Modular Design in Audio Technology

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Abstract

The rapid consumption of technology products and consumer electronics in recent years has contributed significantly towards rising levels of electronics waste (e-waste) at a global scale. By design, many consumer electronics products have reduced usage windows spanning over a few short years due to several factors. This includes limited access to repair services and replacement parts, technological obsolescence and the influence of the market on consumers to consistently buy new products over establishing long term product care, upkeep and ownership. Over-ear headphones are the central focus of the research as this product occupies a unique position, functioning as a highly personal object that connects users to music, media and environment. Despite the important role headphones play in users daily lives, premature disposal is common due to limited repairability and access to spare parts and upgrades. This thesis investigates how modular design can extend the product lifecycle of over-ear headphones by addressing challenges surrounding repair, refurbishment, consumer attachment to products and perceptions of value.

Based on key research findings and consumer behavioural insights, the thesis proposes important considerations for establishing a human centred modular design framework. Key pillars of the framework include functional value, emotional value and attachment, social value, creative value and sustainability value. The research is focused on a multidisciplinary level of analysis of literature on consumer behaviour, circular business principles, modularity as a sustainable design practice and human centred design frameworks. This methodology involved thematic analysis on the information sources to reveal key, recurring themes. Perceived value, emotional attachment and co design through customisation are strong consumer behavioural insights that influence long-term product use and care.

Introduction

The rise of mass consumption within the consumer electronics industry has caused significant environmental concerns in recent years. The manufacture and production of headphones contributes to 80% of the product's overall climate impact. The majority of models are discarded within several short years of use (Herrmann et al., 2023). As a result, electronic waste (e-waste) is produced at an alarming rate and due to lack of recycling initiatives that can efficiently manage the volume of waste, at both a local and global scale. As outlined in Figure 1, this ultimately leads to illegal dumping and incineration of products containing valuable metals and materials that could have otherwise been recovered to re-enter the supply chain. Reduced lifecycle of electronics such as smartphones, laptops, audio devices and wearables is often the result of planned technological obsolescence. This is a strategic engineering approach to intentionally shorten the window where an electronic product can be used before requiring an upgrade (Wieser, 2016). The intention is to create artificial product usage windows by degrading software updates and slowing device speed, so that eventually users have no choice but to purchase a newer model when in theory the device they had been using could have lasted for far longer. Moreover, the majority of electronics products on the market do not facilitate repair or replacement services, hence when one component fails, this can more often than not result in the whole device being unusable. From a consumer perspective, it is most convenient and in some cases, more economical to purchase new when a product fails, especially since the profitability of consumer electronics companies is tied to sales of new products. Market studies in consumer electronics suggest that this sector prioritises product renewal and repurchasing over long-term use (Haines-Gadd et al., 2018).

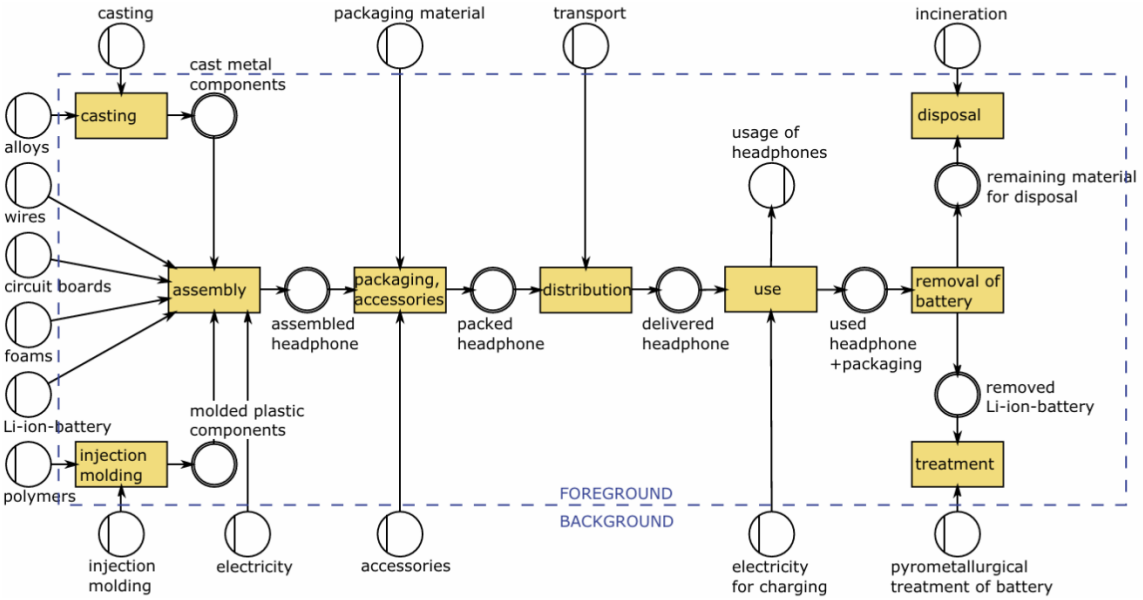

Figure 1 Headphones Supply Chain Overview & Product Lifecycle (Herrmann et al., 2023)

Within this context, headphones have a unique standpoint. Unlike other technology devices, headphones function as an immersive, wearable accessory that plays an important role in how users experience music, media, culture and environment. This makes headphones highly personal products, especially since they are so embedded in daily routines. Over time this can lead to users developing a form of emotional attachment towards the product that surpasses its functional value because headphones are a tool that facilitates emotional regulation, self expression and creativity, often through music (Daelemans et al., 2025). To an extent, headphones shape how users perceive and accommodate their surroundings through connection to music and culture. Despite the emotional and culturally significant role headphones play in daily routines, it remains a significant challenge to repair and source replacement parts for the majority of models on the market. The primary factors that inhibit users from headphones stems from either electronic failure or damage to ergonomic factors influencing ease of use and comfort such as the headband, ear cushions and adjustability. The design of wireless headphone models relies strongly on use of glue, soldering and sealed housings. This strongly discourages repair and disassembly primarily due to the fact that the process to partially dissemble the product becomes destructive, meaning that once it's taken apart it is highly difficult to repair and regain the same functionality and quality of performance as before (Herrmann et al., 2023). Moreover, when a battery, driver, charging port or cable fails, the entire product often becomes economically impractical to repair. This creates a contradiction between the emotional importance of headphones and their relatively short functional lifespan.

Modular design is an emerging practice that challenges technological obsolescence within the consumer electronics sector. The primary aim of modular design is to create a system for long term product use through repair, upgradable and replaceable parts, refurbishment and recycling. Essentially, all products reach end of life however modular design principles argue that the entire product should not be discarded, only the failed component should be removed from the system to either be repaired or replaced In the long run, modular electronics products promise economic savings to users through accessible upgrades, replacement parts and repair services (Ma & Okudan Kremer, 2016). Despite modular design initiatives by companies such as Framework and Fairphone demonstrating promising progress in the shift away from disposable electronics, these initiatives are not mainstream and instead fall into the niche market for eco conscious consumers. Companies that have a mass following such as Apple, Sony and Bose have teams of highly skilled engineers that could in theory integrate modularity within the existing systems to improve product sustainability, however the business models of these companies prioritize renewal over repair and upgrades.

Understanding consumer behaviour and how this influences users choices and preferences within consumer technology and the over-ear headphones market is a primary focus for this research investigation. Whilst some consumers are becoming more aware of their purchasing decisions and how this can ultimately impact the environment, when it comes to consumer electronics products it can be difficult to make environmentally conscious purchasing decisions due to lack of transparency from companies. Transparency refers to openness of brands on the environmental footprint of products, from the production process to the sourcing of ethical

materials, quality and durability. Consumers who source sustainably produced electronics products are the minority, and whilst sustainability is a ‘feel good’ measure for consumers, it does not necessarily translate to a selling point or a reason why a consumer should choose a sustainable product over other products (Kovel et al., 2023). This shapes the argument that sustainability and modularity itself is not enough to promote consumers to purchase a product, and must factor in other behavioural insights that drive and motivate consumers to make ethical purchasing decisions.

This thesis argues that modular design applications in over-ear headphones can challenge the disposable electronics model by extending product longevity through repairability, upgradeability and user perceived value. The research questions below have been established in response to the design challenge.

Primary Research Question:

How can modularity be integrated into the design & manufacture of over-ear headphones with a view to improve the product lifecycle without compromising ergonomic factors and acoustic performance?

Secondary Research Questions:

How can modular design be made desirable?

How do factors such as aesthetics, performance, comfort and price influence consumer behaviour and purchasing decisions?

Chapter 1. Literature Review Findings & Methodology

This chapter summarizes the key findings and themes from the literature review and highlights how analysis of the existing literature can shape a deeper understanding on consumer behaviour and how modular design practices must adapt beyond focusing primarily on repairability to also facilitate emotional attachment and desirability.

1.1 WICKED Context: A high level design challenge

The challenges associated with overproduction and waste management in the electronics sector falls under what can be classified as a wicked problem. According to Rittel and Webber (1973), wicked problems are characterised by complexity, uncertainty and conflicting stakeholder interests, making them difficult to resolve through linear problem-solving approaches. Environmental concerns within consumer electronics arise from overproduction from manufacturers, overconsumption from consumers, and a misalignment between law enforcement and policy makers with the objectives of environmental initiatives and organisations. There is also rising pressure for companies to drive economic growth and technological innovation over sustainability and ethical product development. Balint et al. (2020) argue that technological innovation on its own is not enough to address environmental problems because social, behavioural and cultural factors play a role in human values and decision making processes. Ultimately, wicked problems are solution resistant to linear problem solving because boundaries are not clearly defined and the nature of these problems involve interconnected systems.

1.2 Refurbishment and the Circular Economy

In response to wicked level environmental problems, circularity promotes a shift towards more responsible production and manufacturing, ethical sourcing and end of life considerations such as cradle-to-cradle design (Lofthouse & Prendeville, 2018). Refurbishment promotes circularity because it essentially gives used and returned products a second life through repair, cleaning, testing and restoration. By giving second life products the chance to re-enter the market, this offers a pathway for materials and functional value to be retained rather than being lost through disposal.

Consumer acceptance of refurbished electronics products in the market is based on perceptions of contamination, cosmetic wear, reduced quality and performance (Wallner et al., 2022). A barrier preventing the more widespread adoption of refurbished products in the market is the mixed beliefs and assumptions of consumers that second life products contain traces of previous users such as cosmetic wear, compromised performance and hygiene concerns. Hygiene in particular is a concern with refurbished over-ear headphones because components such as headbands and ear cushions come into direct contact with the skin. Depending on the material, it may be difficult to thoroughly clean, renew and refresh these parts. The study by Wallner et al. (2020) found that consumers are more likely to adopt refurbished products not

through reduced price and warranty but through elimination of visible signs of wear and full replacement of components that come into contact with the skin.

These research findings are highly relevant for over-ear headphones and supports the argument that modular design enables seamless replacement of parts that come into contact with the skin. Hence this influences consumers perceived product value surrounding cleanliness and overall product desirability. Ultimately, refurbishment is not solemnly a technical process, it is highly centred around psychology and experimental processes to influence users perception of value, newness and ownership.

1.3 Consumer Perceived Value and Factors that Drive Purchasing Behaviour

A recurring theme in existing literature and research in the field of consumer behaviour is that perceived value is one of the primary factors that drives purchasing decisions. Perceived value can be defined as a consumer's overall evaluation of a product based on balancing perceived benefits with cost (Zeithaml, 1988). Perceived value of products is often multi dimensional and is highly dependent on the type of user, with values streaming from functional, emotional, social, conditional and environmental needs. Consumer satisfaction is positively influenced through these values which in turn increases purchase intentions towards more sustainable products (Luo et al, 2022). The findings from this study challenge the assumption of traditional economic values that rationalise purchasing decisions are based primarily on price and performance alone. It argues that purchasing behaviour is equally influenced through personal experience, emotions and environment, all of which are psychological factors separate to economics.

These findings suggest that sustainability and modularity itself might not be a strong selling point to consumers. However, modular systems can accommodate perceived value beyond just technical benefits, where functional value and emotional value can emerge through customisation and personalisation, accessible upgrades and replacements and long term product ownership. Essentially a successful modular design system must balance technical, environmental and experiential value propositions to influence consumer adoption and continuous use.

1.4 Emotional Attachment and Durability

Whilst product repairability is essential in promoting long term use, emotional attachment is an equally important if not stronger influence that determines how consumers choose to care for, maintain and keep the products they own over extended periods of time. Emotional durability theory states that meaningful emotional relationships between products and users should be facilitated through human centred design practices with a view to reduce the occurrence of premature replacement (Chapman, 2005). Hence modularity can extend beyond a sustainable design approach into a human centred approach that facilitates the ongoing relationship between users and products. In relation to over-ear headphones, modularity can enable adaptation of a product to suit the user. Examples of product adaptation to the user could be

through upgrades of audio drivers that produce sound functionality, customised aesthetics and design upgrades to facilitate activities such as work, exercise and travel. Moreover, with headphones being a highly personal device, modular design acts as a pathway to preserve material product value and emotional attachment to accommodate for long term use.

1.5. The influence of Information Quality on Consumer Decision Making

Information quality and educational resources are a factor that can also influence perceived value of a product from the consumer's perspective. Zhang (2023) argues that product presentation and positioning equally influence the purchasing intentions of consumers through education and clear communication of the products key functions and benefits. Research into online product reviews highlight that consumers rarely evaluate products in isolation and often purchasing intentions are the result of comparisons between similar products, and how positive and negative reviews impact overall judgement. Consumers constantly analyse existing user product reviews however conflicting reviews can result in uncertainty and impact trust in relation to the product information available (Shan et al., 2025).

These findings are highly relevant to the commercialisation of modular over-ear headphones as consumer understanding of modularity may be limited, making it more difficult to compare modular products with other audio products on the market.

1.6 Methodology

Due to the complex nature of the relationships between consumer behaviour, sustainability and human centred product design, the current stage of the research adopts a qualitative approach with a focus on consumer experience. This study is informed within a wicked problem context, arguing that an interdisciplinary approach is required to approach sustainability challenges through technical, social, behavioural and cultural perspectives. Ethnographic research enables consumer behaviours and perceptions to be examined within natural settings and provides deep insight into motivations and experiences without facilitated interviews.

Chapter 2. Consumer Behavioural Insights and Perceived Value in Sustainable Product Design

This chapter expands on the themes from the literature review relating to consumer behaviour, emotional attachment and perceived value.

2.1 Emotion Attachment as a Driver for Long-term Product Care

Research shows that emotional value and attachment to products is one of the key driving factors that promotes long term use and ownership. Curras-Perez et al. conducted a study with 661 consumers to evaluate how emotional value influences consumer evaluations of products. The findings revealed that emotional value can be strongly influenced through social, environmental and economical sustainability initiatives. In particular, social responsibility initiatives influenced a stronger tie to emotional perceptions of value, highlighting that consumers value not only performance and function but also whether the product fits in with their ethical values and personal beliefs.

2.2 Customisation and Consumer Engagement

The integration of customisation into a product system has emerged as a highly effective strategy for facilitating emotional attachment and higher perceived value. By giving consumers the flexibility and element of choice to customise a product and take part in the product creation process, this can lead to increased emotional value beyond just the product's functional benefits. A sense of uniqueness and self expression can be achieved through co-creation, to produce a personalised product or service tailored towards the user (Tang et al., 2025). Ultimately customisation can create a more positive customer experience, strengthening the relationship between the user and products they choose to care for over time.

Within this same context, Yoo and Park (2016) found that multiple dimensions of perceived value can be achieved through customisation initiatives. These include creative achievement and social value, which in turn influence brand loyalty. The key findings from this study indicate that customer satisfaction is not only derived from a customised product itself, but also through the consumer participating in the design and customisation process. Hence, customisation has the potential to be an engagement mechanism that strongly influences psychological investment in products. Li et al. (2022) further support this hypothesis, arguing that the effectiveness of a product in capturing individual preferences and identities is a driving factor in how consumers assess and evaluate the benefits of a product.

2.3 Barriers to Sustainable Consumption

Perceived quality is a critical factor in understanding consumer behaviour towards sustainable and recyclable products. Kovel et al. (2023) argue that sustainability initiatives alone cannot compensate for poor product quality or limited performance, consumers still expect the product to meet the functional requirements before environmental benefits. The relationship between

perceived quality and perceived value is especially important within consumer electronics. Munnukka and Jarvi (2012) found that electronics and high tech products are evaluated by consumers through intrinsic and extrinsic values, these include product features, reliability, aesthetics and pricing. In relation to modular headphone design, these findings emphasise the importance of the acoustic performance, overall comfort and visual appeal, and that these are not compromised through integrating modularity and repairability.

2.4. Social Value and Identity

Social value, status and identity are additional behavioural considerations that influence consumer purchasing. A study conducted by Koller et al. (2011) revealed that social value and brand loyalty can be enhanced through ecological value, where consumers who support sustainable initiatives are active participants in communicating environmentally responsible choices among peers and the wider community. This highlights that consumers increasingly use consumption of sustainable products as a driver for expression of personal values and social identity, suggesting for some consumers, environmentalism and sustainability is a source of symbolic value.

Although environmentally conscious consumers may be more drawn towards sustainable, niche products and support modular brands such as Fairphone and Framework, this customer segment would likely be considered early adopters. This is an important factor to consider in the commercialisation of modular headphones. As argued previously, perceived value and perceived quality determine consumer purchasing and brand loyalty.

2.5. Implications for Modular Over-Ear Headphones Design

Whilst consumers may communicate positive attitudes towards sustainable products, this does not necessarily translate directly into purchasing and brand loyalty. It is argued by Tang et al. (2025) that perceived value has higher influence over cost factors in consumer purchasing, indicating that consumers are willing to pay higher if not premium costs for products that directly translate their needs and values. Whilst this hypothesis may be valid for consumers who value customisation and personalisation services, it is still important to consider the various customer segments in relation to the headphones and consumer technology market, and how costing and budget influences purchasing behaviour.

These collective insights into consumer behaviour present valuable metrics for increasing perceived value through customisation, engagement in the personalisation process, social value and identity. However this presents a challenge in developing a modular design system that balances all of these factors, in addition to function, performance, aesthetics and comfort. The thematic analysis from the literature on consumer behaviour indicates three primary behavioural themes; emotional attachment, perceived value and customisation. Through human centred design practice, these three behavioural factors can be integrated into the development of a modular design framework to guide product development in the next stages of the project.

Chapter 3. Translating Consumer Behavioural Insights & Modularity Principles into a Human-Centred Design Framework

The previous two chapters have established the significance of consumer behaviour in designing effective products that are both sustainable and functional, and prolonging the product lifecycle through repairability and emotional value. This next chapter focuses on how these findings on consumer behaviour and modularity as a sustainable practice can be translated into a human-centred design framework. In addition to this, business model analysis, competitor benchmarking and insights from headphone product teardowns from the studio-led research provide valuable findings in establishing a product-market fit.

3.1 Consumer Value to Product Design Strategy

Contemporary design research signals that sustainability in products must be integrated through a user centred design approach, to ensure that products still remain desirable and purposeful through extended ownership. In relation to headphones design, modularity and repairability must be balanced with ergonomics, performance and aesthetics. The recurring theme in the literature suggests that consumers are more likely to maintain and keep products for longer through perceived value and emotional connection, in addition to functionality.

3.2 Establishing a Human-Centred Design Framework to Extend Product Lifecycle

The aim of human-centred design is to establish an in-depth understanding of how certain products fit into the daily routines and experiences of users, in addition to their behaviours, primary needs and aspirations. Woodruff’s hierarchy of customer values proposes that users' evaluation process of products occurs across multiple levels, the first being the personal or aspirational level, followed by the consequence level and finally the attribute level (Woodruff, 1997). At the highest level, when a product uniquely captures the aspirations of the user through self expression, identity and enjoyment, these factors alone can drive purchasing behaviour. Following this, the consequent level reveals the direct benefits the product brings such as convenience, comfort, accessibility, ease of use and reliability. At the attribute level is consumer evaluation of product characteristics such as quality of materials, performance and aesthetics (Munnukka & Järvi, 2011).

3.3 Customisation and co-creation to drive consumer engagement and perceived value

Findings from the previous two chapters address the recurring theme of customisation and how this can facilitate multiple dimensions of consumer perceived value. In relation to modular headphones design, customisation can occur across varying levels including aesthetics,

ergonomics and functional attributes of the electronics components, particularly the drivers and battery.

Aesthetics customisation opens considerations into choice of colours, textures, material finishes and even additional personalisation services such as engraving. Ergonomic factors take into consideration environment and comfort. Customisation of headphone models to provide comfort through adjustability, sizing of the headband and ear cushions as well as materials selection are all components that can be tailored towards the needs of the user through a modular design system. User journey mapping is a strategic design practice to understand the role of environment in product use, and factors in how many different environments the user may switch between such as travel, work, exercise and home. Looking at exercise as a scenario for regular headphone use, not all materials in standard headphone models are ideal or suitable for exercising, especially when considering long term product use. An example of a design obstacle faced by the Apple Airpods Max headphones is condensation build up in the internal structure of the headphone as a result of exercise (McGregor, 2023).This is evident through ethnographic research and analysis, many online reviews from consumers state this is an ongoing issue that Apple has failed to address. Additionally use of foam in the ear cushions is not the most suitable material consideration for exercise as it absorbs sweat and excess moisture, is difficult to thoroughly clean and in time can harbour bacteria and mould. A modular headphone system enables users to potentially keep spare parts fit for purpose, for example, waterproof and sweat resistant ear cushion and headband padding attachments that can easily be swapped in and out as needed.

Finally customisation of audio specific components such as the drivers that produce the overall sound quality. This appeals strongly to audio industry professionals, as driver and sound quality is paramount to their line of work. AIAIAI audio is one of the leading modular headphone brands that facilitates upgrades and selection of audio driver units specifically for DJs and studio professionals (AIAIAI, 2026).

3.4 Practice-led Research through Product Benchmarking and Device Teardowns

Benchmarking and competitor analysis are highly relevant and necessary stages of research in the product development process. This practice-led research focussed on reviewing a range of headphone models and brands, to understand the key value propositions, attributes, performance and ergonomic factors. Additionally analysis of the business models of these companies gives valuable insights as to where circularity through modular design can be positioned in the market. Fairphone, a leading modular technology company that currently designs phones and headphones, received the highest rating though IFixit Forum, a community led network and online community that promotes product repairability (iFixit, 2024). Ethnographic research through online customer reviews of leading brands including Apple, Sony, Skull Candy and Bose provide valuable insights into product performance, comfort, quality, all of which users form unique perspectives on perceived value. Bang and Olufsen has a

unique positioning in the audio and headphones market, the business model built on premium personal and home audio embodying luxury and sophistication. The brand promotes longevity through high end, durable materials and promotes circularity through repair services and strongly values the in-store customer experience (Bang & Olufsen, 2025).

3.5 The Proposed Framework to Guide Product Development

Based on research findings, the proposed framework first establishes value across several lenses. These include functional, emotional, social, creative and sustainability values, a summary of these values is included in Figure 2. The next level of the framework involves balancing modular design factors with human-centred design. As the modular headphone concept development continues in the studio practice, the goal is to establish customisation into the user centred framework, especially through comfort, performance and aesthetic as captured in Figure 3. Finally Figure 4 outlines a modularity assessment score rubric has been created to rate further concept development based on key modular design requirements.

Figure 2 Human-Centred Modular Design Values

Modular Design Framework

Modular Framework

Maintenance & upkeep: Users have supporting educational content and resources to properly care for the product

Replace: What stops us from using headphones? Wear and tear: Ear cushions, padding, headband Performance: Battery life

Serviceability (Repair & Refurbishment): For the electronic components that are more complex such drivers and hardware updates

Make it simple: How do design decisions influence how long headphones can last? Mechanisms, number of parts that make up the whole product. How easily can these be repaired or replaced?

Design for disassembly: Establish hierarchy of modularity based on primary product fault points and how these prevent the user from continuing to use the product.

User Centric Framework

Convenience: Accessibility, readily available spare parts, simplicity of swapping in/out custom parts

Aesthetic: Forms, finishes, style, fashion/wearable accessory

Performance: Sound quality, noise cancellation, battery life

Comfort: Adjustability, weight, attachments (padding, cushioning)

Cost: Affordable, mid tier, luxury & high end

Figure 3 Human-Centred Modular Design Framework

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MODULAR HEADPHONE REPAIRABILITY INDEX

├── Repairability (80%)
│   ├── Fasteners
│   ├── Accessibility
│   ├── Modular Components
│   ├── Battery Access
│   ├── Cable Replacement
│   └── Reassembly
│
├── Documentation (10%)
│   ├── Repair Guides
│   ├── Exploded Diagrams
│   └── Troubleshooting
│
├── Parts Ecosystem (10%)
│   ├── Spare Parts
│   ├── Standard Connectors
│   └── Upgrade Compatibility
│
└── Anti-Repair Penalties
    ├── Adhesives
    ├── Proprietary Locks
    └── Destructive Assembly
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Figure 4 Modularity Assessment Rubric

Conclusion

The research conducted up to this stage was focused on a multidisciplinary review of literature on consumer behaviour with a view to guide the studio practice and also establish a higher level philosophical analysis on the significance of modular design in response to wicked level problems such as technological obsolescence and e-waste. The collective experiences, values and motivations of users strongly influence purchasing behaviour and the brands they choose to support. Rather than positioning sustainability and modularity as a technical design component, analysis of literature on consumer perceived value highlights that product longevity is also dependent on personal and social value that translates to long term product care and use.

The research establishes that headphones occupy a unique position in the consumer electronics market, functioning as highly personal devices that promote self expression through connection to music, media and culture. Despite the significance of headphones in users' daily lives, there are ongoing design flaws and challenges surrounding long term product use, often a result of failure of a single component that prevents ongoing use. A critical contribution of the research to the project development has positioned perceived value as a driver for long term product care.

The next stages of the research involve a qualitative and quantitative approach, to continue analysis into consumer behaviour in relation to adoption of circular business models and customisation through modular design. Additionally, a further consideration for the research is conducting A/B testing to evaluate hypotheses in relation to perceived value. A/B testing can ultimately reveal value user insights before refining the design solution in the final stages of product development.

In summary, the research conducted so far argues that designing a sustainable product that users want to keep long term must shift beyond conventional design in terms of repair and replacement, and must enable a heightened user experience through emotional attachment and personal relevance. This approach opens a pathway towards stronger relationships between consumers and extended usage of the technology products they own, in turn reducing environmental impact.

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