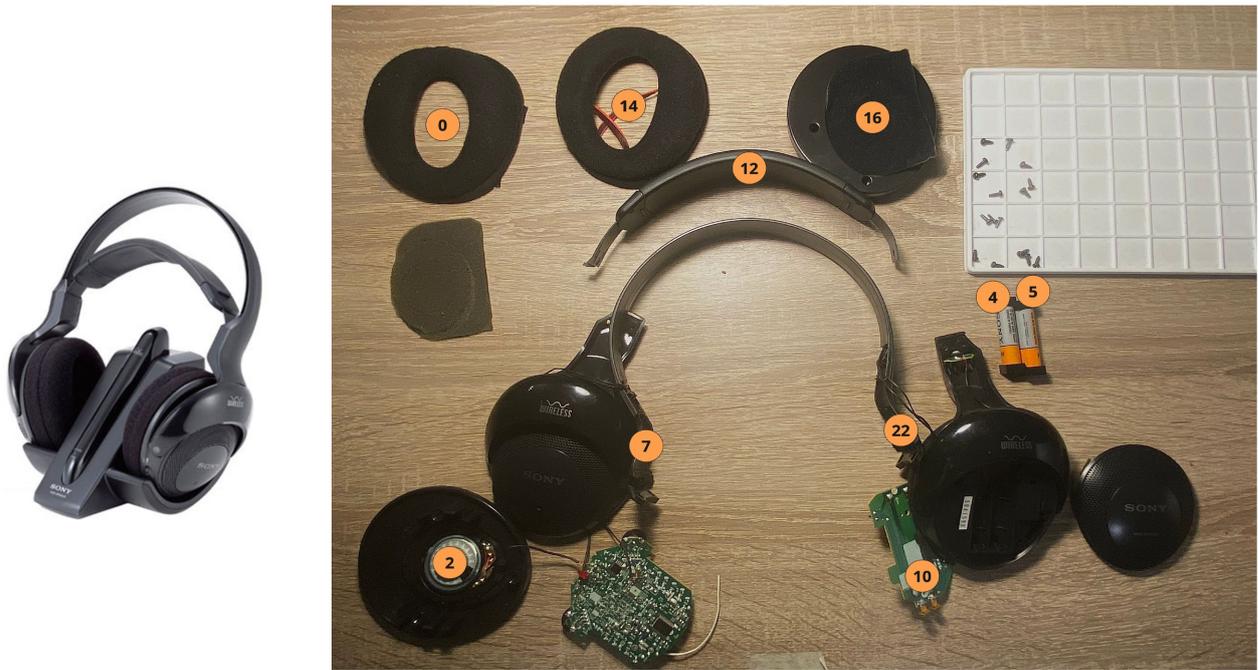
Fig 14: Sony MDR RF820R dismantled view

Component No	Component	Task Description	Tools Required	Task Complexity
0 & 14	Ear cushions	• Pulled out from small crevice, risks damage to the cushion	Tweezers	Medium - Difficult
12	Headband Cushion	• Headset adjuster required full dismantle of headband, through hidden screws, prying and removal of small components like springs	Ph#0 and Ph#00 Screwdriver, Spudger, Tweezers	Difficult
7 & 22	Headband Hinges	• Requires disassembly of ear cup, removal of cushions and the headband through removal of multiple hidden screws. • Wires were channeled through the hinges and had to be cut for full access	Ph#0 and Ph#00 Screwdriver, Spudger, Tweezers, Cutting Pliers	Difficult
7 & 22 (Embedded within Hinges)	Connector Cables	• Embedded within the hinge and headband. Wires have to be cut and resoldered	Ph#0 and Ph#00 Screwdriver, Spudger, Prying tool, Tweezers, Cutting Pliers, Soldering Iron	Difficult
4 & 5	Battery	• Push-button release snap fit cover for easy removal	Hand	Easy
10	Ports	• Soldered onto PCB, requires desoldering	Ph#0 and Ph#00 Screwdriver, Prying Tool, Tweezers, Soldering Iron	Difficult

Table 6: *An overview of task complexities in disassembling the Sony MDR RF820Rs*

5.3.5 Fairbuds XL by Fairphone

A benchmark for repairable design, that features modularity and ease of disassembly will allow us to understand current repair friendly design decisions and help identify opportunities for improvement. The repair complexity is covered in table 7. The disassembly map for this model can be found in Appendix G.

Fig 15: Fairbuds XL dismantled view

Component No	Component	Task Description	Tools Required	Task Complexity
0 & 21	Ear cushions	• A simple twist to unlock mechanism. However, twisting direction was unclear.	Hand	Easy
18	Headband Cushion	• Wrapped around the headband like a sleeve. Could easily be removed by hand	Hand	Easy
5 & 26	Headband Hinges	• Easy to access, but involved multiple steps compared to other priority components	Ph#0 and Ph#00 Screwdriver	Easy - Medium
19	Connector Cable	• Could be unplugged from the earcup modules and removed after removing headband cushions, although hinges get in the way.	Hand	Easy
10	Battery	• Accessible by hand , via a friction-fit cover	Hand	Easy
39	Ports	• Easily Identifiable upon unscrewing the cover, but ribbon connectors, requires care for safe disconnection	Ph#0 and Ph#00 Screwdriver, Tweezers	Medium - Difficult

Table 7: An overview of task complexities in disassembling the Fairbuds XLs

5.4 Safety Considerations

Manufacturer's official statement on self-repair is to discourage consumers from attempting repairs themselves as they believe it poses a safety risk. This is also the reason why repair support materials are not easily accessible to the public. In the case of professional repair, companies prefer to replace the product entirely if a repair involves opening the device. Even then, replacement is often the preferred option due to the cost, labour and safety issues involved in disassembly, diagnosis, repair, and re-assembly.

When designing consumer electronics like headphones, a balance between component accessibility for repair and user safety during disassembly is important to consider. Disassembly involves several safety considerations and a tiered approach based on component lifespan and associated hazards is logical. Priority components with shorter lifespans or higher wear (Class A, e.g., batteries, cushions, main audio connector cables) should have easier and safer access for repair or replacement. More durable priority components (Class B, e.g., charging ports and audio connections) have longer lifespans, making accessibility slightly more limited with strict safety measures, justified. For example, when accessing electronic Class B components like ports and soldered audio cable connections in wireless models, a complete disconnection of the power source (battery) is mandated as contact with these components with the battery still connected poses a safety hazard and may even cause more damage during repair due to short circuiting (Diekmann et al., 2018). In the case of the Sony WH1000XM5s, the lithium-ion batteries were glued into a socket and required to be pried out (Fig 16), which was not a safe option as Lithium-ion batteries pose electrical, thermal, and chemical risks if accidentally punctured or pried out using the wrong tools (Gerlitz et al., 2022). It is important for manufacturers to make sure easy access doesn't increase risk by providing clear instructions or design interventions, enabling safe removal of hazardous parts with minimal or easily accessible tools (PMC, 2021).

Fig 16 : Removal of battery from the Sony WH1000 XM3 (Similar to the XM5) (iFixit, 2022)

5.5 Visual Clutter

All the disassemblies revealed complex circuit boards, with intertwined ribbon cables, glue, and hidden fasteners. When consumers see a product that appears complex due to numerous parts, intricate designs, or unfamiliar technology (Fig 17), they may intuitively feel less capable of performing repairs. This visual complexity can create a psychological barrier, leading them to avoid even attempting repairs. (Lundberg et al., 2024). If a product looks straightforward (perceived as less complex) and is composed of easily identifiable and separable parts (like furniture presented in Fig 18), it encourages users to believe they can successfully make repairs. That is, the higher the self-evaluated skill to repair, the higher the chances that one would try to repair the product. (Lundberg et al., 2024).

Fig 17: Fairbuds XL Main PCB (Android Authority, n.d)

Fig 18: Ikea Furniture Assembly (Ikea, n.d)

5.6 Support Material Effectiveness

Publicly available repair support materials, such as manuals and video tutorials, are important elements in enabling users to perform repairs on their own. The availability of these resources positively influences users' decisions to repair their headphones. However, the true effectiveness of these materials can only be fully realised during the repair action phase, as the clarity, engagement, and guidance play an impactful role in the repair experience.

In this section, we explore how the clarity of instructions, feedback mechanisms and tool recommendations contribute to or hinder the repair process.

5.6.1 Overcoming the Intimidation of Starting the Repair

The initial step in any repair can be intimidating, especially when users face uncertainty about their ability to succeed. The human brain is wired to enjoy engaging in challenges (Deterding et al., 2022). However, the tendency to take on challenges reduces when there is considerable risk involved, such as causing further damage or voiding the warranty (Bayraktaroglu & Idemen, 2024b). This fear is amplified by the first impression of repair support formats. To improve self-repair tendencies, support materials must include clear confirmation points and detailed visuals to be truly effective (Sandez, Pérez-Belis, et al.,2023). For example, the Sony repair manuals (Fig 19) are information dense with unclear outline images that might increase the intimidation factor. On the other hand, Fairbuds XL offers video tutorials to replace components, which has been observed to be a more effective method to increase engagement and reduce intimidation (Sandez, Pérez-Belis, et al., 2023). Furthermore, traditional repair materials do not offer graduated guidance. This involves breaking down the process into manageable chunks to provide a quick overview before the actual repair guidance (Wood, Bruner, & Ross, 1976). A clear, supportive starting point is necessary for repair support materials to help users overcome the psychological inertia to confidently start their repair journey.

5.6.2 Lack of Information, Feedback and Guidance

Once the repair has begun, users often experience confusion due to a lack of task clarity in the support materials. Research on instructional design highlights the importance of feedback in learning and task completion (Mayer, 2009). Specifically, providing timely and relevant feedback improves user engagement and reduces errors (Sweller, 2010). Inadequate feedback is particularly frustrating when dealing with delicate components. For example, the static Sony WH-1000XM5s PDF manuals lack the means to provide these confirmation points, making it difficult to gauge progress. In contrast, the Fairbuds XL uses video tutorials that provide clear, visual and narrative guidance on how to replace the battery, cushions and other priority components. The user-friendly and modular nature of the product helps with this. However, even these videos can fall short if they don't explicitly confirm task completion at each step. These videos can also fall short if lacking detailed close-ups, clear narration, or the ability to pause and inspect specific steps. Users might also feel discouraged by the time taken to accomplish certain tasks. In these scenarios, progress indicators could be employed to allow users to visually gauge their progress, inducing confidence and engagement (Nielsen., 1993, p. 52).
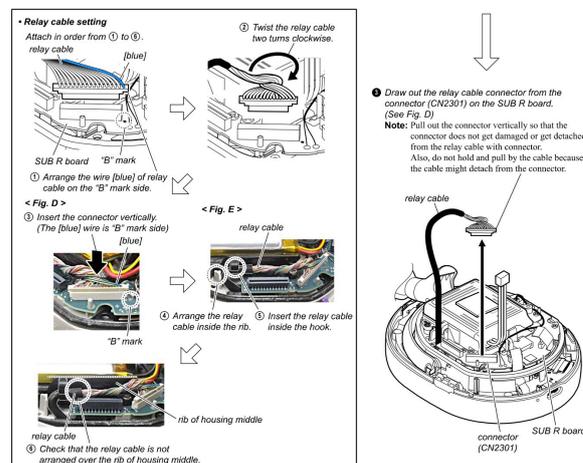
Fig 19: An excerpt from the Sony WH1000XM5 service manual (encompass, n.d)

5.7 Chapter 5 Takeaways

Q2.1: What role do support tools (e.g., repair manuals and repair tutorial videos) play in improving the self-repair experience?

Support tools can improve repair experiences, especially when dealing with unfamiliar fasteners or internal layouts. However, the format of information delivery plays an important role. Video tutorials are generally more effective than static images, especially when they provide close-ups, confirmations of completed steps and graduated guidance.

Q2.2: How have modular and repairable designs impacted self-repair experiences?

- Modular design in the Fairbuds XL improves the repair experience by allowing tool-free access to most class A priority components such as the battery, ear cushions, and audio connector cables.

- On the other hand, Sony models rely on snap-fits, adhesives, or internal routing, making even Class A components like headband or ear cushions harder to access, sometimes requiring full headband disassembly or wire cutting.

- Designs must achieve a balance between safety and accessibility. While Class A components should be easy to access, Class B components like ports and cable plugs to the PCBs require limited, safeguarded access, ideally only achievable after battery removal, to reduce electrical safety hazards.

Q2.3: Where have these solutions succeeded, and where have they fallen short?

Successes:

- Fairbud's modular design and video support tools outperform Sony and AIAIAI, providing a smoother, more transparent repair experience.

- Tool-free access to Class A components in the Fairbuds sets a benchmark for user-friendly repairability.

Shortcomings:

- **Visual Clutter** - Visible circuitry results in visual clutter. This leads to a psychological barrier, discouraging users from attempting repairs.

- Hinges are class A priority components, but their designs consistently pose repair challenges across all models analysed, indicating an opportunity area for improvement.

- Removal of batteries in the case of the Sonys posed a safety risk due to prying needing to be done to lift it out of the socket.

- Lack of clear diagnostic guidance and confirmation points in support materials lead to user confusion and discouragement.

- Static and unclear outline images in manuals increase user intimidation and negatively affect comprehension.

- Video tutorials, while helpful, lack sufficient detail, close-ups, or clear confirmation of completed steps, reducing their effectiveness.

Main Takeaways:

- A tiered access approach to priority components - easy access for class A components (e.g., cushions, audio cables, hinges), and relatively restricted, safeguarded access for class B components (e.g., charging and audio ports) is necessary to balance safety with repairability.

- Though Fairbuds lead in modular design, opportunities remain, especially around tool-free hinge access.

- Future designs should prioritise visual clarity, user feedback, and graduated instruction formats in manuals and video tutorials to support users across technical skill levels and reduce intimidation during self-repair.

06

Project Guidelines and Ideation
Establishing a design framework and developing design directions

Questions explored in this chapter

RO3: Understand ways to trigger and sustain user engagement with repair:

Q3.1: How can we incentivise repair for the average headphone user?

Q3.2: How can we make repair information easily accessible for confident decision-making?

Q3.3: How can we make the process of repair non-intimidating and engaging?

This chapter sets the stage for answering these questions through introducing a framework to guide solution and concept development. Research into emerging technologies and analysis of their advantages and disadvantages can help create a clear path for the ideation process. Identified technologies and derived guidelines will help create a consolidated design framework. This framework will help in identifying the core necessities (needs) , ideal experience factors (wishes) and the means (selected technologies) that will be used to brainstorm concepts (that will answer Q3.1,Q3.2 and Q3.3) focused overcoming specific challenges within the respective phases of the repair process.

6.1 Introduction

This chapter covers the transition from research to design by first establishing a set of project guidelines that reflect user needs, motivations, and challenges identified throughout the repair journey (Repair Interest, Repair Decision and Repair Action). These guidelines, paired with a technology feasibility study will serve as a foundation for idea generation by offering design directions for the development of meaningful, repair friendly design solutions. Through co-creation and brainstorming, the chapter then explores design concepts that aim to incentivise repair behaviour, improve accessibility, reduce intimidation, and sustain long-term user engagement with the repair process.

6.2 Project Guidelines

The main takeaways at the end of every chapter covered so far, were used as the basis to translate the requirements arising from the identified opportunities in each repair phase in the form of needs and wishes (Table 8).

Chapter	Phase	Main Takeaways	Needs	Wishes
3	Repair Interest	• Repair interest requires balancing premium design, choice of materials, and build quality with genuine repairability - products must justify their cost while also being easy to fix, making sure that consumers feel both value and confidence in repairing rather than replacing.	• Perception of quality and durability from the outset	• Materials and finishes that look premium, justify a high price point , but are still serviceable • Create a sense of pride, ownership and agency through self assembly and visible repair features
4	Repair Decision	• For support tools to be most effective, they must be readily accessible in a centralized platform and effectively cover the most relevant information (Ex: Fault Diagnosis for most common issues, comprehensive repair guides for these issues and guides to access tools and parts needed for the repair).	• • Centralized and easy to access point for repair resources • Diagnostic guidance for top 4 headphone malfunction scenarios • Clear indication of what tools and parts are needed for a repair	• Context-aware support that adjusts based on issue and user competence • A decision making agent to decide between self repair and repair service based on user competence profile • Interactive support material search tools and real-time support bots
5	Repair Action	• A tiered access approach to priority components - easy access for Class A components (e.g., cushions, audio cables, hinges), and relatively restricted, safeguarded access for Class B components (e.g., ports, PCB connections) - is necessary to balance safety with repairability. • Future designs should prioritize visual clarity, user feedback, and graduated instruction formats in manuals and video tutorials to support users across technical skill levels and reduce intimidation during self-repair.	• Class A priority components should be tool-free and quickly swappable • Class B priority components should require safeguards. • Clear visual hierarchy in layout and disassembly steps • Step-by-step documentation with dynamic visual guides • Feedback mechanisms to help users assess progress or correctness • Instructions that adapt to experience level	• Custom repair walkthroughs using user profile or device symptoms • 2 way communication channels between user and support system to improve instructions on request. • Promote active disassembly of the product to instil a sense of agency and pride in the user post the repair

Table 8: An overview of project guidelines in the form of needs and wishes

6.3 Technology References

To study the feasibility of the proposed project guidelines, targeted research was conducted on a selection of emerging technologies (Table 9). The analysis considered both the opportunities and limitations of these technologies in relation to how they could realise the proposed design guidelines into a tangible solution. A detailed overview of each technology can be found in Appendix H.

Technology		Description	Advantages	Disadvantages
Modular Gateway Design (e.g., NextGen Energy Meter)		Isolates priority components into a single, user-replaceable module	• Simplifies disassembly • Reduces service dependency • Extends product life	• May increase product size • Waterproofing and sealing issues
Large Language Models (e.g., ChatGPT-4 Turbo)	 **ChatGPT-4 Turbo**	AI models providing intelligent repair dialogue and support	• Personalised repair help • Conversational guidance • Supports various user skill levels	• Needs verified data
Retrieval Augmented Generation (RAG)		Combines user queries with external sources for contextually accurate support	• Accurate, up-to-date answers • Dynamic troubleshooting • Reduces manual lookup	• Complex implementation • Requires high-quality data sources
Augmented Reality (AR)		Overlays repair instructions visually in real-time	• Hands-free guidance • Boosts confidence • Ideal for disassembly steps	• Needs device compatibility • High development time
Virtual Reality/Digital Twins (VR)		Immersive repair training environments for users or service teams and virtual replicas of devices that simulate performance and component status	• Safe learning space • Useful for technicians • Repeatable scenarios	• Requires VR hardware • Not suitable for live device repair • Expensive setup
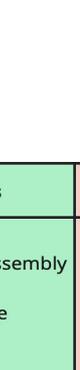
3D Printing		On-demand fabrication of replaceable parts (e.g., cushions, hinges)	• Reduces wait times • Enables local repair • Extends part availability	• Requires 3D printer access • Inconsistent print quality • Limitations to parts it can print (eg: batteries)
Visual AI Diagnostics		Uses images or video to detect damage or incorrect assembly	• Assists non-technical users • Quick status assessment • Works in apps	• Varies with image quality • Still a maturing technology
NFC/QR Code-Based Part Identification		Tags parts with scannable codes to guide replacements or tutorials	• Speeds up part identification • Simplifies linking to resources • Streamlines logistics	• Adds production steps • QR codes can fade over time
Interactive Instruction Platforms		Digital repair guides with clickable steps, animations, or dynamic pathways	• Step-by-step clarity • Adaptive to user input • Reduces intimidation	• High learning curve • Device-dependent • Requires user to download an application and connect to bluetooth
IoT-Based Diagnosis		Sensors within the device transmit fault/health data to apps or cloud	• Automated issue alerts • Reduces guesswork • Early problem detection	• Raises privacy concerns • Sensors add hardware complexity
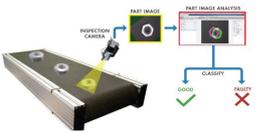
Table 9: An overview of advantages and disadvantages of emerging technologies

6.4 Consolidated Design Framework

Project guidelines were aligned with relevant emerging technologies to connect research insights with possible practical applications. Table 10 illustrates how the guidelines across the repair phases can be achieved through technologies discussed in Table 9. Together, they provide clear directions to explore repair-supportive solutions that are both technically feasible and user-centred.

Phase	Research Question	Needs	Wishes	Relevant Technologies
Repair Interest	**Q3.1: How can we incentivise repair for the average headphone user?**	• Perception of quality and durability from the outset • Create a sense of pride, ownership and agency through self assembly and visible repair features	• Materials and finishes that look premium, justify a high price point , but are still serviceable	• **3D Printing -** Users could 3D Print their own parts instIlling a sense of ownership and agency. • **Modular Gateway Design** - Designing components/assemblies as modules can help with intuitive self- assembly.
Repair Decision	**Q3.2: How can we make repair information easily accessible for confident decision-making?**	• Centralized and easy to access point for repair resources • Diagnostic guidance for top 4 headphone malfunction scenarios • Clear indication of what tools and parts are needed for a repair	• Context-aware support that adjusts based on issue and user competence • A decision making agent to decide between self repair and repair service based on user competence profile • Interactive support material search tools and real-time support bots	• **IoT-Based Diagnosis-** Simplifies and streamlines the diagnostic process by letting user identify the problem by just pressing a button • **RAG Systems -** Can access and provide repair information in a centralised knowledge base • **Interactive Instruction Platforms -** Can provide an dynamic interface that adapts to users needs during the diagnosis process • **LLMs (ChatGPT)** - Can provide interactive support based on user context • **Visual AI Diagnostics** - Can streamline diagnosis by effectively communicating problems using common tools like phone cameras • **NFC/QR Part Identification** - Readily accessible and visible touchpoint to access repair information
Repair Action	**Q3.3: How can we make the process of repair non-intimidating and engaging?**	• Class A priority components should be tool-free and quickly swappable • Class B priority components should require safeguards. • Clear visual hierarchy in layout and disassembly steps • Step-by-step documentation with dynamic visual guides • Feedback mechanisms to help users assess progress or correctness • Instructions that adapt to experience level	• Custom repair walkthroughs using user profile or device symptoms • 2 way communication channels between user and support system to improve instructions on request. • Promote active disassembly of the product to instil a sense of agency and pride in the user post the repair	• **Modular Gateway Design** - Can make parts easily accessible and swappable • **Augmented Reality (AR)** - Can provide guided interfaces with repair technicians who can mentor users through a repair process • **Digital Twins (VR)** - Can reduce the fear that users have with attempting a repair and making mistakes • **LLMs (ChatGPT)** - Can learn about user requirements and adapt instructions accordingly. • **Interactive Instruction Platforms -** Can provide an dynamic interface that adapts to users needs during the repair process

Table 10: *Consolidated table linking technologies with project guidelines*

6.5 Co-Creation Sessions

To ensure a diverse and thorough approach to ideation, two separate co- creation sessions were held. One, with students from TU Delft (Fig 20) and another with creatives at the Accenture Industry X office (Fig 21).

The sessions were based on the "How might we" framework (Faculteit Industrieel Ontwerpen, 2010). Each research question under Research Objective 3 was re-framed into a "How might we" (HMW) statement, aimed at promoting idea generation around the main challenges of each repair phase. Along with the HMW statements, "How can we" (HCW) statements were also used within each phase to guide and inspire concept generation. Each of these prompts were also provided with a user quote from an imagined persona, helping them to step into the shoes of the user and understand the issues they faced within each phase (Appendix I). This persona-based approach helped ground the ideas in real world scenarios, making the ideation process more user-centred. Additionally, semi-disassembled models of the Sony MDR RF820R and Fairbuds XL were used as physical props during the brainstorming sessions. These models allowed participants to directly interact with the components, explore repair possibilities, and visualise the challenges users might face when performing repairs.

Fig 20: Co-creation session at the Faculty of Industrial Design Engineering (TU Delft)

Fig 21: Co-creation session at the Industry X ID office (Eindhoven)

6.6 Ideation Clusters

The ideas generated were clumped based on similarity of ideas. This generated 12 different concept directions (Fig 22).

Fig 22: Ideation Clusters

Some of the concept ideas generated had different design intentions but could be achieved with the same design approach (Ex: "self-assembly to promote a sense of ownership and agency (1)" and "ease of disassembly (12)" and non- intimidating design (11)"). Based on this observation, concept directions were further clumped to give 8 concept directions. From the 8 directions, 3 were selected (Table 11, green boxes) based on reasons provided in table 11.

No.	Concept Direction	Contributing Original Concepts	Explanation	Selection	Reason
1.	Unintimidating, Intuitive Assembly & Disassembly	1,11,12	Combines self-assembly, non-intimidating design, and tool-less disassembly. Uses accessible fasteners and visual cues to make opening and reassembling simple and intuitive.	Yes	Strengthens emotional attachment and lowers repair barriers through hands-on familiarity and approachable design.
2.	Diagnosis Without Disassembly	7	Utilises RAG-based systems and the smartphone as a tool to run diagnostics without needing to open the headphone. Uses historical repair data and intelligent suggestions.	Yes	Addresses a major missing link in repair tools, as identified during fieldwork and literature study; improves repair success and confidence.
3.	Interactive Repair Guidance App	9	A mobile interface provides real-time, step-by-step repair support via animations, interactive cues, and part identification, guiding users through the process.	Yes	More engaging and feasible than AI chatbot (#4); provides a more controlled and visual experience that can be directly integrated into product use.
4	Personalisation (Aesthetic+ Functional)	3,6	**Aesthetics and comfort -** customisation (swappable parts) and age freindly materials (materials thar adapt to user during prolonged use). **Functional -** Adaptive audio tuning based on user preference. Increases emotional bonding and makes the product feel uniquely theirs.	No	While beneficial for user engagement, personalisation does not directly improve repairability or reduce barriers to disassembly. The adaptive audio feature is software-centric and adds complexity without contributing to the core goals of accessible, repair-friendly physical design.
5.	Education Platform	5	Community-based or institutional learning environments (repair cafés, school electives) to teach product care and repair.	No	Valuable support concept but peripheral to physical product design; more suited to service or strategic design intervention rather than an integrated product design approach.
6.	AI Repair Assistant	10	A chatbot-based assistant that answers repair questions in real time.	No	Conceptually redundant due to overlap with the more interactive and structured guidance app; offers less UX control.
7.	Upgrade + Financial Incentive Model	2,4	Modular upgrade program tied to a subscription model that ensures product longevity and ongoing support.	No	Business-focused strategy with limited relevance to core product design; would be better handled as part of a commercial roadmap.
8.	Standard toolkit, 3D-printed parts.	8	A custom-designed tool provided with the product to assist disassembly and reassembly, combines with support materials to allow users to generate spare parts as and when needed using 3D printing methods.	No	Low innovation potential; generic toolkits already exist, and this adds cost with marginal benefit. 3D printing is not yet widely adopted by average consumers and is limited to generating only mechanical spare parts like hinges.

Table 11: Overview of 8 Clumped Concepts

6.7 Chapter 6 Takeaways - Selected Concept(s)

RO3: Understand ways to trigger and sustain user engagement with repair:

Q3.1: How can we incentivise repair for the average headphone user?

Concept 1A (Fig 23): Through intuitive design and ease of assembly, the headphones will be presented to the user in disassembled state upon purchase (like an Ikea product). This would encourage the user to assemble the product themselves, thus promoting a sense of agency, pride, and ownership of their headphones. This would also improve their technical familiarity with the assembly and disassembly process, making repair and replacement of parts less intimidating in future, when a malfunction occurs.

Fig 23: Concept 1A- Intuitive Assembly/Disassembly

Q3.2: How can we make repair information easily accessible for confident decision-making?

Concept 2 (Fig 24): This concept introduces a Repair Assistance feature in a digital repair platform, employing a Retrieval-Augmented Generation (RAG) system for quick malfunction diagnosis. The RAG system will refer to a knowledge base that contains information ranging from Repair Cafe logs about commonly reported issues and company provided databases on common issues and faults identified to pinpoint the most likely causes. The system employs AI powered LLM models to learn about the user through the conversation and adapts to the user's contexts (e.g., technical competency, tools available) as the conversation progresses and recommends the best way forward for the repair (self-repair or DIY).
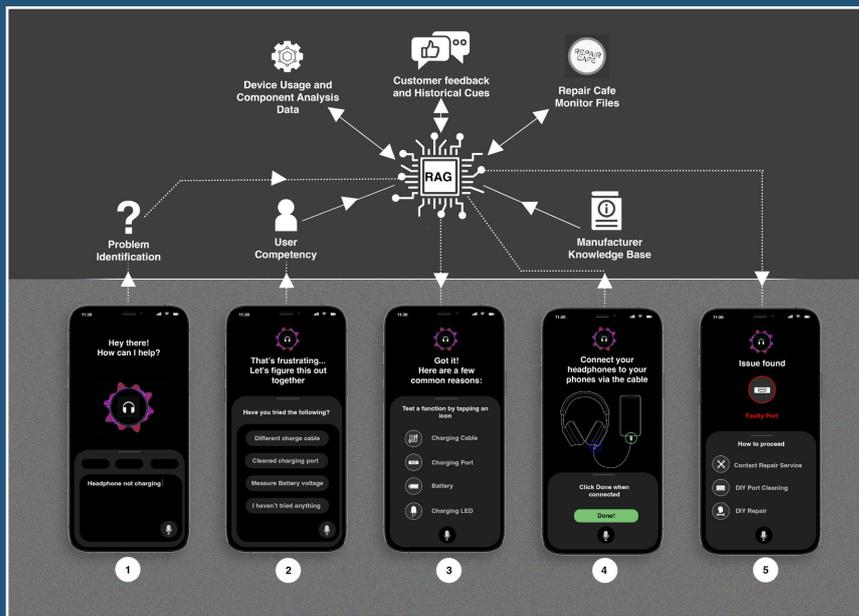
Fig 24: Concept 2- Malfunction diagnosis via RAG systems

Q3.3: How can we make the process of repair non-intimidating and engaging?

Concept 3 (Fig 25): Similar to concept 2, once a faulty component is identified, the digital platform will guide users through the repair process step by step, using dynamic 3D animations. AI powered LLM models will facilitate two-way interactions, allowing users to request instruction clarification, when unclear. Progress indicators will also be implemented to help users understand where they are in the process. Feedback mechanisms can also be implemented to instil confidence in users, assuring them that they are on the right path in the repair process.
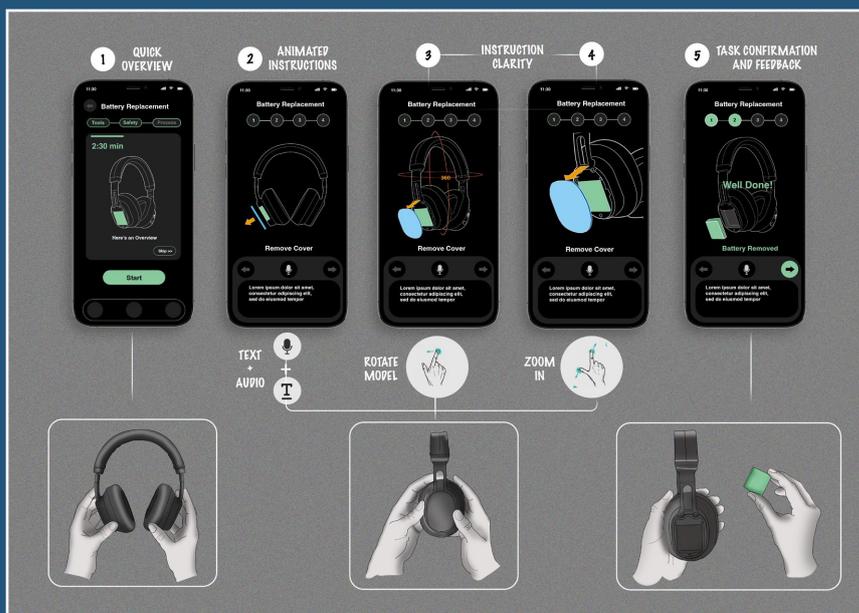
Fig 25: Concept 3- Guided interactive repair assistance

Concept 1B (Fig 26): To minimise visual clutter and present a less intimidating view, priority parts should be accessible and visible, with the components like the circuit board being hidden from view, thus reducing the visual clutter and intimidation factor. This design will also clearly indicate a level of disassembly intended for service professionals and protect novice users from safety hazards and potentially damaging internal components.
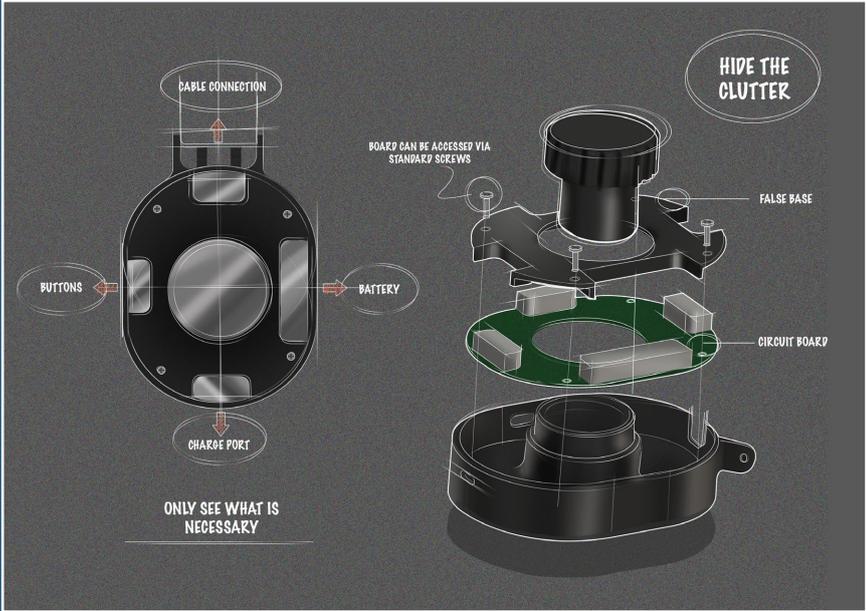
Fig 26: Concept 1B - Concealed circuitry for visual clarity

Concepts 1A,1B, 2 and 3 will be combined into a single holistic concept (Fig 27) - A repair friendly headphone accompanied by an AI powered diagnosis and repair digital platform. For this project, the scope is narrowed down to address the top 4 most frequent malfunction scenarios for headphones. Out of these, mechanical damage (broken hinges) and worn-out cushions are visually apparent malfunctions and will be left out for the diagnosis scenario. Therefore, diagnosis is only confined to audio and charging problems and repair guidance focused only on the class A (head and ear cushions, battery, audio connector cable, hinges) and class B priority components (audio and charging ports).
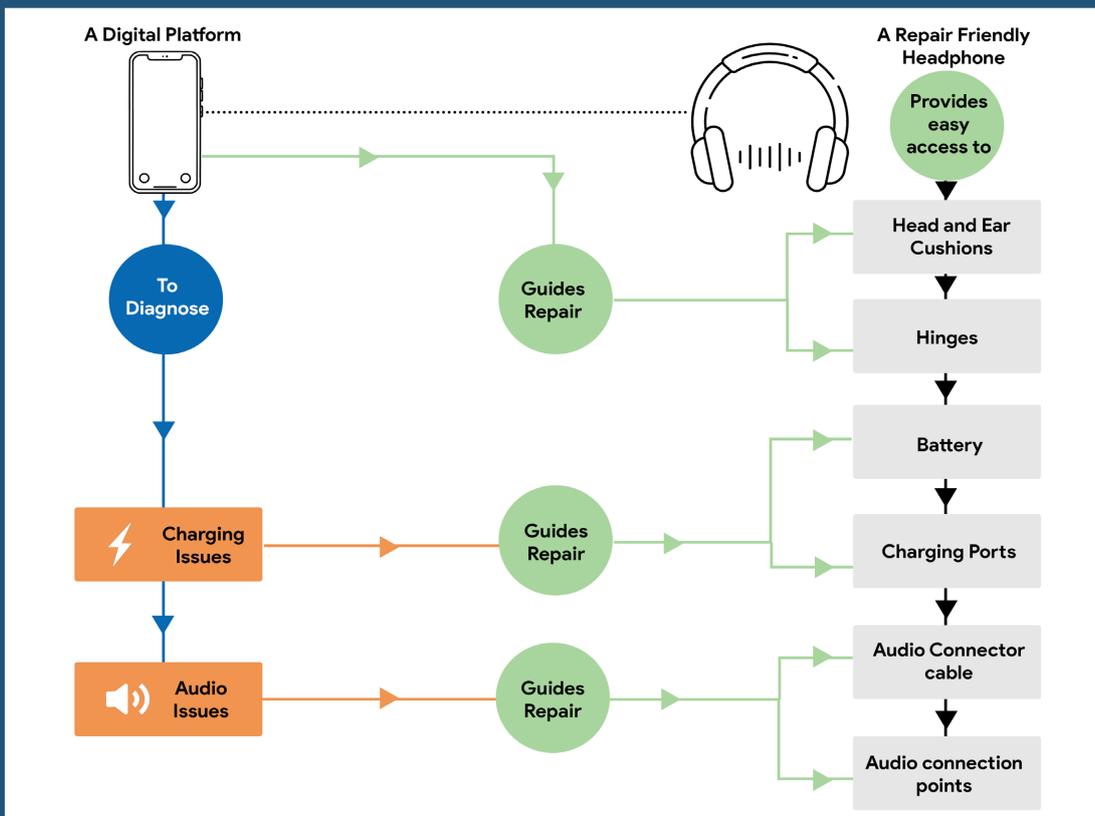
Fig 27: Combined concept and project scope

07

Concept Development
Iterative Prototyping

Questions explored in this chapter

RO3: Understand ways to trigger and sustain user engagement with repair.

Q3.2: How can we make repair information easily accessible for confident decision-making?

Q3.3: How can we make the process of repair non-intimidating and engaging?

This chapter aims to answer these questions by first developing a headphone design that encourages intuitive disassembly, making repair less intimidating and more accessible to novice and intermediate users (Q3.3). It will then explore an AI-driven digital platform with the purpose of delivering clear, personalised repair information to support confident decision-making (Q3.2). By combining insights from both these concepts generated by conducting preliminary user tests, this chapter aims to form a basis for a more integrated and holistic concept in the next chapter. This integrated concept will answer Q3.1.

7.1 Introduction

With the concept scope and guidelines established, this chapter will explore the iterative development of the concepts:

- A headphone designed for intuitive assembly and access to priority components
- A digital repair and diagnosis platform powered by AI and LLMs.

Each concept is developed separately in this chapter, focusing on meeting design requirements derived from the project guidelines such as accessibility, clarity, safety, adaptability and engagement. However, to capture a realistic user experience, early testing involved both concepts together to generate useful data for further development. A more integrated and holistic approach to the concepts chosen will be explored in the following chapters.

7.2 Concept Requirements

Taking cues from the design guidelines established in Chapter 6, concept requirements can be derived and divided among the headphone concept (Table 12) and the digital diagnosis and repair platform (Table 13) to better direct and guide the development process.

7.2.1 Headphone Design requirements

Category	Requirement	Approach
Assembly/Disassembly	Intuitive design	Use familiar mechanisms; avoid tools; hand-only assembly
	User-friendly assembly	Assembly at purchase should feel non-intimidating
Component Priority & Visibility	The arrangement of priority components will need to follow a tier-based approach. Parts need to be visible and accessible in the order of priority: Priority A -> Priority B -> Non Priority	Priority A Cushions, connector cables and hinges will be easily identifiable and removable by hand Priority B Audio and charging ports (visible only after removal of priority A components like the battery; requires one standard tool) Non priority components like the circuit board can be hidden to avoid visual clutter and user intimidation
Safety & Accessibility	Clear access cues	Priority A Components can be exposed to indicate clear serviceability Colour coding and visual cues can be imprinted on the device to communicate removal of priority B components.
	Safety measures	The architecture has to be designed so that priority B components (ports) can only be accessed after disconnection from the power source to prevent electrical safety hazards.

Table 12: Headphone Design Requirements

7.2.2 Digital Repair and Diagnosis Platform requirements

Category	Requirement	Approach
Accessibility	User awareness	Platform should be discoverable when needed, despite infrequent use
	Seamless entry	Clear entry points post-purchase (e.g., QR code, device prompt)
Context awareness	Adaptive instructions	Passive data collection to gauge user competence
	Two-way communication	Allow users to ask questions and get clarification
Information & interaction	Reliable knowledge source	Manufacturer-provided repair data
	Accessible diagnostic tools	Use available tools (phone camera, microphone, charging cable, headphone parts)
	Transparency & learning	Encourage users to participate in diagnosis to ease them into performing a repair.
Repair decision support	Informed recommendations	Provide enough information for users to be able to make confident decisions between DIY and service based repair based on user competency and task complexity
Instruction delivery	Balanced content	Mix dynamic visuals + text; avoid visual overload
Resources access	Tool/Part support	Provide pathways to access tools and replacement parts if user chooses to repair

Table 13: Digital repair and diagnosis platform requirements

7.3 Headphone Design Iterations

7.3.1 Overview of Iterations

The physical prototyping process began with an exploratory approach. The first 3 prototype versions (Fig 28) were explored with the aim of finding the best methods to provide simple, intuitive disassembly and easy access to the priority components. With each prototype, there were some explorations that worked and some that didn't work as intended or did not match the established concept requirements. For more information on the first 3 versions, refer Appendix J. Version 3 was used for preliminary user testing, which provided enough feedback to understand where optimisations can be made for Version 4 (Fig 29).
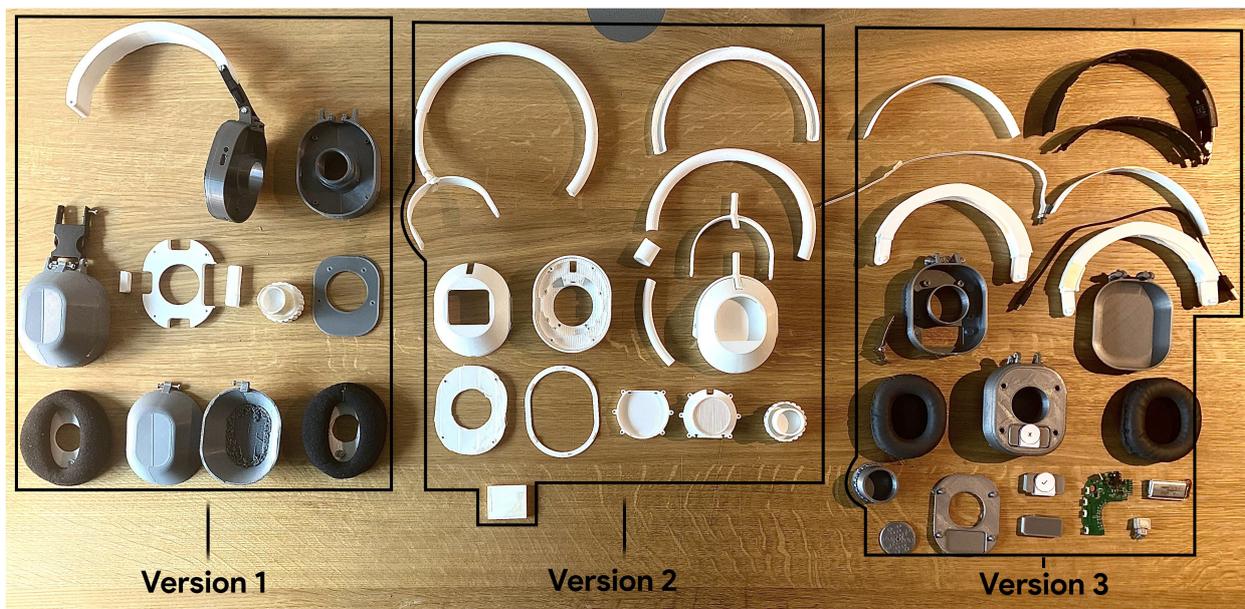
Fig 28: Early headphone prototypes (V1 – V3; Left to right), disassembled

7.4 Version 4 - A Tier Based Approach

PRIORITY A

Ear Cushions
Magnetically mounted onto earcups

Exposed after right ear cushion removal,

Battery
Accessible via a pull tab

2 screws exposed after battery is removed

Head Cushion
Wrapped around the headband and secured with velcro

Exposed after head cushion removal,

Audio Cable
Unplugs like standard USB-C from each earcup

Hinges
Hinge can be squeezed out to seperate from earcup

Headband cover slides sideways and hinge can be lifted out

No Tools Needed

PRIORITY B
Audio and Charging Ports

4 screws to remove back cover and unfasten ports

Ports can be slid out like SD Cards

1 Tool (Ph#00)

Fig 29: Tier based approach to designing the headphone framework

7.5 Digital Repair Platform

7.5.1 Overview of Platform Typologies

The digital platform development followed a slightly different process, but with the same user-centric approach focused on accessibility, adaptability and artificial intelligent support. 3 different platform formats that were explored to identify the most efficient method for delivering guided diagnosis and repair support.

Option 1 - Automated self-diagnosis application

A hardware-integrated system that connects to an application via bluetooth and uses internal sensors embedded within the headphone to run automated tests (Fig 30) on headphone components and generate repair scenarios.
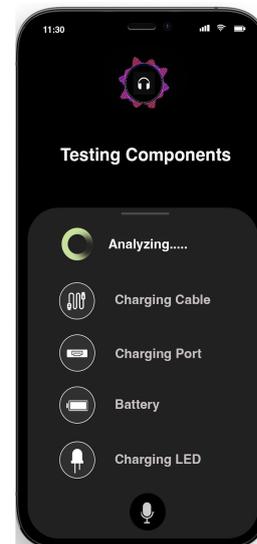
Fig 30: Automated self diagnosis application

Option 2 - Standalone bluetooth-connected application

An application that connects to the headphone via bluetooth and receives live data from it (Fig 31). Instead of using sensors to directly diagnose the problem, it will ask the user to conduct a series of tests and verify if these steps have been done properly (E.g.: removal of battery and replacement confirmations). Based on user actions performed on the device, the application sends confirmation and feedback every step of the way (refer Appendix J).
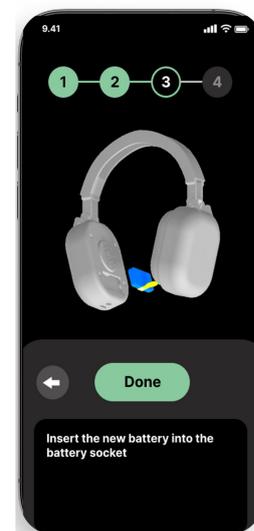
Fig 31 : Bluetooth connected application

Option 3 - AI Chatbot on messaging platforms (WhatsApp/Telegram)

A conversational AI assistant integrated into popular messaging platforms (Fig 32) that uses LLMs to guide users through diagnosis and repair processes in natural language.
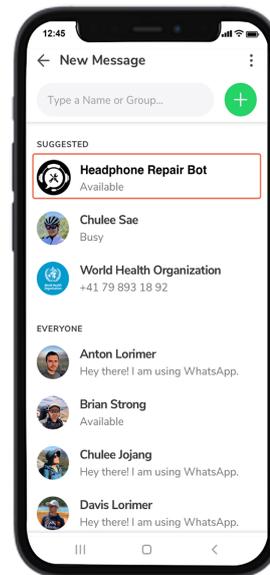
Fig 32 : Chatbot integrated into popular messaging platforms

For a detailed account of the advantages and disadvantages of each platform, refer to Appendix J.

Ultimately, the self-diagnosis application was rejected due to not meeting the requirement of actively involving the user in the diagnosis process, which was a core requirement. To make an informed decision on the selection of the most suitable platform for further development, two interactive mock-ups were created and tested with users (refer Appendix K for methodology).

1.   A standalone application (Fig 33)
2.   A chatbot integrated into a messaging platform (Fig 34)

Fig 33: Testing with Standalone Application

Fig 34: Testing with Chatbot

These mock-ups were tested along with a rough physical prototype of the headphone, based on Version 4 of its design. The goal of this testing was to compare the platforms in terms of overall user experience.

User testing (refer Appendix K for results) revealed that while the chatbot's conversational flow was easy and a familiar user experience, requiring excessive typing from the user was a drawback. On the other hand, the standalone app required an initial learning curve but was appreciated for its simple, button-based navigation. The selected concept would need to address the issues observed during testing.

7.5.2 Selected Solution: AI Chatbot on Messaging Platforms

Comparing advantages and disadvantages for each platform as well as analysing insights from testing helped to conclude that the AI-powered chatbot integrated on a messaging platform was the optimal solution. This was because the platform meets the core requirements - universal accessibility, personalised guidance, and adaptive interaction, all while facilitating user understanding and agency in the repair process.

Accessible, Familiar, and Low-effort Interface

Unlike custom-built apps, this solution operates within popular messaging platforms like WhatsApp and Telegram, avoiding the friction generated in downloading separate support tools during a moment of need. Since most users already interact with WhatsApp or Telegram daily, users can simply start chatting on the existing interface (Fig 35). Embedding the AI assistant within these platforms allows intuitive access to support, without the need to remember or locate a separate tool.
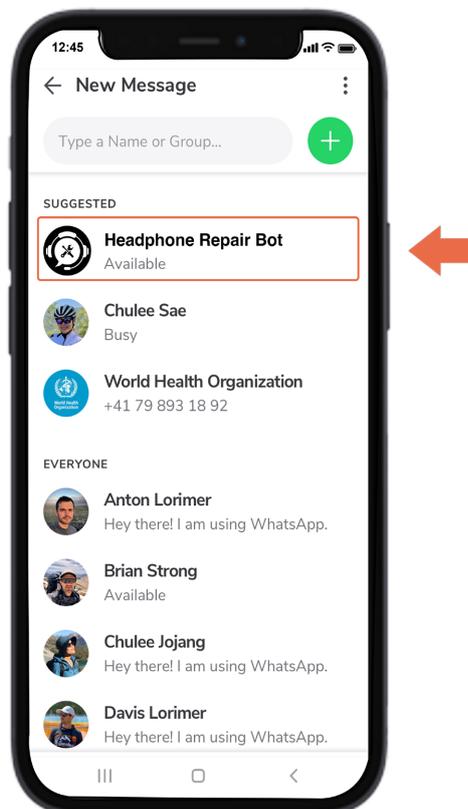
Fig 35: Repair chatbot integrated into Whatsapp

Two-Way Conversational Flow and Multimedia instruction Delivery

Messaging platforms support a range of media types - text, images, video clips, and audio messages, that can be used to accommodate different learning preferences and communication styles (Fig 36). Powered by LLMs, the chatbot can maintain a natural conversation, allowing users to ask questions and clarify doubts. This conversational support reduces the cognitive load linked with traditional repair guides.

Progress Indication and Guidance:

Leveraging the use of icons that are already embedded within messaging platforms, the chatbot can use visible milestones to help users understand where they are in the diagnostic or repair process (Fig 37). These icons can also help with delivering more direct and clear visual cues through use of their colours and universal familiarity.
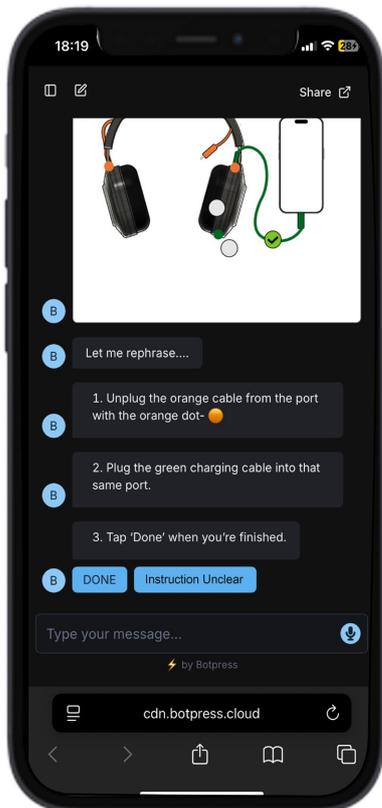
Fig 36: Multimedia instructions and clarification
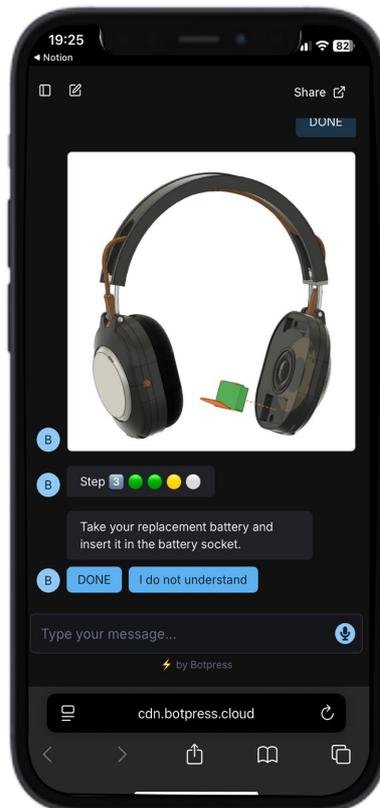
Fig 37: Using icons as progress indicators

Smart Repair Pathways

After analysing the diagnostic insights and user competence, the AI bot can suggest whether a DIY repair or professional servicing is more appropriate. Using messaging platforms features to send live locations, contacts and website links can be leveraged to generate pathways to repair service centres and purchasing tools and spare parts. (Fig 38)
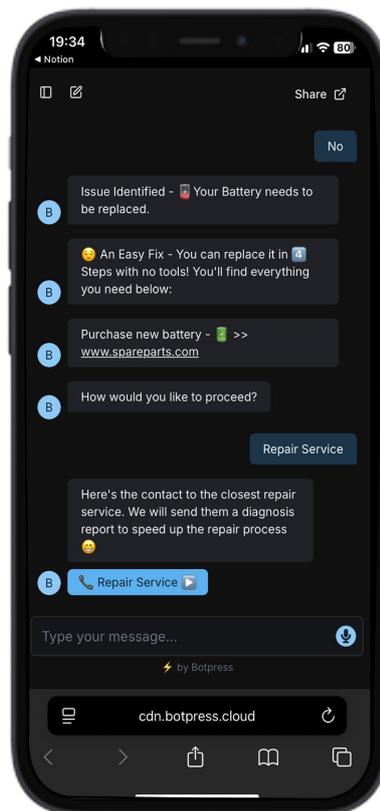
Fig 38: Generating repair and resource pursuit pathways

The chatbot was developed using Botpress - a conversational AI platform that enables users to build, deploy, and manage intelligent chatbots and AI agents. For a detailed overview of development of the chatbot, refer to Appendix L.

7.6 Chapter 7 Takeaways

Q3.2: How can we make repair information easily accessible for confident decision-making?

An AI-driven chatbot integrated into familiar messaging platforms like WhatsApp/Telegram allows for repair and diagnosis guidance to be readily available, personalised, and adaptive to the user's competence, thus providing support for clear and confident repair decisions.

Q3.3: How can we make the process of repair non-intimidating and engaging?

The tier-based approach of designing the headphones allows for a balance of safety and accessibility to priority components. Combined with the interactive, multi-modal instructions provided by the chatbot, the solution reduces intimidation by simplifying steps and using familiar interfaces and tools. Adaptive instructions and progress indicators can help keep users stay motivated and engaged throughout the process.

Main Takeaway:

This chapter has explored a foundation for making headphone repair accessible, adaptive, engaging, safe and user-friendly. However, the physical and digital solutions require further refinement and integration into a fully cohesive concept, which will be explored in the following chapter.

08

Final Concept
Concept Integration

Questions explored in this chapter

RO3: Understand ways to trigger and sustain user engagement with repair.

Q3.1: How can we incentivise repair for the average headphone user?

Q3.2: How can we make repair information easily accessible for confident decision-making?

Q3.3: How can we make the process of repair non-intimidating and engaging?

This chapter covers refinement of both concepts - both in terms of how physical materials and digital support- can encourage users to repair. It will touch upon the headphone's premium look and disassembly (Q3.1 &Q3.3). It also explores how the integration of the chatbot with the headphone can be realised in the context of introduction, malfunction, and repair decisions (Q3.2 & Q3.3).

8.1 Introduction

This chapter covers how the headphone's physical design and its digital repair assistant work together to encourage long-term user engagement. It begins with CMF design decisions that increase the product's perceived value, making it feel worth keeping and repairing. Colour coding will also be used to help with assembly and diagnosis guidance. It then explores how the repair chatbot is introduced and recalled through the user journey, ultimately identifying the most effective way to connect users to support when they need it.

8.2 Headphone Design

The headphone consists of 3 ports. The 2 ports on the right (top and bottom) can charge the headphone as well as deliver audio. The port on the bottom of the left ear cup is only capable of delivering audio (Fig 39). These ports are also marked with colour to help with guidance. The audio cable connecting the 2 ports is orange and two orange imprints near the audio ports signify the link. The charge cable is green, and the charge port is marked with a green imprint (Fig 39). In a normal usage scenario, the orange port at the top right ear cup will be used as a connection point to the left ear cup to transfer audio. In a diagnosis scenario, it will be used as a backup port to diagnose charging issues. The green charge port serves a similar diagnostic purpose for testing audio issues (Fig 39).

Fig 39: Port location, function, and colour coding
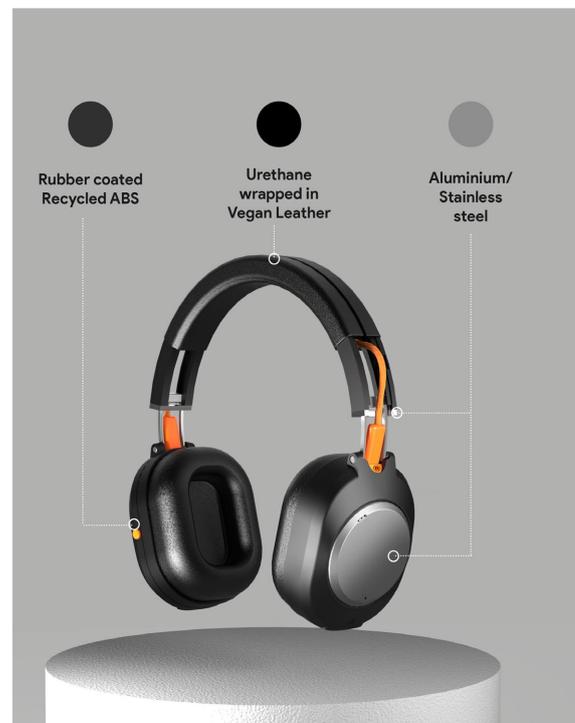
Fig 40: Headphone Colour, Material, and Finish

The look and feel of a product have an influence on the user's emotional attachment and willingness to repair it. Headphones in the 200–400 Euro price range are expected to embody a level of quality, durability and aesthetic that users connect to long-term value. If a product feels cheap or overly utilitarian, users are more likely to view it as disposable - regardless of its repairability features. While products like the Fairbuds XL succeed in modularity and ease of repair, they fall short in delivering the robust, premium materiality typically expected at this price point. Therefore, the headphone concept uses velvet-finished plastics for the earcups to create a tactile, soft-touch experience, paired with brushed metal accents on hinges and adjustment sliders to depict visual and physical durability (Fig 40). These decisions were guided by a mood board (Appendix M) designed to capture the balance between technical honesty i.e., modular, clearly serviceable parts (e.g., exposed and prominent audio cables) and emotional desirability (i.e., a sense of premium elegance).

8.3 Headphone Disassembly

8.3.1 Ear Cushions

The ear cushions are attached to the ear cups via magnets and can be detached by just simply pulling the cushions outward (Fig 41). Though not the most sustainable option, it offers a better alternative to using snap fits that needed a lot of force to release and could break if the user accidentally used too much force (Appendix J). This option was also better than using twist lock mechanisms as magnets offered better feedback, when fastened. Additionally, the cushions are interchangeable between the right and left ear cup and the magnets are positioned symmetrically around the cushion fastener (Fig 42) so that it could be fastened in any orientation, avoiding confusion for the user.

Fig 41: Ear cushion removal

Fig 42: Symmetric alignment of magnets

8.3.2 Battery

Once the right ear cushion is removed, it reveals the battery that can easily be removed by peeling (Fig 43) and pulling (Fig 44) pull tab. These instructions are printed on the pull tab as well (Fig 42). The pull tab provides safe and easy access to the battery without having to use prying tools (as in the case of the Sony WH1000XM5s.)

Fig 43: Peeling open the pull tab

Fig 44: Battery Removal

72.

8.3.3 Headband Cushion

The headband cushion is folded over the headband frame. This design mainly takes cues from the Fairbuds XL model, with minimal optimisations, like using Velcro as a fastening mechanism instead of magnets (Fig 45).

Fig 45: Headband Removal

8.3.4 Audio Connector Cable

Once the headband cushion is removed, the whole audio cable, which is a USB C to USB C type cable can be removed. Like the Fairbuds XL design, the cable is held in place under the headband cushion. It connects the right ear cup to the left ear cup. The cable can be accessed by simply unplugging the connector from each ear cup (Fig 46).

Fig 46: Unplugging the audio cable

8.3.5 Headband Hinges

The hinges in this design use a squeeze to unlock mechanism. To make sure that the hinges do not accidentally release during use, the USB cable connector acts as a stopper/lock that prevents the hinge from squeezing (Fig 47). The hinges can be disconnected from the ear cup by squeezing the prongs out of the ear cup sockets (Fig 48).

Fig 47: USB cable locks hinges
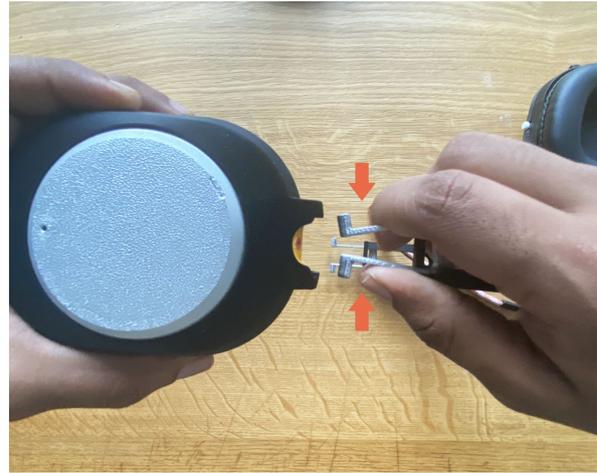
Fig 48: Squeeze mechanism to remove hinges

8.3.6 Headband Adjuster

The headband adjuster is necessary to account for different head sizes, for a more comfortable fit. In this design, it is integrated with the hinge. While the "squeeze to unlock" design of the hinge releases it from the ear cup, the slider mechanism part of the design releases it from the headband frame. When the headband cushion is removed, a visual cue to slide the headband cover is revealed (Fig 49; 1). The headband cover (which was locked in place via the head cushion) can now be slid in the direction of the arrow cue, revealing opening slots (Fig 49; 2). The hinge can then slide backwards along the rail (Fig 49; 3), lifted and then pulled out from these slots (Fig 49 ; 4), thus completely removing the hinge from the headband.
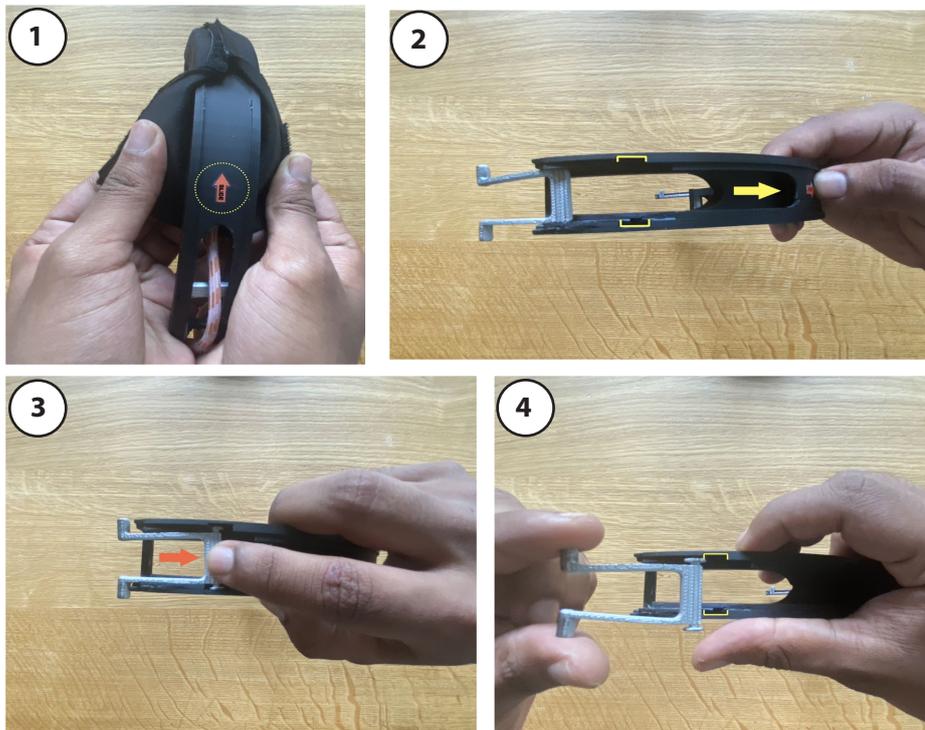
Fig 49: Removal of hinge from headband

8.3.7 Charging and Audio Ports

The charging and audio ports are priority B components, since they tend to last longer than all the priority A components. They are also electronic components that should only be accessed when the power source (Battery) is disconnected. To achieve this, they can only be accessed by removing 4 screws, out of which 2 screws are beneath the battery. The presence of the hidden screws is indicated using a visual cue that is revealed when the right cushion is removed (Fig 50, white circle). When the screws are removed, they can be placed on the magnets (that were used to fasten the cushion) to avoid misplacement during disassembly (Fig 50, orange circles). Removal of the 4 screws unfastens the back cover of the headphones as well as the ports (Fig 51). The ports are connected to the Main PCB via SD connectors and are colour coded to the audio (orange) and charging (green) colours, so that when the back cover is removed, the ports can be easily identified (Fig 51), slid out (Fig 52) and swapped for replacements.

Fig 50: Visual cue indicates screws under the battery

Fig 51: Removal of back cover unfastens and reveals colour coded ports

Fig 52: Ports can be slid out from SD card type connectors on the main PCB

8.3.8 Non-Priority Components

All non-priority components (Main PCB, Microphone cable, Driver, etc.) are enclosed within a unit underneath the back cover and visually separated from the ports to avoid visual clutter and intimidation for novice and intermediate repairers. This unit can be accessed via 4 visible screw points along the circumference of the unit (Fig 53). After removal, the circuit board (Fig 54) is revealed.

Fig 53: Screw positioning to access non-priority components

Fig 54: Headphone circuit board (Non-priority components)

8.4 Headphone - Platform Link

To introduce the chatbot repair assistant, it is important to design a thoughtful introduction that links the assistant to the hardware to enable first-time discovery, easy onboarding, and long-term recall. A user journey-mapping decision tree (refer Fig 55) to explore multiple entry points into the repair platform - from unboxing and assembly to later repair needs so that the product and platform feel naturally linked across time. The challenge is determining when and how users should discover the digital assistant. Should it happen as they assemble the headphones? During digital setup? Or only in the event of a malfunction? Each option offers benefits and trade-offs. This section maps and evaluates the possible user scenarios to identify the most engaging long term integration strategy.

**YEAR 0
HEADPHONE
INTRODUCTION**

User recieves disassembled headphones

HOW DOES THE USER DISCOVER THE CHATBOT?

**OPTION 1
QR CODE**

QR Code printed on the

- Scannable using any smartphone camera

- Most accessible and persistent point of entry

May be overlooked if not highlighted during unboxing.

**OPTION 2
NFC**

NFC Enabled feature - A sticker prompts user to

- Just tap the phone- no app or scanning needed.

- Offers a seamless premium user experience.

- Users may not know they can tap—needs clear instructions.

- Not all phones support NFC or have it enabled.

- Slightly more expensive to implement than QR codes.

**OPTION 3
VOICE TRIGGERS**

User says: "Help with my headphones" triggers WhatsApp invite or sends link to phone

- Reduces all friction- just say a phrase.

- Users must know the phrase and have a compatible assistant.

- Adds technical complexity.

**OPTION 4
COMPANION APP
INTEGRATION**

The bot is embedded into the Equaliser companion app for the headphones

Repair and setup live in the same digital ecosystem.

- Novice or casual users may uninstall or ignore the app post-setup.

Users might not want another app just for occasional repair.

Assumes user downloads the app in the first place, which is not guaranteed.

CHATBOT DISCOVERY
Opens AI Assistant on messenger service.

The chatbot recognises the start of a conversation and guides user through assembly.

At the end of the assembly process, the app prompts the user to return to it for any future repair assistance.

Every 6 months, the Bot sends proactive message (e.g., "Still working okay?")

**YEAR 1- 2
MALFUNCTION SCENARIO**

**OPTION 1
QR CODE**

- Always accessible and visible

- Familair Channel to Repair Help

**OPTION 2
NFC**

- Not always visible.
- Low recall or reuse unless explicitly remembered

**OPTION 5
VOICE TRIGGERS**

- not always visible.
- Depends on user memory of original prompt

**OPTION 4
COMPANION APP**

App likely uninstalled or ignored

Fig 55: User Journey map decision tree

Ultimately, the 'QR code-on the product' approach (Fig 56) emerges as the most reliable method for initiating user engagement. This approach was selected because of its high visibility and familiarity, allowing users to access self-assembly guidance without facing the friction of setting up an application or using unfamiliar technology. To maintain engagement and reminders, a follow-up system can be set in place where the repair bot periodically checks in with users every six months. This low-effort, non-intrusive engagement brings awareness of the support system at a time when issues are likely to arise.
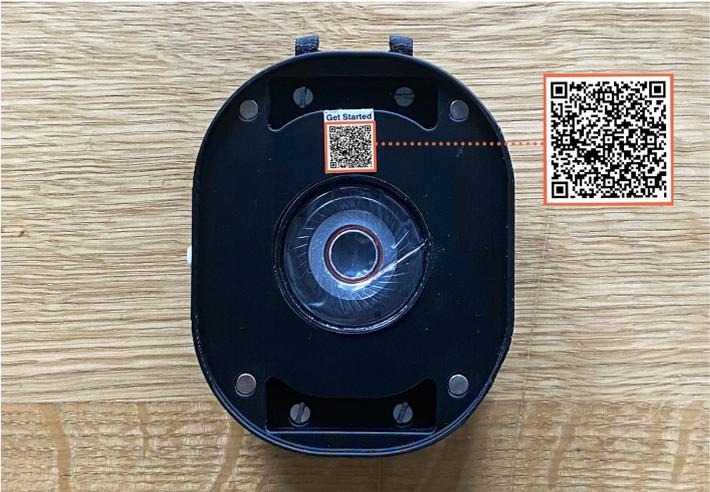
Fig 56: *The QR code is placed below the cushion of the left ear cup*

`8.5 How does the concept work?

Phase 01 – Headphone Purchase and Assembly

User receives headphones partially assembled.

User notices a QR code on the headphone. Upon scanning, the messenger platform launches with a welcome message.

The user can opt to let the bot guide them through the assembly process.

The headphones come semi-assembled and require just three simple steps to fully assemble - attaching the ear cushions, plugging in the audio cables, and connecting the headband hinges to the ear cups. This reason behind this approach will be covered in the next chapter.

Clear instructions and videos guide users through each step, with the option to request simpler explanations if needed.
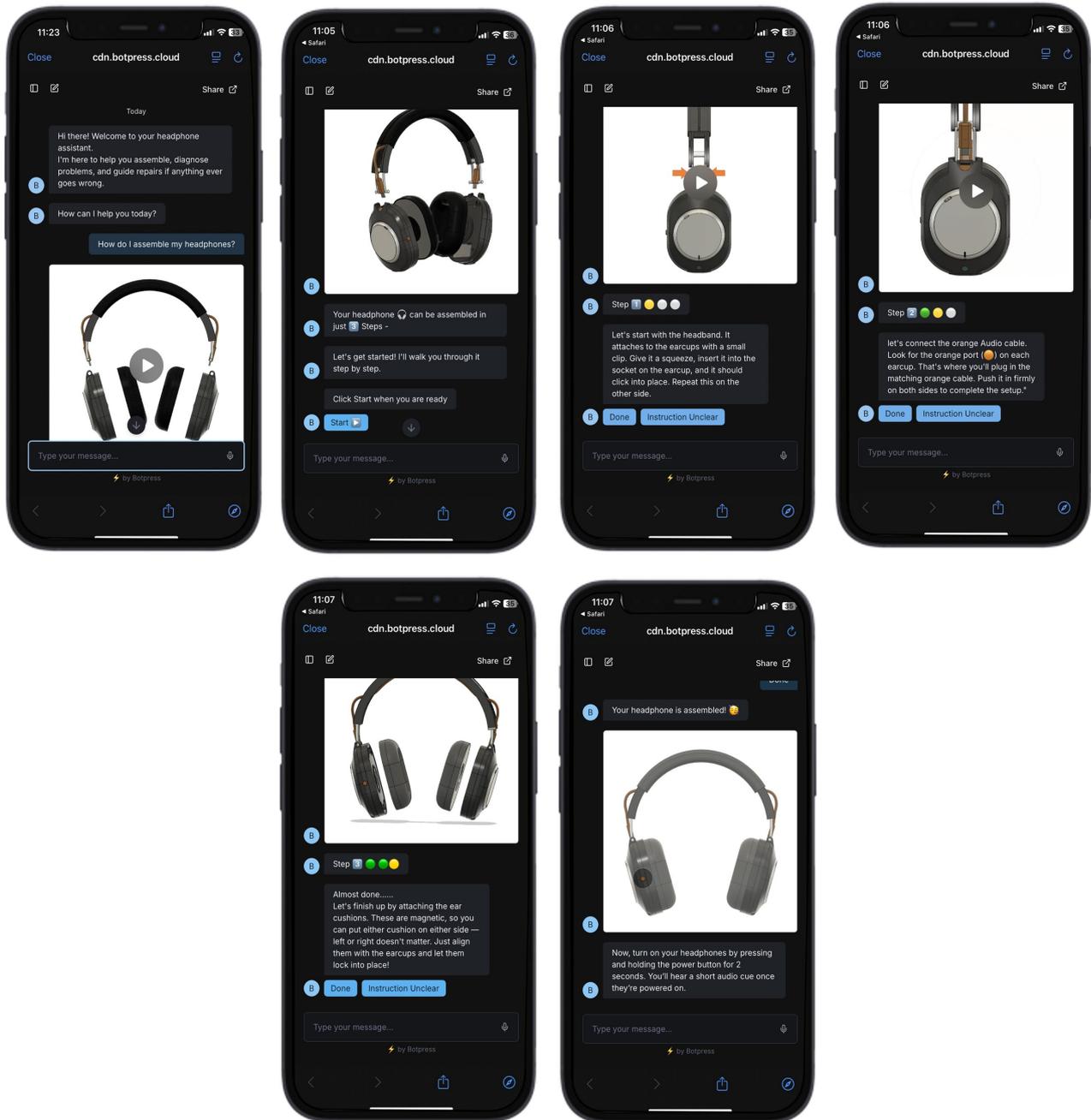
6 Months Later

To support user retention, a follow-up system can be implemented where the repair bot checks in with users every six months. These low-effort, non-intrusive interactions help keep users aware of available support, especially at a time when issues are likely to arise.

Phase 02 – Headphone Malfunction Scenario

User uses the QR code to access the bot again or they access the bot through their messaging platform contacts.

The user inputs their problem prompt - "Headphones not working" (Technical novices generally start with vague problem descriptions)

The bot tries to narrow down the issue by asking a few more questions to clarify the problem and provides a set of default options to ease the user into not having to type a lot.
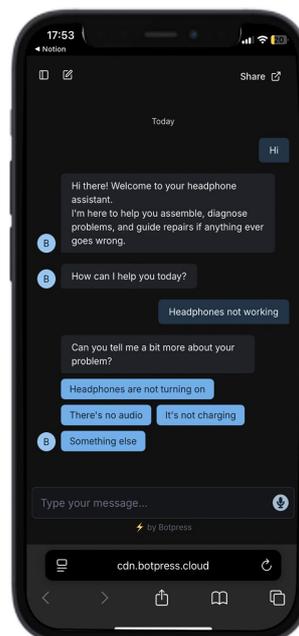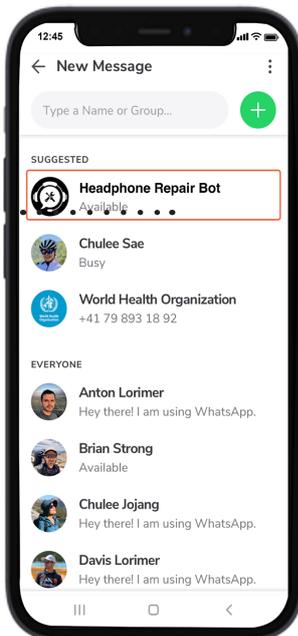
Phase 03 – Diagnostic Mode

Once the bot clarifies the broader issue, it moves into diagnostic mode. In this stage, the user will be asked to actively engage with the app and the headphone to figure out the issue. This scenario can be branched out further based on the issue at hand – Charging (Phase 3.1) or Audio (Phase 3.2).

Phase 3.1 Charging Issues

The bot provides an overview of the components that are most likely causing the problems - Charging cable (1), Charging port (2) or Battery (3) and asks the user to connect their headphone to an external device (phone) using the green charging cable, accompanied with visual media to help with task clarity. It then asks the user to put on their headphones and sends an audio file.
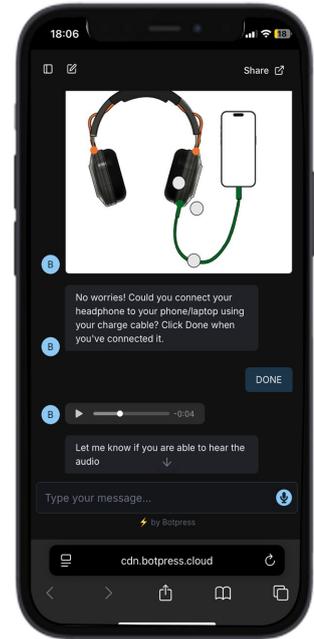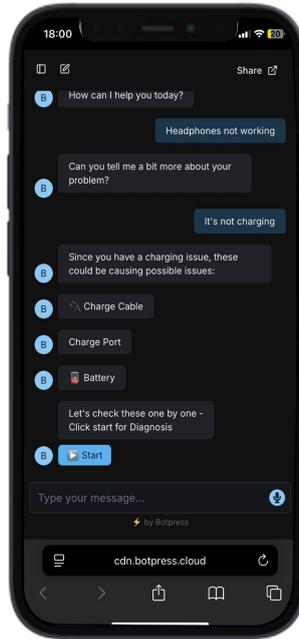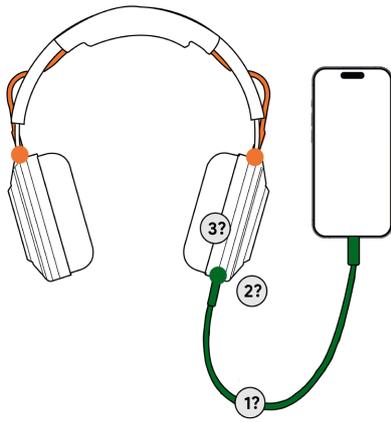
Q: The bot asks the user to play the audio and to confirm whether they can hear the audio.

No

Yes

If no, the bot has established that it might be a problem with the charge cable (1), or the charge port (2) and the battery (3) might not be the issue as battery problems do not affect wired audio delivery.

If yes, the bot has established that the green charge cable (1) is working, and it might be a problem with the green charge port (2) (Unlikely, as the port still delivers audio, but is not verified) or a battery (3) problem.
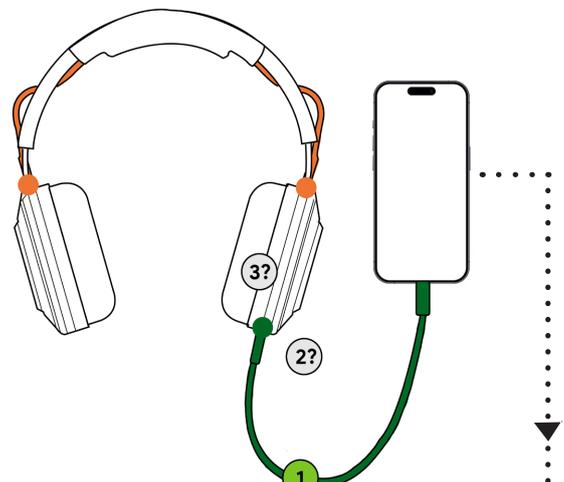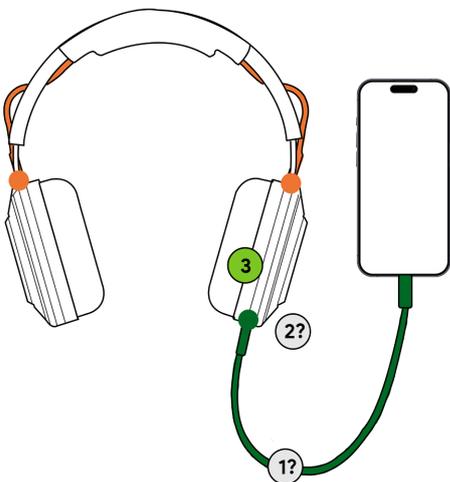
For now, let us say the user says yes. To verify whether the issue is the green charge port (2) or the battery (3), the bot now prompts the user to remove the orange audio cable from the right orange port and to plug in the green charge cable into the orange port. It sends the user visual media to help with task clarity.

In a scenario where the user does not understand the instruction, the bot can also rephrase the instruction as and when needed. It records this information in conversational memory and continues to modify its next set of instructions accordingly using LLMs.
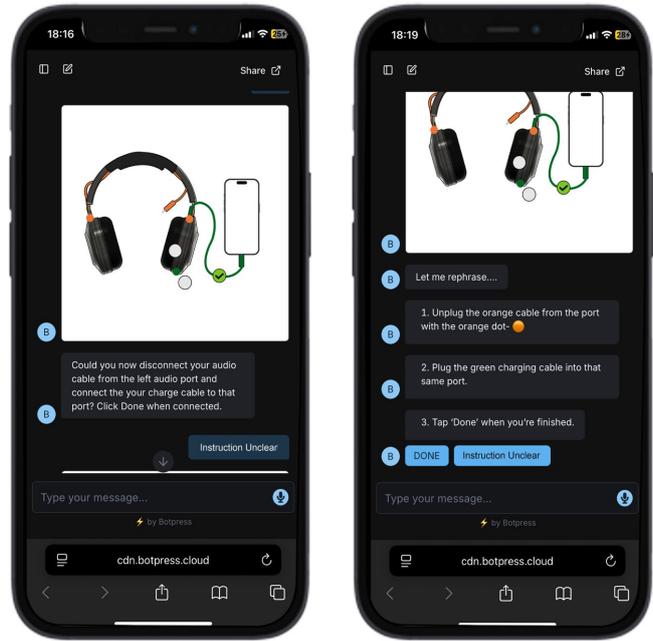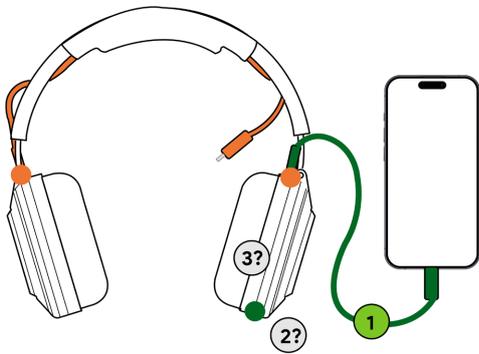
Diagnosis Result

Q: The bot asks the user if the headphones are charging.

Yes

Yes - The problem is most likely the green charge port (2) as the battery (3) is now capable of accepting charge through the orange audio port.

No
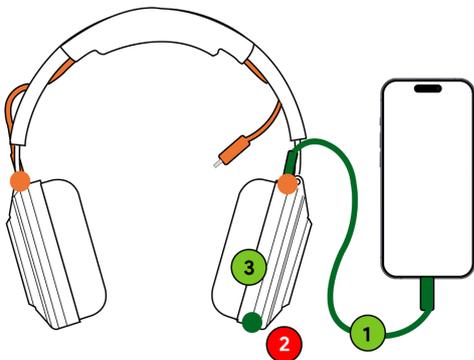
No - The problem is most likely the battery (3) as it was established in the previous audio test that the orange audio port could deliver audio efficiently and it is unlikely for both ports to be malfunctioning as their connection pathways are independent, which means the battery is not accepting charge.
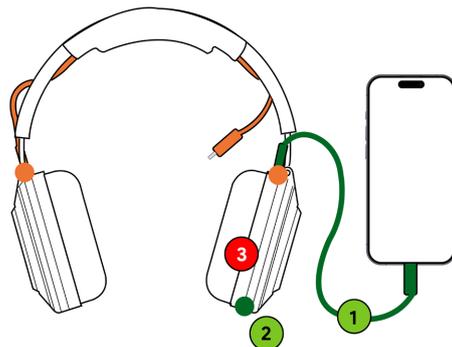
In this case, let us say the battery is malfunctioning, the bot delivers a message with information required to perform the repair (technical complexity, number of steps, links to purchase resources needed for the repair - tools, new battery, etc.).
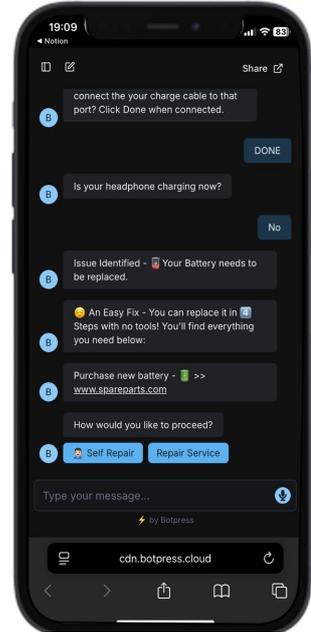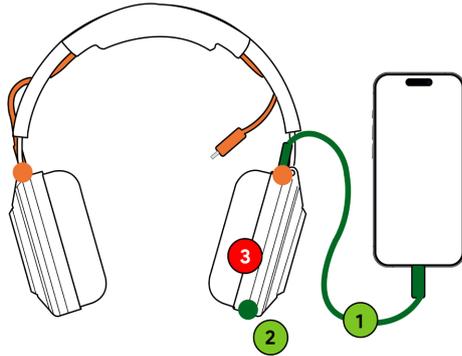
User Decision

Q: The bot gives the user the option to choose between a repair service and self repair.

Self Repair

The bot enters repair mode, where it sends the user repair instructions. Accompanied by these instructions, are videos with animations depicting how to proceed with the repair, along with icons as notification progress bars, showcasing progress along the way. At every step of the way, the user can request a rephrasing of instructions for clarity or confirm when a step has been done.
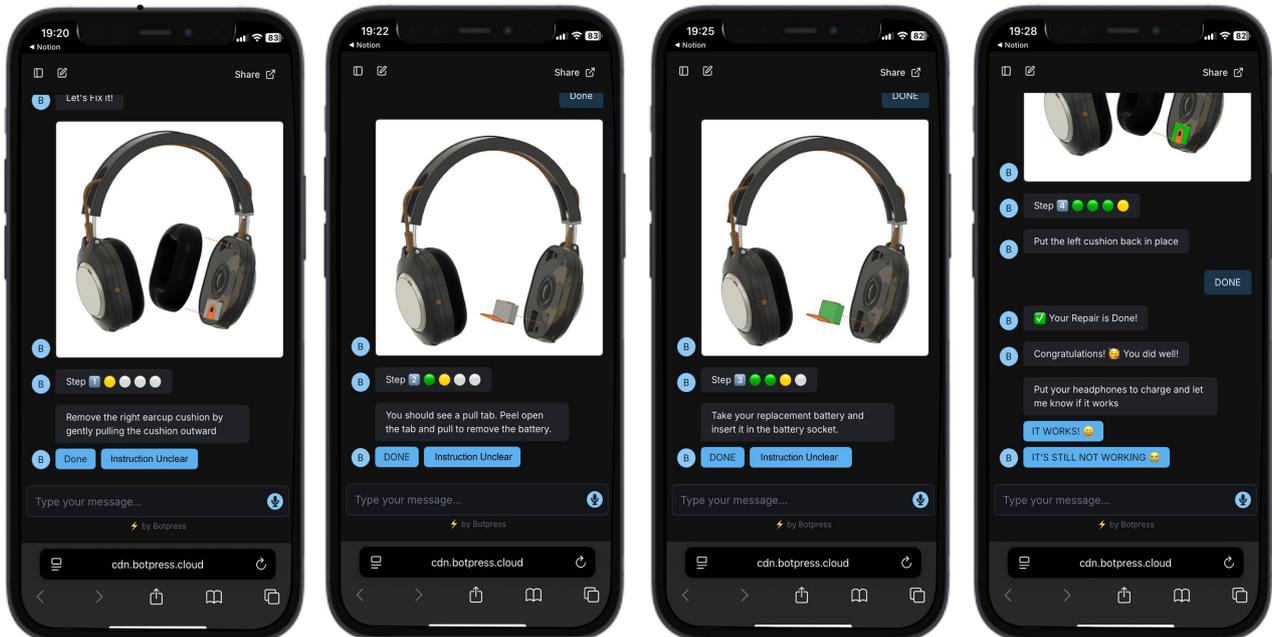
Repair Service

The bot provides a link to the nearest repair service along with the option to send them a diagnosis report to speed up the repair process.
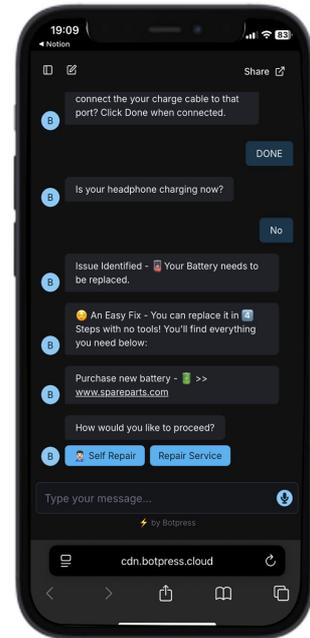
Phase 3.2 – Audio Issues

Under audio issues, the most reported malfunction is audio malfunction in one ear cup when connected via bluetooth.

Like the charging issue case, the bot provides an overview of the components that are most likely causing the problem - Audio port (1), Audio Cable (2) or Driver (3) and asks the user to connect their headphone to an external device (phone) using the green charging cable. The bot, then asks the user to put on their headphones and sends an audio file. This is to test if the ear cup still works in a wired scenario.
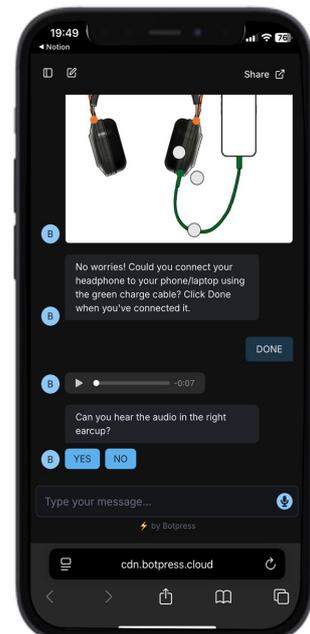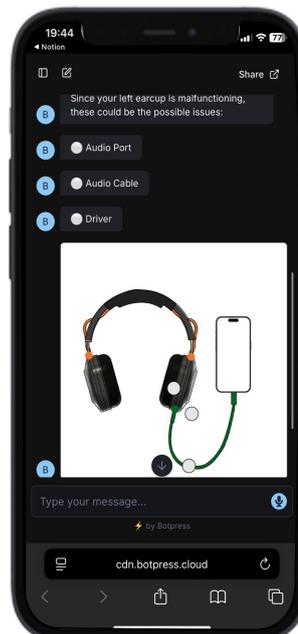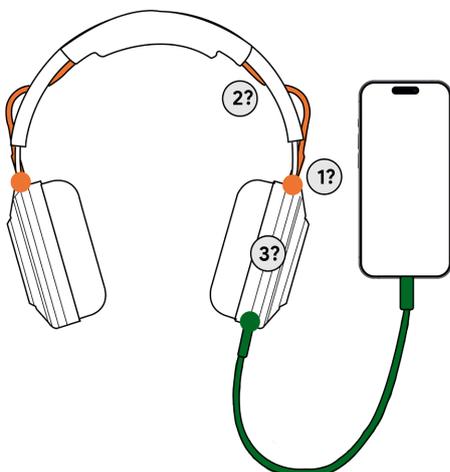
Q: The bot asks the user to play the audio and to confirm whether they can hear the audio.

84.

No

The bot has established that there might be an internal problem or driver problem (3).

Yes

The bot has established that the internal driver (3) is working, and it might be an audio port problem (1) or an audio cable problem (2).
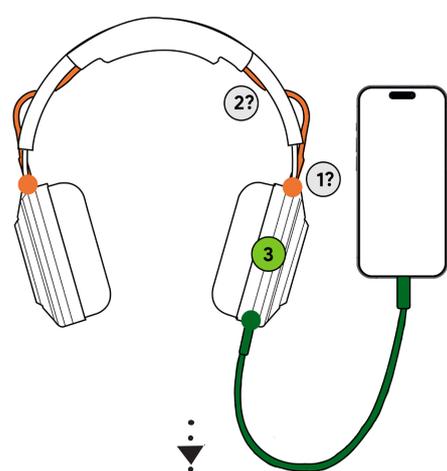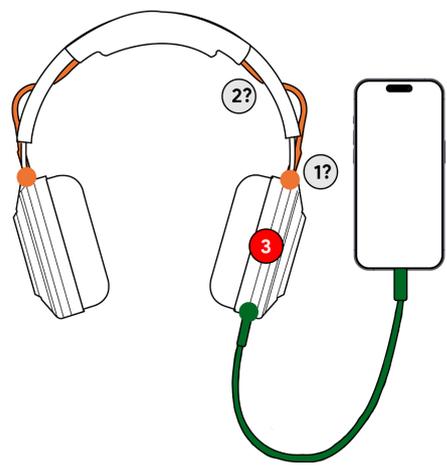
For now, let us say the user says yes. To verify whether the issue is the audio port (1) or the cable (2), the bot now prompts the user to remove the cushion and remove the orange audio cable (2) from the right orange port (1) and to plug it into in the green charge port. It sends the user visual media to help with task clarity.

The bot sends the user an audio file and asks them to play the file while holding the headphones closer to their ear.

Great!
Now remove the head cushion from the headphones.

DONE

1. Unplug the orange cable from the orange port on the right earcup.

2. Plug it into the green port on the right earcup.

Click Done when connected

DONE   Instruction Unclear
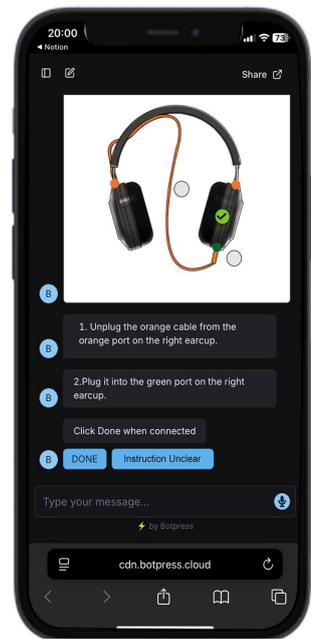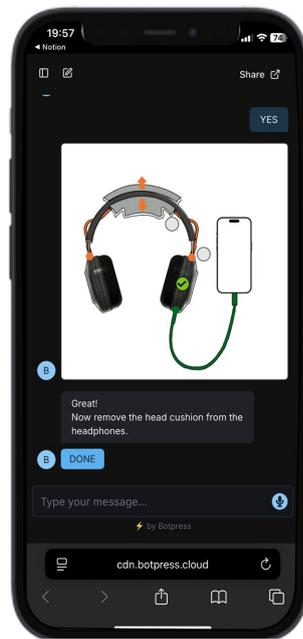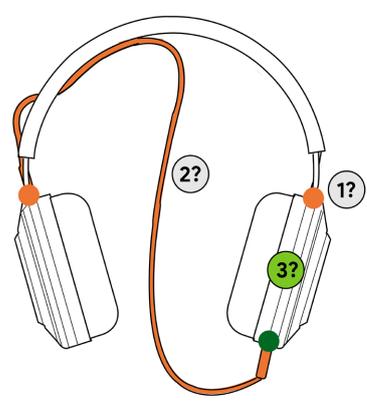
**Q: The bot once again asks the user to play the audio
and to confirm whether they can hear the audio.**

Yes

No

The right orange audio port (1) is faulty as the green charge port was working during the previous audio test and the current test confirms the orange cable is working (2). The problem cannot be the left audio port as if it was faulty, the left port would not be receiving power and would also be mute, which is not the case.

The problem is most likely the orange audio cable (2) as it was established in the previous audio test that the green charge port could deliver audio efficiently and the driver (3) was functioning, which means the orange cable (2) is not transferring audio.
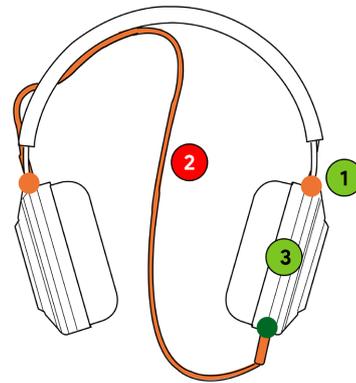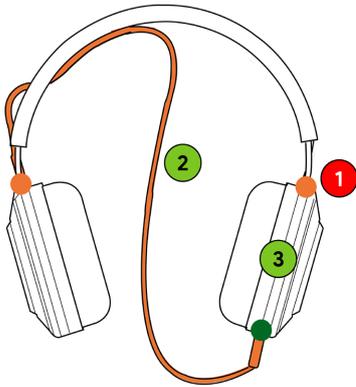
▶ **Phase 04 – Repair Scenario**

In this case, let us say the audio port (1) is malfunctioning. The bot shares details about how complex the repair is through the number of steps it takes and tools needed, providing the necessary information to allow the user to make a confident decision. The user can then choose to repair it themselves or get help from a professional.

Since this fix needs a #00 screwdriver, the bot notes if the user has the tool needed based on whether they go forward with the self-repair option. This helps the bot understand their technical skills and the tools they have on hand. Based on this, the bot uses conversation memory to adjust it's technical language and advice for future repairs.
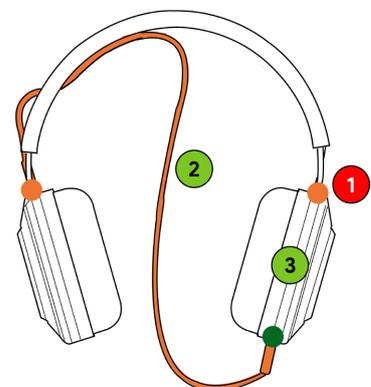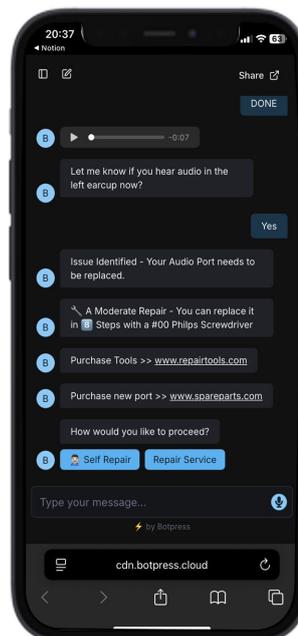
Q: The bot gives the user the option to choose between a repair service and self repair.

Self Repair

The bot enters repair mode, where it sends the user repair instructions. Accompanied by these instructions, are videos with animations depicting how to proceed with the repair, along with icons as notification progress bars showcasing progress along the way. At every step of the way, the user can request a rephrasing of instructions to be clearer or confirm when a step has been done.
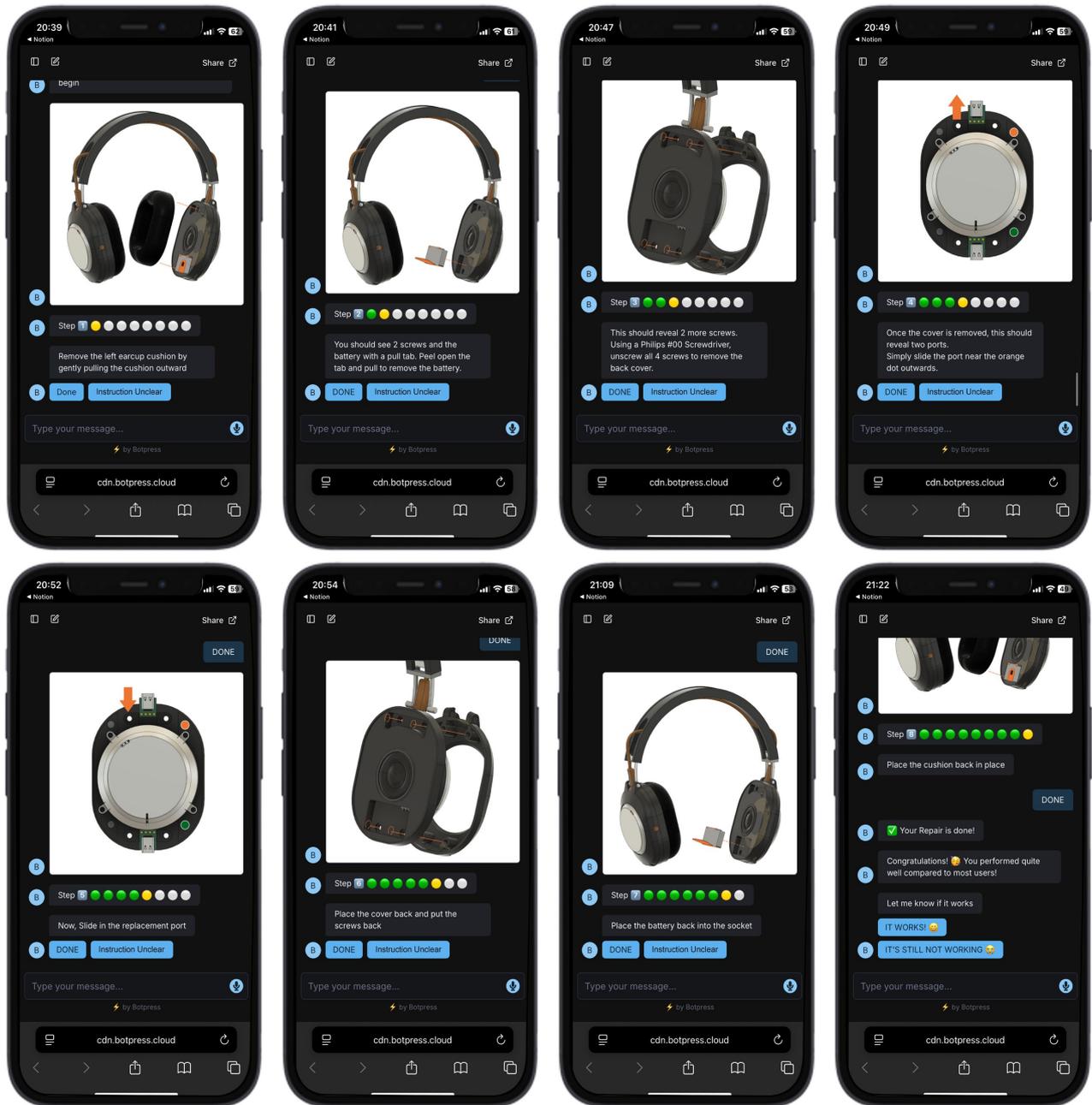
Cushion and hinge repairs need no diagnosis and are direct repair scenarios. See battery replacement section for cushion removal and replacement; Appendix L for hinges.

8.6 Chapter 8 Takeaways

Q3.1: How can we incentivise repair for the average headphone user?

By using premium CMF choices, such as velvet-touch plastics and metal accents - the headphones feel valuable and worth holding on to. But beyond material appeal, the design also captures a careful balance between technical honesty and emotional desirability. Visual cues like exposed audio cables, visual access guides on the product and clearly modular components subtly communicate serviceability, encouraging users to see repair as part of the product experience rather than an afterthought. When a product feels both elegant and transparently built, users are more likely to maintain it, not just because it looks good, but because it makes sense to do so.

Q3.2: How can we make repair information easily accessible for confident decision-making?

A QR code printed on the product connects users directly to the messenger-based chatbot. This provides a frictionless and unobtrusive method of access for the user to avail services from the platform as and when needed. The refined concept aims to facilitate streamlined diagnosis scenarios followed by a smooth transition to repair and guidance with the help of an intuitive design and an application that leverages AI to enable users to make confident decisions as they navigate through repair scenarios at the time of a noticeable malfunction in their headphones.

Main Takeaway:

Q3.3: How can we make the process of repair non-intimidating and engaging?

Encouraging repair begins with making the product feel worth repairing. By using soft-touch plastics and metal accents, the headphones project a sense of quality and longevity that nudges users to value and maintain them. But emotional value alone isn't enough. Timely and easy access to repair support in a time of need is important. An accessible and unobtrusive platform that uses multimedia features and concise information at important decision points is introduced to reduce uncertainty and make the experience intuitive, even for first-time repairers. Together, the intuitive design and accessible support system help shift repair from a chore into a confidence-driven choice.

09

Concept Evaluation
User Testing, Discussion and Future Scope

Questions explored in this chapter

RO3: Understand ways to trigger and sustain user engagement with repair.

Q3.1: How can we incentivise repair for the average headphone user?

Q3.2: How can we make repair information easily accessible for confident decision-making?

Q3.3: How can we make the process of repair non-intimidating and engaging?

This chapter covers user testing and evaluation to investigate how assembling the headphones first-hand can create a willingness to repair later (Q3.1). It also assesses how effectively the chatbot guide provides users with accessible repair information to support confident decision-making (Q3.2). Drawing on these insights, the chapter evaluates the overall concept, highlighting its limitations and exploring opportunities for future development (Q3.3).

9.1 Introduction

The final chapter reviews the evaluation of the repairable headphone prototype and it's supporting digital repair platform. User testing explored how well the combination of modular design and a chatbot guide helped participants complete repairs. The tests revealed both strengths, such as ease of assembly and positive user engagement, as well as limitations, including redundancies in the digital platform. Based on these insights, opportunities for improvement and future development come to light.

9.2 Physical Prototype and Accessories

The headphone prototype was 3D printed using white PLA plastic and presented to users in a partially disassembled state (Fig 57). The opened box presented 2 QR code stickers to access the chatbot. One on the top interior face and one on the bottom interior face (Fig 58). The set up consisted of a green USB-C charging cable, the headband, headband cushion and audio cable pre-assembled into a single unit, the two earcups (the left earcup consisted of an integrated power button), and the cushion units left detached to reveal a QR code sticker on the left ear cup to access the chatbot. This configuration was decided to achieve a balance between making the assembly process engaging and approachable without being overwhelming, particularly for novice users. A fully disassembled product might have introduced unnecessary complexity or intimidation, while this setup allowed users to experience meaningful interaction with core assembly steps (like plugging in cables and fastening hinges) in a way that felt achievable.

Fig 57: Prototype presented to testing participants upon unboxing.

Fig 58: Prototype presented to testing participants upon unboxing.

9.3 User Testing

A sample size of 11 participants (Fig 59) took part in the user testing, comprising:

- 6 novice users with little to no experience in electronics or repairs
- 4 intermediate users with some prior hands-on experience with basic repairs (e.g.: replacing light bulbs)
- 1 advanced user with professional-level technical skills

The group included an age range from 24 to 45 years old (Fig 60), with a roughly equal gender distribution (Fig 61). While the primary goal was to evaluate how accessible and understandable the repair system was for novice and intermediate users, the inclusion of an advanced user also allowed for early insights into how the platform could scale to meet the needs of more technically inclined users in future developments.

The prototype simulated visual and audio feedback through an LED in the right ear cup and an audio driver in the left ear cup, respectively (refer Appendix N).

9%
36%
55%

■ Novice ■ Intermediate ■ advanced
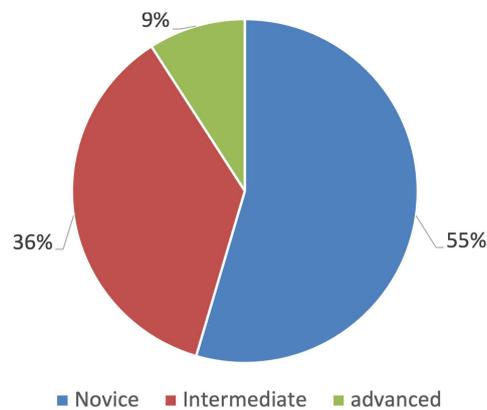
Fig 59: Repair competency of test participants

9%
18%
73%

■ 25 -30 years ■ 33 - 40 years ■ 42 - 45 years
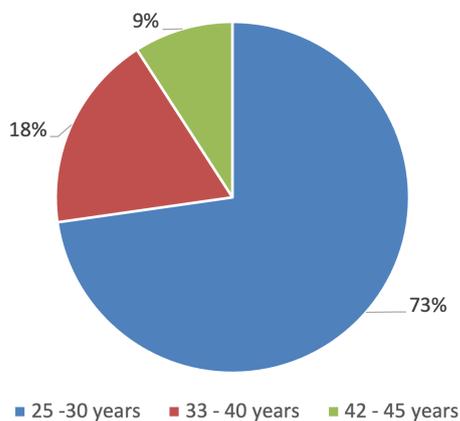
Fig 60: Age distribution of participants

45%
55%

■ Female ■ Male
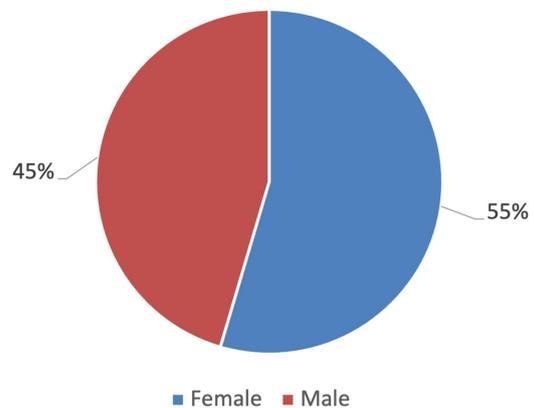
Fig 61: gender distribution

For all participants, a charging issue was simulated post assembly, when participants tried to turn on the headphones and observations were made as to how they go about discovering, diagnosing and solving the issue using the resources provided. Users were asked to think out loud during the testing process, when performing tasks and were encouraged to ask questions during the test. The testing methodology is divided across 3 phases –

- Phase 01 – Self Assembly (Fig 62 ; Fig 63)

- Phase 02 – Diagnosis (Fig 64)

- Phase 03 – Repair Guidance (Battery Replacement) (Fig 65)

For more information on the methodology, refer Appendix N.

Fig 62: Headphone assembly (User 11, Novice)

Fig 63: Headphone assembly (User 8,Novice)

Fig 64: Diagnosis phase - audio check
(User 2, Novice)

Fig 65: Repair Phase - battery replacement
(User 1, Novice)

After the testing session, participants were asked a series of questions specific to each phase of the process to gather targeted feedback and insights.

Phase 1 (Self Assembly)
Q1 What was your first reaction upon seeing the headphones disassembled?
Q2 Did you notice the QR code before or after trying to assemble?
Q3 How easy or difficult was assembly? What challenges did you face?

Phase 2 (Diagnosis: Charging issue)
Q4 What was your first step when the headphones didn't work?
Q5 Was it easy to describe the problem to the chatbot?
Q6 How helpful was the chatbot in identifying the issue? What worked well and what didn't ?

Phase 3 (Repair Guidance)
Q7 How clear were the chatbot's instructions for battery replacement?
Q8 Did you face confusion during the repair? At which steps?
Q9 Did you feel that assembling the headphones yourself had an influence on your ability to repair the product?

9.4 Observations and Results

Assembly:

• Users responded positively to seeing the headphones disassembled, as the fastening points were clearly visible and intuitive. This clarity made them confident and even excited to assemble the product.

• However, in their eagerness to assemble the product, 8 out of 11 users overlooked the QR code on the box and the headphones and, after assembly, didn't recall seeing it at all (Fig 66).

• All users successfully assembled the headphones without using the chatbot. The entire assembly process took under 2 minutes for all participants. Most users credited the colour-coded ports and cables for making the process easy to follow.

Did users notice the QR code?

27%

73%

■ Participants who noticed the QR code on the packaging

■ Participants who did not notice the QR code at all
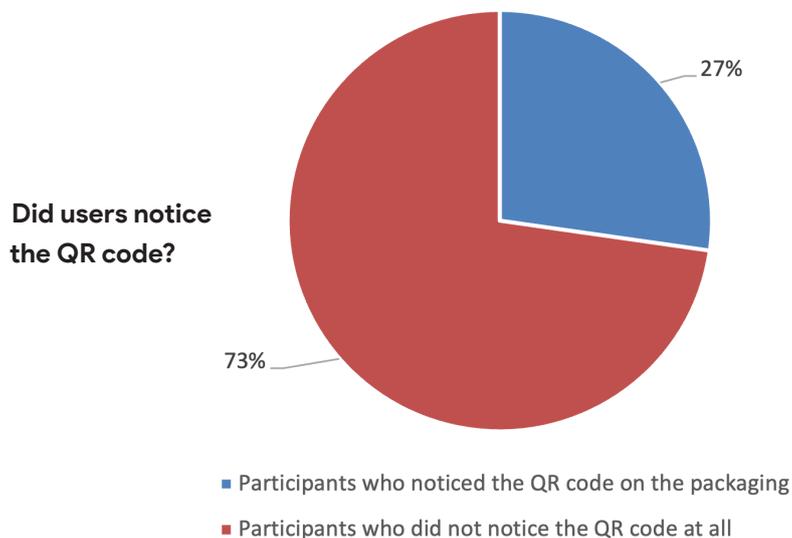
Fig 66: Users who overlooked the QR Code. (All participants overlooked the QR code on the product)

94.

Diagnosis:

• Since users didn't recall seeing a QR code, they almost immediately started to figure out the problem themselves. They began by attempting to charge the headphones. After realising the device wasn't responding, most said their next step would be to search online for solutions. It was only with some prompting, that they noticed the QR code on the product.

• The chatbot was able to identify and isolate the issue effectively with all the different user inputs encountered, even when user input had spelling errors (Fig 67).

• Most users found the chatbot's instructions clear and easy to follow. One novice user noted difficulty due to the lack of language options as English was not their first language. This affected their comprehension of tasks. However, the associated videos helped in making up for the lack of textual comprehension.

• Some users didn't fully grasp the purpose of certain diagnostic steps, like plugging the charging cable into the audio port but trusted the chatbot's guidance regardless. Users felt that in actually performing the instructed tasks to narrow down issues, they felt greater confidence in the final diagnosis.

• While the diagnostic process felt long and drawn out for more technically experienced users, novice users appreciated the thoroughness and support.

• When presented with the choice to self-repair or repair service, participants felt that information about costs associated with each option (cost of spare battery, cost of repair service in total) was missing and would have helped them make a more informed and confident decision.

My headphones are not turning on

My headphones suddenly stopped working, what do I do?

He Does the headphone turn on?

User Spelling Error (The bot was still able to comprehend the intent)

Can you solve headphones not switching on?

Fig 67: Overview of different user inputs when describing the problem

Repair Guidance:

• Battery replacement instructions were rated clear by all participants. For simple steps like cushion removal, many relied on the written instructions alone without needing to watch the accompanying videos.

• Slight hesitation was observed when users had to remove specific parts such as the battery pull tab. In this case, the videos helped clarify the steps. Users suggested automatic, looping videos would reduce the number of clicks needed during the process.

Influence of Self-Assembly on Repair Confidence:

- 9 out of 11 users reported that assembling the headphones themselves improved their familiarity with the components (Fig 68). 5 out of these 9 users were novice repairers.

- 4 out of the 6 novice users specifically mentioned feeling a sense of pride from the process and expressed increased confidence in performing repairs like battery or cable replacements in the future.

- The 2 users that said no (Fig 68), said they would usually forget about the assembly process after year or so, but stated that it wouldn't be difficult to recollect since the assembly and disassembly was fairly simple.

Suggestions made by participants post testing:

- Participants showed strong curiosity about tackling more complex repairs like port replacements or internal wiring, indicating demand for expanded repair guidance.

- Users also suggested using the unboxing experience as an opportunity to better engage users with the repair chatbot by:

1. Creating a compelling initial interaction to motivate users to explore repair options.
2. Crafting a stronger narrative around the product's repairability.

- 7 out of 11 users said they would likely discard the packaging after purchase (Fig 69) and wouldn't remember the QR code on the headphones after a year. Instead, their first action when facing issues would be to search online for instructions. This indicates the need to improve onboarding, either by redesigning the unboxing experience to make repair information more memorable or by establishing alternative, more accessible pathways to the repair platform through internet search.

Did you feel assembling your headphones yourself had an influence on your ability to repair the product?

18%

82%

■ Yes ■ No

Do users keep the packaging and manual after the unboxing?

36%

64%

■ Users who discard the packaging and manual

■ Users who keep the packaging and manual
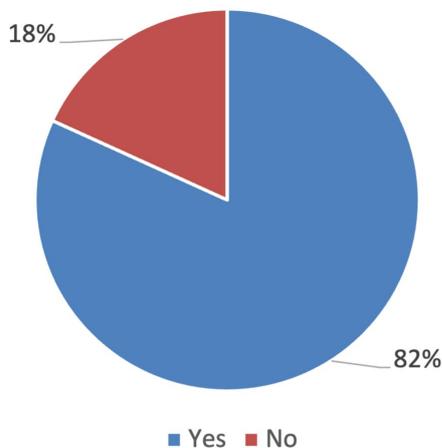
Fig 68: Do users feel self assembly positively influenced their repair behaviour?
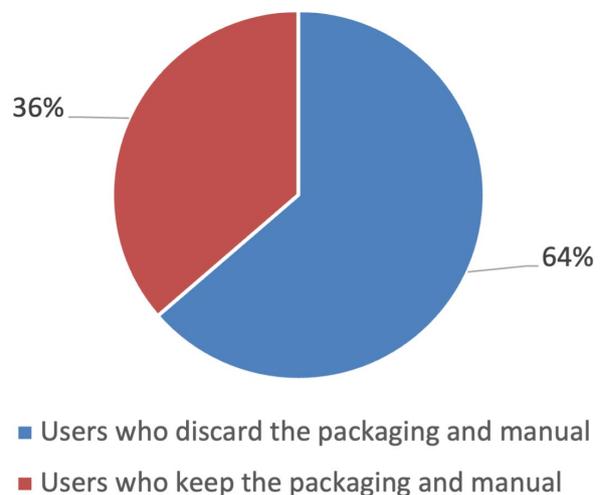
Fig 69: User retention of packaging and manuals post-unboxing

9.5 Evaluation and Discussion

User testing offered strong validation for the core idea: that combining a modular product design with an intuitive digital guide can make repair more accessible, especially for people without technical experience. Most users were able to navigate the repair journey confidently, suggesting that when the physical product is designed clearly and the instructions are well-structured, the act of repair becomes less intimidating, even enjoyable.

That said, a few important problems came to light. One of the more surprising takeaways was that when something is physically intuitive to assemble, users are less likely to engage with digital support, even when it's meant to be a key part of the experience. The QR code, for example, went unnoticed by many. This raises a design question: How do you make sure users actually engage with helpful digital tools when the physical interaction feels self-explanatory? It's a reminder that digital entry points need to be better timed or more embedded into the experience, not just visually present.

Another insight is around how users followed the chatbot's instructions. While most followed along without hesitation, a few didn't always understand why certain steps were being asked of them and although that didn't stop them, it does present an opportunity: This system could not only guide users, but also teach them, building their confidence and knowledge along the way. Right now, it helps people get the job done; with a few tweaks, it could also help them understand what they're doing and why.

There was also a clear divide in how different users experienced the system. While novice users appreciated the clarity and support, more technically experienced users felt the process could be more direct and streamlined. While the current system keeps adaptability in mind, the results from the test, presents the opportunity to build upon the adaptive nature of the chatbot to a greater technical scale and into something that can cater to different comfort levels and skip over steps that might feel redundant for advanced users.

Overall, the concept does what it sets out to do for its main target audience: it lowers the barrier to repair for technical novices and makes the process accessible and approachable, and encourages users to take ownership of their products. But it also points to opportunities for improvement in the physical design of the headphone, especially in how the digital experience is introduced, and how different types of users might move through it. These reflections are further explored in the following sections on concept limitations and concept potential, which dive deeper into what held the design back, what needs to be tested further, and where it could evolve.

9.5.1 Concept Limitations

While the prototype demonstrates a promising proof of concept for repair-centric design, several trade-offs and limitations became apparent during development and testing:

1. Trade-offs in Comfort, Durability, and Portability

Certain features commonly found in high end commercial headphones like swivel joints for folding, comfort and durability, water resistance, and fine-tuned ergonomic comfort were not prioritised in this project. These were conscious trade-offs made to keep the design simple, repairable, and achievable within the project time-frame. That said, these features could absolutely be explored and integrated in future iterations, with more time for refinement and testing.

2. Material Considerations and Environmental Impact

Magnets were used for cushion attachment to increase ease of replacement. However, they tend to leave a larger carbon footprint during production processes and pose difficulties in recycling. Additionally, metal components, while chosen for durability, contribute heavily to production-related emissions (Herrmann et al., 2023). These compromises were accepted to prioritise product durability and longevity. Still, the environmental cost of materials remains a challenge for scaling sustainably, especially when designing for circularity.

3. Design for Manufacture

The current design is not yet optimised for mass production. The headband includes undercuts that complicate injection moulding, and the left and right ear cups (despite their similarity) require separate moulds due to subtle asymmetries. Refining part geometry and exploring symmetrical mould solutions will be necessary for cost-effective scaling.

4. Need for a better introductory link between headphone and chatbot

User testing revealed that the unboxing experience has potential to be treated as a narrative touch-point, clearly showcasing the product's repairability through a well-illustrated and defined story that ultimately informs and points users toward digital support. An eye-catching pamphlet could direct attention to the repair agent or since most users naturally turn to online search when facing issues, the chatbot should also be accessible via search engines or the brand's official site, beyond physical access points like the box or product.

5. Diagnostic Logic Limitations

The current diagnostic approach assumes that at least one functional port is available for comparison. In rare scenarios where both the audio and charging ports are damaged, such as from internal shorting or liquid ingress, this logic breaks down, potentially resulting in misdiagnosis. A fall-back mechanism or advanced fault detection method is needed to handle such edge cases without confusing users. In such scenarios, a bluetooth connected application that derives live data from the headphone would have been useful.

6. Charging Verification Steps

Right now, users have to check if an LED lights up to confirm charging, but its size and placement means they keep turning on the headphones and shifting their focus between the chatbot interface and the headphone. This can be frustrating. A more user friendly approach might be moving the LED to a more visible spot- like a light strip around the ear cup, or using an audio signal instead, which grabs attention more naturally, especially when the sound isn't the issue being diagnosed.

7. Prototype fidelity

The prototype used for testing was 3D printed in PLA, which, while functional for evaluating the basic interaction, gave the product a somewhat fragile impression due to the material's inherent brittleness. This may have skewed perceptions of durability. A future round of testing with a high-fidelity prototype - featuring the intended materials, such as rubberised plastics and metal accents, would allow for more realistic feedback on product quality, finish, and perceived robustness. Additionally, the project did not explore the internal electronics and audio quality in detail. Functional circuit integration and testing will be important to consider in future iterations to assess electrical performance, safety, and compatibility.

8. Colour-Based Cable Identification

The chatbot's diagnostic process currently relies on identifying cables by colour (e.g., "insert the green charging cable"). While USB-C was selected for standardisation, users replacing the standard cable with a cable of a different colour, may receive incorrect instructions unless they manually update the bot about the colour change. Although a minor issue, this approach needs further refinement, perhaps through user prompts or visual verification to avoid confusion during the diagnosis phase.

9. Spare Part Verification Gap

Once the bot identifies a faulty component, it introduces a link to purchase a spare part for replacement. However, confirmation of a successful repair only occurs after the repair has occurred. In rare instances where the true issue lies deeper in the circuitry, the bot may misdiagnose the issue and lead users into purchasing spare parts when that part might not necessarily be causing the issue. In such scenarios, a bluetooth connected application that derives live data from the headphone would have provided a more solid diagnosis.

10. Repair Cost Transparency

Users reported difficulty in making informed decisions between self-repair and service centre options due to the lack of cost-related information. Future versions of the chatbot should integrate rough estimates for spare parts, service charges and shipping to help users weigh their options more confidently and reduce post-diagnosis frustration.

11. Access to Complex Repairs

In the interest of time, the current testing methodology focussed on high-frequency and high functionality repairs such as battery replacement. However, the guidance flow for replacement of priority B components like charging ports and audio jacks are yet to be tested. These repairs typically require more delicate handling. Future iterations must investigate how users respond to the guidance provided by the bot in these contexts.

12. Testing Limitations with Older Adults

Participant testing did not include many older adults, whose interactions with technology differ from younger users. Further research is needed to assess how this demographic engages with chatbot-guided repair and whether accessibility needs such as larger text, slower pacing, or voice prompts should be incorporated into future versions.

9.5.2 Concept Potential and Future Scope

Beyond addressing the limitations mentioned in the previous section, the concept has strong potential to evolve in both functionality and scale. The following section explores ways in which it could be further developed to offer greater value, not only to users but also to repair services and manufacturers.

1. Beyond Headphones

Using familiar messaging apps as repair guides offers a simple, scalable way to support users across many types of consumer electronics. Since people already use platforms like WhatsApp and Telegram daily, this approach lowers barriers and makes repair more accessible. Adapting the chatbot for devices like smartphones, laptops, and wearables could create a seamless ecosystem that encourages repair, reduces electronic waste, and empowers users to repair and maintain a wider range of products with confidence.

2. Back-end value for manufacturers

If fully integrated into a company's customer support infrastructure, the chatbot could go beyond offering repair guidance. By analysing anonymised user conversations, it can catalogue recurring failure types, usage patterns and frequently asked questions. These insights could feed back into product development pipelines, helping engineers refine designs, identify weak components and pro-actively address design flaws in future iterations.

3. Speed up repair processes at repair centres

For users opting for a professional repair service, the chatbot could collect pre-diagnostic data through its conversations with the user and relay this information to authorised service centres ahead of time. This would allow technicians to pre-identify required tools or replacement parts, considerably reducing repair turnaround times and improving operational efficiency at scale.

4. Integrating and testing on real platforms

The chatbot was initially implemented on WhatsApp. However, it was taken down before testing due to platform restrictions on unauthenticated business accounts. As this was a non-commercial student project, it could not be registered as a legitimate business. Moving forward, deploying the chatbot through verified platforms such as WhatsApp Business, Telegram or a dedicated brand-owned web interface would enable proper long-term usability testing, improve platform reliability, and generate more data about the system's value during future testing.

5. Voice-Based Chatbot Interface

Especially for users less comfortable with text interfaces or who may be multitasking during repair, a voice-based version of the chatbot could make the interaction more natural. This could also be a fall-back in situations where the user is unable to type due to both hands being occupied during a repair or for users who are facing accessibility issues.

6. Language Support Gaps

One user flagged the lack of language options as a barrier to following instructions. While English was sufficient for most, multilingual support or automatic language detection will be necessary for broader accessibility, particularly in global markets. This was not implemented in the current version due to the project timeline and scope limitations, but it remains an important development opportunity.

7. Visual Recognition for Part Identification

Users could upload or scan photos of their damaged headphones, and the chatbot could use computer vision to identify the faulty components visually (like broken hinges). This is especially useful when users don't know the part names and would streamline both diagnosis and part ordering. The same vision-based technology could be used to accurately measure a user's ear size, enabling the automatic recommendation and ordering of correctly sized ear cushions, reducing the guesswork involved in choosing from pre-set size profiles online.

8. Dynamic Assembly/Disassembly Animations

Instead of static videos, the chatbot could serve interactive 3D models or real-time animations that users can rotate or zoom into at their own pace. This would be especially valuable for more complex repairs like port replacements, which require visual precision. With features of messaging platforms evolving over time, this could also be practically possible in the near future.

9. Smart Part Ordering and Inventory Sync

The chatbot could connect with a back-end inventory system and suggest exact-matching parts based on the user's product model and diagnosis. It could also flag out-of-stock parts and offer alternatives, shipping estimates, or local pickup options, helping close the loop between diagnosis and action.

10. Collaborative Repair Mode

For community events like co-repair workshops and repair cafes, the chatbot could have a multi-user mode (through group chat features on messaging platforms) where multiple participants (e.g.., a user and a facilitator) can interact with the same repair journey. This could be used for teaching or brand-led workshops around sustainability at times when in person services are limited.

11. Return and Warranty Support Integration

Given the risk of misdiagnosis, especially in edge cases where the actual issue lies in the circuit board or internal wiring, future iterations of the system should connect users with return or extended warranty policies. Automating this pathway would reduce user frustration in cases where parts were unnecessarily ordered.

12. Integration with E-Waste and Recycling Pathways

To align with sustainability goals, the chatbot system could eventually introduce pathways to guide users toward responsible recycling or trade-in programmes for components they no longer need, helping close the loop on circular product use.

9.6 Conclusion

This project marks a promising first step toward making repair more intuitive, accessible, and engaging. While the current focus was on headphones, the principles behind this system - modular design, clear digital guidance, and integration through popular messaging platforms - have the potential to extend well beyond a single product category.

The results show that when users are supported with the right combination of thoughtful design and timely digital assistance, repair becomes less of a chore and more of an empowering experience. There are still areas to refine, but these are opportunities for growth rather than setbacks.

With further development and collaboration, this approach could evolve into a broader, more robust ecosystem that supports repair across a wide range of consumer electronics. In doing so, it can help shift mainstream expectations around product ownership, encouraging users to see repair not as a last resort, but as a normal and rewarding part of the product lifecycle.

This project is only the beginning, but it points to an exciting future where repair is not just possible, but desirable. Blending thoughtful design with emerging technologies can help make that future a reality.

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Appendices

Appendix A - Project Brief and Timeline

IDE Master Graduation Project

TUDelft

DESIGN FOR our future

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	Ramesh	7584
Initials	-	
Given name	Rishi	
Student number	5937124	

IDE master(s) IPD ✔ DfI ☐ SPD ☐

2nd non-IDE master

Individual programme (date of approval)

Medisign ☐

HPM ☐

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

Chair	Ruth Mugge	dept./section Design Organisation and
mentor	Yichen Jin	dept./section Design Organisation and
2nd mentor	Alicia Ville	
client:	Accenture	
city:	Eindhoven	country: The Netherlands

optional comments: Professor Ruth Mugge's expertise in consumer behavior, Yichen Jin's technical knowledge, and Alicia Ville's industry experience in circular product design at Accenture create a strong balance of insights to develop a practical and impactful solution.

! 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)

Ruth Mugge

Digitally signed by Ruth Mugge
Date: 2025.03.04 15:00:41 +01'00'

Name Ruth Mugge   Date 4-3-2025   Signature

107.

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:

Sign for approval (SSC E&SA)

L. Boot

Digitaal ondertekend door L. Boot
Datum: 2025.03.11
16:25:27 +01'00'

Name ___Lisette Boot___   Date ___11-03-2025___   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:

Sign for approval (BoEx)

Monique von Morgen

Digitally signed by Monique von Morgen
Date: 2025.03.12
09:43:24 +01'00'

Name ___Monique von Morgen___   Date ___12/3/2025___   Signature _____

108.

Personal Project Brief – IDE Master Graduation Project

Name student Rishi Ramesh   **Student number** 5937124

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

Project title Repair Friendly Headphones: Leveraging intuitive design and artificial intelligence to encourage consumer

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 project explores Fixophobia - a phenomenon where consumers and value chain actors exhibit reluctance, distrust, or negative emotions toward repair practices. Focused on headphones, the project aims to explore how design interventions and Artificial Intelligence support systems can be used to improve user willingness to repair rather than replace. This project aims to work in line with the objectives of the Netherlands Organization for Scientific Research (NWO) and the Knowledge and Innovation Communities (KIC) by focusing on user-centric design to promote innovation for positive societal attitudes towards repair.

Consumers play an important role in the circular economy, especially regarding product repair.Their main interest lies in balancing cost-effectiveness and functionality; many consumers are motivated to repair items as a means to save money while extending the life of products they already own. This interest is paired with emotional attachments to items, especially if they have sentimental value or are in good condition. Barriers such as a lack of knowledge about repair processes, inadequate access to tools and resources, or perceived inconvenience can prevent them from undertaking repairs.(Image 1)

Manufacturers have a vested interest in the shift toward a circular economy, as it affects production, design, and profitability. Repairability can improve brand reputation and loyalty, especially with eco-conscious consumers. Currently, the challenge lies in the fact that many business models prioritize planned obsolescence, encouraging shorter product life spans to boost sales. Shifting to a model focused on durability and repairability require initial investments and replanned business models.

The project presents the opportunity to rethink the design framework of headphones, while keeping repairability in mind. It will also explore the integration of AI into repair practices. From diagnosing faulty parts to playing advisory and assistive roles during repair, AI presents opportunities to boost consumer confidence in repair practices.

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

introduction (continued): space for images
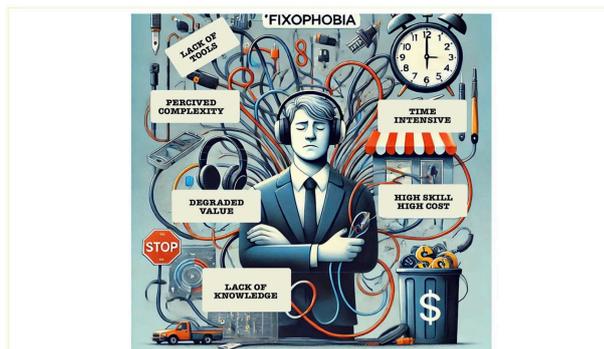
image / figure 1

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)

Many consumers lack the skills, confidence or tools to repair their headphones, which discourages them from attempting repairs and fuels the inclination to replace rather than fix. The perception that repairs are inconvenient, time-consuming, and complicated only supports this mindset. Furthermore, past unsuccessful attempts at repairing have created a negative stigma, further preventing consumers from attempting to repair their products in future. The absence of accessible official repair support, or the difficulty of navigating existing resources, only adds to the frustration, making consumers less likely to engage in the repair process themselves.

An in depth understanding of these barriers can highlight opportunities to design a repair friendly support system or design intervention that addresses the above mentioned issues.

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 solution that simplifies headphone repair and maintenance by incorporating a repair-friendly design, while utilizing artificial intelligence as a supportive tool to address users' hesitance to repair.

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)

Week 1-2:Conduct a thorough literature review and background analysis on Fixophobia and consumer behaviour regarding DIY repairs/ Analysis of AI integration scenarios
Week 3-4: Analyze existing solutions and market study (e.g., iFixit, modular headphones, Fairbuds,etc, component analysis) Literature review and Interviews with Repair Cafes, AI and Technical Experts on possibilities.
Week 5-6-7: Ideation/Brainstorming Concept Directions, Low-Fi prototyping and Testing (AI and Industrial Design)
Week 8: Midterm Evaluation / Select Concept Direction
Week 9-10: Verify and validate Concept feasibility with experts (relook and redefine concepts, if needed)
Week 11-12-13: Concept Refinement and Finalisation (Iterative Prototyping - 3D Printing)
Week 14-15: Hi-Fidelity Prototype development (AI Prototype & Physical Prototype - 3D Printing)
Week 16: Greenlight Meeting/80%report
Week 17-18: Conduct tests with users (A/B Testing) and make fine adjustments/draft a future development list based on results.
Week 19: Finalize Graduation Deliverables (Report, Showcase,Appendix report)
Week 20: Graduation

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	17th February, 2025
Mid-term evaluation	14th April, 2025
Green light meeting	6th June, 2025
Graduation ceremony	4th July, 2025

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)

I'm excited to work on this project as it offers a unique opportunity to explore the intersection of AI, industrial design, and repairability. With prior experience in repairability projects, I'm curious to see how AI can revolutionize this space. AI is a dynamic and trending topic across many fields, but I've yet to see it integrated into the 'Design for Repair' space, making this project an exciting chance to explore uncharted territory.
What excites me the most about this project is that I have the opportunity to redesign the way people interact with AI. Ultimately my goal is to develop a fresh approach, stepping away from the traditional prompt-to-result model and exploring more engaging, interactive and open-ended interfaces that might possibly inspire future versions of the technology.

On a personal level, this is my first project working on AI, and I look forward to deepening my knowledge of its capabilities and limitations in the context of not just repairability, but industrial design as a whole, knowledge I can apply to future projects. Ultimately, I want to be part of the movement shaping the future of Industrial Design and AI. By developing experience and knowledge at the intersection of these topics, I hope to create solutions that inspire others in the field and open new avenues for AI integration in physical product design.

111.

Graduation Project Timeline 2025
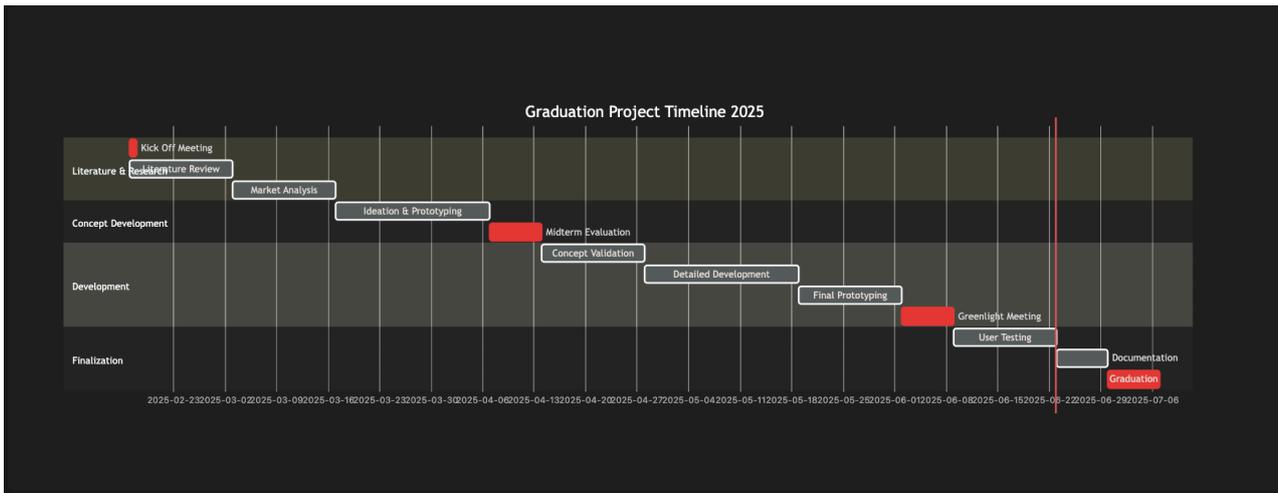
February 2025

- Week 1-2: Kick Off, Literature Review & Background Analysis
  - **Kick Off Meeting - Decide Dates and Finalise Brief with Supervisory Team**
    - Focus on Fixophobia and consumer repair behaviour
    - Analysis of AI integration possibilities
    - Documentation of findings
    - HREC Documentation

- Week 3-4: Market Analysis & Expert Consultation
    - Study existing solutions (iFixit, modular headphones, Fairbuds)
    - Schedule and conduct expert interviews - AI and Technical Design
    - Review AI implementation scenarios

March 2025

- Week 5-7: Ideation
    - Ideation and brainstorming sessions
    - Low-fidelity prototyping
    - Initial testing of concepts
    - AI integration exploration

- **Week 7: Midterm Evaluation (Pre- poned)**
    - Present progress and findings
    - Select primary concept direction
    - Gather feedback from supervisors

April 2025

- Week 9-10: Concept Validation
    - Expert consultation on feasibility
    - Concept refinement based on feedback
    - Technical validation of AI components

- Week 11-13: Detailed Development
    - Iterative prototyping
    - 3D printing of components
    - AI system development

May 2025

- Week 14-15: Final Prototyping
    - High-fidelity prototype creation
    - AI system integration
    - Physical prototype refinement

- **Week 16: Green light Meeting**
    - Present 80% complete report
    - Demonstrate working prototype
    - Gather final feedback

June 2025

- Week 17-18: User Testing
    - Conduct testing
    - Document results
    - Create future development roadmap

- Week 19: Documentation
    - Finalize graduation report
    - Prepare showcase materials
    - Complete appendix documentation

- **Week 20: Graduation**
    - Final presentation
    - Project defense
    - Submission of deliverables

112.

Appendix B - Repair! Elective Coursework

2.Gentle dismantle

The gentle dismantle process let us understand how the device is constructed, what can be improved and this contributed directly to the hotspot mapping and the disassembly maps whcih shall be discussed We have 3 main subsystems and the disassembly:

- Right ear
- Left ear
- Headband

The disassembly of the device will be dicsussed keeping these in mind.
The ⚠ sign will be used in areas which were a roadblock to the gentle dismantle

2.1 Gentle dismantle – Right Earphone

1.Removing the ear cushions with a puck
⚠ This needed more force than anticipated and felt like it would damage the product, not intuitive

2. The cushion can be lifted off along with the foam covering underneath

3. Unscrew all the 6 screws holding the back cover in place

4 Gently remove the back cover and detatch the touch sensor to remove the cover fully

5. Gently remove all the cables, use a spudger if necessary, avoid metal tools
⚠ Removing the cables is delicate and the jst cable started splitting apart when a bit of additional force was applied

6. Gently remove the battery, with a spudger

7. Unscrew the PCB at the bottom and remove carefully

8. Using the spudger, remove the foam and plastic gasket which holds down the other components

9. The headband pieces can be freed after removing the screws

10. The sleve for the cables can be removed along with the charging port PCB by hand

11. The microphone array can be removed from the enclosure by hands and prying with a spudger if necessary

12. The spudger can be used to remove and reveal the headphone driver as the last step
⚠ It is difficult to go past this step since it needs desoldering of the driver and removal of the driver from the plastic housing didn't feel possible without irreversable component damage

2.2 Gentle dismantle – Left Earphone

The left side is in many ways symmetric to the right with some variations, this has been focused on

1.Removing the ear cushions with a puck
⚠ This needed more force than anticipated and felt like it would damage the product, not intuitive

2. The cushion can be lifted off along with the foam covering underneath, the screws for the back-cover can then be removed

3. The 4 cables connecting to the main board can be removed, by hand or with a tweezer

4 The main PCB is secured with 3 screws which can be removed to take the PCB partially off, since the remaining cable is soldered to the driver

5. Unscerw the cable sleve plastic section and this gives access to the button PCB and the microphone array.

6. The headband can be gently removed now and the headband is fully seperated from the headphone now

2.3 Gentle dismantle – Headband

1.Remove the smaller plastic pieces at the hinges of the headband

2. Unscrew the plastic part to reveal the pivot and free part of the headphone cable

3. Unscrew the plastic cap piece connected to the main headband at the bottom and pry with puck
⚠ Not easily visible and once the screw is removed, it is very difficult to screw back in seamlessly

5. The swivel and the adjustment piece are attatched as a single unit

6. The leather and the adhesive tapes can be pulled back with some force to reveal the foam and the rest of the headband
⚠ This step could damage the leather and the comfort of the band

7. ⚠ For a true dismantle, to pull out the wire, it will have to be cut, since its crimped with a connector bigger than any of the holes it is passed through

4. Hotspot analysis

4.1 Right Earphone

High Priority Parts Identified –

1.Battery

2. Earphone Cushion

3. Driver

4.Main PCB

5. Jack/Button PCB

General project information	
Brand name	Sony
Product category	Headphones
Authors	un Gopkumar, Rishi Rame
Date	Mar-24
Location	TU Delft

Overall HotSpot Results

Total:		Average:		
-time to disassemble	1196 sec	- time per step	56.3 sec/step	
-number of tasks	79	- force	4	[]=low
-number of steps	39	- accessibility	5	[]=cle
-number of tools	3	- positioning	5	[]=max

4.2 Left Earphone

High Priority Parts Identified –

1.Jack/Button PCB

2..Earphone Cushion

3. Main PCB

4. Driver cover

General project information

Brand name	Sony
Product category	Headphones
Authors	un Gopkumar, Rishi Rame
Date	Mar-24
Location	TU Delft

Overall HotSpot Results

Total:		Average:		
- time to disassemble	1196 sec	- time per step	56.3 sec/step	
- number of tasks	79	- force	4	[1=low .. 5=high .. 10=extreme]
- number of steps	39	- accessibility	5	[1=clear .. 5=moderate .. 10=difficult]
- number of tools	3	- positioning	5	[1=easy .. 5=moderate .. 10=difficult]

4.3 Headband

High Priority Parts Identified –

1. Headband Plastic

2. Swivel Joint (Left and Right)

3. Head band Cushion

HotSpot Mapping Datasheet

General project information

Brand name	Sony
Product category	Headphones
Authors	un Gopkumar, Rishi Rame
Date	Mar-24
Location	TU Delft

Overall HotSpot Results

Total:		Average:		
- time to disassemble	1196 sec	- time per step	57.8 sec/step	
- number of tasks	79	- force	5	[1=low .. 5=high .. 10=extreme]
- number of steps	38	- accessibility	5	[1=clear .. 5=moderate .. 10=difficult]
- number of tools	3	- positioning	6	[1=easy .. 5=moderate .. 10=difficult]

6. Assessment results

Hotspots on economic level ⬤
1. Main PCB (Left Earphone)
2.Jack/Button PCB (Left Earphone)
3.Accessory PCB (Right Earphone)

Due to complex components, specialized tools, obsolescence, and the cost–effectiveness of replacement over repair.

Hotspots on environmental level ⬤
4.Earphone Cushion (Both Sides) – Due to mixed, inseperable materials
5.Headband – Due to mixed, inseparable materials
6. Driver Enclosure – Due to mixed, inseparable materials

Hotspots on function critical level ⬤
7.Battery – Deterioration of battery over product lifetime.
8.Swivel Joints (Both Sides) – Due to fragility
4.Earphone Cushion (Both Sides)– Due to wear and tear over time
5.Headband – Due to wear and tear over time
9.Driver – Compenent failiure is a critical failure
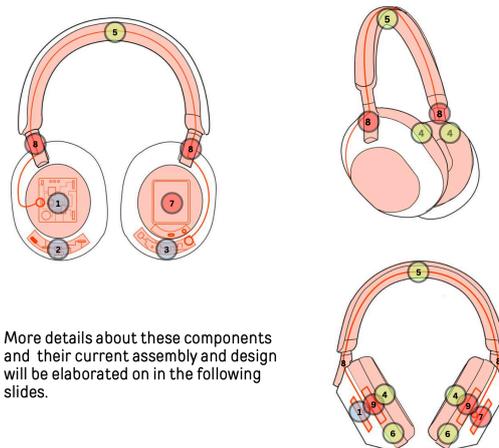
More details about these components and their current assembly and design will be elaborated on in the following slides.

115.

8.Redesign Overview

In our redesign of the Sony WH1000MX5s headphones, we've made significant improvements for accessibility and maintenance, detailed across subsequent pages. Key changes include relocating the Priority Parts sensor to the Right Earphone. Technical enhancements, such as easy battery access and glue-free cushion fabric attachment, streamline maintenance. Swivel joint hinges are now outside for simple disassembly, and combining enclosures reduces glue usage. These changes are explored in depth in the subsequent pages, offering comprehensive insights into the redesign process and its benefits.

Modular Parts for easy Dissassembly

Cushion fabric seperable from fabric

Swivel Hinges on the outside

Easy Access to Driver

Easy Access to Battery

Redesign

Cushion Fabric

Technical Redesign

Taking cues from the older version of the same line of headphones (Sony WH1000XM4), The Cushion fabric is now designed to hook onto the snaps that hold the cushion foam in place. This eliminates the need for glue.

User Aspects Redesign

By Using the visible snaps as hooks to hold the fabric in place, the redesign effectively communicates to users that the cushions are replaceable and separate components. This approach contrasts with the opacity and permanence of glue, providing users with a clear visual cue that encourages and facilitates maintenance and replacement tasks.

Redesigned ear cushions based on the previous generation

Redesign

Swivel Joint (Seperating Earphone from headband)

Technical Redesign –

In the redesign we had changed the original ball bearing based swivel into a plastic tapered part which is snap fit but can still swivel. The cable was routed through the top to allow for a quick dismantle without disturbing any of the other cables

User Aspects Redesign –

This trade-off impacts user experience: while external ball bearings may offer smoother operation, they also enable easy replacement if damaged. Relocating the hinge externally necessitates careful cable routing to preserve aesthetics. The visible cable(after removing the cover) placement simplifies repair disassembly, facilitating easy dismantling for repairers.
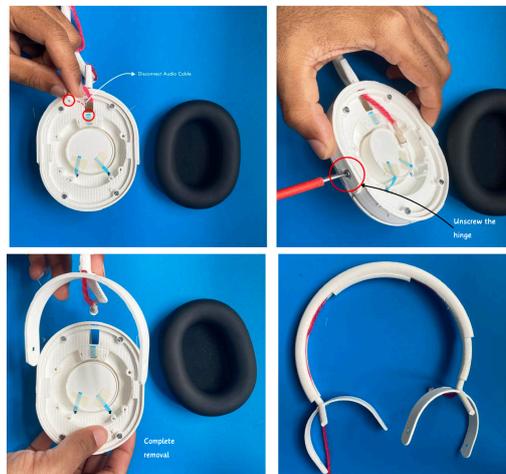
L to R disassembly process for the connector and swivel joint

Redesign

Driver Enclosure

Technical Redesign –

The Driver Enclosure was combined with the battery enclosure (Clumping). The battery layer is stacked (Stacking) over the enclosure layer. 6 captive screws hold the unit in place as opposed to the heavy amount of glue used in the earlier redesign.

User Aspects Redesign –

A significant departure from the previous assembly method involves replacing seamless glue adhesion with visible screws for securing components. By combining the Driver Enclosure with the battery enclosure, users now encounter six visible captive screws holding the unit in place, a stark contrast to the heavy reliance on glue in earlier designs.
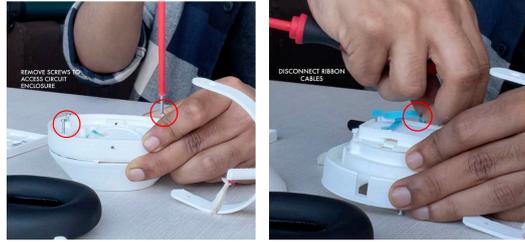
L to R opening up the driver enclosure

10. Policy

In this section we use the French Repairability Index(FRI) as a base to discuss legislative implications on repair and how how it can be optimised to satisfy legislative guidelines.

French Repairability index

The headphones were asessed similar to the scale of the smartphone, since there isn't a specific set of criteria for ANC(Active noise cancelling) headphones with certain aspects changed like the display being replaced by the audioDriver(APPENDIX A).
The main criteria of the FRI are:

Documentation :
The availability of free technical documentation from the manufacturer is crucial for repairers and consumers who would like to make small repairs themselves. This documentation typically includes disassembly diagrams, repair manuals, and diagnostic information and in some cases even PCB schematics if the company was really open.

Unfortunately, in the case of the Sony XM-5, it was challenging to locate comprehensive documentation as a consumer, even after over 30minutes of searching various websites for relevant documentation Third-party manuals were available but only through

unofficial channels(FIGURE) or leaked information, and manuals for the older models like the XM-4 were found leaked on websites like reddit the lack of official repair manuals from Sony itself was surprising. This scarcity of documentation can make it difficult for users to perform repairs independently, potentially leading to them seeking professional assistance or replacing the device altogether.

Ease of disassembly

The ease of disassembling the product for repair. This considers:
- The types of tools needed (common vs. specialized)
  - Not a lot of specialised equipment was needed for the teardown since it could be done mostly with a spudger and a single J000 screwdriver , it did demand soldering iron for the driver disconnect, however it is technically quite difficult and could be unreliable to use connectors since this could cause potential sound issues making the experience less than ideal.
- The types of fasteners used (screws, clips, adhesive, etc.).
  - The same type of screw is used throuought which is also a positive, not needing many tool changes. There is adhesive in several places which need to be removed by prying
- The accessibility of key components or priority parts.
  - The disassembly of certain critcal components like the headband of headphones is impossible to do without irreparable damage and lowers the repairability score of the headphone. The key and priority components as well take several steps before they can be accessed, this is un-ideal

Schematics found on unofficial websites(Sepeedyspares.com)

Puck, Spudger, Scewdriver
(FIXFANS 2.0mm PH00 Phillips Screwdriver With Plastic Spudger Opening Tool for PS4 Controller Repair Kit - Amazon.com, n.d.)

Cost of spares
- Due to the unavialability of spares, a lot of those which exist in the market are fakes or scavenged parts with very varying costs.
- Some parts come as large inseperable subsystems like the headband which results in a high cost

Availability of spares
- Not too many spares are available to the consumer, shockingly even commonly damaged components like ear cushions are very difficult to find.
- The parts are presumably only available to service centeres or the manufacturer directly(Communication with Keita, 2024).This may result in longer repair turnaround times, as consumers may need to wait for parts to be sourced and shipped from centralized distribution centers when they need to get things repaired.
- This also increases reliance on sony service centers to handle even small things like replacement of cushions which could come at a large cost to the coustomers as well.

Sony can empower consumers to undertake very simple repairs themselves or seek assistance from local repair professionals without over-reliance on the company. Additionally, enhancing communication channels and transparency regarding spare parts availability can foster trust and confidence among consumers, ultimately improving the overall repairability and sustainability of electronic products
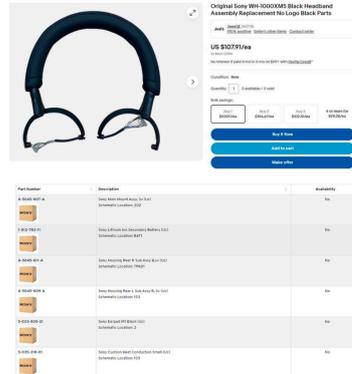
Cost of non Sony seller on e-bay(above)
Sony genuine parts not available to the average consumer(below)

Product specific

This headphone could fall into the category of Active Noise Cancelling headphones which is a more specific category into which the Sony XM5 headphone falls into. This comes with an additional layer of complexity and risk of the software which helps with the ANC function getting corrupted during use or an update. since it runs complex algorithems for cancelling noise. Sony has an app which is installed with this device and allowing for onthe air updates, this can reset firmware. This is in favour of the device since it is important for this. The headphone also has multiple microphones which is a product specific feature and it could be useful to have diagnostics for the ANC feature to let the user know if there is a damage.
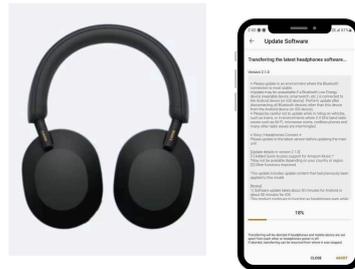
Discussion and conclusion

The headphones scored a 3.4 on the modified scale which was used for assessment in this report. This can be improved from a FRI standpoint by allowing better access for documentation and for consumers as dicussed in the respective sections. Critical components have several steps before access, in the revised designthe steps have been reduced bettering the score. Increasing the availability of spares could be benificial to sony since that would also work against the vast amount of non-OEM parts as well. It is also worth noting that even if the product were re-designed perfectly for repair, it would still score only a 4/10 if the other discussed shortcomings persisted.

App for the headphone

3.4 /10

FRI score (modified smartphone scale)for exisiting design

15.2 Appendix – Availability of Documentation (FRI)

Commitment on the availability over time of the documentation (in years)		Column B Repairers		Column C Consumers	
Type of documentation		**Duration of availability**	**Subtotal**	**Duration of availability**	**Subtotal**
1.1.A	The unequivocal identification of the product (type of product, trademark, trade name, model, and possibly, serial number)	if X ≤ 4 years	0	Not available	0
1.1.B	A dissasembly map or exploded view	if X ≤ 4 years	0	Not available	0
1.1.C	Wiring and connection diagrams	Not available	0	Not available	0
1.1.D	Electronic boards diagrams	Not available	0	Not available	0
1.1.E	List of necessary repair and test equipment	Not available	0	Not available	0
1.1.F	Technical manual of instructions for repair	if X ≥ 7 years	7	Not available	0
1.1.G	Diagnostic fault and error codes	if X ≥ 7 years	7	Not available	0
1.1.H	Component and diagnosis information	Not available	0	Not available	0
1.1.I	Instructions for software and firmware (including reset software)	Not applicable	7	Not available	0
1.1.J	Information on how to access data records of reported failure incidents stored on the product	Not applicable	7	Not available	0
1.1.K	Technical bulletins	Not applicable	7	Not available	0
1.1.L	Specific guidance for self-repair (recommended operations, safety and repair instructions, any implications for the guarantee)*			Not available	0
1.1.M	How to get access to professional repairers			if X ≥ 7 years	7
1.1.N	Failures detection and required action (consumers approach)			if X ≥ 5 years	5
1.1.O	User and maintenance instructions			if X ≤ 5 years	5
Total sub-criterion 1.1			35	17	52 /182
					2.9 /10

118.

15.5 Appendix – Price Criterion and Category Specific Scoring

Price criterion

PRICE Criterion	RATING			
	Value (euros)	Score (%)	POINTS (/100)	FINAL SCORE (/10)
Pre-tax price of the most expensive spare part (list 2)	109	25.98%	20	2.0
Average pre-tax price of other spare parts (list 2)	50			
Manufacturer's pre-tax price of concerned model	306			

Category specific scoring

Remote assistance	Column B Repairers		Column C Consumers		D : Remote a... point. – C : Remote di... application, de... – D : Remote su... remote control ...
	Condition	Subtotal	Condition	Subtotal	
5.2.A Type of remote assistance	Up-to-date informations on website	1	C : Remote diagnosis assistance	2	
Total sub-criterion 5.2		1		2	3 /5
					6.0 /10

Type of reset softwares	Column A Producer		Column B Repairers		Column C Consumers	
	Condition (impossible/possible)	Subtotal	Condition (impossible/possible)	Subtotal	Condition (impossible/possible)	Subtotal
5.3.A Electronic card reset	Impossible	0	Impossible	0	Impossible	0
5.3.B Firmwares reset	Possible	1	Possible	1	Possible	1
Total sub-criterion 5.3		1		1		1 3 /6
						5.0 /10

15.4 Appendix – French Repairability index

Commitment on the availability over time of spare parts (in years)	Column A Producer		Column B Spare parts retailers		Column C Repairers		Column D Consumers	
List 2 : Broken / malfunctioning parts	Duration of availability	Subtotal	Duration of availability	Subtotal	Duration of availability	Subtotal	Duration of availability	Subtotal
3.1.A Battery	if X ≥ 7 years	7	if X ≥ 4 years	0	if X ≥ 7 years	7	Not available	0
3.1.B Display device	if X ≥ 7 years	7	if X ≥ 4 years	0	if X ≥ 7 years	7	Not available	0
3.1.C Front-facing camera	if X ≥ 7 years	7	if X ≥ 4 years	0	if X ≥ 7 years	7	Not available	0
3.1.D Rear-facing camera	if X ≥ 7 years	7	if X ≥ 4 years	0	if X ≥ 7 years	7	Not available	0
3.1.E Charger	if X ≥ 7 years	7	if X ≥ 4 years	0	if X ≥ 7 years	7	Not available	0
Total sub-criterion 3.1		35		0		35		0 70 /140
								5.0 /10

Commitment on the delivery time of spare parts (in working days)	Column A Producer		Column B Spare parts retailers		Column C Repairers		Column D Consumers	
List 2 : Broken / malfunctioning parts	Delivery time	Subtotal	Delivery time	Subtotal	Delivery time	Subtotal	Delivery time	Subtotal
3.3.A Battery	if 5 days ≥ X > 3 days	2	if 5 days ≥ X > 3 days	2	if 10 days ≥ X > 5 days	1	Not available	0
3.3.B Display device	if 5 days ≥ X > 3 days	2	if 5 days ≥ X > 3 days	2	if 10 days ≥ X > 5 days	1	Not available	0
3.3.C Front-facing camera	if 5 days ≥ X > 3 days	2	if 5 days ≥ X > 3 days	2	if 10 days ≥ X > 5 days	1	Not available	0
3.3.D Rear-facing camera	if 5 days ≥ X > 3 days	2	if 5 days ≥ X > 3 days	2	if 10 days ≥ X > 5 days	1	Not available	0
3.3.E Charger	if 5 days ≥ X > 3 days	2	if 5 days ≥ X > 3 days	2	if 10 days ≥ X > 5 days	1	Not available	0
Total sub-criterion 3.3		10		10		5		0 25 /60
								4.2 /10

Commitment on the delivery time of spare parts (in working days)	Column A Producer		Column B Spare parts retailers		Column C Repairers		Column D Consumers	
List 1 : Functional parts	Delivery time	Subtotal	Delivery time	Subtotal	Delivery time	Subtotal	Delivery time	Subtotal
3.4.A Charging connector	if 5 days ≥ X > 3 days	2	Please select the right information from the drop-down list.		if 10 days ≥ X > 5 days		Please select the right information from the drop-down list.	
3.4.B Connectors	if 5 days ≥ X > 3 days	2	if 5 days ≥ X > 3 days	2	if 10 days ≥ X > 5 days	1	Not available	0
3.4.C Mother board	if 5 days ≥ X > 3 days	2	if 5 days ≥ X > 3 days	2	if 10 days ≥ X > 5 days	1	Not available	0
3.4.D Buttons	if 5 days ≥ X > 3 days	2	if 5 days ≥ X > 3 days	2	if 10 days ≥ X > 5 days	1	Not available	0
3.4.E Microphone	if 5 days ≥ X > 3 days	2	if 5 days ≥ X > 3 days	2	if 10 days ≥ X > 5 days	1	Not available	0
3.4.F Speaker	if 5 days ≥ X > 3 days	2	if 5 days ≥ X > 3 days	2	if 10 days ≥ X > 5 days	1	Not available	0
Total sub-criterion 3.4		12		12		6		0 30 /72
								4.2 /10

Commitment on the availability over time of spare parts (in years)	Column A Producer		Column B Spare parts retailers		Column C Repairers		Column D Consumers	
List 1 : Functional parts	Duration of availability	Subtotal	Duration of availability	Subtotal	Duration of availability	Subtotal	Duration of availability	Subtotal
3.2.A Charging connector	if X ≥ 7 years		Please select the right information from the drop-down list.		if X ≥ 7 years	7	Not available	0
3.2.B Connectors	if X ≥ 7 years	7	if X ≥ 4 years	0	if X ≥ 7 years	7	Not available	0
3.2.C Mother board	if X ≥ 5 years	5	if X ≥ 4 years	0	if X ≥ 7 years	7	Not available	0
3.2.D Buttons	if X ≥ 7 years	7	if X ≥ 4 years	0	if X ≥ 7 years	7	Not available	0
3.2.E Microphone	if X ≥ 7 years	7	if X ≥ 4 years	0	if X ≥ 7 years	7	Not available	0
3.2.F Speaker	if X ≥ 5 years	5	if X ≥ 4 years	0	if X ≥ 7 years	7	Not available	0
Total sub-criterion 3.2		38		0		42		0 80 /168
								4.8 /10

Appendix C - Headphone Innovation Cycles

The Innovation Diffusion Curve

To better understand the market positioning of repairability-first products, the Everett Rogers' Innovation Diffusion Model (Rogers et al., 1983) was used (Figure Below). This model segments consumers into categories based on how quickly they adopt new technologies and innovations.

- **Innovators category:** Fairbuds XL fits within the appeal to a niche audience of early adopters who prioritise sustainability over mainstream performance metrics.

- **Early Adopters segment:** AIAIAI TMA-2 falls into the, attracting users who value modularity and repairability without sacrificing high-performance sound.

- **Early Majority and Late Majority categories:** In contrast, mainstream headphone brands like Apple, Bose, and Sony cater to users who prioritise convenience, performance, and brand reputation over repairability.
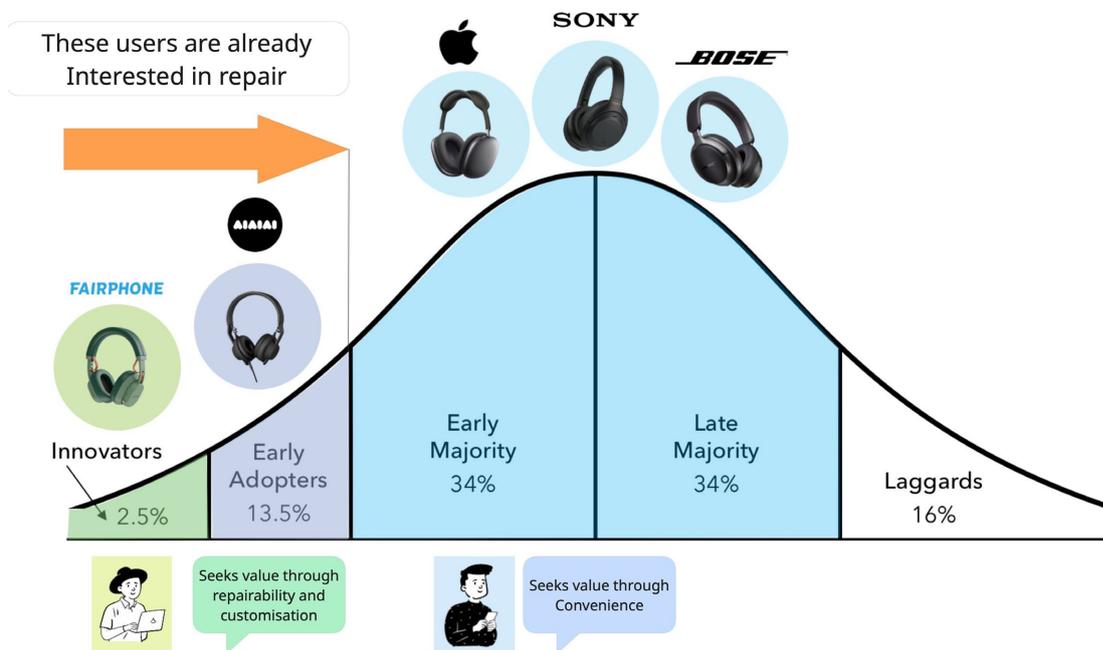
The Innovation Diffusion/Technology Adoption Curve (Rogers et al., 1983)

Each of the companies under early majority and late majority categories specialise in a performance based feature that sets them apart from the competition.

Apple:
Spatial Audio integration for immersive

Bose:
Superior comfort for extended use.

Sony:
Industry-leading Active Noise Cancellation (ANC).

Unique product offerings by major headphone brands

Consumers in the early majority and late majority segments tend to prioritise ready-to-use solutions with well-defined features. These consumers generally seek value in a good user experience and performance through convenient, ready to use solutions over customisation driven novelty offered by AIAIAI or sustainability driven novelty offered by Fairphone.

Therefore, to encourage repair adoption among casual users, repair-first companies must offer convenient mainstream solutions that link sustainability and mainstream user expectations. Expanding repairable product offerings beyond niche markets and including features that cater to mainstream consumer preferences could increase the attractiveness of repairability-first headphones in the broader market.

Appendix D - Warranty Coverage, Financial Costs and Spare Parts

A strong warranty can reduce the financial burden of repairs, while limited coverage may discourage users from attempting repairs at all. The following section will analyse warranty coverage for three popular headphone models.

Sony WH-1000XM5

- **Standard Warranty:** 1 year (varies by region)
- **Covers:** Manufacturing Defects
- **Excludes:** Water damage, accidental damage, battery degradation, and normal wear & tear.

Sony WH1000XM5

Fairbuds XL by Fairphone

- **Standard Warranty:** The Fairbuds XL headphones and their replaceable parts are covered for 24 months from the date of delivery to the original purchaser. However, the battery is covered for 12 months from the date of delivery.
- **Extended Warranty:** An additional one-year extended warranty for the Fairbuds XL, totaling three years of coverage. To qualify, you must register your product within 90 days of purchase. Note that the extended warranty does not cover the battery.
- **Covers:** Manufacturing defects, materials, and/or design during normal use.
- **Excludes:** Damage caused by misuse, accidents, or unauthorised modifications. Normal wear and tear. Consumable components, such as the battery, beyond their respective warranty periods. (Fairphone, 2023)

Fairbuds XL

AIAIAI TMA-2

- **Standard Warranty:** A 2-year limited warranty
- **Extended Warranty:** By registering for a free AIAIAI membership account and registering the product through this account, members can extend the standard warranty by an additional year, totaling 3 years of coverage.
- **Covers:** Manufacturing defects and damages occurring under normal use during the warranty period.
- **Excludes:** Normal wear and tear, misuse, use contrary to the product's manual instructions, unauthorised disassembly, and acts of God. AIAIAI's warranty policy does not explicitly mention coverage for consumable components like batteries. Therefore, unless a battery-related issue stems from a manufacturing defect, it is likely not covered under the warranty (AIAIAI Audio, n.d.).

AIAIAI TMA 2

While all three headphone models offer some level of warranty protection, there is a noticeable difference in their approach to supporting repairability. Fairbuds XL and AIAIAI TMA-2 provide reasonable warranties that align with their sustainable design philosophy. In contrast, it is interesting to note that Sony's warranty only covers battery deterioration for the first year, when the battery in the WH-1000XM5 typically starts deteriorating in the second year (Herrmann et al., 2023). This gap means users who are likely to be facing battery issues in the second year would be more inclined to replace or upgrade their headphones. This limitation places a financial burden on users and may discourage repair attempts, pushing them toward replacement instead.

Focusing on consumer repair, this study will focus on the cost of replacement parts and exclude costs of professional repair services. Consumer willingness to pay tends to vary based on user persona and the type of repair needed. Generally, consumers would be willing to pay 20 - 30% of the cost price of their consumer electronics during the first three years of use (Sandez et al., 2023 ;Bracquené et al., 2018; Cordella et al., 2019; Rames et al., 2018). Interviews with active headphone users at repair cafes align with this finding. The Interviews suggest that headphone users with intermediate technical knowledge, often budget a repair cost ranging from roughly 10–35% of the original headphone price. This is a rough estimate and the breakup of this range for specific types of malfunction is depicted in the figure below.
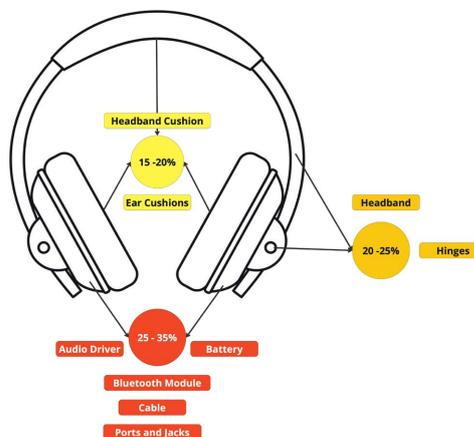
A cost breakup for how much consumers are willing to pay for repair based on the component needed to be repaired

Spare Parts Availability and Prices

In the scenario where the warranty coverage for the headphone expires, consumers base their decision on contextual elements that determine a user's ability to access, afford and use provided repair solutions. The table below summarises results from a study of competitor spare part costs. The results suggest that spare parts from Fairphone and AIAIAI generally fall within or near the upper limit of what users are willing to pay. The Sony WH1000XM5s present challenges due to limited spare parts provided officially by the company. It is relevant to note that the part that is most likely to fail in this model of headphones are the headband hinges. Though Sony provides replacement headbands through their official parts provider - encompass (WH1000XM5/B Sony Replacement Parts - Sony, n.d.), the headband costs 34% of the original headphone cost, which goes beyond the repair budget threshold for this category of malfunction. Furthermore, as noted in Table 1, availability of these parts are not perpetual. As products age, their demand decreases. Maintaining inventory for products with decreasing demand becomes increasingly expensive. Storage costs, the risk of the spare parts themselves becoming obsolete (due to newer material standards or design changes even within spares), and the tied-up capital make it uneconomical (Nahmias & Olsen, 2015).

Headphone model	Headphone Investment Price	Critical Component Failiure (25 - 35 % of Investment Price)					Mechanical Component Failiure (20 - 25%)		Wear and Tear Components (15 - 20%)		Available from Time of product release
		Battery	Speaker	Connecting Cable	Bluetooth module/PCB	Ports and Jacks	Headband Hinges	Headband	Headband Cushion	Ear Cushions	
AIAIAI TMA 2	300 Euros	30% — 90 Euros (Integrated in Headband module)	30% — 90 Euros (Integrated in Ear cup module)	20% — 60 Euros (Integrated in Headband module)	20% — 60 Euros (Integrated in Headband module)	30% — 90 Euros (Integrated in Ear cup module)	Not included in design	20% — 60 Euros	20% — 60 Euros (Integrated in Headband module)	17% — 50 Euros	Undisclosed
Fairbuds XL	250 Euros	8% — 20 Euros	16- 32% — 40 - 80 Euros (Varies Depending on Right or Left)	6% — 15 Euros	32% — 80 Euros (Integrated in Earcup Module)	32% — 80 Euros (Integrated in Earcup Module)	8% — 20 Euros	8% — 20 Euros	8% — 20 Euros	6% — 15 Euros	5 Years
Sony WH1000XM5	290 Euros	7% — 20 Euros (through an unofficial third party supplier)	Not Available	34% — 100 Euros (Integrated in Headband module)	17% — 51 Euros (through an unofficial third party supplier)	17.5% — 51 Euros (through an unofficial third party supplier)	34% — 100 Euros (Integrated in Headband module)	34% — 100 Euros	34% — 100 Euros (Integrated in Headband module)	4% — 12 Euros (through an unofficial third party supplier)	Undisclosed

An overview of spare part availability and associated costs of AIAIAI TMA 2, Fairbuds XL and Sony WH1000XM5 (Top to bottom)

Appendix E - Repair Cafe Visit (1st March, 2025)

To understand how important diagnosis is to the repair process, let's consider a real-world scenario observed at a Repair Café. At the café, the repair process for a Sennheiser audio headset was observed to take around 45 minutes. However, most of the time - approximately 30 minutes - was spent in disassembly and diagnosis. This brings to light, the difficulty of identifying the malfunction in consumer electronics, especially when the underlying problem is not immediately apparent. In a scenario, where even repair volunteers, who have technical knowledge and experience, diagnosing a problem can be a time-intensive process. Therefore, for a typical user with limited technical knowledge, such a prolonged diagnosis could be discouraging and may reduce their interest in proceeding with the repair action. It also suggests the importance of having reliable tools or clear instructions for diagnosis, which were observed in earlier sections to be currently lacking in many consumer headphone repair systems.
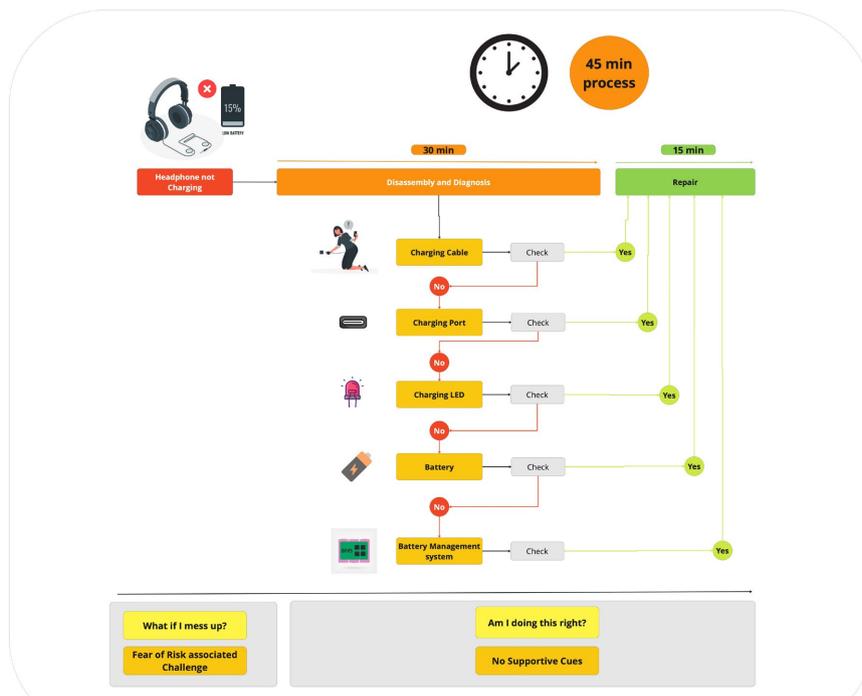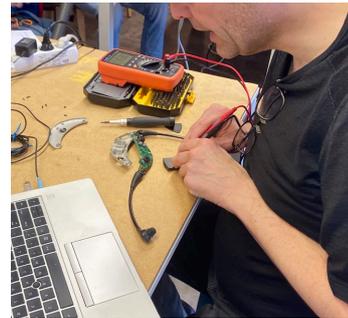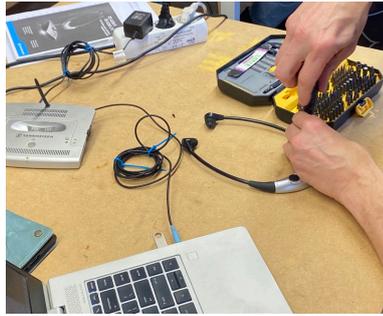
Appendix F - Repair Forums and Diagnosis Application Reviews
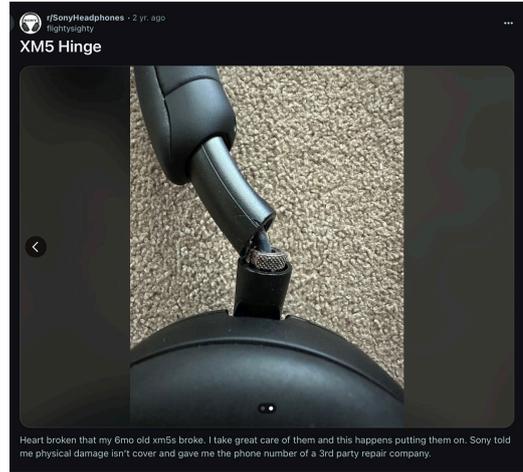
Xm5 hinge broke

Bro how is sony not yet sued for this thing, still in warranty, obviously a design flaw, it broke when I was putting it on and noticed it was awkwardly sitting and took it off to see the issue and it broken in my hand. They are asking rs16000($200) for repairing it.

r/SonyHeadphones · 2 yr. ago
flightysighty

XM5 Hinge

Heart broken that my 6mo old xm5s broke. I take great care of them and this happens putting them on. Sony told me physical damage isn't cover and gave me the phone number of a 3rd party repair company.

r/fairphone · 2 yr. ago
AirportPositive3415

Fairbuds XL not charging anymore

Issue

I somewhat recently got the Fairbuds XL and was using them frequently. Yesterday they ran out of battery and now the charging LED doesnt turn on anymore and the headphones are out of power. Would this rather suggest the battery or the charging port is dead? Or might it be some other problem anybody else has also faced before?
Thanks!

Unlock the full potential of your Fairbuds & Fairbuds XL.
• Switch between a selection of pre-tuned EQ presets
• Tune the Fairbuds & Fairbuds XL to your liking with more

Fairphone B.V.
Developer

Ratings & Reviews

2.7

★★★☆☆
14 Ratings

Pho-o-no   1 ✎   Dec 2024

Hi all, i recently bought a fairphone 5 and got fairbuds with them. So i wanted to give then a go.

When trying the actice noise cancelling I heard a lot of static noise, but only in my left ear. I know the static noise is part of how ANC works and have to admit that I have never used or experieced active noise cancelling before, so cant compare to other manufacturers. But i really am surprise with the volume and especially that I only hear it in my left ear.

Could it be that the bud is broken? Could it be that my ears are broken? Or is this just some getting used to?

Popular Forum Questions

No Answers

0 Score

How do I fix a loose wire in the right ear
Fairphone Fairbuds XL

Appendix G - Disassembly Maps

G1 - Sony WH1000XM5

Motion Type

= Hand Motion

= Single Motion tool

= Multiple Motion tool

Penalties

○ = Product Manipulation

◉ = Low visibility/identifiability

△ = Uncommon Tool

✕ = Non Reusable Connector

Target Components

Ⓟ = Priority Component

= Function Critical Component

Connectors

S.F = Snap Fit
F.F = Friction Fit
C.Plug = Cable Plug
R.Plug = Ribbon Cable
Ph #00 = Philips Screw Size #00
Ph #000 = Philips Screw Size #000

Sli = Slide through
Glu. = Glued
Sold = Soldered
R.Plug = Ribbon Cable
Twist = Twist Lock
Lift = Unfastened
Seeve = Seeve

Force Intensity

Low   Mid   High

Type of tool

(H) = Hand
(Sp) = Spudger
(Pl) = Pliers
(Sc) = Screwdrivers
(Tw) = Tweezers
(SI) = Soldering Iron
COT = Change of Tool

Component List

Components - Left
0. Cushion L
1. Cushion Frame L
2. Foam L
3. Circuit Housing (Back enclosure)
4. Circuit Housing Cover
5. Button/Jack PCB Cable
6. Feedback microphone cable
7. Left microphone array cable
8. Left microphone array (4 microphones)
9. GST Connector to Right side
10. WPAD Ring cable
11. Left Driver Contact Points
12. Silicone spacer 1 (WPAD)
13. Silicone Spacer 2 (Feedback microphone)
14. Circuit board
15. Hinge Fastener
16. Hinge Fastener Adhesive/Foam
17. Hinge cap R
18. Hinge cap L
19. Silicone Spacer (Purple, Left microphone array)
20. Jack/Button PCB
21. Button 1 (V)
22. Button 2 (P)
23. Jack
24. Driver Sensor cap
25. Driver.L
26. Ear Cushion Lining (Fabric)
27. Driver Bracing

Components - Right
28. Cushion R
29. Driver Enclosure (Sponge)
30. Circuit Housing
31. Touchpad sensor
32. Circuit Housing Cover
33. Battery cables
34. Battery connection to board (under the tape)
35. Battery
36. GST Connector to Left side running to left side
37. Microphone array right side
38. Feedback microphone connector or battery temperature connection
39. Feedback microphone cable
40. Ribbon cable connecting accessory board to USB PCB
41. Silicone spacer 1 (WPAD)
42. Silicone Spacer 2 (Feedback microphone)
43. Driver cable exit
44. Driver wire connections
45. USB type-C PCB
46. Driver.R
47. Ear Cushion Lining fabric
48. Driver Bracing
49. Foam + Plastic Gasket
50. Hinge Cap R
51. Hinge Cap L

Headband
52. Cushion- headband
53. Connecting band
54. Cap for adjustment piece(R)
55. Cap for adjustment piece(L)
56. Connecting wire
57. Swivel and adjust Hinge(R)
58. Swivel and adjust Hinge(L)

127.

G2 - Sony MDR - RF820R

Motion Type
- = Hand Motion
- = Single Motion tool
- = Multiple Motion tool

Penalties
- ○ = Product Manipulation
- ◉ = Low visibility/identifiability
- ⚠ = Uncommon Tool
- ✕ = Non Reusable Connector

Target Components
- Ⓟ = Priority Component
- = Function Critical Component

Connectors
S.F = Snap Fit
F.F = Friction Fit
C.Plug = Cable Plug
R.Plug = Ribbon Cable
Ph #00 = Philips Screw Size #00
Ph #000 = Philips Screw Size #000

Sli = Slide through
Glu. = Glued
Sold = Soldered
R.Plug = Ribbon Cable
Twist = Twist Lock
Lift = Unfastened
Pull = Pull out
Push.B = Push button
Cut = Cutting wires
Unhk = Unhook

Force Intensity
Low   Mid   High

Type of tool
(H) = Hand
(Sp) = Spudger
(Pl) = Pliers
(Sc) = Screwdrivers
(Tw) = Tweezers
(Sl) = Soldering Iron
COT = Change of Tool

Components - Left
0. Cushion.L
1. Audio Driver Frame. L
2. Audio Driver.L
3. Battery Cap
4. Battery cell 1
5. Battery cell 2
6. Circuit Enclosure.L
7. Headband Hinge L
8. Headband adjuster Spring.L
9. Battery Circuit Board
10. Charging Prongs

Components - Headband
11. Headband Frame
12. Headband Adjuster
13. Adjuster Circuit board

Components - Right
14. Cushion.R
15. Audio Driver Frame. R
16. Audio Driver.R
17. Main Circuit Board
18. Volume Adjuster
19. Tuning Adjuster
20. Circuit Enclosure.R
21. Power LED
22. Headband Hinge R
23. Headband adjuster Spring.R

G3 - Fairbuds XL by Fairphone

Legend

Motion Type
- = Hand Motion
- = Single Motion tool
- = Multiple Motion tool

Penalties
- ◯ = Product Manipulation
- ◉ = Low visibility/Identifiability
- △ = Uncommon Tool
- ✕ = Non Reusable Connector

Target Components
- ℗ = Priority Component
- = Function Critical Component

Connectors
S.F = Snap Fit
F.F = Friction Fit
C.Plug = Cable Plug
R.Plug = Ribbon Cable
Ph #00 = Philips Screw Size #00
Ph #000 = Philips Screw Size #000
Sli = Slide through
Glu. = Glued
Sold = Soldered
R.Plug = Ribbon Cable
Twist = Twist Lock
Lift = Unfastened

Force Intensity
Low / Mid / High

Type of tool
(H) = Hand
(Sp) = Spudger
(Pl) = Pliers
(Sc) = Screwdrivers
(Tw) = Tweezers
(SI) = Soldering Iron
COT = Change of Tool

Component List

Components - Left
0. Cushion. L
1. Cushion Frame.L
2. Cushion Fabric. L
3. Foam.L
4. Battery Cap
5. Hinge Frame.L
6. Adjust Slider.L
7. Headband Frame Cover. L
8. Adjust Slider Stopper.L
9. Headband Cushion Spacer.L
10. Battery
11. PCB Cover
12. USB C Connector.L (to Right Side)
13. Battery Connector
14. Microphone Cable. L
15. Driver Ribbon Cable.L
16. Driver Enclosure.L
17. Audio Driver

Components - Headband
18. Headband Cushion
19. USB Connector Cable
20. Headband Frame

Components - Right
21. Cushion. R
22. Cushion Frame.R
23. Cushion Fabric. R
24. Foam R
25. Main PCB Cap
26. Hinge Frame.R
27. Adjust Slider.R
28. Headband Frame Cover.R
29. Adjust Slider Stopper.R
30. Headband Cushion Spacer.R
31. Main PCB Cover
32. Main PCB
33. Power Button PCB
34. Toggle PCB
35. Toggle Ribbon connector
36. Power Button Ribbon connector
37. USB C Connector.R (to Left Side)
38. Charge Port Ribbon connector
39. Charge Port
40. Microphone Cable
41. Feedback Microphone cable
42. Driver Ribbon Cable. R
43. Audio Driver.R
44. Driver Enclosure.R

Appendix H - Emerging Technologies

"The NextGen energy meter" by Accenture

"The NextGen energy meter" (for Netbeheer Nederland) project, which I learned about during a visit to the Eindhoven office, offers an interesting example of sustainable design in practice. A key feature of its design is the modular gateway, which allows users to replace components themselves. This is achieved by concentrating the most critical parts of the meter into a single user-replaceable module. This user-centric approach reduces the need for service callouts and the transportation costs that go with them. By making it easier for people to handle certain maintenance tasks, the meter's modularity supports both cost-effectiveness and a longer working life for the product. Beyond that, the project prioritised minimising the meter's footprint, which directly cuts down on material use and streamlines logistics. This approach to modularity, focused on user-serviceability and resource efficiency, could serve as an inspiration or cue to redesigning the headphone architecture through concentrating critical components in replaceable modules.

Large Language Models (Chat GPT 4 Turbo)

Advanced large language models (LLMs), like the architecture under ChatGPT 4 Turbo offers opportunities for enhancing consumer repairability through their sophisticated natural language understanding and generation capabilities (Vaswani et al., 2017). By training these models on extensive repair documentation and using their reasoning and inference abilities, they can easily interpret user queries and provide tailored guidance, diagnose issues, and suggest relevant procedures. Furthermore, their generative capacity can extend to curating or creating multimedia content (images and videos) to illustrate repair steps, while contextual awareness allows for personalised support throughout the repair process.

ChatGPT-4 Turbo

Retrieval Augmented Generation (RAG)

Retrieval Augmented Generation (RAG) systems build upon the capabilities of language models by retrieving external knowledge into solution generation processes (Lewis et al., 2020). Instead of relying solely on their pre-trained knowledge, RAG systems first retrieve relevant information from external sources, such as databases or document collections called Vector databases, based on a user's query. This retrieved information is then combined with the original query and fed into the language model to generate a more accurate, up-to-date, and contextually relevant response, thereby generating factually accurate responses.
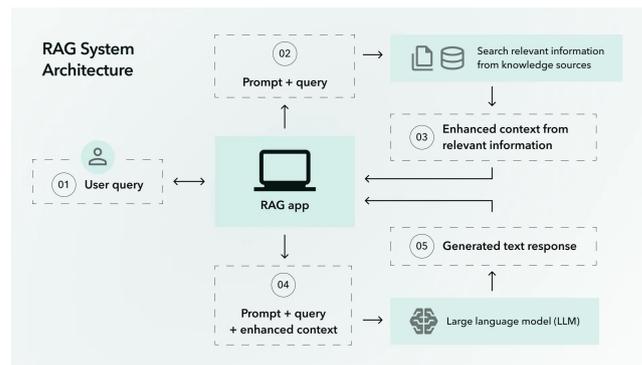
This approach was explored in an internal case study at Van Berlo for consumer repairability of VanMoof E-Bikes. In the context of headphone diagnosis, a RAG system could be useful. By accessing a knowledge base of technical specifications, repair manuals, user forums, and expert troubleshooting advice, the system could provide users with detailed guidance on identifying and resolving headphone issues.

Augmented Reality (AR)

Augmented Reality (AR) holds significant promise for democratising headphone repair by overlaying digital repair instructions directly onto the physical device. Users could wear AR glasses or use their smartphone cameras to see interactive, step-by-step guides that highlight specific components, demonstrate removal techniques, and even confirm correct reassembly (Solomashenko et al., 2025). This visual guidance can demystify complex procedures, making repairs more accessible to individuals without specialised technical skills and reducing the likelihood of errors, thereby encouraging more users to attempt repairs themselves rather than replacing their headphones.

Virtual Reality (VR) / Digital Twins

Virtual Reality (VR) and Digital Twin technology can create an immersive and risk-free environment for headphone repair training and troubleshooting. A highly detailed digital twin—a virtual replica—of a specific headphone model could allow users to practice disassembly, component identification, and reassembly in a simulated 3D space before touching the physical device (Meta for Work, 2025). Furthermore, this technology could facilitate remote expert assistance, where a technician could view and guide a user through a repair in a shared virtual environment, providing real-time feedback and instruction regardless of geographical distance.

3D Printing

3D printing offers a transformative solution to the perennial challenge of replacement part availability, a major barrier to headphone repair. With access to 3D printers and digital design files, users could fabricate their own custom or out-of-production headphone components, such as ear cup housings, headband connectors, or intricate plastic clips (XDA Developers, 2025). This on-demand manufacturing capability not only reduces reliance on manufacturers for spare parts but also empowers a decentralised approach to repair, significantly extending the lifespan of headphones that might otherwise be discarded due to a single broken part.

Visual AI Diagnostics

Visual AI Diagnostics can greatly streamline the repair process by providing automated and accurate assessments of headphone damage. By simply taking a picture or video of their malfunctioning headphones, users could leverage AI algorithms to identify damaged components, pinpoint the precise nature of the fault, and even suggest a list of necessary replacement parts or potential repair steps (Cadence, 2024). This immediate and intelligent diagnostic capability eliminates the need for guesswork, reducing frustration and making the initial troubleshooting phase of repair far more efficient and user-friendly.
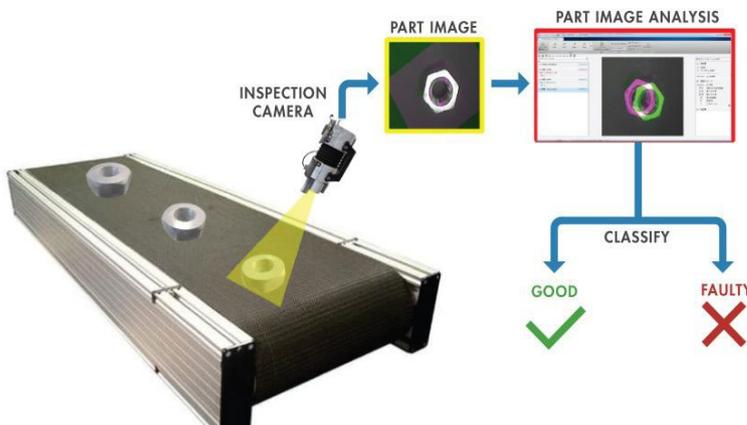
NFC/QR Code-Based Part Identification

NFC (Near Field Communication) and QR code-based systems can revolutionise the identification and sourcing of headphone replacement parts. By embedding small NFC tags or QR codes directly onto internal components or packaging, users could simply tap their smartphone or scan the code to instantly access a wealth of information about that specific part, including its specifications, compatibility with different headphone models, and direct links to purchase genuine or compatible replacements (Singh, 2020). This seamless identification process would significantly reduce the time and effort required to find the correct parts, thereby lowering a major hurdle to successful headphone repair.

Interactive Instruction Platforms

Interactive instruction platforms offer a dynamic and engaging approach to teaching headphone repair, moving beyond static manuals to personalised, adaptive learning experiences. These platforms can incorporate multimedia elements such as videos, animations, and simulations, allowing users to actively engage with the repair process rather than passively absorbing information (Kids First Services, n.d.). Features like gamification—including points, badges, leaderboards, and challenges—can significantly boost user motivation and retention, turning a potentially daunting task into an enjoyable learning journey (Hurix Digital, 2025; Opigno, 2023). By providing immediate feedback on completed steps and tracking progress, these platforms empower users to develop practical repair skills at their own pace, making repair more accessible and encouraging a proactive stance towards maintaining their electronics (Sensei LMS, n.d.).

IoT-Based Diagnosis

Internet of Things (IoT) based diagnosis can transform headphone repair from a reactive to a proactive process. By embedding sensors within headphones, real-time performance data could be continuously monitored, allowing the system to detect anomalies, predict potential failures, and even alert users to issues before they become critical (Raja, 2023). This predictive maintenance capability could trigger timely repair recommendations, provide early warnings about component degradation, or even automatically order necessary parts, ensuring that headphones are serviced before minor issues escalate into irreversible damage, thereby prolonging their functional life.

Appendix I - Brainstorming Template

"I've never thought about repairing my headphones - if they break, I just replace them."

HMW

incentivise repair interest?

HCW

strengthen the emotional connection between users and their headphones?

make repair feel as exciting as getting something new?

Phase 1 : Repair Interest

"I want to fix my headphones, but I don't know if it's worth it or how to do it."

HMW

make repair information easily accessible for confident decision-making

HCW

make diagnosing headphone issues simple and accessible?

ensure spare parts, repair info and costs are easy to find?

guide users on what they can fix vs. what needs professional repair?

Phase 2: Repair Decision

"I want to fix my headphones, but I'm afraid it will be too complicated and I might mess up."

HMW

make the process of repair non intimidating, engaging and fun?

HCW

make the disassembly and repair process feel intuitive, even for beginners?

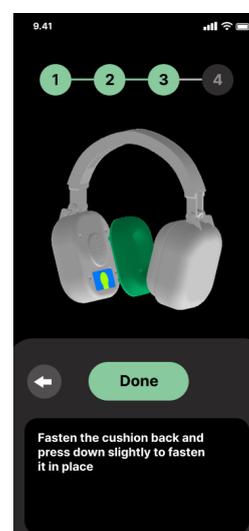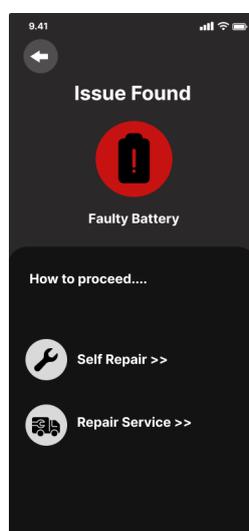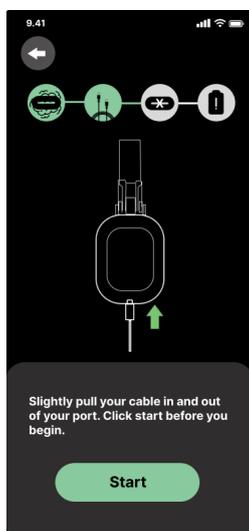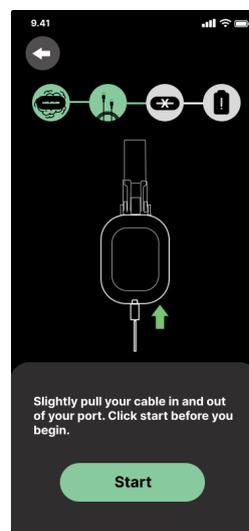provide supportive cues and feedback during the repair process?

Phase 3: Repair Action

Appendix J - Prototype Iterations

J1 - Headphone Design Iterations

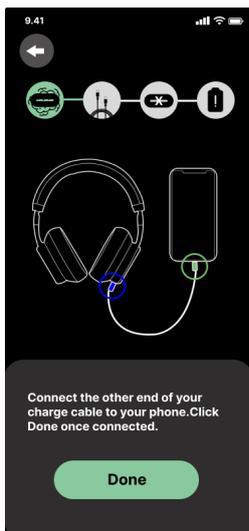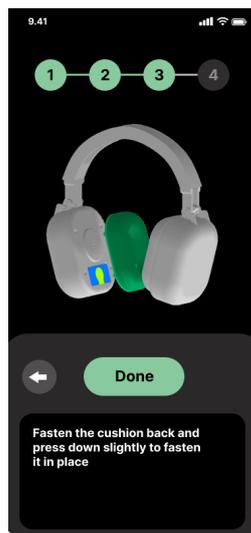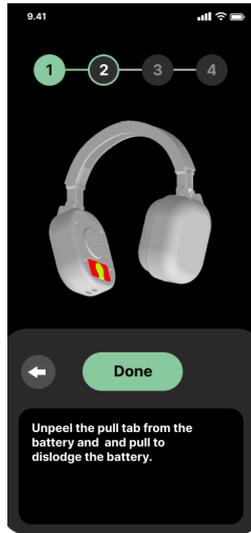| Components	Version 1	Version 2	Version 3	User Testing 1	Version 4
Ear Cushion	Magnetic attachment with symmetric alignement (attaches in any orientation)	Snap fits at the enclosure rims .Unfastens snaps via a push button. Rejected: Too much force required, may result in broken snaps	Extrusions on the cushion frame that fit into the enclosure via friction fits. Symmetric alignment (attaches in any orientation) Rejected: Friction fit tightness wear out over time. Cushion becomes loose	Recieved positively.	Magnetic attachment with symmetric alignement (attaches in any orietnation)
Headband Cushion	Unexplored in this version	Sleeve Over Headband that can be zipped up and down Rejected: requires disassembly of earcups from headband to remove cushion.	Hooked onto snap fits for headband cover	To be tested	Magnets
Hinges	Squeeze buckle mechanism	Ball and Socket Joint (snap fits) with a swivel hinge at the sides of the earcups. Rejected: Ball and socket Requires too much force to remove. The swivel Hinges, although beneficial for comfort adds complexity to the modular design and requires extensive disassembly to remove.	Squeeze to unlock with the usb connector as a lock for the hinge	Optimistaion: Provide clear indiactors for how to remove the USB and how the hinge can be squeezed	Squeeze to unlock with the usb connector as a squeeze lock for the hinge. Clear disassembly triggers provided.
Headband Adjuster	Unexplored in this version	Part of ball socket mechanism Rejected: Requires too much force to remove and requires uncommon precision tools.	Guided out of headband through a guided rail system when the headband cover is removed	To be tested	Guided out of headband when the headband cover is removed
Battery	Access from the back of the enclosure via flip lid (like a hood). Rejected: Adds another hinge mechanism that is likely to break and complicates the design.	Access from the back of the enclosure via snap fits (Push button to open). Rejected: Needs to be more accessable than ports. Right now, it as the same level of accessability as ports. Space for battery is an issue.	Accessable by removing the ear cushion. Can be ejected via a pull tab.	Recieved positively.	Accessable by removing the ear cushion. Can be ejected via a pull tab.
Charging port and Audio Jack	Access from the back of the enclosure via flip lid (like a hood). Rejected: Adds another hinge mechanism that is likely to break and complicates the design. Is too accessable for a low failiure part.	Snap fit cover that can be accessed via squeezing prongs behind the cushion.	Snap fit cover that can be accessed via squeezing prongs behind the cushion. Optimisation: Ports are attached via pogo pin connectors to the main PCB.	Optimisation: Communicate how the port can be pulled out through the design	Snap fit cover that can be accessed via squeezing prongs behind the cushion. Ports are attached via pogo pin connectors to the main PCB.
Connector Cable	Type C connectors are embedded into the headband Rejected: Type C Connectors are likely to face strain during hinge folding scenarios	Type C Cable connection point placed under the ear cushion. Rejected: Takes up too much space within the driver enclosure. Risk of damage is high due to bending wires at the hinge.	Type C to type C cable placed under headband cushion. Connector point is outside the enclosure and acts a s a lock for the hinge.	Optimisation: Make the fact that it is a USB connector that can be pulled out more clear	Type C to type C cable placed under headband cushion. Connection points outsid ethe earcup enclosure modified to communicate disassembly interaction
Other components (PCB, Microphone)	Placed under a screwed in false base that only reveals the battery, ports and connector cable connection Rejected: Takes up too much space in the enclosure design	Placed under a screwed in hood attached via 6 screws that are only revealed when the snap fit cover (with prongs) is removed.	Placed under a screwed in hood attached via 6 screws that are only revealed when the snap fit cover (with prongs) is removed.	Out of scope for testing	Placed under a screwed in hood attached via 6 screws that are only revealed when the snap fit cover (with prongs) is removed

J2 - Digital platform typologies evaluation table

Platform Typology	Description	Adavntages	Disadvantages
Automated Self-Diagnosis Application	A hardware-integrated system that connects to an application via bluetooth and uses internal sensors to run automated tests on headphone components and generate repair scenarios.	• Real-time, automated diagnostics • minimal user interaction required.	• Does not facilitate user participation or understanding • lacks transparency in the process • Depends on costly sensor integration • No means to gather competence data for personalised repair instructions.
Standalone Bluetooth-Connected Application	An application that connects to the headphone via bluetooth and receives live data from it. Instead of using sensors to directly diagnose the problem, it will ask the user to conduct a series of tests and verify if these steps have been done properly (Eg: removal of battery and replacement confirmations) Based on user actions performed on the device, the application sends confirmation and feedback every step of the way.	• Facilities active participation of the user in the diagnostic and repair process. • Interactive support • Verifies user actions gathers useful data on user behaviour to generate personalised instructions and advice	• Requires users to download a new app for an infrequent task -likely reducing adoption • unfamiliar interface: higher user learning curve. • Intensive development and maintenance effort on the manufactures end.
AI Chatbot on Messaging Platforms - WhatsApp/Telegram	A conversational AI assistant integrated into popular messaging platforms, using LLMs to guide users through diagnosis and repair processes in natural language.	• Highly accessible: leverages platforms users already use • Adapts dynamically to user competence • supports audio, text, and visual media; • minimal development overhead.	• Relies on user-reported data • Limited direct access to hardware-level diagnostics due to lack of bluetooth connection capabilities. • Might not be the best interface for guided repair and diagnosis

J3 - Bluetooth connected application interface screens

Hey there!
How can I help ?

Charging Issue   Audio Issue

Broken Hinge   Cushion worn out

None of the above?

Enter you issue here (Eg: My cushions keep falling out) |

That's frustrating...
Let's figure this out
together

Please select what you have already tried

Different Charge Cable

Cleaned the charging port

Measured Battery Voltage

I have not tried anything yet

Proceed>>

Got it!
These could be the
possible causes:

Clogged Port

Faulty Cable

Damaged port

Battery Issue

Let's start the diagnosis process step by step

Start

Connect your charge cable to your headphone.Click Done once connected

Done

Connect the other end of your charge cable to your phone.Click Done once connected.

Done

Use another cable to connect both devices.

Done

Skip >>

Gently wiggle your connector side to side. Click start before you start wiggling.

Start

Now wiggle your connector up and down.Click start before you start wiggling.

Start

Slightly pull your cable in and out of your port. Click start before you begin.

Start

Slightly pull your cable in and out of your port. Click start before you begin.

Start

Issue Found

Faulty Battery

How to proceed....

Self Repair >>

Repair Service >>

---

1   2   3   4

Done

Fasten the cushion back and press down slightly to fasten it in place

Screen 1

1 — 2 — 3 — 4

Done

Remove the left cushion cover by gently pulling the cushion outward.
This should reveal the battery

Screen 2

1 — 2 — 3 — 4

Done

Unpeel the pull tab from the battery and and pull to dislodge the battery.

Screen 3

1 — 2 — 3 — 4

Done

Insert the new battery into the battery socket

Screen 4

1 — 2 — 3 — 4

Done

Fasten the cushion back and press down slightly to fasten it in place

Screen 5

1 — 2 — 3 — 4

Success!

Complete

Your Repair is done!

Appendix K - User Testing Methodology V1

Questions to be answered:
Ease of assembly and disassembly
Does self-assembly at the beginning help with ease of disassembly later?
How effective is the diagnosis interface? Compare the standalone app with the chatbot interface
How effective is the repair guidance interface? Compare the standalone app with the chatbot interface

Participants:
5 (3 Novice, 1 Intermediate, 1 Advanced)

Methodology:

Phase 1: Self-Assembly

Category 1: 3 users - Self-assemble the headphones first
1 Novice (No prior repair/DIY experience)
1 Intermediate (Some repair/DIY experience)
1 Advanced (Repaired headphone before)
Category 2: 3 users Receive pre-assembled headphones
1 Novice (No prior repair/DIY experience)
1 Advanced (Some repair/DIY experience)
Purpose of this split:
Measure if self-assembly makes users more confident and more successful at diagnosing & repairing.
Measure this through comparing task completion times, error rates, and perceived difficulty.
(The rest of this section is not relevant for category 2 users. Skip to phase 2)
2.   Observe without assisting.
3.   Record:
Time to complete.
Points where the user hesitates.
Errors made (e.g., wrong connections, backward pieces).
4.   Post-task quick interview:
A basic reflection on the assembly process

Phase 2: Diagnosis (Charging Issue) - Repeat process with Standalone app and Chatbot Interface

1.Simulate a charging failure (Instruct user: "Your headphones aren't charging. Use the app to diagnose the issue.")
2.   Record:
User's ease with natural language input ("headphones not charging").
Comprehension of the diagnosis flow. (Do they follow instructions accurately?)
Specifically, what are the misunderstandings or UI confusions.
Confidence in diagnosis
3.   Post-task quick interview:
"Was the app's diagnosis clear?"
"Do you trust the diagnosis of the app"?

Phase 3: Repair Guidance (Battery Replacement)
1.   After diagnosis, the user chooses the DIY repair option.
2.   User follows the in-app 3D instructions to replace the battery.

Observe Points of hesitation (e.g., identifying the battery, using fasteners, cues and triggers effectiveness, whether they needed to redo steps.

4.   Post-task short interview:

"How easy or difficult was it to follow the 3D instructions?"
"Where would you rank this application with respect to Video tutorials and traditional instruction manuals?"
"Why this ranking?

Results

Phase 1: Self-Assembly (Category 1 participants only)

•Ease of Assembly:
All users in the self-assembly group completed the task successfully. The modular design and clarity of part fitting supported intuitive assembly, though novice users required more time.
Novice user: "I didn't really know what I was doing at first, but the way the parts clicked together made it kind of obvious."

•Fidelity-related confusion:

Across all groups, users misidentified the USB-C to USB-C connection due to prototype limitations.
Intermediate user: "Wait, is this a USB-C? I thought that was just some placeholder part."

•Link to Assembly and Confidence (Q3.1):
Users who assembled the headphones were noticeably more confident during later disassembly, recalling part placement and screw positions with ease.
Intermediate user: "Because I put it together myself, I sort of remembered where everything goes... it wasn't scary to open it up again."
Novice user: "Yeah, it didn't feel like I'd break something because I knew what was inside."

Phase 2: Diagnosis Interface (Chatbot vs. Standalone App)

•Chatbot Interface (Q3.2):
Universally familiar and easy to engage with. Participants appreciated the tone and immediacy but disliked typing out technical issues.
Novice user: "I wasn't sure what exactly to type, but I liked that it felt like I was just texting someone for help."
Intermediate user: "It's good, but I wouldn't want to explain every little thing by typing. A mix of both typing and options would be nice."

•Standalone App (Q3.2):
Users were slower to engage initially, partly due to reluctance in downloading a repair-specific app. Once inside, the UI was praised for clarity, especially the use of action buttons to guide the process.
Intermediate user: "I probably wouldn't download a whole app just to fix something once. I'd just call the repair service immediately to see if my product was still in warranty."
"But I liked how I could just click and move forward—no guesswork."

Novice user: "It was kind of hard at first, but once I started using it, it was very clear what to do."

Phase 3: Repair Guidance (Battery Replacement) (Q3.3)

•Instruction Flow:
The chatbot and standalone instructions were perceived as superior to both videos and manuals due to their precision and lack of filler content. Participants successfully followed the guide, with occasional pauses at technical steps.

Novice user: "YouTube videos always have so much blah-blah. This was just... do this, now do that. Much better."

Advanced user: "I just followed it step-by-step like building a model kit."

•Points of hesitation:
Minor confusion occurred while identifying the USB C connector due to prototype fidelity and unlocking certain fasteners. Most users completed the task within a 2 – 3 mins with minimal need to repeat steps.

Intermediate user: "I wasn't sure which part went in first – the connector or the hinge, but I guess If I figure it out once, it would be easy later"
Novice user: "The little arrows helped, but maybe make them pop more?"

Repair Instruction Format User Ratings
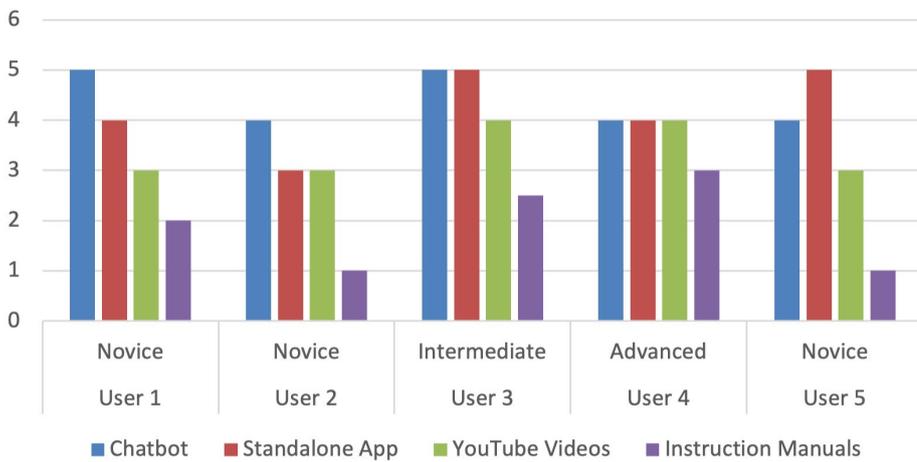
Appendix L - Chatbot Development

L1 - Development

1. Platform Overview

The AI Chatbot was developed on Botpress - an open-source conversational AI platform designed for creating scalable, modular chatbots with low-code tools. It features a visual flow editor, AI task handling, built-in NLP capabilities, and integrations with popular messaging platforms like WhatsApp Telegram, Instagram, Microsoft Teams and many more. It was chosen for this project due to its flexible conversation design system and ease of connecting logic-based workflows with AI-generated responses.

2. Conversation Design: Nodes and Cards
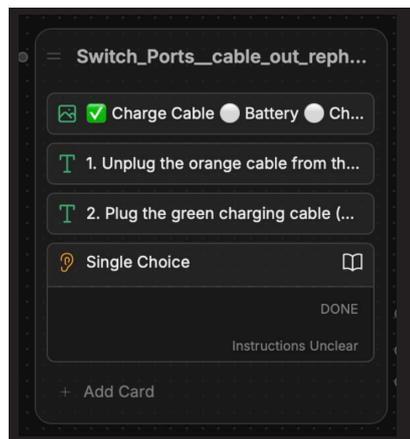
Cards Used:
- Text Cards: Used to display step-by-step repair instructions and system prompts.
- Image & Video Cards: Embedded in key stages of diagnosis and repair to visually support the user.
- Input Cards: Capture user responses (e.g., Yes/No questions, Raw Input).Input cards can store user input for conditional logic that can be used by the bot for later stages and decision making. This will be explained further under AI Task cards.

3.Workflows
'
This modular system allowed for easy branching and reusability across multiple workflows (workflows refers to set structure or flow of nodes). This flow can be linear or non-linear.

4. AI Task and Transition cards

For the purposes of this project, the repair workflows (Battery replacement workflow) is linear, but diagnosis would require the bot to be able to navigate through multiple branches based on user input. To help categorise and navigate through issues, AI Task cards are used.

AI Task Cards are Botpress's interface with generative AI capabilities (The Deep Seek R1 was used in this case). These cards are used to:
•   Translate vague user input into repair-specific actions. (Transition and Task Cards)
•   Make decisions on how to navigate through the guided workflow (Transition Card)
•   Offer natural language explanations when users requested help. (Task Card)

AI tasks are context-aware and can be enhanced using stored variables from the conversation history.

Here is an example:
An input node asks the user about their issue. The responses is recorded in a variable – @workflow.task. Another node is created containing AI Transition cards with issue intents – Audio issue, Charging Issue, uncertain. Etc. This node uses the input stored in the @workflow.task variable and categorises the user issue according how close it matches the AI Task cards listed. This must not be confused with keyword identification. The AI Task card does not identify keywords but views issue intents statement as one whole entity that communicates the user's intent behind the input.

4. Autonomous Nodes

Autonomous Nodes in Botpress allow the chatbot to leverage language models to interpret open-ended user input. Instead of following only predefined buttons or rigid paths, these nodes analyse free-text input and attempt to determine the user's intent. In this headphone diagnosis bot, Autonomous Nodes were used to create fallbacks for the bot to carry on a conversation when the predicted workflow is not being followed. However, because Autonomous Nodes are driven by LLMs, they don't always follow fixed flows. They're great at making sense of complex or vague inputs, but they can also produce responses that drift from the bot's intended behaviour. That's why they were used within clearly scoped interactions — for example, only within a diagnosis step — and paired with fallback logic. To manage this flexibility and keep the bot aligned with the repair journey, the system relied heavily on Hooks.

5.Hooks

Hooks in Botpress are blocks of code that can run at key stages of the conversation — before user input is handled or after an action is taken. In this project, Hooks were essential for controlling the limits of what the Autonomous Nodes could do -

Here's how Hooks supported the system:

•   Intercepted unclear or irrelevant input before it confused the logic.
•   Checked confidence scores or missing variables, and routed users back into safe, known workflows.
•   Maintained a consistent experience, even when users typed unexpected messages.

So while Autonomous Nodes enabled a natural and intelligent interaction style, Hooks made sure that experience remained structured, safe, and goal-oriented - nudging the conversation back on track when needed.

Together, they created a bot that felt responsive but still stayed focused on helping users fix their headphones. Here is the code for a hook that was used to keep the conversation restricted to the knowledge base provided –

```typescript
async function hook(event: IO.IncomingEvent, context: LLMZ.CreateContext): Promise<void> {
  /** Your code starts below */

  // >>>>>>>>>>>>>>>>>>>>>>>>
  // This hook is generated and managed by the "agi/kbo" integration.
  // This hook provides your autonomous nodes with a Table of Contents of the included knowledge of
  // the knowledge bases used in your autonomous nodes (those included on the `search` tool).
  // Do not edit this file manually.

  const searchTools = context.tools.filter((x) => x.name === 'search')

  await Promise.allSettled(searchTools.map(appendSearchToolTableOfContent))

  async function appendSearchToolTableOfContent(search: LLMZ.Tool) {
    type SearchMetadata = { kbs: string[]; searchScope: 'all' | 'specific' }
    const meta: SearchMetadata = search.metadata?.kbs ?? {
      kbs: [],
      searchScope: 'all'
    }

    const kbs = meta.searchScope === 'specific' ? meta.kbs : Artifact.knowledge_base.map((x) => x.id)

    const passages = await Promise.allSettled(
      kbs.map((kbId) =>
        client.searchFiles({
          query: event.preview,
          consolidate: true,
          contextDepth: 2,
          limit: 2,
          tags: {
            purpose: 'master-summary',
            kbId
          }
        })
      )
    ).then((x) => x.flatMap((y) => (y.status === 'fulfilled' ? y.value.passages.map((p) => p.content) : [])))

    if (passages.length) {
      context.instructions += `## Table of Contents (for tool \`${search.name}\`)
`
    }
  }
}

// End of the hook
// <<<<<<<<<<<<<<<<<<<<
```

147.

6. Knowledge Base

A Knowledge Base (KB) in Botpress is a structured set of documents or text entries that the AI assistant can reference when responding to user questions or generating replies. Unlike scripted dialogue, the KB allows the bot to answer questions with flexibility, pulling directly from a curated set of information. This makes it especially useful for technical support, FAQs, or repair guidance. For this project , the Knowledge base was a word document that was uploaded to the platform for the AI Agent to refer to when answering queries. The knowledge base contained the following info –

Charging Issues
Q: My headphones won't charge. What should I try first?
A: Try the following steps:
1.   Use a different charging cable.
2.   Clean the USB-C charging port on the left ear cup.
3.   Check the battery voltage, if possible.
4.   If none of these work, continue with deeper diagnosis.
Q: How do I know if the charging port is faulty?
A: Connect the charging cable to the top port of either ear cup. If the headphone begins charging, the issue is with the bottom charging port. If it doesn't charge, try the other earcup's top port. If it charges there, the battery or the original port is likely the issue.
Q: What should I do if neither port works?
A: This may indicate a deeper internal problem. Options include visiting a certified repair service

Audio Issues
Q: I have no sound / only one side working / distorted sound. What do I do?
A: First, determine your connection type: Bluetooth or wired.
•   If wired, try switching the audio cable.
•   If Bluetooth, check which ear cup isn't working and try connecting the charging cable to that top port to see if it charges.
•   If it charges: likely a cable issue.
•   If not: likely a port or driver issue.
Q: What if the sound is muffled or distorted?
A: Record a short clip of the audio using your phone.
Depending on the characteristics, this could be caused by:
•   A damaged driver
•   Loose internal wiring
•   A degraded component inside the cup

Each issue has a repair animation, part link, and service option available.

General Repair Guidance
Q: How are the audio and charging cables designed?
A: Orange = Audio cable (USB-C, connects both earcups at the top near the headband through orange ports)
Green= Charging cable (USB-C, plugs into bottom green port of right ear cup)

Q: How do I replace the battery or charging port?
A: Follow the repair worklfow for each component:
•Text instructions
•Video or animation
•Safety tips (e.g., use pry tools, wear gloves)
•Purchase links to components

## 7. Bot Integration Into Existing Platforms

Integrating the Botpress bot with WhatsApp or similar platforms is quick using the built-in Twilio integration. Simply install Twilio from the Integrations tab, connect your account, and link your WhatsApp-enabled number. The same bot can also run on multiple platforms like Telegram, Messenger, and web chat - just install the relevant integrations for each.
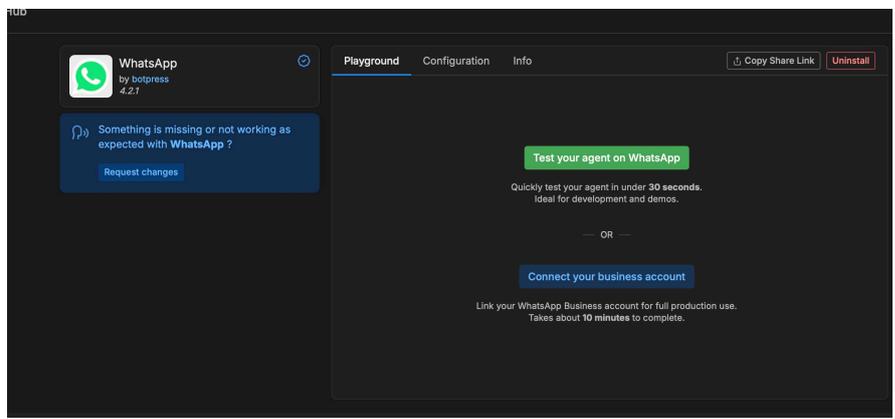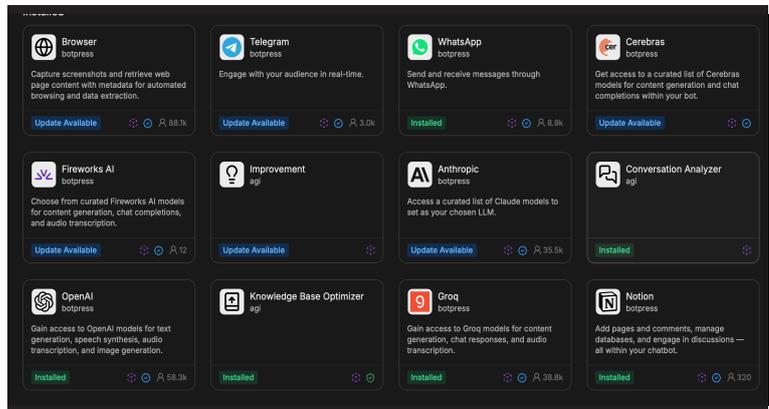
L2 - Hinge Repair Screens
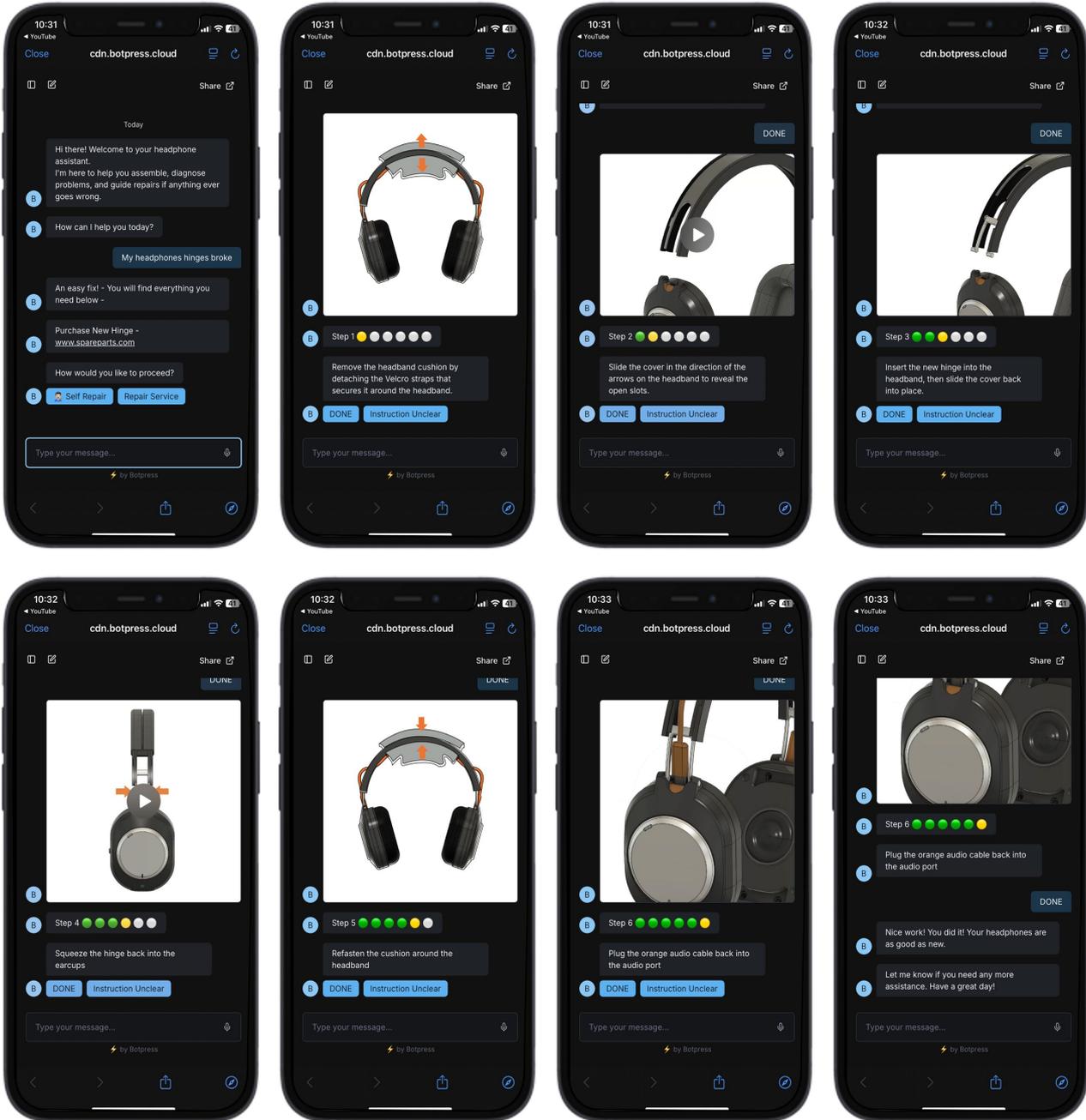
Appendix M - CMF Mood board
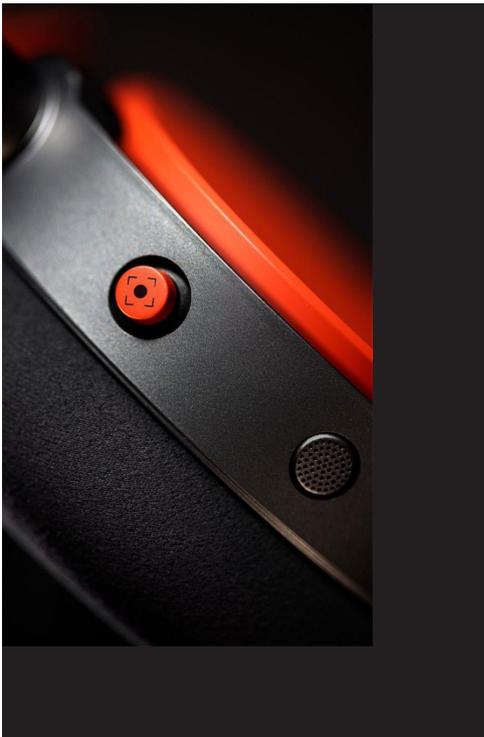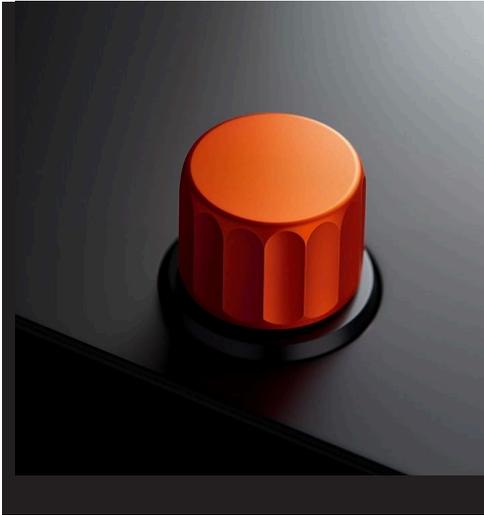
Appendix N - User Testing V2 - Prototype, Methdology and Results

N1 - Test Prototype

To mimic real-world headphone behaviours during testing, electronic components were integrated into the prototype:

The right ear cup houses a nodemcu esp8266 Wi-Fi board soldered to a lithium-ion battery. The researcher remotely controls an LED on this unit to simulate charging status, turning it on or off as users proceed through diagnostic steps.

The left ear cup contains a Bluetooth speaker driver paired with the researchers' Phone, allowing playback of sample audios after repair tasks to simulate audio functionality. This combination of visual (LED) and audio feedback creates a realistic and responsive user experience without a fully functioning hardware prototype.

The chatbot interface is a fully functional prototype, accessible through QR code stickers placed on both the product and its packaging. During testing, participants were asked to use the researcher's phone when scanning QR codes or accessing the chat interface. This was necessary because some users were operating company-issued devices, and scanning QR codes on those devices, posed potential digital privacy and security concerns.

Battery powered Nodemcu esp8266 Wi-Fi board in the right ear cup

Audio driver integrated into the left ear cup

N2 -Code for Wi-Fi Board

The following code was used to remotely switch an LED on and off using an ESP8266 nodemcu Wi-fi board.

```
#include <ESP8266WiFi.h>
const char* ssid = "hotpsot name"; //wifi ssid / wifi name
const char* password = "hotspot password"; //wifi password
int ledPin = LED_BUILTIN; // GPIO13

WiFiServer server(80);
void setup() {
 Serial.begin(115200);
 delay(10);
 pinMode(ledPin, OUTPUT);
 digitalWrite(ledPin, LOW);
 // Connect to WiFi network
 WiFi.mode(WIFI_STA);
 Serial.println();
 Serial.println();
 Serial.print("Connecting to ");
 Serial.println(ssid);
 WiFi.begin(ssid, password);
 while (WiFi.status() != WL_CONNECTED) {
   delay(1500);
   Serial.print(".");
 }
 Serial.println("");
 Serial.println("WiFi connected");
 // Start the server
 server.begin();
 Serial.println("Server started");
 // Print the IP address
 Serial.print("Use this URL to connect: ");
 Serial.print("http://");
 Serial.print(WiFi.localIP());
 Serial.println("/");
}
void loop() {
 // Check if a client has connected
 WiFiClient client = server.available();
 if (!client) {
   return;
 }
 // Wait until the client sends some data
 Serial.println("new client");
 while(!client.available()){
   delay(1);
 }
 // Read the first line of the request
 String request = client.readStringUntil('\r');
 Serial.println(request);
 client.flush();
 // Match the request
 int value = LOW;
```

```
if (request.indexOf("/LED=ON") != -1) {
  digitalWrite(ledPin, HIGH);
  value = HIGH;
}
if (request.indexOf("/LED=OFF") != -1) {
  digitalWrite(ledPin, LOW);
  value = LOW;
}
// Set ledPin according to the request
//digitalWrite(ledPin, value);
// Return the response
client.println("HTTP/1.1 200 OK");
client.println("Content-Type: text/html");
client.println(""); //  do not forget this one
client.println("<!DOCTYPE HTML>");
client.println("<html>");
client.print("<body style='background: #00979C'>");
client.println("<h1 align ='center'>");
client.println("<font-color='red'>");
client.println("Headphone testing");
client.println("</font>");
client.println("</h1>");
client.println("<bg color ='#00ff00'>");
client.println("</bg>");
client.println("<p align ='center'>");
client.print("Led is Now: ");
client.println("</p>");
if(value == HIGH) {
  client.println("<p align ='center'>");
  client.print("On");
  client.println("</p>");
} else {
  client.println("<p align ='center'>");
  client.print("Off");
  client.println("</p>");
}
client.println("<br><br>");
client.println("<p align ='center'>");
client.println("<a  href=\"/LED=ON\"\"><button>Turn On </button></a>");
client.println("<a  href=\"/LED=OFF\"\"><button>Turn Off </button></a><br />");
client.println("</p>");
//client.println("<p>");
//client.println("<marquee direction='right'>");
//client.println("Developed by Rishi Ramesh ");
//client.println("</marquee>");
//client.println("</p>");
client.println("</body>");
client.println("</html>");
delay(1);
Serial.println("Client disonnected");
Serial.println("");
}
```

Phase 1: Self-Assembly

Users received the disassembled headphone components (Fig FIXME) in a box with QR codes on the lid and ear cup. They were free to explore and assemble without instruction. No electronic feedback was used in this stage; assessment was based on physical assembly only.

Phase 2: Diagnosis (Charging Issue)

After assembly, the headphones were non-functional by design. Participants were tasked to find out why. This part of the test was focussed on observing ho well users recall the QR code.

Remote control of the charging LED provided real-time visual feedback during diagnosis. Users interacted with the chatbot's diagnosis feature, which included questions and interactive checks. When the chatbot requested charging verification, the researcher remotely activated the LED on the right ear cup via Wi-Fi to simulate system response. This LED activation helped users confirm that their actions were "working" within the scenario, simulating product feedback.

Phase 3: Repair Guidance (Battery Replacement)

Following diagnosis, participants attempted battery replacement guided by the chatbot. At this point, switched on the LED in the left ear cup to simulate a successful repair outcome. In some cases, the LED was toggled off to simulate a recharging attempt post-replacement.

N3 - Observations and Results

1. Ease of Assembly & First Impressions

Observation:

Most users approached the self-assembly task with curiosity or neutrality, though design clarity and part labelling strongly influenced confidence levels. Visual cues (magnets, port colours) were appreciated, while subtle issues (missing left/right labels, connector ambiguity) occasionally disrupted flow.

Reflections:

•Visual Guidance Works:
Users frequently relied on physical affordances. Colour-coded ports and magnets served as intuitive cues. This underscores how "design speaks" when users skip or overlook instructions.

•Confidence Is Built Through Doing:
Novices expressed increased self-belief after assembling, even when unsure at first.

Quotes:

•"The colours of the ports really helped" – User 1 (Novice, 40–45)
•"I feel like I've done something wrong in assembly...because I didn't follow a manual." – User 6 (Novice, 25)
•"Left and right indicators were there... but missing on the headband." – User 2 (Novice, 23)
•"Magnets made it intuitive." – User 4 (Intermediate, 35)
•" There is a satisfaction in building something myself." – User 5 (Novice, 26)

2. QR Code Discoverability & Digital Entry Point

Observation:
Relying solely on the QR code was not failproof. Users didn't always notice it or understand why it was there, particularly if not prompted. A recurring suggestion was to provide a physical card or label it more clearly.
Reflections:

•Discoverability Needs Redundancy:
The QR code as the main interaction trigger is promising, but not obvious. Adding redundancy (e.g., physical guides, packaging cues) could bridge the attention gap.

•User Habits Persist:
Some users instinctively start assembling without checking digital aids.

Quotes:

•"Probably wouldn't care for the QR the first time." – User 5 (Novice, 26)
•"QR needs to be more identifiable. I didn't notice it at all." – User 4 (Intermediate, 35)
•"Would prefer a piece of paper explaining everything instead." – User 3 (Advanced, 35)

3.Diagnosis Interface & Natural Language

Observation:
Users were largely comfortable typing their issues, though clarity and feedback transparency varied. Most novice users welcomed the chatbot's structure but expressed minor frustration when responses were slow or vague. More technically experienced users wanted more transparency and control over the diagnosis process.

Reflections:

•Trust is Built Through Feedback Loops:
Users appreciated the feeling that the chatbot "tested" or validated issues before suggesting solutions. However, the lack of visible logic made some advanced users doubt its depth.

•Language Input Felt Natural:
Most users described issues in intuitive phrases. The chatbot's success depended on understanding broad phrasing and offering clear prompts.

Quotes:

•"The diagnosis confirmation was nice... it made me believe it more because I actually tested something." – User 6 (Novice, 25)
•"Diagnosis process wasn't very transparent. I didn't know why it was asking me to do steps like plugging in the cable into this other port." – User 3 (Advanced, 35)
•"Bot takes a lot of time to interact with." – User 4 (Intermediate, 35)
•"It was very intuitive. I liked that it jumped straight to it." – User 5 (Novice, 26)

4. Repair Guidance Interface (Battery Replacement)

Observation:
Users found the repair instructions clear and accessible, especially when visuals and step-by-step structure were present. However, there was a call for improvements like auto playing videos, text-to-speech, or more overview-based content. Chatbot delivery was considered efficient but lacked flexibility at times.

Reflections:

•Chatbots Help, But Pacing Matters:
Chatbots were praised for cutting fluff, but sequential progression sometimes slowed down experienced users or created confusion when a step wasn't clear.

•UI Improvements Can Improve Clarity:
Features like a progress overview, optional voice narration, or faster navigation would improve comprehension for both novices and pros.

Quotes:

• "I really like the chatbot. It's straightforward." – User 7 (Novice, 25)
• "I didn't see the video. Autoplay would help to reduce the number of times I would have to click." – User 5 (Novice, 26)

5. Emotional Response & Repair Motivation

Observation:
Users, especially novices, felt empowered by completing the task themselves. For some, this shifted their perception of repair from intimidating to achievable. Intermediate and advanced users still expressed concerns about longevity, fragility, and the depth of customisation.

Reflections:

•Repair = Empowerment (for Novices):
Many novices expressed pride in accomplishing the task and were open to trying more advanced repairs.

•Experienced Users Demand More:
Advanced users focused more on material quality, transparency, and customisability than just functionality.

Quotes:

•"Before I pay professionals, I know what the issue is. That's nice." – User 2 (Novice, 23)
•"Feels a bit fragile…" – User 3 (Advanced, 35)
•"Assembling it made repair easier later." – User 4 (Intermediate, 35)
•"I'd like to try something more complex." – User 2 (Novice, 23)

(User Quote Excerpts taken from transcripts through Condens.io)