Circular Design of a Network Speaker

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Abstract

The EU aims to be a circular economy by 2050, which is the driving force behind this master thesis. Circular transformation is one possible strategy to handle the climate crisis and achieve sustainable development. A circular economy is a system that aims to keep the value of products, materials, and resources in use as long as possible while minimising waste generation (Svenskt Näringsliv, 2022). Designing for circularity is important in the development of products, since 80% of the environmental effects of a product are decided in the concept creation phase (McAloone and Bey, 2009). In this master thesis, written in collaboration with Axis Communication, it is investigated how circularity can be implemented in a design process, with the aim to redesign a network speaker with a focus on circular material flows.

The development process in this master thesis has followed the design method Double Diamond. The process initiated with an extensive research phase where employees at Axis were interviewed and in parallel, information about the subject was collected. Guidelines regarding designing for reuse were considered, and different concepts were created and evaluated in accordance with Ulrich and Eppinger (2012). Continuing, the project followed an iterative development process where the final concept was improved and developed, to finally generate a prototype.

The result is a network speaker designed for reuse, focusing on a modular design consisting of more standardised components and with the possibility to update and change dimensions on the circuit boards. The concept consists of two identical halves that together create the inner side cover, which the speaker driver is mounted on from the outside. Using the same component and adding a middle part, a tweeter, and a port creates a bigger variant of the same model.

Keywords: Circular Economy, Product Development, Design for Circularity, Design for Reuse, Network Speaker

Sammanfattning

EU siktar på att vara en cirkulär ekonomi till år 2050, vilket är drivkraften bakom detta examensarbete. Cirkulär transformation anses vara en möjlig strategi för att tackla klimatkrisen och uppnå hållbar utveckling. En cirkulär ekonomi innebär ett system som syftar till att behålla värdet av produkter, material och tillgångar i användning så länge som möjligt och samtidigt minimera att generera avfall (Svenskt Näringsliv, 2022). Att designa för cirkularitet blir därför viktigt i utvecklingen av produkter, då 80% av en produkts klimatpåverkan bestäms i designfasen (McAloone and Bey, 2009). I detta examensarbete, skrivet i samarbete med Axis Communication, undersöks hur man kan implementera cirkularitet i designprocessen, där syftet är att designa om en nätverkshögtalare med fokus på cirkulära materialflöden.

Utvecklingsprocessen i detta examensarbete har följt designmetoden Double Diamond. Processen inleddes med en gedigen undersökningsfas där anställda på Axis intervjuades parallellt som information om ämnet samlades. Riktlinjer gällande att designa med avseende på återanvändning togs i beaktning, och olika koncept skapades och utvärderas enligt Ulrich and Eppinger (2012). Fortsättningsvis följde projektet en iterativ utvecklingsprocess där slutkonceptet förbättrades och utvecklades, för att slutligen generera en prototypframtagning.

Resultatet är ett högtalarkoncept designat för återanvändning med fokus på modulär design, som består av fler standard komponenter och med möjlighet till uppdatering och dimensionsändring av kretskortet. Konceptet består av två identiska halvor som tillsammans skapar en inner kåpa som högtalarelementet monteras fast i utifrån. Genom att använda samma komponenter och addera en mittendel, en diskanthögtalare och en bas port skapas en större variant av samma modell.

Nyckelord: Cirkulär ekonomi, Produktutveckling, Design för Cirkularitet, Design för återanvändning, Nätverkshögtalare

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Lund, June 2023

Emma Christensson and Lovisa Bringman

Table of contents

Abbreviations

BC	back cover
COGS	cost of gods sold
CSRD	corporate sustainability reporting directive
DPP	digital product passport
EMS	electronic manufacturing service
FEM	finite element method
IK	impact protection
IP	ingress protection
LCA	life cycle assessment
PCB	printed circuit board
REACH	registration, evaluation, authorisation, and restriction of chemicals
RMA	return material authorization
RoHS	restriction of hazardous substances in electrical and electronic equipment
SD	speaker driver

1 Introduction

This chapter presents the background for the thesis, the problem and the purpose as well as introduce the company involved.

1.1 Background

Climate changes are happening more rapidly than ever, and the threat is severe. A consequence of the increased greenhouse emissions is a warmer climate, where every tenth of a degree will have a large impact (Världsnaturfonden WWF, 2022). According to Världsnaturfonden WWF, a 2°C or even 1.5°C global temperature increase will have enormous effects on the planet and will most likely start a snowball effect, impossible to stop or reset. Rising temperatures will increase the risk of extreme weather, such as strong heat waves and the melting of mountain glaciers that might raise the sea level by several meters. They describe that human actions are the reason for the rapid change in climate with our large consumption and burning of fossil fuel. Since the Paris Agreement was decided upon in 2015, 194 countries have signed the convention, legally binding them to cut their respective greenhouse emissions to ensure that global temperatures incline below 2°C whilst making efforts to stay around a 1.5°C increase (United Nations, n.d.). On the other hand, the Circularity Gap Report accounts for an estimated global temperature increase of 3.2 degrees, despite participating countries cutting their greenhouse emissions. According to Circularity Gap (2021), we can expect a 3 to 6 degrees increase in global temperature with the current economic model and the release of 65 billion tons of greenhouse gas emissions during the year 2030.

One of the reasons behind increased greenhouse gas emissions is the extraction of material resources. According to European Commission (2020), the extraction process currently contributes to more than 50 % of greenhouse gas emissions. The combination of a growing global population that requires more resources, together with the increasing consumption rate of products, creates 2.5 billion tons of waste each year only in the EU (European Parliament, 2021). Electronic and electrical waste, e-waste, is the fastest-growing waste stream in the EU (European Parliament, 2020). However, only 20 % of the e-waste generated in 2019 was recycled (Shin, 2020).

As stated by Ellen MacArthur Foundation (2019), one solution to tackle the climate issue is transforming the global economy from being a linear to a circular economy. A circular economy is achieved by circulating products and materials at their highest product value, eliminating waste and pollution through the regeneration of nature (Ellen MacArthur Foundation, 2019). In the new action plan for 2050 presented by the European Commission, it coherently says that by increasing global circularity and separating financial growth from the extraction of raw materials, societies will highly influence whether the promises of the European Green Deal can be ensured (European Commission, 2020). They continuously say that, among other things, it ensures net-zero greenhouse gases by 2050.

The definition of circular economy varies, but one definition is that it is a model with closed loops which is created by reuse, repair, refurbishment, recycling, as well as sharing and leasing to be able to keep the product, components, and materials in the highest possible form of value (Bourguignon, 2016). By globally applying a circular economy approach, the elevation of the global temperature can stay below the 2°C line (circularity-gap, 2021). Unfortunately, Circularity Gap (n.d.) reports a decrease in global circularity from 9.1 % to 7.2 % from 2018 to 2023.

Currently, there are several emerging laws and regulations initiated by the European Commission, supporting the transformation to a circular economy and a more sustainable Europe. One example is the Right to Repair legislation, which will make reparations easier by requesting companies to provide and enable easy access to spare parts (www.europarl.europa.eu, 2022). Another example is the regulation REACH (Registration, Evaluation, Authorisation and Restriction of Chemicals), which is, according to the European Commission (n.d.), meant to restrict the use of dangerous chemicals for all products manufactured, sold, or imported to the EU. To also create transparency regarding the environmental effects of products and company activities, the European Commission has formed regulations like the Corporate Sustainability Reporting Directive (CSRD) and the Digital Product Passport (DPP) (European Commission, 2023; European Commission, n.d.).

Several companies are now starting to transform their business strategies with the ambition to become climate neutral or at least to decrease their impacts on the global environment. One major competitor on the audio side is Bosch, and according to their sustainability report 2021, they strive to create a closed loop from production to recycling (Bosch, 2022). Today, Bosch (n.d.) discloses reusing materials and products within the company or through recycling processes. Bosch reduces their use of materials by applying guidelines and principles linked to design for environment in their product development process.

Additionally, Electrolux Sverige (n.d.-a) will decrease their climate emission in production by the year 2025 by 80 % and be fully climate neutral by 2030. Electrolux Sverige further describes that the goal is to eliminate all waste generated from production units and to develop products with optimal energy. Lastly, their aim is to also have at least 50 % recycled material in their products by 2030 (Stena Recycling Sverige, 2020).

Other companies addressing the topic of circularity are Philips (n.d.-a), who by 2025 have the ambition of having 25 % revenue from circular products, and Canon, whose circular approach is to recirculate products close to the customers by recycling their products and using the materials in new products or by reusing parts (Canon Global, n.d.).

According to McAloone and Bey (2009), 80% of the environmental effects of a product are decided in the concept creation phase of product development. Including decisions regarding sustainability and circularity early in the design process will therefore have a huge impact on the final solution and its climate impact. Moreover, Weinert (n.d.) says that transformation specifically needs to happen in the manufacturing and industrial sector to meet the effects of the climate crisis and for societies to become more sustainable.

1.2 Axis Communications

As stated by Axis Communications (n.d.-a), it is a Swedish company working with product development within the security sector and business optimization. The company was founded in 1984 by Mikael Karlsson, Martin Gren and Keith Bloodsworth and has, since 2015, become a part of Canon Group. Axis account for being committed to creating a smarter and safer world by specializing in network solutions within areas such as access control, video surveillance, intercom, and audio systems. Their products are used all over the world in subway stations, shopping malls and company buildings (Axis Communications, n.d.-a). Their New Business branch develops, among other things, audio technologies like network speakers, which provide information in emergency situations, enable two-way communication, make announcements as well as increase overall security (Axis Communications, n.d.-b). Continuously, Axis (n.d.-b) describes that network audio gives remote flexibility and easy control. It is possible to play background music and schedule prerecorded messages or spontaneous announcements, making it easier to deliver non-critical information regarding instructions or reminders as well as crucial safety information in emergency situations.

Axis products are sold to distributors, who then sell to resellers or system integrators, which lastly sell to the end customer (Axis Communications, 2022). They further explain that their business model is based on long-term collaboration with partners with a strong global presence to get the products to the market.

Axis signed the UN Global Impact initiative back in 2007 and, from then on, continuously works to address global challenges in regard to climate, inequality, poverty, peace, justice, prosperity, and environmental degradation, as well as anti-corruption, human rights, environment, and labour (Axis Communications, n.d.-c). Continuing, Axis works with four cornerstones in their everyday work; respect people, protect our planet, innovate responsibly and be trustworthy.

1.3 Problem description

Whilst climate change is more present than ever and politicians establish new sustainability legislation and regulations, Axis strives to take responsibility by creating sustainable products. This thesis project is conducted within the New Business branch of Axis, specifically within their Audio department. As mentioned before, a circular economy aims to preserve products, components, and materials at their maximum value through processes like reuse, recycling, repair and refurbishments (Bourguignon, 2016). The Audio department at Axis is expanding their product portfolio and thus, can significantly determine the future climate impact of their released products. This thesis is based on the department´s expressed desire to gain knowledge regarding design for circularity and if circular guidelines can be applicable in current and future project work, as well as to explore how a current speaker could be redesigned to increase its circularity. The department traditionally prioritize factors such as time and cost in their project work but seek to visualize the implications of having circular material flows as a primary project focus instead.

The speaker which will be redesigned is referred to as Snobben, a network speaker developed at New Business during 2020 to 2022. In accordance with Neutel (2023), Snobben is an all-in-one speaker system, used to make prerecorded or live messages to deliver instructions or to warn off intruders. Continuously, the product consists of four different designs; two ceiling speakers in two different sizes, Woodstock and Snoopy, see Figure 1.1, and two pendant speakers in two sizes, Sally and Linus, see Figure 1.2. The product delivers clear security- and public announcements, whilst it can secondarily play background music. Following, the product is meant for indoor and semi outdoor use, which means under roof of outside entrance. In addition, it is self-testing, meaning it can play something and listen to itself for testing of the system. Currently, the speakers have a five-year life warranty (Neutel, 2023).

Figure 1.1. Ceiling Speakers - Woodstock and Snoopy (Axis Communication, 2023).

Figure 1.2. Pendant Speaker - Sally and Linus (Axis Communications, 2023).

1.4 Purpose and research questions

1.4.1 Purpose

The purpose of this thesis project is to redesign an existing network speaker at Axis, with focus on circular material flows. By doing so, the ambition is to help Axis gain a larger perspective on circularity and how to implement it in the design process. Before improving a speaker of choice, design takeaways regarding circularity will be identified. Desirably, key results can be applied in future processes within research and development departments and inspire to close the loop. The presented work in this thesis will contribute to Axis future circularity path.

1.4.2 Research questions

RQ1: How can a network speaker be designed to support circular material flows?

RQ2: What design guidelines are applicable?

1.4.3 Contribution

The main project contribution is that it shows how circularity can be incorporated into network speaker design. But also, it visualizes some concrete design features that minimize the environmental impact of Axis network speakers when implemented. These features and tools can serve as guidelines and inspiration for increasing circularity in other electrical products within similar product families. Additionally, the project will show whether current design guidelines apply to this type of product.

1.5 Delimitations

In this thesis the design of all electrical components like circuit boards and batteries will be outside the project scope when implementing key take aways in the design phase. Neither will efficient energy consumption during the product use phase be included in the scope. Nor will a detailed, circularity related business model be presented in this thesis.

2 Theory

Following is the subject of circularity with relevant theoretical guidelines presented. Other areas of interest will also be explained, like the science behind sound and speaker.

2.1 Circularity

As mentioned before, there is not one globally used definition of Circular Economy. However, the EU-commission currently explains a circular economy as a system that aims to keep the value of products, materials, and resources in use as long as possible while minimising waste generation (Svenskt Näringsliv, 2022). Svenskt Näringsliv also points out that the main objective is to be resource efficient and to design products with circular design in mind; to achieve a longer product life, to reuse components, to design for repair, to minimize production waste and to recycle.

Furthermore, as stated by Svenskt Näringsliv (2022), circularity might be one step in minimizing the climate impact made by humans, whilst circularity done wrong can harm more than help. When designing for circularity, it is crucial to have a holistic mindset to create the most sustainable solution. They point out that the circulation of products might generate more emissions if it requires more energy and materials than when not considered. Additionally, circularity is described as complex, but material resources are not endless, and the current linear system also has many downsides for the climate. Svenskt Näringsliv also states that laws and regulations adapted and constructed to fit a linear economy partly prevent the change towards a more circular economy.

2.1.1 Laws and Regulations

The European Parliament's goal is that the EU will be a circular economy by 2050 (www.europarl.europa.eu, 2021). They have presented an action plan, called the EU Circular Economy Action Plan 2050, with strategy suggestions to achieve a circular economy for the EU by 2050. The action plan is one step in the European Green

Deal and involves, amongst other things, electronic products, batteries, packaging, and plastics. The European Green Deal aims to reduce carbon emissions by 55% by 2030 and be carbon neutral by 2050 (www.europarl.europa.eu, 2020).

The Right to Repair legislation is another cornerstone to reach a circular economy by 2050 (www.europarl.europa.eu, 2022). According to the European Parliament (2022), companies will be required to provide repair instructions to enable reparations by customers themselves or by an independent repair site. As of today, as many as 77% of the consumers in the EU would willingly repair their products instead of buying a new product. Moreover, repairing electronic devices would affect the environment positively by reducing used resources, decreasing greenhouse gas emissions, and decreasing energy consumption and e-waste. Reduction of e-waste is specifically essential since the amount of e-waste is increasing rapidly. Lengthening the warranty period is one suggestion discussed by the European Parliament to include in the proposal for the law. Also, it forces manufacturers to offer information about repair and maintenance for free.

The Corporate Sustainability Reporting Directive (CSRD) is a law that requires companies to report on the impact of their activities regarding the environment and human rights (European Commission, 2023). The European Commission states that this will allow investors and customers to attain data more easily on the conducted sustainability work and the impact of purchasing or investing in a product. This new reporting law aims to push companies to be transparent about their business impacts to enable customers to make conscious purchasing choices.

Digital Product Passport (DPP) will provide information to enlighten consumers about how the product affects the environment throughout its life cycle (European Commission, n.d.). El-Kretsen (2021e) see increased traceability as a possible sale incentive that companies can profit from rather than being extra work. Traceability will give companies a better overview of the product's usability, lifetime, and weaknesses.

As previously mentioned, the REACH regulation restricts the usage of certain chemicals manufactured, sold, or imported to the EU (European Commission, n.d.). According to European Commission (n.d.), REACH is legally binding for all member states, and as of today, the regulations include 233 chemicals. The RoHS directive's (Restriction of Hazardous Substances in Electrical and Electronic Equipment) goal is to prevent the risk associated with electronic products and electronic waste for both the environment and humans. The European Commission explains that this applies through restrictions on ten hazardous substances in electronic equipment, such as flame retardants and heavy metals.

2.1.2 E-waste

According to El-Kretsen (2021a) products have a longer lifetime now than before, even so, the products are changed more rapidly. They explain that the reasons for this may involve products being more frequently used, the change in esthetic trends as well as new, innovative technical solutions being created. By properly handling these electronic products, it is possible to prolong the lifetime of the products. For example, having regular maintenance or cleaning of the product.

The European Parliament (2020) encourages the EU to strive for products with longer life cycles with the help of repair and reuse. Because electronic and electrical waste, also called e-waste, is the waste stream that is currently growing most rapidly within the EU. The European Parliament describes that e-waste might consist of damaging materials for the planet and for people, why some chemicals have been banned in legislation.

2.1.3 Recycling of e-waste

According to El-Kretsen (2021b), 80 % of all the products and components that El-Kretsen collects go through the recycling process. However, approximately 50 % of the consisting plastic are recyclable from electrical products (El-Kretsen, 2021c). This is because many products have integrated metals and plastics, as with thin metal alloys and glued solutions, making recycling more difficult (El-Kretsen, 2021b). One guideline to keep in mind when designing for recycling is, to use as few and clean materials as possible (El-Kretsen, 2021b).

Recyclability for metals is higher than for plastics which is problematic since the percentage of plastic in products has increased (El-Kretsen, 2021b). El-Kretsen (2021b) explains that most metals are recycled today, but sometimes it decreases in quality due to thin metal alloys used in printed circuit boards (PCB). These are hard to recycle back to their original structure and require a great deal of energy. Unfortunately, with plastics, mechanical properties are damaged each time the metal is recycled, describes El-Kretsen (2021b). The economic factor here is also vital. Recycling small amounts like alloys is more costly than extracting new metal material (El-Kretsen, 2021b).

In terms of plastic recycling, mechanical designers have a responsibility and a big influence on the amount of plastic that can be recycled from a product. El-Kretsen (2021c) states that more plastic can be cleanly extracted from the products if eco-design and recyclability are present from the earlier concept stages of the design process. For recycled plastic to be profitable, recycling plastic must give market leverage. El-Kretsen (2021c) describes that it is easier to use virgin plastics since they have a high-quality surface finish and ensure high mechanical properties. Moreover, the production of recycled plastic is not currently at the production rate companies require. El-Kretsen (2021c) states that companies need plannable manufacturing processes, which recycled plastic can´t ensure in the same way. Additionally, laws and regulations have increased regarding the use of recycled plastic compared to before, making it harder for companies to choose greener alternatives.

According to El-Kretsen (2021d) the main problem with metals is the small amounts leading to high economic costs and difficulties in knowing where the metals exist in the products. They state that the recycling of Rare Earth Elements (REE) from electronics was as little as 1% in 2021.

2.1.4 R strategies

According to Skärin, Rösiö and Andersen (2022), the R strategies can be used when designing products regarding circularity. The most common R strategy is the 3R; Reduce, Reuse and Recycle. Skärin, Rösjö and Andersen underline that the 3R mainly focuses on a linear economy and one single life cycle, not considering several product life cycles. The current knowledge about circular economy led to include more Rs in the methodology (Skärin, Rösiö and Andersen, 2022). Figure 2.1 shows a comprehensive 10Rs approach, where higher up in the list means a higher circular strategy (Potting et al., 2017). For example, sharing products is preferred over refurbishment since sharing would lead to the product being used by more users, explains Potting et al.

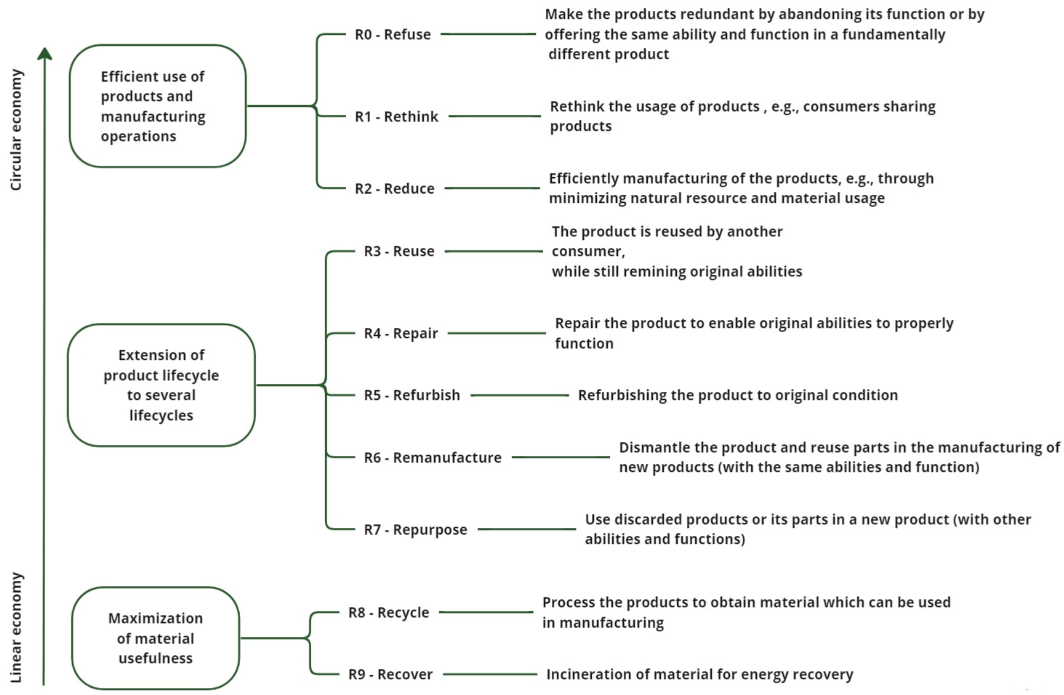


Figure 2.1. A schematic illustration showing the 10Rs (based on Potting et al., 2017).

Refuse

As described by Reike, Vermeulen and Witjes (2018), refuse means to refuse products that are harming the planet and are unnecessary. Furthermore, it implies giving value to the consumer and offering the same function differently. Continuously refusal also includes avoiding raw material extraction and restricting hazardous substances (Ltd, 2022).

Rethink

Rethink means inventing new approaches and innovative solutions which minimize the climate impact of products and systems (Lombard Odier, 2020. One example could be to intensify product usage through product sharing (Galan, 2020).

Reduce

In line with Reike, Vermeulen and Witjes (2018), to reduce is to create the same value and function for the consumer but with less. They continuously imply that it is done through increased efficiency in production or by reducing the material in a product. Their main objective is to minimize the production of waste but also to minimize materials in products.

Reuse

Reuse focuses on the usage of the product in more than one cycle (Reike, Vermeulen and Witjes, 2018). They states that the definition most commonly refers to the product being used again by a new customer without refurbishment, repair or rework. Some cleaning might be done, and the product is sold on a secondary or secondhand market (Reike, Vermeulen and Witjes, 2018).

Repair

Reike, Vermeulen and Witjes (2018) address the reparation and maintenance of a product and describe it as prolonging the product's lifetime. Continuing, it might include the replacement of defective parts or recovery of broken functionalities. Different actors can manage these actions, such as the customer themselves, the manufacturing site or an independent repair site (Reike, Vermeulen and Witjes, 2018).

Refurbish

Refurbishment refers to product renovation (Reike, Vermeulen and Witjes, 2018). Reike, Vermeulen and Witjes continuously described it as replacing or repairing many components to achieve an upgraded product.

Remanufacturing

According to Reike, Vermeulen and Witjes (2018), a multi-component product is disassembled, inspected, and cleaned during remanufacturing. They further explain that in remanufactured products, some or all components are recycled, and the remanufactured products' lifetime is expected to be shorter than for new products.

Repurpose

The definition of Repurpose is to find a new function for old and discarded products or components, giving the material a chance to start a new life cycle (Reike, Vermeulen and Witjes, 2018).

Recycle

Recycling aims to transform post-consumer product waste into pure materials by using equipment to shred, melt and separate the material (Reike, Vermeulen and Witjes, 2018).

Recover

Recover mostly refer to the process in which the energy encapsulated in waste is captured. Used in combination with producing energy and incineration (Reike, Vermeulen and Witjes, 2018).

2.1.5 Design Guidelines

Several guidelines on how to improve the product development process regarding the environment have been found in the literature. Therefore, a selection of guidelines is presented here, with relevance to the topic of circularity.

The 10 Golden Rules are general guidelines for what to consider when designing new products concerning the environment and the products' lifecycle (Luttropp & Lagerstedt, 2006). Some guidelines might contradict each other, but the rules can be a reminder throughout the design process. For instance, Luttropp & Lagerstedt (2006) list rules number 4, 8 and 10:

Golden Rule 4: *Promote repair and upgrading, especially for system dependent products* (Luttropp & Lagerstedt, 2006, p.1401).

Golden Rule 8: *Prearrange upgrading, repair and recycling through access ability, labelling, modules, breaking points, and manuals* (Luttropp & Lagerstedt, 2006, p.1401).

Golden Rule 10: *Use as few joining elements as possible and use screws, adhesives, welding, snap fits, geometric locking etc. according to the life cycle scenario* (Luttropp & Lagerstedt, 2006, p.1401).

The Eco-Design Checklist is also a tool for designing more environmentally friendly products (Johansson, Sundin and Wiktorsson, 2019). The Eco-Design Checklist consists of several questions, divided and gathered into eight sections. Johansson, Sundin and Wiktorsson explain that the checklist does not hand out any right or wrong answers but provides questions to generate discussions and to remind the designer of what to think about when designing with sustainability in mind. One example of a question to ask in the design process is: *How is the product currently disposed of?* (Johansson, Sundin and Wiktorsson, 2019, p.171-172).

Shahbazi and Jönbrink (2020) list several design guidelines regarding circular strategies, for instance, *Make exchange of faulty components easily accessible* and *Design standardized components across different products and models.* In addition, Shahbazi (2020) has also listed several actions to take into consideration for each specific R in the 10R strategy. One example being: *The ability to change appearance, i.e., the exterior, can be a means of giving a product longevity.*

Furthermore, Motalli (2022) redefined the Design Ladder by Danish Design Center (n.d.), focusing on circularity and to what extent a company works with circularity in the Circular Design Ladder. Motalli explains that the Circular Design Ladder consists of four steps: Optimization, Innovation, Transformation and Regeneration (see Figure 2.2). She states that the optimization step focuses on designing the current product better by choosing smarter materials with higher recycling rates, for example. The innovation step aims to rethink the product by finding new circular ways to deliver customer value. Further, the transformation step means the company redesigns its business model and leads with a circular strategy. Lastly, she describes that the regeneration addresses the whole organization and the fact that the organization practices in an environmentally friendly system, not only focusing on the offers from the company. The correlation between the fourth step in both Design Ladder and Circular Design Ladder is the involvement of the leadership to address the whole vision for the organization, and not only looking at a single project or product, resulting in a more significant impact.

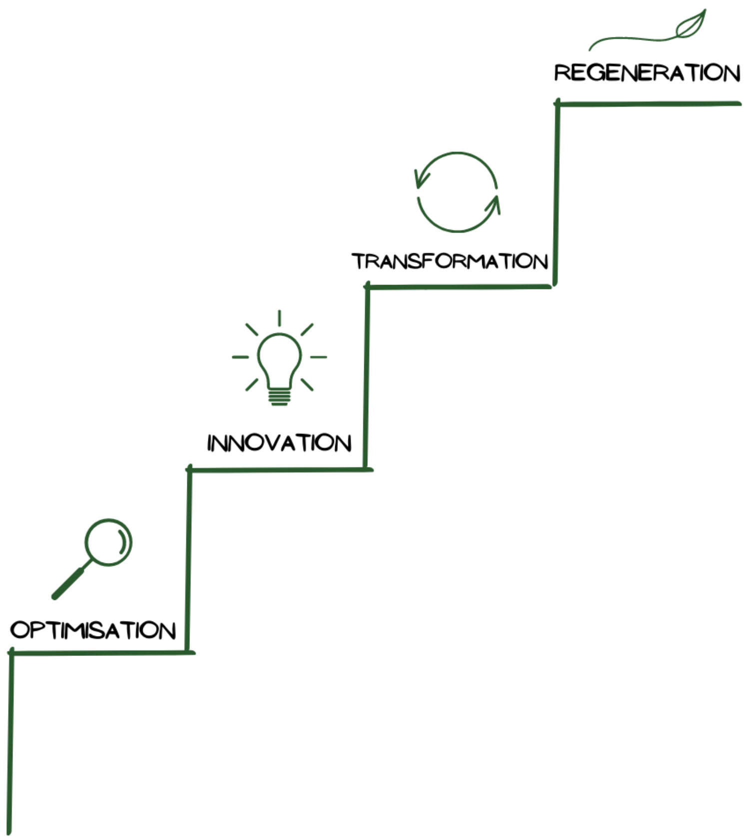


Figure 2.2. The Circular Design Ladder (based on Motalli, 2022).

2.1.6 Design for prioritized R strategies

The following will introduce potential ways to implement the R strategies in the design stage, focusing on the four R: s prioritized in this project; Reduce, Reuse, Repair, and Recycle.

2.1.6.1 Design for Reduce

Design for reduce goes hand in hand with optimal product design (Dazer et al., 2022). The engineering industry is answerable for significant effects in terms of climate change. According to Dazer et al. (2022), most constructions are built for the worst-case scenario since that inquire a reliable design. Designing for reduction is, therefore, a must if the industry wants to limit its environmental impact.

Vital factors to reduce in a circular economy are energy usage, raw material, and water consumption (Mangla et al., 2023). Reducing material consumption in production decreases carbon emissions, creating a more sustainable production process. Mangla et al. (2023) state that, by design concerning reduction, the aim is to optimize the use of material resources whilst keeping the mechanical strength of the product. Continuing, there are different ways of doing this and one of these production methods is to design for additive manufacturing, where optimizing methods are used before 3D printing is conducted. When the product is designed to be reduced and optimized, factors like topology, support structures, and orientation is of focus. Optimum part combinations can also be a factor to look at, as well as to use of sustainable materials, like biomaterials, to minimize material usage (Mangla et al., 2023).

2.1.6.2 Design for Reuse

Plumeyer and Würl (2019) define the reuse of a product as the enabling of maintenance or cleaning of the product or its components. In addition, they explain that it also covers the reuse of the components, which includes the repair process, the refurbishment, and the rework of the components before it becomes waste.

Design for reuse means designing with standardized components as well as minimizing parts (Bovea and Pérez-Belis, 2018). Moreover, according to Conti and Orcioni (2020), both modular design and traceability are mentioned as essential factors for the reusability of components. Traceability will inform about the estimated residual life of the used component and the expected remaining lifetime for the used product for the secondary market. In addition, the design needs to be self-explanatory and structured in a straightforward manner to facilitate modifications in the reuse phase (Ahonen and Nurmi, 2004).

Ahonen and Nurmi express that the true benefit of designing for reusability is the investment for the future and the possibility to quickly develop reliable systems. Where they explain that one crucial factor is that the design provides flexibility and modification of the design without lowering the performance. A good redesign of components or reusing of parts can increase the reliability of the product (Conti and Orcioni, 2020).

2.1.6.3 Design for Repair

Modularity seems to increase the reparation rate and make it easier and more efficient to repair the product (Amend et al., 2022). In addition, when designing for repair, the inclusion and availability of repair instructions are crucial for decreasing repair barriers.

Easy disassembly and reassembly of products are essential to increase repairability and for the end-of-life process to be economically justifiable (De Fazio et al., 2021). They explain that one method that can be used when designing for repairability is creating a Disassembly Map to analyse every action performed while taking the product apart, to grade how easy the product is to later repair. Continuing, four crucial parameters to consider in the Disassembly Map are sequence depth, reusability of fasteners, disassembly time and type of tools required to be used. The disassembly map help to understand the product architecture and structure, enabling designers to understand better how to redesign the product to enable easier disassembly and repair. De Fazio et al. (2021) highlight the importance of grouping or clustering components based on similar end-of-life expectancy into subassemblies to increase accessibility in the design.

Regarding the reusability of fasteners, it is important to look at the force required to later release them (De Fazio et al., 2021). Explaining that high force intensity correlates to a higher risk of damage. Designing with regard to visibility is important to increase the disassembly time and ease the disassembly process, preventing connectors and fasteners from being hidden. When designing for repairability, creating a design that only requires standardized tools to ensure that the repair stations have the required tools to perform a repair (De Fazio et al., 2021). Designers should use something other than non-reusable connectors since it requires spare parts.

2.1.6.4 Design for Recycle

Design for Recycle targets the design choices to enable identification, separation, and recycling of materials (Bovea and Pérez-Belis, 2018). Moreover, consider to what extent the product is easily disassembled to improve the recycling efficiency (Vanegas et al., 2018). Hallack et al. (2022) supports Bovea and Pérez-Belis reasoning by presenting similar areas to consider when designing for recycling and end-of-life. These include avoiding hazardous substances since the treatment during end-of-life has a significant, negative effect on the environment if hazardous substances are used in the products. Another key factor is the recognition of the materials through marking or labelling the parts. Moreover, when designing for end-of-life, the joints are one important factor. Hallack et al. (2022) explain that joints should be integrated when possible, and the variation of different joints should be kept at a minimum. In addition, they continue by stating that materials such as ink, coating and paint should be avoided to preserve plastic as pure as possible. Finally, the disassembly sequence should be easy, with various and general descriptions, including easy access to joints and only requiring one tool to disassemble the product. All these guidelines are equally important to consider, express Hallack et al. (2022).

2.2 Sound and speakers

According to Liberg (2023) the most critical components of an electromagnetic speaker driver are the permanent magnet, the copper voice coil connected to a diaphragm and its suspension, which can be seen in Figure 2.3. By running an alternating current through the copper coil, located in a tight gap inside the magnet, a force will drive the copper coil back and forth. In addition, Liberg explains that since the coil is connected to the suspended diaphragm, the diaphragm will move along with the force applied and create the pressure fluctuations known as sound waves that will propagate through the air. Further, acoustic shortcuts are avoided by placing a speaker driver in an enclosure, enabling the speaker to create sound even at low frequencies. As lower frequencies are a vital aspect of a loudspeaker's perceived quality, this is often a desired design.

Moreover, the air volume inside plays a significant role in diaphragm movement and sound generation, continuous Liberg (2023). The back cover also have protective functionalities in terms of water and dust protection and impact resistance. Finally, Liberg explains that avoiding unintended vibrations from the enclosure walls are desired.

Continuing, the task of a loudspeaker is to reproduce soundwaves within the interval of human hearing by movement of its membrane. To do this, the membrane needs to move, preferably, linear towards the input signal (Liberg, 2023). The result is heavily dependent on the moving area, i.e., size of the membrane, speaker manufacturers normally choose to combine several speaker drivers to better cover the bandwidth of human hearing. Liberg describes that examples of smaller speakers used for high frequencies are tweeters, while bigger elements, woofers are used for lower frequencies.

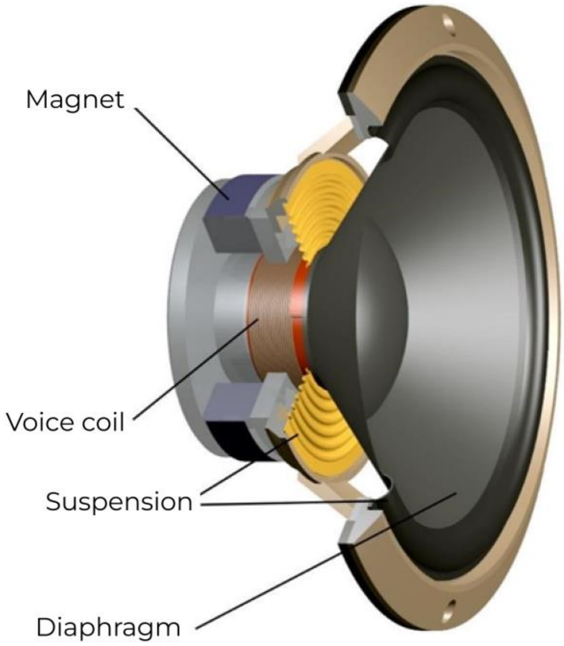


Figure 2.3. Showing the inside of a speaker driver (Wykes, 2020).

3 Method

This chapter introduced the method process for the entire thesis and included methods within each process step. It also describes how each method was implemented and executed during the project.

3.1 Method description

3.1.1 Double Diamond

The methodology used in this master thesis is called the Double Diamond method. The Double Diamond method was developed by the British Design Counsel (2019) and consists of four stages; Discover, Define, Develop and Deliver (see Figure 3.1). The first diamond is related to the problem, while the second relates to the solution. The method is supposed to help designers develop innovative solutions to complex problems through a more structured process. In the method, the user alternates between divergent- and convergent thinking by initially looking at problems and solutions more broadly and then excluding ideas by focusing on certain ones, explains the Design Counsel. Furthermore, the method allows for a great deal of freedom to iterate, especially in the solution space, the second diamond, meaning that withing the divergent/convergent hills/slopes of the diamond, concepts can be refined and improved back and forth.

Design Counsel describes that the initial step of the Double Diamond method is the discovery stage. In this step, the team is supposed to grasp all the possible causes of an issue and the target problem. Mind maps, multi-perspective problem framing, reversed brainstorming, and desk- and field research are some methods that can be applied at this stage (Elmansy, 2021). Elmansy explains that the team thinks broadly and keeps a divergent mindset at this stage.

Elmansy (2021) describes that in the second step, the team narrows the scope and distinguishes the root causes. Here the problem is further defined before the team starts defining possible solutions.

The third step generates the initial solutions to the defined problem (Design Council, 2019). Since this is a divergent thinking stage, the team is encouraged to keep an open mind, even to the crazier ideas. Simpler 2D- or 3D models could be used to display the generated concepts. The concept solutions are then discussed concerning the set requirements through discussions with relevant parties in a focus group or through other chosen evaluation methods.

In the final stage of the Double Diamond method, the team will test the different solutions created during the development stage, continues the Design Counsel. They will refine the concepts that work and eliminate those that do not work, until the final product is formed.

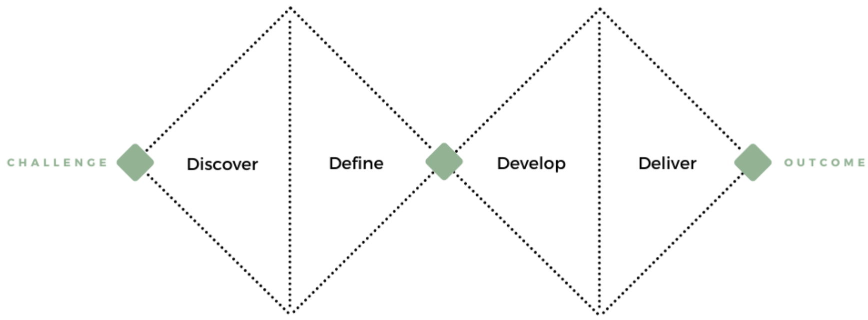


Figure 3.1. Visualization of the Double Diamond method (based on Design Council, 2019).

Double diamond was used as the method process for the entire thesis work and the four stages; Discover, Define, Develop and Deliver can be seen as the outlining structure of chapter four. In each stage different activities were conducted iteratively, see Figure 3.2 for an overview over the project process.

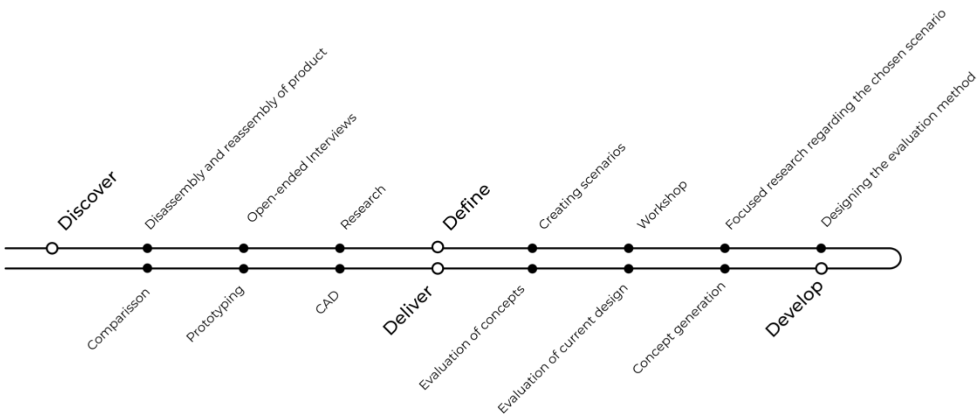


Figure 3.2. A schematic overview over the project process.

3.1.2 Discover

The purpose of the discovery phase was to better understand the product, the company, the subject of circularity, and the trends within this area. The team (consisting of the two authors, Emma and Lovisa) has chosen to mainly explore the issue by conducting parallel desk- and field research. The desk research involved reviewing resources to understand and explore the subject and to conduct a literature review. The field research included disassembly and reassembly of the product and interviews with relevant parties at Axis connected to Industrial Design, Mechanics, Audio, Environment, Repair, Innovation, and Product Management.

3.1.2.1 Disassembly and reassembly of product

De Fazio et al. (2021) state that product disassembly helps designers to understand the product architecture and structure, enabling a better understanding of how to redesign the product.

Therefore, the four models within Snobben were disassembled and reassembled in the mechanical laboratory on Axis premises. All the included parts were inspected, the screws were counted, and the material was noted. The products were then reassembled to test the assembly sequence and how self-explaining or easy it was for two individuals, previously unfamiliar with the products, to mount them back together.

3.1.2.2 Open-ended interviews

According to Höst, Regnell and Runeson (2006), one alternative for executing interviews within a master thesis is the open-ended approach. Further, they describe that the goal of an open-ended interview is to understand the person's experience of a subject. The interviewer follows an interview guide with open questions about the area to explore the subject further. Höst, Regnell and Runeson explain that the interviewee steers the conversation with their expertise and what they want to share. The gathered data is qualitative, meaning the words and descriptions from the interview is the collected data.

To gain an understanding of the subject and how Axis works with circularity, open-ended interviews were conducted with 19 employees at Axis. The selection of people was made based on their role and expertise within the subject after a discussion with the supervisor at Axis. For some departments, several different persons were interviewed for a broader perspective. The interviews were mainly done in person at Axis headquarters, but a few were made via teams, with both of us participating in each interview. The interview guide consisted of some base questions and then added individual questions for respective areas of expertise (see examples of questions in Appendix A Interview Questions). The persons interviewed is shown in Table 3.1.

Table 3.1. Interview persons.

Interview date(s)	*Interviewee role*	*On-site/virtual*	*Reference*
2023-01-17, 2023-01-23, 2023-03-03	Experienced Engineer	On site, On-site, Virtual	A
2023-01-24, 2023-03-16, 2023-04-26	Audio Lead Engineer	On-site; On-site	B
2023-01-25, 2023-02-02	Repair Development Engineer	On-site, Virtual	C
2023-01-27	Senior Engineer	On-site	D
2023-01-30, 2023-02-09	Senior Environmental Engineer	On-site, On-site	E
2023-01-30	Experienced Environmental Engineer	On-site	F
2023-02-01	Experience Industrial Designer	On-site	G
2023-02-02	Industrial Designer	On-site	H
2023-02-08	PMT Project Manager	On-site	I
2023-02-09	Senior Engineer	Virtual	J
2023-02-13	Product Manager Audio Software and Applications	Virtual	K
2023-02-15	Senior Design for Assembly Engineer	Virtual	L
2023-03-06, 2023-03-16, 2023-05-10	Experience Mechanical Engineer	On-site, On-site, Virtual	M
2023-03-06	Expert Engineer	On-site	N
2023-03-07, 2023-03-10, 2023-04-14	Experience Design for Production Engineer	Virtual, On-site, On-site	O
2023-03-08	Expert Engineer	On-site	P
2023-03-08	Expert Engineer	On-site	Q
2023-03-09	Senior Engineer	Virtual	R
2023-03-09	Experienced Engineer	Virtual	S
2023-05-04	Experienced Mechanical Engineer	On-site	T
2023-02-08	PMT Project manager	On-site	U
2023-05-10	Electrical Engineer	On-site	V

3.1.2.3 Literature review

A literature review analyses the current knowledge base in an explored area, explains Höst, Regnell and Runeson (2006). Renner, Muller and Theissler (2022) state that searching in electronic databases is preferred since this results in great quality journals and articles. Moreover, searching in several databases gives the best result and a broader perspective on the subject. Renner, Muller and Theissler also explain the decision of keywords to be able to search for answers to the research questions.

Renner, Muller and Theissler describe the Integrative Review as a form of review which provides new knowledge. By reviewing and criticizing representative literature, it is possible to get a broader perspective within the specific area. They state that this method serves as an overview, and the main objective is to understand the state of knowledge and combined perspectives.

With this background, the Integrative Review approach was used in this master thesis when conducting the literature review. It was decided that LubSearch and ScienceDirect would be used as electronic databases for the literature review. The following words were used as the keywords in the search.

Keywords: Design for Reuse OR Design for Repair OR Design for Recycle OR Design for Reduce AND for products OR for components.

These words were chosen to gain broader knowledge about existing guidelines in the design process but with different circularity approaches.

Relevant articles were summarized, and newer articles were preferred over older ones since circular economy is a dynamic subject where updates and news happen continuously.

3.1.2.4 Research

General research was conducted to gather information about the subject, including googling, reading reports, and looking at companies' sites. Firstly, circular economy was studied more in-depth. Several companies' work was also investigated, concerning the subject, for inspiration and knowledge about the current market, such as Bosch, Electrolux and Canon. Much effort was put into reading and understanding the laws and regulations connected to circularity, mostly looking within the EU. Recycling of electronic products (e-waste) was another explored area, both the recycling process and problems related to metal recycling and conflicting materials. Lastly, the possibilities with traceability and circularity were investigated. This research was the foundation for the four scenarios developed and later used to define the focus area.

Additionally, an email was sent to the employees at the Audio Department, the Access Control Department, and the Project Managers at New Business (including consultants working at Axis at the time being) to understand the current circularity work within the Audio teams. The email reached around 45 persons with the following questions included:

- Do you work with sustainability at Axis today?
- If so, how do you work with this? Please describe.

3.1.3 Define

To define the focus for this master thesis, it was decided to conduct a workshop with employees at Axis, where four scenarios were presented. Since circularity is a broad and complex subject, it was only possible to focus on some aspects during this thesis project. Therefore, the employees at Axis were asked to decide which scenario would benefit Axis the most and defined the scope. After this, different concepts were evaluated based on guidelines used as guidelines, from the literature, used as a checklist to make the solutions as suitable for the specific topic as possible.

3.1.3.1 Creating scenarios

The scenarios were based on Axis current business model and inspired by four levels in the 10R strategies. The four levels were chosen, as well as the scenarios formulated, with inspiration and background from gathered information during the Discovery phase. The four Rs were selected based on relevance to the company business model and possible improvements highlighted by the audio team.

The ambitions with the scenarios were to give the reader a short description of a potential use case to set it into context. Moreover, the team aimed to indicate what types of value creation could be developed within each scenario and how Axis might address this potential. Lastly, each scenario had a list of potential development areas to be further investigated in the master thesis. These development areas were inspired by guidelines applicable to the specific scenario. The scenarios were discussed with the supervisor at LTH prior to the workshop.

3.1.3.2 Workshop

Knapp, Zeratsky and Kowitz (2016) describe that one method to use for workshops is the Sticky Decision. The sticky decision includes Art Museum, Heat Map, Speed Critique and Straw Poll.

They explain that the Art Museum has its name from watching art in a museum - quietly observing art pieces. Concepts, initially generated by all or a few participants from the workshop, are put up on a wall and separated.

Knapp, Zeratsky and Kowitz (2016) present the Heat Map session as one approach to get an overview of features and functions most liked in each concept. During the session, all the participants are handed several dot stickers. The participants are not allowed to present their ideas to ensure that the idea can stand on its own and that the participants are not affected by other people. The idea is to quietly put dot stickers on the parts they like and two or three dots on the ones they like even more. They state that clusters of dots - a heat map, is the goal.

Continuing, the Speed Critique opens for discussion regarding all concepts. Knapp, Zeratsky and Kowitz (2016) detail it as gathering everyone around one concept at a time, setting a timer, and starting the discussion. They describe that both positive and concerning aspects of the idea should be pointed out, as well as possible question marks. Further, it is essential not to come up with new ideas during this session nor decide what to include in the prototype, but to get a hold of opinions and thoughts.

In the Straw Poll, all participants get one dot each, representing their vote, explains Knapp, Zeratsky and Kowitz (2016). The participants get time to decide (around ten minutes) which idea or concept to vote for and write this down privately. When the time is up, they all put their vote on the concepts, and everyone gets less than one minute to present their decision briefly. They state that they will make informed decisions since all participants have unique expertise and have participated in the prior sessions.

A two-hour workshop was conducted to be able to define and narrow down the scope within circularity. Before the workshop, four scenarios were described; Reduce, Reuse, Repair, and Recycle (). These scenarios were the foundation for the workshop and were developed based on gathered information from research, see Section 3.1.2.4. Except for the preparation of scenarios, logistics were sorted before the workshop. Despite time limitations, the team had a well-defined schedule to get as much valuable information out of the workshop as possible. All four scenarios were printed and placed around the room following their Art Museum setup. All participants had a personal envelope with Post-it notes and several round sticky notes. Knapp, Zeratsky and Kowitz (2016) continuously inspired the layout for the workshop.

The workshop started with an introduction of the agenda and a walkthrough of circularity concerning material flows and related laws and regulations. The introduction was organized so that participants, without prior knowledge of the subject, would have a basic idea. Secondly, all scenarios were presented to the group on a screen. Then the Art Gallery was performed according to Knapp, Zeratsky and Kowitz. After the Art Galley was conducted, four heap maps were produced. The team then gathered around one scenario at a time, and a Speed Critique session was performed according to Knapp, Zeratsky and Kowitz (2016). This gave the participants insights regarding each scenario to help them to make a truly informed final decision. Any question marks could then also be lifted and would help the team in their future work process. Lastly, the final voting was conducted using the Straw Poll method (Knapp, Zeratsky and Kowitz, 2016). The main objective was to hear the participants' thoughts and opinions regarding the scenarios and decide which scenario to continue with. The workshop was recorded and transcribed to collect all information from the discussions. Apart from narrowing the scope of the thesis, the purpose was to gather insights from different departments at Axis that, in the development stage, could be valuable when designing concepts. The participants had varied expertise and roles within Axis to get a broad perspective during the workshop. Involved participants can be seen in Table 3.2.

Table 3.2. Workshop participants.

Workshop date	*Participants role*	*On-site/virtual*
2023-03-01	VP New Business	On-site
2023-03-01	Senior Engineer	On-site
2023-03-01	Experienced Environmental Engineer	On-site
2023-03-01	Repair Development Engineer	On-site
2023-03-01	Experienced Engineer	On-site

As mentioned, the four scenarios were developed based on data from the conducted research. Each presented scenario began with a short text introducing what type of business model the company was utilizing, followed by some points describing the added value, including what Axis would need to implement to achieve that business model. Lastly, points were described as areas to be explored further if that scenario was chosen as the final (see Appendix B Scenario Posters).

3.1.3.3 Focused research regarding the chosen scenario

After a focus was defined, more in-depth data was collected regarding the specific topic with relevant guidelines in mind, see Table 4.4. More interviews were done, as well as a literature review. The interviewees were chosen based on their relevance to the final scenario and the network speaker, see

Table 3.1. Extra time was put on the bullet points of exploration which received the most votes or "heat". The data collected in this stage was used to evaluate strengths, weaknesses, and possibilities in the current design with guidelines of the winning scenario in mind. A sample of the interview questions that were asked can be seen in Appendix A Interview Questions.

3.1.3.4 Evaluation method

To make unbiased decisions, the concepts must be evaluated, and one or a few concepts must be selected for investigation and further development. According to Ulrich and Eppinger (2012), selecting concepts includes evaluating each concept based on customer needs and comparing their strengths and weaknesses.

One method for choosing concepts is decision matrices. Ulrich and Eppinger (2012) describe the process as creating a list of specified criteria, where the criteria can be weighted. Each concept can then be rated against these criteria. According to Ulrich and Eppinger, the Concept Screening method consist of six steps:

1. Prepare the matrix
2. Rate the concepts
3. Rank the concepts
4. Combine and improve the concepts
5. Select one or more concept
6. Reflect on the process and the achieved result

With the Concept Screening method, the rating is either a "+", "– ", or a "0". The "+" equals better than, the "–" equals worse than and zero stands for being equally good. First, all of them are rated against a reference concept, serving as the baseline, which is not rated. They explain that the reference concept could be a generated concept or an already existing design. Then the ratings for each concept are summarized, and a decision can be made.

The team used the concept screening for the first step of the evaluation and the guidelines as a checklist. The checklist was prepared with relevant reuse guidelines from the literature to quickly get an overview of the strengths and weaknesses in concepts in concerning circularity.

3.1.4 Develop

One method to generate ideas is brainstorming (Motte and Bjärnemo, 2022). Brainstorming sessions might vary in execution, but some characteristics remain. Spontaneous ideas are welcome, expresses Motte and Bjärnemo (2022), and the starting point is that all ideas are good ideas. Therefore, it is also important not to criticize the ideas at this stage. Moreover, the focus is to produce many ideas because quantity often results in quality.

In this thesis project, the development stage included brainstorming sessions within the team and with Axis employees. In addition, continuous interviews were conducted with employees at Axis when needed.

3.1.4.1 Mind mapping

The Mind Mapping method is utilised to form as many ideas as possible during a limited time (Atlassian, n.d.). Before the ideation section begins, a central question is formulated regarding the explored topic. The question is formulated on a whiteboard for the group to look back on, explains Atlassian. Then the participant has five minutes to write down ideas that answer the question without trying to overthink the answers. After five minutes, generated ideas are grouped and branched out to explore more ideas. Atlassian states that this step should take 10 minutes. Lastly, five minutes are used to review the ideas and lift particularly liked ideas which can be further explored.

Initially, a very free concept generation session was conducted based on knowledge gathered from interviews and research in the discover - and define stage. In the session, the team utilised the Mind Mapping method to develop more innovative solutions and spark creativity. The question to be answered was: "What are areas of improvement to increase circular material flows?". The method was performed with post-it notes that later were grouped on a whiteboard based on their connection to a component.

3.1.4.2 XYZ-method

The XYZ-method, also called the Idea Exchange method, is one method to generate new ideas and thoughts (Motte and Bjärnemo, 2022). First, a group of people, x persons, are gathered and introduced to a mission statement explained by Motte and Bjärnemo (2022). Next, each person develops and illustrates y ideas on paper for z minutes. Then the paper with ideas is exchanged within the group, and the team will try to continue developing the ideas they got. Iterate this process until the paper returns to the original inventor of the ideas. X times y, ideas will be generated.

For each Post-it note created during the Mind Mapping method, the XYZ-method was used by the team ($x = 2$), where each person developed three ideas ($y = 3$) for four minutes ($z = 4$) and then added improvements and solutions to each other's ideas.

Then the generated ideas and the Post-it were grouped into the focus areas or areas of improvement listed in section 4.2.8. The team then picked and combined different ideas from the various groups of ideas and created a few complete concepts. The concepts were then described with a short text and rough sketches. At this stage, the areas of improvement were discussed during a workshop with two Axis employees. During the one-hour workshop, the two axis employees and the two members in the team used the Mind Mapping method to generate more ideas and possible solutions.

Later, the team's concepts were iterated and improved with some of the ideas from the workshop. The six concepts were then designed in Figma to describe and understand them better. A few inspirational pictures were also added to visualize the idea. Finally, these concepts were presented to a senior engineer at Axis to get input and further discuss the solutions.

3.1.4.3 Evaluation of current design

Firstly, the current Snobben design was evaluated against guidelines used as a checklist, which also helped to define potential improvement areas. After the team performed the evaluation, it was discussed with a relevant employee at Axis. Based on the evaluation, the team created a matrix to rate the components in the current design. Assumptions were then made to interpret the guidelines and evaluate the concepts.

3.1.4.4 Evaluation of Concepts

Then all the concepts were evaluated with the Concept Screening method, where the current Snobben design was used as a reference concept. Then each concept got a plus, a zero or a minus for each checklist criteria, based on their design. The evaluation was performed by the team.

3.1.5 Deliver

During a workshop, the team discussed and combined the two finalists into one concept. The finalists were combined by drawing sketches, brainstorming how solutions could be merged and, lastly, discussing the pros and cons of different solutions.

The combined concept was improved and adjusted continuously. This step was iterative, with a continuous discussion between the team, employees at Axis and with feedback from a mingle conducted at New Business.

3.1.5.1 CAD

The concept was created, by the team, as a 3D model in CREO. During the iterations, some adjustments were made to the 3D models to improve the concept. For instance, a port was added to increase the frequency span, and the port was simulated in WinISD to ensure correct limits. WinISD is a software that is used by the Audio department at Axis to simulate how a speaker element will preform depending on different design features such as volume and input power. In this case more specifically, cone extrusion and rear port air velocity were examined with different volumes, port dimensions and high pass filters to confirm that the values from the redesign were within the correct limits. The aim was to achieve the same frequency span as the current speakers to meet the product requirements.

3.1.5.2 Prototypes

The 3D models were printed in two different 3D printers. First, it was printed in white plastic. Initially, five parts were printed and assembled with screws and nuts. Then, the prototype was discussed with a mechanical engineer at Axis to get insights into the person's view of the concept and potential problems with the design. The prototype was also presented at a workshop for people at New Business to get more opinions about the concept.

Secondly, eight parts of the model were printed in a softer, black plastic, resulting in the final concept. Finally, this model was assembled, and associated components mounted.

3.1.5.3 Comparison

A comparison was made between the redesign and the current speaker design to understand how the new design affected the sound quality and sound experience. This comparison was made in WinISD, where the speaker driver for the smaller speaker was added as the speaker component. Then, parameters such as the air volume, port dimension and a high pass filter were inserted according to the design. The comparison was done by looking at the graph for Sound Pressure Level. The air volumes in each design were also calculated and compared.

4 Results

This chapter include four stages; Discover, Define, Develop, Deliver, and findings within each stage.

4.1 Discover

The following section consists of data gathering, where a case study of Axis Communications and their work related to circularity was explored. The chapter consists of an examination and description of the studied speaker design, followed by insights from internal interviews with relevant departments regarding their work process and Axis current circularity initiative.

4.1.1 Data gathering

4.1.1.1 Information regarding the current design - Snobben

As mentioned before, Snobben is the name of the network speakers explored in this thesis, and the current Snobben design can be seen in Figure 4.1 and Figure 4.2. According to Neutel (2023), project priorities for Snobben included Cost of Goods Sold (COGS), time and quality.

Figure 4.1. The current speaker design (Axis Communication, 2023).

Figure 4.2. The bigger respectively speaker driver (Axis Communications, 2023).

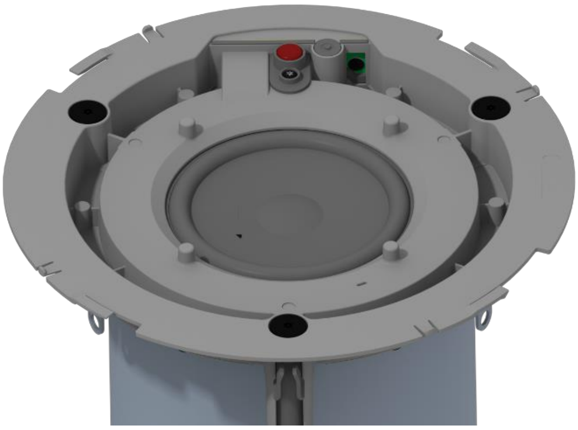


Figure 4.3. Showing the front baffle of the current design of Snobben.

The following section will explain the constituent part of Snobben, starting with the showing an exploded view if the components, Figure 4.4 and Figure 4.5 with explaining names for the components in Table 4.1.

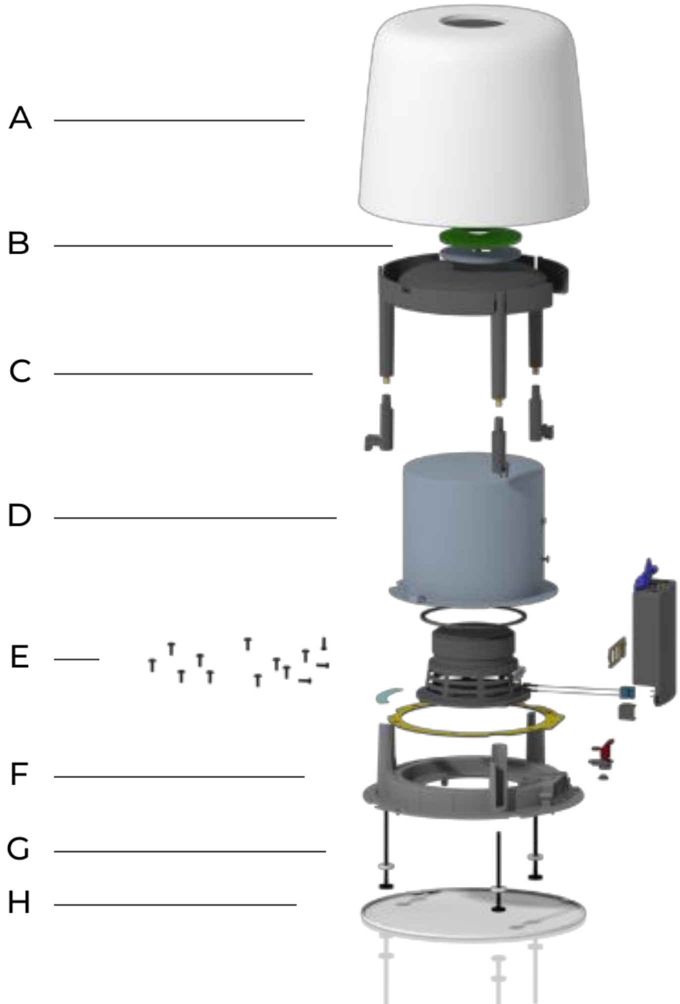


Figure 4.4. Exploded view of the components in the current Snobben design.

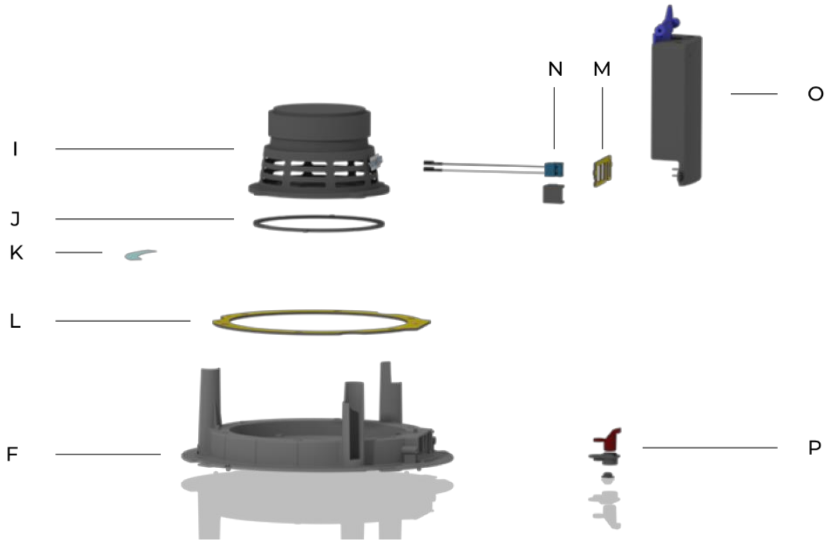


Figure 4.5. Exploded view, close up of the inner parts.

Table 4.1. Guiding list for the parts in Snobben.

Component	***Component Letter***
Cover	A
Weight	B
Installation Screws/Clamps	C
Back cover	D
Screws	E
Front baffle	F
Long Screws	G
Mesh	H
Speaker driver	I
Gasket	J
Vent	K
Gaskets	L, M
Cables	N
PCB and PCB-box	O
Light Guide	P

From the disassembly/reassembly process, it was discovered that Snobben consists of around five larger components, the heaviest component (other than the speaker driver) being the back cover (D). Connected to the back cover is the front baffle (F), which the speaker driver connects to from the inside of the back cover. The black aluminium case is the PCB-box (O). The box is mounted on the front baffle with three screws and then connected to the speaker driver (I) via cable openings in the front baffle. For the enclosure to be airtight, there is a gasket between the front baffle and the back cover and the speaker driver and the front baffle, L respectively J in Figure 4.5. The gaskets are glued to the other components. A turquoise vent (K) is also visible in the same figure. The mesh (H) is at the front of the speaker and can be seen in Figure 4.4. For the rest of the components, Table 4.1 together with Figure 4.4 and Figure 4.5 illustrates what each component is.

Regarding the material, most of the plastic used in Snobben is bioplastics, and all the aluminium is recycled. The only spare part currently available for the product is the mesh. The SD opening, the mesh and most screws are reused from previous speakers, but all the other components are new for this product (Neutel, 2023). Some of the requirements for Snobben can be seen in Table 4.2 below. The listed requirements are the ones that might affect the redesign and will be taken into consideration.

Table 4.2. Example of requirements for Snobben.

Example of requirements
Temperature: -30°C up to 50°C
Thickness: up to 60mm
Height: Maximum 150mm
Plenum rated (UL 2043)
PoE class IEEE 802.3af (No DC power option)
Indoor and outdoor use (protects against rain or spraying water at a 60° angle)
IP44

Lastly, from the disassembly and reassembly conducted by the team as well as through gathered information in accordance with Axis Communications (2023), a general assembly sequence could be determined:

- Gaskets are placed on the front baffle.
- The speaker is attached to the front baffle from the back.
- The cords are assembled, run through the front baffle from outside the interface area and connected to the speaker driver.
- Gaskets are placed on the edge of the back cover.

- The front baffle is assembled onto the back cover.
- The PCB-box with PCB is assembled separately.
- The connector pins, visible in Figure 5.11, on the PCB is mounted together with the cables, and the outer part of the PCB-box is mounted with three screw joints on the side of the back cover.

4.1.1.2 Audio inputs regarding Snobben

The current design was discussed with interviewee B. Several areas of improvement were mentioned with the current Snobben design regarding audio quality and several compromises that had been made.

The back cover was one of the discussed components. The back cover is slightly cupped in the current design because a flat surface design turned out to get its own eigenfrequency. The volume of the back cover is the essential factor and partly not the shape, meaning that the sides could hypothetically be rounded instead of the current cylindrical design. Although, it was noticed that a squared shape impaired the sound quality, thus not desirable. Additionally, the back cover could not be higher than in the current design because it needs to fit in all types of ceilings, also stated in Table 4.2. Another topic discussed with interviewee B was the mechanical parts behind the speaker mesh. The parts are black to decrease the visibility through the mesh, which is strictly a design feature.

Interviewee B argues that there is always a risk of over or under-specification when designing a new product, partly because the use cases have yet to be fully known. Additionally, some outdoor requirements, stated in Table 4.2, might need to be revised. Interviewee B questions how many customers request this type of speaker for outdoor use. Adding outside requirements and protective features like weather impregnation means decreased audio quality. When Axis added the weather impregnation on the speaker driver, it impaired the movement of the element and partly the frequency span.

4.1.1.3 Repair insights

About 2% of Axis products are reported for returns (Brorsson, 2023). According to Brorsson (2023), out of 2%, about 50% is repaired (the number for Audio products is even lower). The objectives for repairing products;

- Repairing the product is better than sending a new unit.
- Wants to repair as close as possible to the customer.
- It is faster to repair. (Because it is more likely that the component needed for repair is in stock than the whole product.)

Furthermore, some products needing repair are sent to Return Material Authorization (RMA) sites with spare parts and test equipment to serve some of the products. If the RMA cannot repair the part, it is sent directly to Electronic Manufacturing Service (EMS). Brorsson (2023) explain that Axis aims to return more products to the RMA sites and decrease the number of products sent to EMS.

It is always cheaper to repair the product on a component basis locally than to send a new product and by local the same continent counts (Brorsson, 2023). The repair cost may reach a maximum of 50% of COGS, excluding the transportation cost. During the last years, the repair cost was accepted to cost 100% of COGS because of the lack of components, states Brorsson (2023). Transportation is an expensive additional cost that has recently increased, but the numbers must be clarified. If a product is refurbished, all the esthetic components are changed so that the product looks new on the outside, leading to higher reparation costs and possibly scrapping functioning parts.

One problem that prevents RMA from repairing the product is the need for more test equipment (Brorsson, 2023). Some products require advanced testing with expensive equipment, which is impossible to obtain for each product — leading to prioritizing which products to perform repairs on. This is usually affected by the sales volumes, meaning that many of the products under New Business are selling too low quantities now to be prioritized for repairs since it is no profitability, describes Brorsson (2023). He further states that another challenge for RMA is the continuous updates Axis performs on its products. Updates make it difficult for RMA to know the product version and, thus, how to repair it. Moreover, the repaired product needs to be clarified in the same test as the new products even after five years of usage. Otherwise, the RMA sites would need their own test, which would require development and maintenance.

Of the products from Audio, about 61% of the returned products are repaired (Brorsson, 2023). However, 42% of the repaired products are sent to EMS, and only 7% are repaired by an RMA partner (see Figure 4.6), due to a lack of equipment to perform flashing and testing of the speakers. The reason is that these tests require a sound-isolated box, which is both expensive and space-consuming. The goal is to have a 50% repair yield on the products. The aim is also to increase the RMA pool and decrease the returns to EMS.

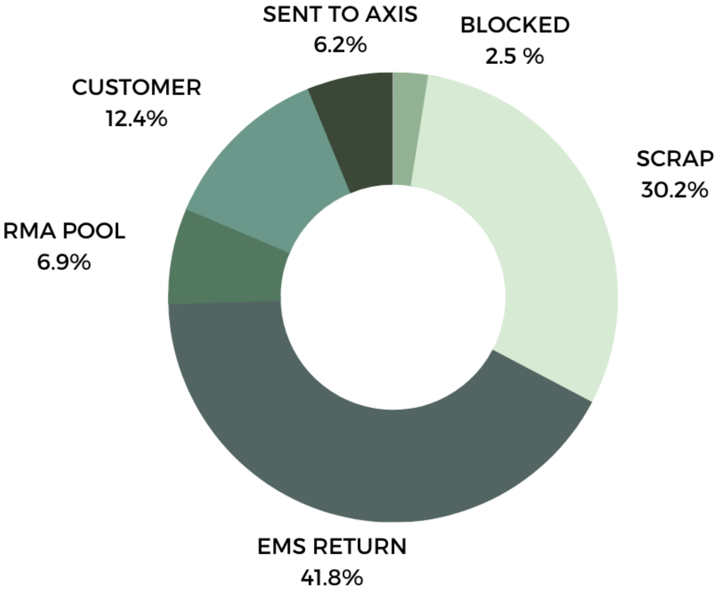


Figure 4.6. Showing the action for each reported audio repair.

Looking at all Axis products, Brorsson (2023) states that customers have returned as many as 17 000 products for repair after the warranty period, meaning they were willing to pay for the repair themselves to keep the products longer. The different repair diagnoses can be seen Figure 4.7 below.

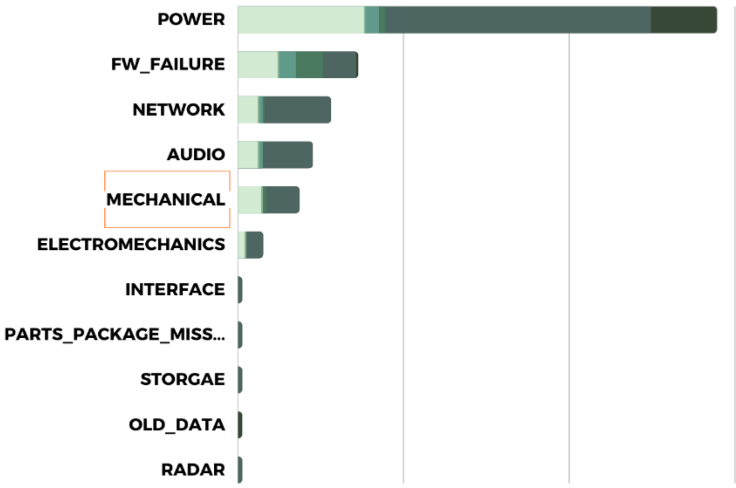


Figure 4.7. Diagnosis for potential reasons behind the repairs.

Most return reasons consist of electrical problems, as seen in Figure 4.7. Only some products are sent back due to mechanical problems (Jonsson, 2023). So far, returns have yet to be reported for Snobben as this is a relatively new product.

All products are tested according to a control plan to ensure high product quality and consistent production, as describes Jonsson (2023). Sometimes, the test equipment is too advanced and eliminates products due to errors that the human ear most likely would not detect, Jonsson continues. In addition, the tests are not designed by a routine-based process. Instead, Axis trust the experience of their employees to analyse the individual product features to design test requirements (Jonsson, 2023).

4.1.1.4 Industrial Design vision for Axis

After interviews with interviewees G and H, the product image of Axis speakers was described as recognizable, high-quality speakers. The product image is highly important and should be visible through the product design. Regarding sustainability, the interviewees push the mechanical teams to choose sustainable materials.

4.1.1.5 Axis current circularity status

Around 2017/2018, Axis started to look closer at circularity in terms of extended product life and resource utilisation. The Innova project stated that Axis controls about half of the product journey (Zenit Design, 2020). Their control extends from raw material extraction to delivery to end customers and maintenance of broken products (Axis Communications, 2023). On the other hand, Axis knows very little about what happens to the products after customers discard them since Axis sell its products through distributors and resellers.

Looking closer at the Audio Department within New Business at Axis, around 72% state that they work with sustainability at Axis, and 18% say they do it to some extent according to the answers from the emails sent out by the team (mentioned in Section 3.1.2.4. From the answers, 9 % do not work with sustainability at Axis. The response from mechanical engineers at Axis has some variation regarding how they work with sustainability. Some have a sustainability mindset in the concept process and strive to present sustainable solutions to the product manager. Several people mentioned that they choose green materials for their products and follow REACH and RoHS regulations. One mentions the Axis guidelines and the Green Design Evaluation Tool as tools they use in projects to be more sustainable. The logistics and the choice of suppliers and EMS regarding the shortest transportation distance were discussed by two people. One respondent brings up that the product should be easy to disassemble. Another speaks of minimising the number of components and sharing parts between different products, although often difficult to accomplish. Most have sustainability in mind when designing new products, but the sustainability aspect often gets under-prioritised due to time and cost. The mechanical engineers also feel the lack of clear guidelines to follow. The people express that they do what they can and what they think are good environmental choices but need real insight into how decisions affect the final impact. Ultimately, this approach results in different actions for products and projects, depending on the people involved.

Moreover, most teams and projects work in silos, with little collaboration between departments. As stated in the interviews, Axis is on the first step of the Circular Design Ladder (Motalli, 2022), still optimising each project and each department. There are many possibilities for improvement in the areas, the major ones being directions from the management and clear guidelines regarding circularity to use in the processes. Moreover, innovative solutions outside the regular business model could greatly benefit Axis.

4.2 Define - Take aways

After conducting interviews and research during the Discovery phase, the conclusion was that Axis, after selling to distributors, have little control and information about the product and the product lifecycle, negatively affecting the possibilities for a circular transformation. The opposite of becoming circular is therefore the lack of ownership. The following section includes takeaways and insights from the workshop and follow-up interviews.

Following are short contexts of the probable use cases for Axis to be explored in this thesis but with design for circular material flows as the focal point, as explained in Creating scenarios 3.1.3.1. The four levels (the four scenarios) of chosen actions were Reduce, Reuse, Repair and Recycle. The foundation for these selected Rs is also presented in the following sections. For a more exact definition and explanation of each scenario, see Appendix B Scenario Posters.

Reduce – As earlier mentioned, Axis speakers are produced in Poland, whilst electrical components are purchased from China and since Axis mainly sell in the US, the logistical chain gets long (Axis Communications, 2023). Therefore, Axis could benefit from design optimization, in terms of product weight or shape, to lower its environmental footprint. Secondly, in accordance with Interviewee B, the product requirements can be interpreted as overspecified, creating a heavier product with more components than necessary. Reduce had enough incentives and improvement opportunities and was therefore chosen as a possible path. The context of the scenario was that it would be the approach with the least change for Axis. The main objective was to optimize and minimize the amount of material, the variety of material, the weight, the number of components, et cetera. Lastly, to optimize the upstream of the product to be more efficient and sustainable.

Reuse – With the European Green Deal and the Circular Economy Action Plan 2050, circularity is getting increased attention. In accordance with Axis Communications (2023), the company is unaware of the end-of-life process for its products. It could increase circularity if a take-back system were implemented and be able to reuse old parts in new products. The need for design regarding reuse was previously described by Neutel (2023) when mentioned that only screws, mesh and SD-opening were reused between all audio products at Axis. Thirdly, it was mentioned that companies like Canon are currently reusing old parts (Canon Global, n.d.). Therefore, the team saw an incentive for Axis to utilize Design for Reuse in their development processes, hence the choice of Reuse as one selected level to be presented. In the scenario, it was stated that for Axis to achieve a more significant environmental impact, Axis has to increase its ownership or extend its partnership with resellers to implement a take-back system.

Repair – As mentioned by Brorsson (2023), Snobben speakers are currently not repaired since they cannot perform certain audio tests at RMA, contributing to many products being transported to EMS. Since the aim, according to Brorsson, is for Axis to increase repair yield and decrease the number of repairs sent to EMS, the team discovered enough incentive for Design for Repair to be chosen as a scenario to be presented. In the scenario, it is then explained that Axis, in its future business model, will focus on addressing problems and opportunities regarding repair since, in 17 000 cases, the customer has been willing to pay to repair their product after the warranty period (Brorsson, 2023).

Recycle – The main objective is to ensure the product is recycled and does not end up on landfills by taking responsibility for the product at the end-of-life. As of today, Axis do not have partnership or collaborations with recycling centres, states interviewee E. Continuously, new laws and regulations are introduced, which will pressure companies to take greater responsibility for their products at the end-of-life. On this note, many Axis products contain substances that are difficult to recycle. For instance, foam gaskets are glued to the component, which is the case for most of the products within Audio, including the foam gaskets on Snobben.

4.2.1 Workshop take aways

Regarding Level 2 – Reuse, upgradeability was the bullet point that got the most "positive heat" regarding value creation. The participant felt Axis was not incorporating or focusing on reusability in their R&D teams. The development teams are aware that it will be upgraded versions for most Axis products. However, because of time pressure and budget limitations, parties account for having a short-term design mindset in the design process. While predicting future market requirements is difficult, some features are reoccurring and static over speaker generations. The platform has been changed in new versions. It was also discussed that speakers are an excellent product to design for upgradeability because the main components have looked the same for several years. Axis uses the same electrical interface components in all speakers, which will likely not change.

A critical aspect that differentiates Axis speakers from competitors is that they are developed for cyber security, which is constantly changing the requirements of the products. The trade-off with designing regarding upgradeability is that Axis products would be designed bigger to leave space for future versions, making heavier products.

During the workshop, leasing as a business model was discussed and summarized as a high threshold reformation for Axis. Since the current business model does not allow for a takeback system, Axis would need to own its products or change its distributor agreements. The customers do not necessarily have to be the end customers. Axis could lease the products to the distributors as well. It was also mentioned that their current business model is portrayed as a successful company strategy, where 170 distributors (approximately) as end customers is more manageable than having millions of users with leasing as a business model. If Axis were to implement reuse in its business model, it could also gain other customers who value a greener approach. To Axis's knowledge, customers are purchasing and selling used Axis cameras, meaning that a business case exists. However, it is believed that the customers buying used Axis cameras today are different from those they are currently segmenting. This customer group might simply want a surveillance camera but does not care as much for the cyber security factor and therefore is fine with a lower security standard.

Currently, companies are gaining profit by advancing technology rather than reducing and simplifying solutions. One incentive to "Design for Reduce" could be that since most electrical products are mainly manufactured in Asia, transportation of Axis products will continuously be long and unsustainable, making it essential to design lighter products to lower the climate impact.

Designing with concern to repairability would create more sustainable customers, which are incentives for both Axis and the customers. In addition, their customer satisfaction could increase significantly.

4.2.2 The winning scenario

The winning scenario from the workshop was “Reuse”. This scenario got three out of five votes in the final voting and, so forth, focused the thesis on the following design prioritize:

- Define strengths and weaknesses in the current product design from a reuse perspective
- Choose material that ages well
- Create a timeless design
- Design to facilities updates
- Design to be able to separate components and parts
- Enable accessibility of the PCB through the mechanical design

The motivation for the winning scenario was that Axis would likely address all other scenarios in the future. However, the participants felt that the “Reuse”-approach was not the area to be primarily addressed but would greatly benefit Axis and had room for investigation and innovation. The discussion also included that repair and reuse are very closely connected.

4.2.3 Reuse insights

After conducting more interviews with mechanical engineers, audio specialists and electrical engineers, all parties accounted for probable platform updates from one speaker version to the next, which could mean the circuit board would be updated. The mechanical components looked the same from one version to another except for possibly re-dimension of components based on design changes to the circuit board. The speaker driver could also be upgraded, but the whole mechanical design would have to be changed since it is designed around the specifications of the speaker driver.

The upcoming trends and customer needs are the best guess of what the market might want, together with inspiration from competitors at exhibitions and feedback from installers on how the product might be improved, describes interviewee P.

Interviewee Q states that the PCB might break or need an update requiring the whole PCB to be replaced. Furthermore, Snobben belongs to PoE class 3, which allows 15W. The next class, PoE class 4, allows for 25W. According to Interviewee Q, most of the Axis competitors have PoE class 4, so he thinks Axis should transition to PoE class 4 to compete on the market. The change to PoE class 4 requires a larger PCB. Specifically, the power part on the PCB will increase, which could increase in both y- and x-direction by approximately 30-40%.

Interviewee P adds that change will happen in the functionalities and the software to develop more innovative products but require larger and better processors.

While some components need to be updated and changed, others will remain the same. Interviewee M explains that the speaker driver to withstands for a long time and rarely gets replaced. Replacing the speaker driver results in a whole new product since many components in the design circulate the speaker driver, such as the back cover and the front baffle. Furthermore, interviewee P mentions the speaker's shape as a design feature that most likely will not change. The form can be seen as a container lasting for several years.

Concerning areas of development, the audio quality could be optimised, expresses interviewee B. One example is that the speaker driver is slightly lowered in the back cover. This solution disperses the sound inefficiently. A broader dispersion angle is more beneficial for sound experience and covers more area, which is beneficial since the use case for Snobben is to play background music and make announcements. A broader cover area would lead to fewer required speakers for the same area. A second one, pointed out by interviewee M, is the front baffle holding the speaker driver, see Figure 4.3, which has many pits causing the sound waves to spread in an undesirable way, worsening the sound quality even more. Thirdly, interviewee B states that the volume of the back cover is not big enough to handle the power and vibrations that appear in the box but was compromised to have an aesthetic appeal. Continuously, describes that more air volume results in a lower frequency span. Whilst the addition of a tweeter would increase the upper-frequency span. Hence, there is room to improve the frequency range and the audio quality.

In addition, the speaker was designed and calculated for the smaller one. Then the bigger one was designed by mainly scaling the smaller one. There is, therefore, improvement potential to create a more optimal design for the bigger speaker. One example is the thickness that needs to be scaled.

Moreover, since the speakers are IP44 classified they must be partly waterproof. The classifications require the speaker's diaphragm to be in a water-repellent material. However, this type of material does not transfer sound optimally, explains interviewee B. Interviewee O also mentions that higher IP classifications increase difficulties in manufacturing, because of the required pressure to compress gaskets of waterproof materials, like silicone.

Interviewee M defines other problem areas. One is the heavy speaker driver overloading the thin front baffle to crack in transportation. Another problematic area is the installation screws, which might be damaged during installation and de-installation since the treads are easily worn out. In addition, the mesh rattles and vibrates when played loudly, which disturbs the sound experience. Lastly, the PCB is designed to be put on the side of the back cover, making the pendulum speaker tilt. This was addressed by adding a rubber plate to act as a counterforce, adding a component and an extra assembly procedure during installation, expressed interviewee M.

In Table 4.3 it can be seen how the components in the Snobben design were evaluated from most to least likely of failure (to brake and need of replacement) in both production (scoring made by interviewee O) and in use (represented by returns, made by interviewee U). Grading 3 represents a high probability of failure, while 1 represents a low probability.

Table 4.3. Grading of probability of failure for the components in Snobben.

Component	***Grading by production***	***Grading by return***
Gasket	3	2
Screws	2	1
Thread of mounting screw	2	1
Mesh	1	2
Cover	1	1
Front baffle	1	1
PCB	1	3
PCB-box	1	1
Back cover	1	1
Speaker driver	1	1

Table 4.3 shows that the gasket and the PCB-box were rated 3. Interviewee O explains that the gasket often sticks to something and brakes, while interviewee U says that the component with the most returns due to failure is the PCB. However, as shown in Table 4.3, interviewee U assigned the gasket a two with the explanation that it is deformed and can no longer be used after disassembly. The screws and the thread of mounting screws got a two from production, mainly because some screws brakes when mounted, and the mounting screws can be fastened incorrectly, damaging the threads of the screws. The PCB does not get a high score from production because problems with the PCB are handled before final assembly, whereas many are fixable, and only a few PCBA must be scrapped.

Additionally, interviewee O addressed that every newly created product leads to the need for replacement or changes of machines and tools.

With all this said, according to interviewee M, the product feedback so far is exclusively positive, and the customers are expressing how beautiful the Snobben speaker is.

4.2.4 Guidelines for reuse

The guidelines in Table 4.4 are the most applicable for this type of product and, therefore, used for this thesis. The following guidelines were retrieved from Shahbazi and Jönbrink (2020) and Shahbazi, (2020) but limited to fit and be related to Design for Reuse and Axis as a company.

Table 4.4. Evaluated guidelines.

Extended life
The design aim to extend the value life of the product.
Future
The product is aligned with current and upcoming laws and regulations.
The material and components in the product will be available in the future.
Upgrade
The product is easy to upgrade.
It is easy to dismantle the product non-destructively.
The platform (components that do not change through all generations of a products) is designed durable, robust and reliable for several lifecycles and can withstand several upgrades.
The modules/subsystems most likely to need an upgrade or exchange is easily accessible.
The product is easy to repair at RMA
The product is easy to repair by the customer
The product is easy to repair by the installer themself.
Standardised
Joints are standardised.
The product consists of joints and connectors that easily can be opened and closed multiple times.
The product requires standardized tools across products and models.
Assembling of the product requires one single type of tool.
The product consists of some standardized components across different products and models.
Modules
The product is designed in modular construction.
No cross-dependencies exist between modules.
Components with a high plausibility of change are modular and isolated.
Isolation
Parts that wear out is easily accessible and isolated from other systems.
Components are easily accessible and have reachable directions.
Design
It is possible to change exterior of the outer shell.
The design is timeless and compatible.
Wear and tear
The product does not have components subjected to stress, wear, break or fail - In production.

The product does not have components subjected to stress, wear, break or fail - During transportation.
The product does not have components subjected to stress, wear, break or fail - During use.
The product does not have materials that easily are discoloured.
Components clearly indicate when they are worn out and need exchange.
Exchanges components are marked or easy to recognise.
Materials
There are no adhesives and glue in the product.

(Shahbazi and Jönbrink, 2020; Shahbazi, 2020)

4.2.5 Assumptions

The following assumptions were made by the team before evaluation. The assumptions were formed based on data and insights gathered during all interviews and workshops.

- Following laws and regulations is limited to the laws Right to Repair, REACH and RoHS.
- An easily accessible circuit board enables an easy upgrade.
- A design that allows the PCB-box to be changed in size and dimension is easy to upgrade.
- A system that enables add-ons/extensions and upgrades of the sound quality contributes to an easy upgrade.
- Solutions without adhesive are preferable.
- Solutions with gaskets that return to the original state at disassembly are preferable.
- Disassembly of the product might happen more than X times non-destructively.
- All components (excluding the circuit board) will be reusable.
- The circuit board is the component in need of an upgrade.
- A solution possible to disassemble non-destructively is easy to repair at RMA.
- A self-explanatory solution is easy to repair at RMA.
- A solution with only one possible assembly sequence is easy to repair at RMA.
- Screws already used at Axis are preferred.
- Well-known mechanical joints on the market are considered standardized.

- Joints that do not brake during disassembly are considered easily open and close.
- Well-known tool types on the market are considered standardized.
- Components already constructed at Axis are considered standardized.
- Correlated components in both speaker models are considered standardized.
- The PCB is considered to be plausible for change during a lifetime.
- The front baffle and back cover potentially change during a product update from Axis.
- PCB, gasket, and screws are parts considered to wear out.
- By reachable directions, it is assumed that parts can be disassembled/reached by the outside.
- A timeless design is considered a minimalistic design.
- A customisable design is considered a timeless design.

4.2.6 Evaluation of current design

The results from the conducted evaluation can be seen in Table 4.5. The team conducted the evaluation based on the assumptions stated in Section 4.2.5 and later reworked it with a mechanical engineer. Table 4.5 was later part of the foundation for the development focus. The same table displays some examples from the evaluation. See Appendix C Evaluation of Snobben for the entire evaluation.

Table 4.5. Evaluation of current design.

Guidelines	***Not at all***	***To some extent***	***Fulfils***
Extended value life of the product.			
Materials and components will be available in the future.			
Easy to dismantle product non-destructively.			
Modules most likely of upgrade/exchange is easily accessible.			
Easy to repair at RMA.			
Product assembly requires one type of tool.			
No cross-dependencies exist between modules.			
Possible to change exterior of outer shell.			
Timeless and compatible design.			
No components are subject to stress, wear, break or fail – in production/transportation/use.			
No adhesives and glue in the product.			
Parts that wear out is easily accessible and isolated from other systems.			
Designed in a modular construction.			
Product requires standardised tools across products and models.			

An evaluation matrix was created to better understand how the different components affect the probability of failure and the impact of reusing that component, see Figure 4.8 The gasket, the PCB and the front baffle all got high scores in the matrix. The high scores were given based on the information presented by interviewees O and U regarding the PCB being the main return reason, the gasket being hard to handle, and that interviewee M mentioned the risk of cracking the front baffle during transportation.

Concluding all data gathered regarding the PCB being the most likely of upgrade and failure from interviewee Q, the team decided that the PCB is critical from a reuse perspective. Nevertheless, the back cover, and the speaker driver also got high ratings because they make up for most of the product's weight and volume. They are also the most robust and will manage several life cycles and, therefore, essential to be reused between models and for longer periods. Lastly, it was also mentioned by interviewee M, that the design circulates around the speaker driver meaning that if different speaker drivers are used it can be assumed that surrounding components need to be different for every speaker. Since according to Table 4.4, standardization is stated as a guideline for reuse, the speaker driver was rated a highly important component to be reused, see Figure 4.8.

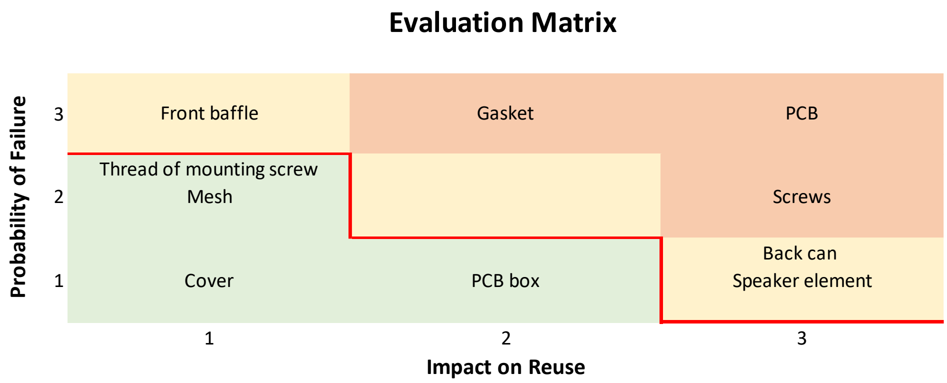


Figure 4.8. Evaluation matrix over a component's Probability of Failure and Impact on Reuse.

4.2.7 Defined vision

From insights and analyses of the current design, a product vision was defined. The team determined that the redesign would provide a first-class audio experience encased in a sleek, minimalistic design. The circuit board mechanics allow for easy upgrading, and Snobben can be disassembled and reused without the use of glue. In addition, most parts can be reused when upgrading audio quality.

4.3 Develop

As described, the third step of the double diamond method is the Develop stage. In accordance with Section 3.1.1 and Section 3.1.4, concepts and ideas are displayed and presented in the following sections. In addition, concepts and ideas developed by the team through brainstorming sessions, amongst other methods, are also described in 3.1.4.

From data gathered in Section 4.2.3. it was established that some components had a high impact on reuse and a high probability of failure. These components are, therefore, the main focus of the generated concept below. Per Figure 4.8, the back cover, the gaskets, the PCB, the front baffle, the screws, and the speaker driver were areas to be looked at. Mechanical solutions related to the mesh, the cover, the thread of mounting screws and the PCB-box will, therefore, not be explored further in this thesis project. Although it should be stated that if the critical components are dependent on non-critical components, the latter could be considered in the concept generation.

Additionally, based on the guidelines in Section 4.2.4 and the vision defined by the team, the design prioritises for the generated concepts can be summarised as the following:

- Minimizing screws
- Modular back cover
- Gasket solutions without glue
- Static speaker driver
- A mechanical design which allows for the PCB to be upgraded

4.3.1 Concept generation

The following are presented concepts that are meant as possible implementations of a final circular design solution for network speakers.

The Mind Mapping method resulted in 9 different areas to explore further, with 32 ideas, see Figure 4.9.

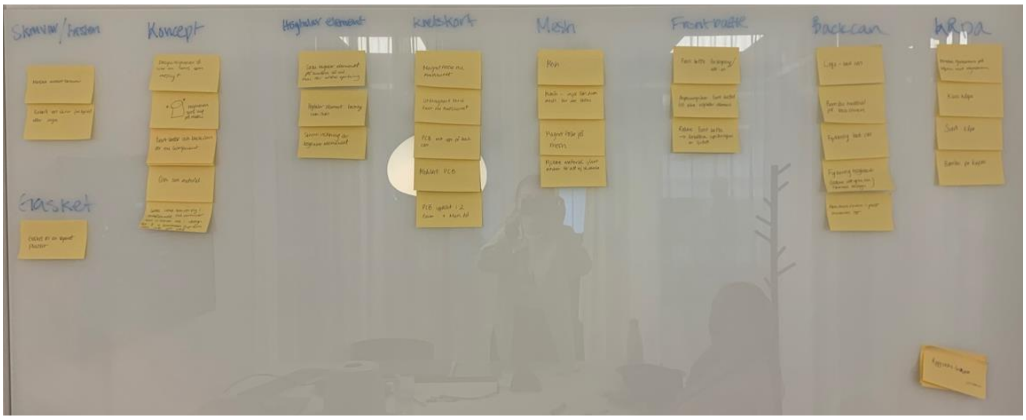


Figure 4.9. Results from Mind mapping.

The XYZ-method generated more than 150 possible solutions with different aspects in mind.

These initial concepts were general and should display possible development routes for future work. The following sections describe the six different concepts that were generated.

The light bulb concept

The main objective of the light bulb concept is to minimise the number of screws. The front baffle and the back cover are designed as one component in the same material, eliminating the need for screws to mount them together. The concept's name refers to the installation of the speaker driver, where the speaker driver is screwed, from the outside, into the front baffle / back cover like a light bulb. The threading is believed to make the speaker airtight, after consultation with interviewee B. In addition, this requires zero screws. About the PCB-box, the box itself will be mounted onto the front baffle / back cover with an attachment which enables the size of the PCB and, therefore, the PCB-box to change. The attachment will remove dependencies between modules and allow for PCB components to be added without redesigning or replacing other speaker components. Additionally, the concept takes the mounting of the PCB, in the PCB-Box, into consideration. The idea is to have a track on the sides inside the box to ensure the PCB stays in place, minimising the usage of screws. The concept and inspiration can be seen in Figure 4.10.

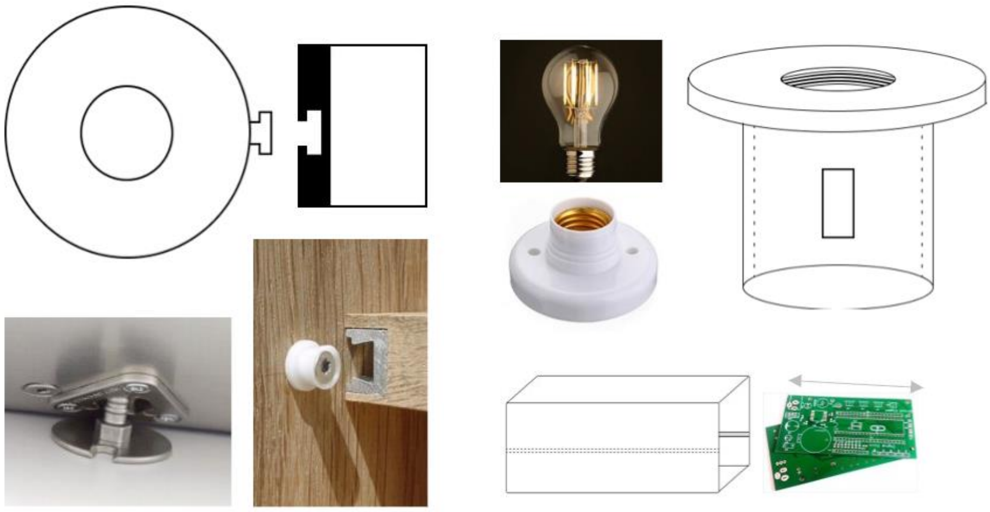


Figure 4.10. Sketches and inspiration (from pinterest.se) for the Light Bulb concept.

One of the advantages of this concept is the minimisation of different materials. Unlike the current design, with one material for the back cover and another for the front baffle, the concept has combined the front baffle and the back cover and uses one material. The minimising of screws will most likely shorten the assembly time. Moreover, avoiding many different screws might decrease the need for warehouse storage and the waste generated from screws at end-of-life. Another advantage is that the PCB-box in this solution can be altered in size if needed. Here the attachment on the BC does not limit the PCB-box in any way. In the current design, the whole back cover will be discarded if the PCB-box increase or decreases in size.

The disadvantage of having one component is the increased complexity of producing the component. In addition, screwing in the speaker driver like a light bulb is a new concept and might be hard to implement.

The box concept

The box concept drastically differentiates itself from the ordinary round design, with a more suitable rectangular design in terms of modularity. For the modules to be connected, several possible wall connections can be seen in Figure 4.11. A gasket could be placed between the sides to enable an airtight seal. In addition, the speaker driver is mounted from the outside in this concept. It is also displayed that a smaller tweeter could be added and connected through a mounting structure that would not require any side replacements or deconstruction but to view the tweeter as an add-on when the customers want to upgrade their frequency span, see Figure 4.11. This concept was inspired by a modular, transparent speaker by transparent sound with a focus on repairability and modularity (Transpa.rent. n.d.).

This concept focuses on reusing as many sides of the back cover as possible. By enabling some sides to be changed whilst others can be kept, more sides can be reused when a customer, for instance, wants a broader frequency span. Even so, the larger and the smaller version of Snobben can contain more of the same components increasing the production quantity whilst decreasing the production of different tools. Another aspect is that this type of solution could increase efficiency in transportation compared to the current design since rectangular components are easily stacked in a secondary package compared to circular. Meaning that more components could be delivered in the same amount of space, minimising the carbon emissions from the logistic chain.

In the current design, all gaskets are compressed to the extent that they need to be replaced when the speaker driver is disassembled. However, the outer mounting of the speaker driver for this concept enables easy and nondestructive speaker disassembly, hence fewer parts need to be taken apart to access the speaker driver, see Figure 4.11.

A negative aspect to this concept that was discussed where that a square shaped speaker put more demand on the work of the installer. The speaker must be aligned when mounted in the ceiling since it is more noticeable than a round speaker that can be mounted at any angle.

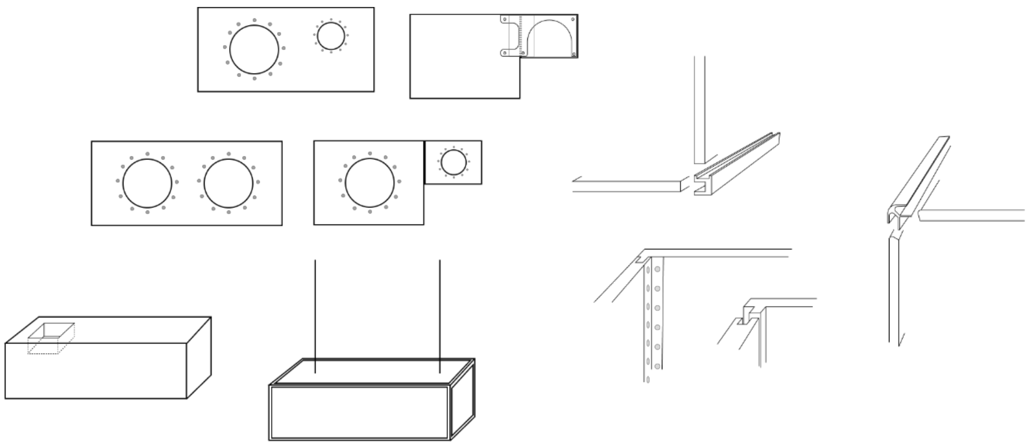


Figure 4.11. Illustration of the different features of the box concept.

The oval concept

Like the box concept, this concept has a similar underlying idea of modular design whilst keeping the current design's more rounded shape. The back cover is split in half vertically, see Figure 4.12. Compared to the current design, the back cover, and the front baffle are one component. To extend the speaker when an upgrade is desired, the two parts on the back cover is connected with a middle part that provides more volume to the back cover and give the speaker a more oval design. This design adds a tweeter for increased frequency range and a modular PCB attachment. The modular PCB attachment consists of an additional plate which enables a more adaptable screw insertion of the box. As mentioned, the PCB-box could expand in size in the future; therefore, this flexible screw insertion is an added feature. The speaker driver is also mounted from the outside in this concept.

The identical side components increase the quantity of those parts while decreasing the creation of an extra tool. Furthermore, using the same speaker driver in all models increases the order quantity of speaker drivers, which is good since Axis is a relatively small purchaser; the increased volumes will increase their influence.

The mounting from the outside will raise the speaker driver compared to the current design, allowing for better sound spread. Secondly, if the speaker driver needs to be released from the back cover, not as many gaskets will have to be replaced compared to the current design.

A vertical cross-section allows for components to be built on build-on, which is favourable compared to the current design, which has height requirements according to Table 4.2.

On the downside, the change in shape will require a new solution for attaching the mesh. In the current design, the mesh is rotated to fasten, a solution impossible for the oval concept. In addition, if the solution is not adequately sealed by having the speaker driver mounted from the outside, problems with IP classification might arise. Also, there is a small risk that the speaker driver could be stolen when having it mounted from the outside. This was discussed with interviewee M, and the risk was determined to be irrelevantly small.

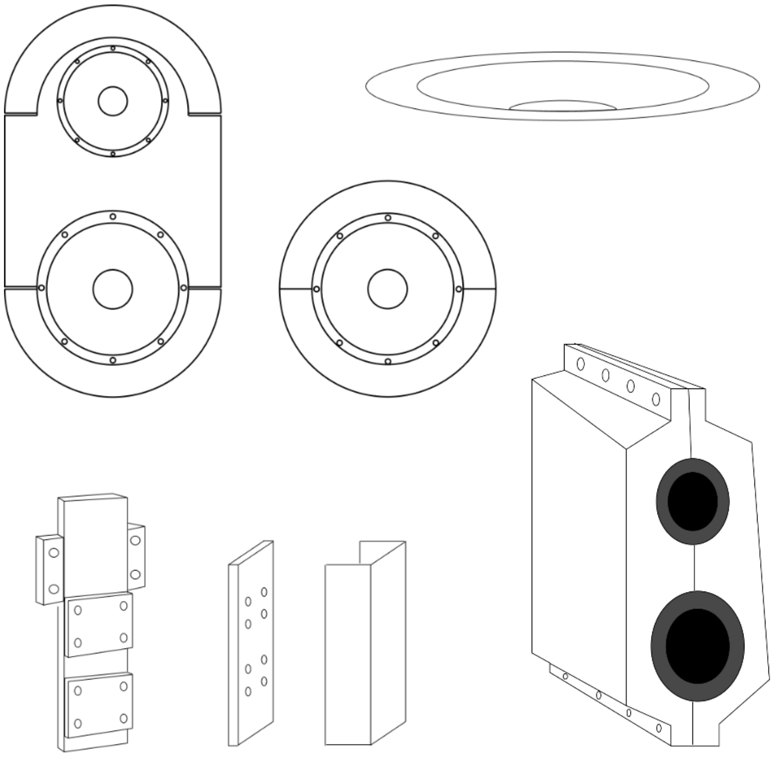


Figure 4.12. Illustration of the oval concept.

The no glue concept

As the name implies, this concept addresses the problems of using glue by eliminating glue in assembly. Instead of using adhesive to fasten the foam gasket and to achieve airtight sealing, the solution is to use a more oversized foam gasket with bent edges to hold the foam gasket in place during assembly. The bent foam gasket will be placed on top of the back cover and have one part bending inwards, inside the back cover, and one covering the outer edge of the back cover, see Figure 4.13.

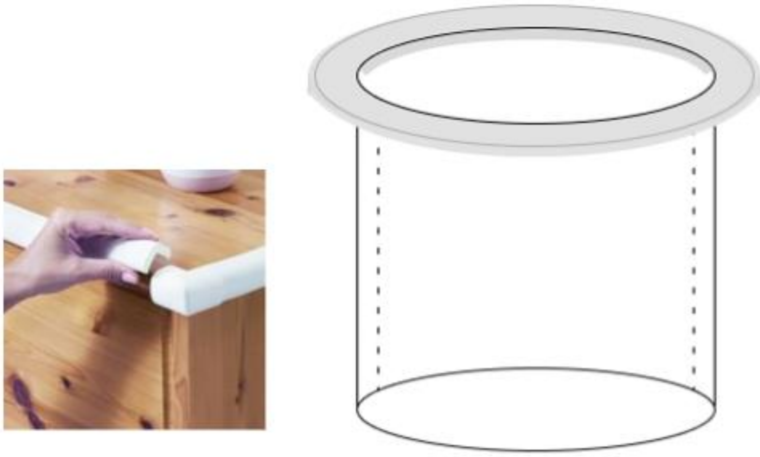


Figure 4.13. Inspiration (from pinterest.se) and illustration of the bent foam gasket without adhesive.

The speaker driver in this concept is assembled from the outside and with a stylish minimalistic style to ensure a clean design while facilitating easy speaker disassembly. Moreover, the PCB-box have an expandable design to prepare for dimension changes in the PCB. This is inspired by an extendable table, where two tabletops are dragged apart, creating a space in which an add-on in the form of an extra tabletop is placed, thus getting a more extended table. The same design approach was implemented in this concept; the PCB-box consists of two halves that create a box together. These halves are designed to be dragged apart, allowing an extra part to be inserted and thus resulting in a longer PCB-box, see Figure 4.14.

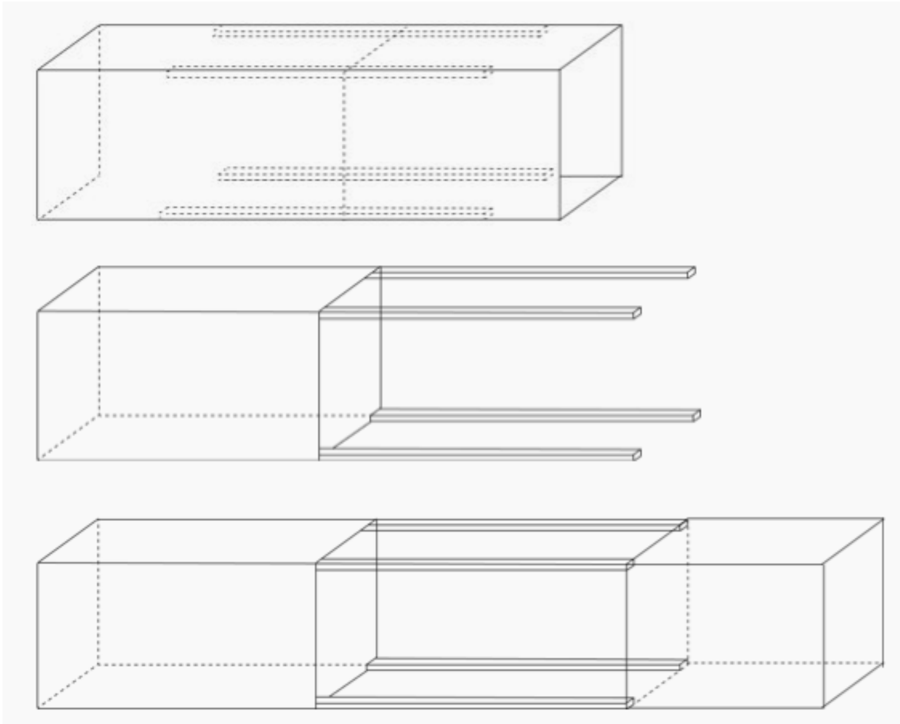


Figure 4.14. The extendable design for the PCB-box.

The elimination of adhesive gives great advantages for disassembling the product in repair and production. According to interviewee O, the gaskets get deformed when assembled and will not recover during disassembly, which leads to the need for a new gasket in re-assembly. The adhesive is also challenging to remove. On the other hand, the foam gasket is bigger than the current one, meaning more material is being used. The PCB-box enables dimension changes in the future. However, it might make the box more complicated to manufacture.

The PCB-box concept

This concept explores the possibility of expanding the focus area to other products in the Audio Department at New Business but with the sole focus on PCB placements. Since the evaluation of Snobben showed that the speaker was more upgradeable if the PCB-box was isolated, an isolated PCB-box would be applied to other speakers at New Business. Figure 4.15. shows a 2D illustration of the cross-section of another speaker, Mulan, portrayed with an isolated PCB-box. The concept also includes implementing a cover hiding the separation of the PCB-box from the rest of the speaker and enabling a more timeless design. In addition, the shell can be replaced instead of the whole back cover.

The favour of this is the easily upgradable PCB (the module most likely to upgrade according to interviewee Q) and making the product easier to recycle by easily removing the PCB from the rest of the components. Having the PCB isolated also enables upgrades of the PCB in the future without the complexity of retaining the exact dimensions.

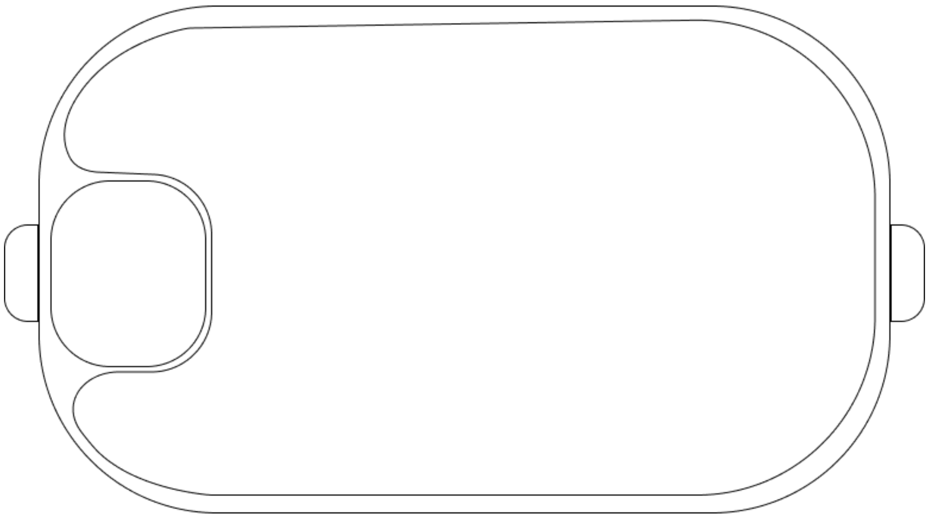


Figure 4.15. A 2D display of the cross section of the Mulan speaker with an illustration of PCB-box placement.

The Bluetooth concept

The last concept is aimed towards a different customer segment, speakers for personal use. Since it was discovered that external parties are selling used Axis cameras, this concept explores the possibilities of developing a Bluetooth solution that enables the user to switch their network connection to a Bluetooth connection. This solution would be more suitable for home use than the current network connection. With this solution, Axis would need to expand its distributor relationship. It is expected that Axis distributors would enable a take-back system and later sell these used speakers at a lower price with the possibility of adding the Bluetooth module.

This concept benefits Axis since it would reach a more extensive customer group and launch an additional product unit onto the market. However, the downside might be that Axis's core competence, using network connection to ensure security, is a function that will be lost in this concept. This could weaken Axis's brand.

4.3.2 Concept selection

As mentioned in the method (Section 3.1.4.3), the team rated the concepts according to a self-made checklist inspired by Reuse guidelines. See the following explanation for the shortenings in Table 4.6.

REF – Reference design, the current Snobben speaker
LB – The Light Bulb concept
B – The Box concept
O – The Oval concept
NG – The No Glue concept
PCBC – The PCB-Box concept
BL – The Bluetooth concept

Table 4.6. Evaluation of concepts.

Extended life	***REF***	***LB***	***B***	***O***	***NG***	***PCBC***	***BL***
The design aim to extend the value life of the product.	0	NA	NA	NA	NA	NA	NA
Future							
The product is aligned with current and upcoming laws and regulations.	0	NA	NA	NA	NA	NA	NA
The material and components in the product will be available in the future.	0	NA	NA	NA	NA	NA	NA
Upgrade							
The product is easy to upgrade.	0	+	+	+	+	NA	0
It is easy to dismantle the product nondestructively.	0	+	+	0	+	NA	0
The platform (components that do not change through all generations of a products) is designed durable, robust and reliable for several lifecycles and can withstand several upgrades.	0	+	-	0	0	NA	0
The modules/subsystems most likely to need an upgrade or exchange is easily accessible.	0	0	0	0	0	NA	0
The product is easy to repair at RMA.	0	+	0	0	0	NA	0
The product is easy to repair by the customer.	0	NA	NA	NA	NA	NA	0
The product is easy to repair by the installer themself.	0	NA	NA	NA	NA	NA	0

Standardised							
Joints are standardised.	0	-	0	0	-	NA	0
The product consists of joints and connectors that easily can be opened and closed multiple times.	0	+	0	0	0	NA	0
The product requires standardised tools across products and models.	0	NA	NA	NA	NA	NA	0
Assembling of the product requires one single type of tool.	0	NA	NA	NA	NA	NA	0
The product consists of some standardised components across different products and models.	0	0	+	+	0	NA	0
Modules							
The product is designed in modular construction.	0	0	+	+	0	NA	0
No cross-dependencies exist between modules.	0	NA	NA	NA	NA	NA	0
Components with a high plausibility of change are modular and isolated.	0	+	0	+	0	NA	0
Isolation							
Parts that wear out is easily accessible and isolated from other systems.	0	NA	NA	NA	NA	NA	0
Components are easily accessible and have reachable directions.	0	+	+	+	+	NA	0
Design							
It is possible to change exterior of the outer shell.	0	0	0	0	0	NA	0
The design is timeless and compatible.	0	0	0	0	0	NA	0
Wear and tear							
The product does not have components subjected to stress, wear, break or fail - In production.	0	NA	NA	NA	NA	NA	0
The product does not have components subjected to stress, wear, break or fail - During transportation.	0	NA	NA	NA	NA	NA	0
The product does not have components subjected to stress, wear, break or fail - During use.	0	NA	NA	NA	NA	NA	0
The product does not have materials that easily are discoloured.	0	NA	NA	NA	NA	NA	0

Components clearly indicate when they are worn out and need exchange.	0	NA	NA	NA	NA	NA	0
Exchanges components are marked or easy to recognise.	0	NA	NA	NA	NA	NA	0
Materials							
There are no adhesives and glue in the product.	0	+	0	0	+	NA	0
Total points	0	7	4	5	3	NA	0

The evaluation resulted in the Light Bulb and Oval concepts scoring the highest, see Table 4.6. At the same time, the checklist was not applicable to the PCB concept and with no significant design changes in the Bluetooth concept, it mainly scored zeros.

4.4 Deliver

The fourth and last step of Double Diamond is the Deliver stage. In accordance with Design Council (2019), the concept was refined and improved until the final concept were shaped. Both CAD-models and prototypes were created in this stage, as described in Section 3.1.5.

4.4.1 CAD-models

A few features were combined from the workshop, which then created a new concept. The combined features were the PCB attachment from the Light Bulb concept, see Figure 4.10 and the modular design of the back cover with a tweeter from the Oval concept, see Figure 4.12. The new concept that was created can be seen in Figure 4.16 and Figure 4.17. Since the main idea and focus was to design for reuse and upgradeability, the idea was to keep the same speaker driver from the smaller speaker version to the bigger speaker version whilst keeping the same audio experience as the bigger Snobben speaker has today. As previously discussed by interviewee B, this could be achieved through an increased frequency span when upgrading to the larger version.

Furthermore, interviewee B expressed that an increased frequency span can be achieved either through an increased back volume or by adding a tweeter for the higher frequencies and a bass port to achieve lower frequencies. According to interviewee B a tweeter and a port do not require more volume, meaning that when comparing the larger ceiling speaker and the redesigned ceiling speaker, the same audio quality could be achieved whilst the redesigned ceiling speaker is still smaller. Initially, only the tweeter was added to the middle part of the speaker, see Figure 4.17. The port was later dimensioned through WindISD and can be seen in the final concept.

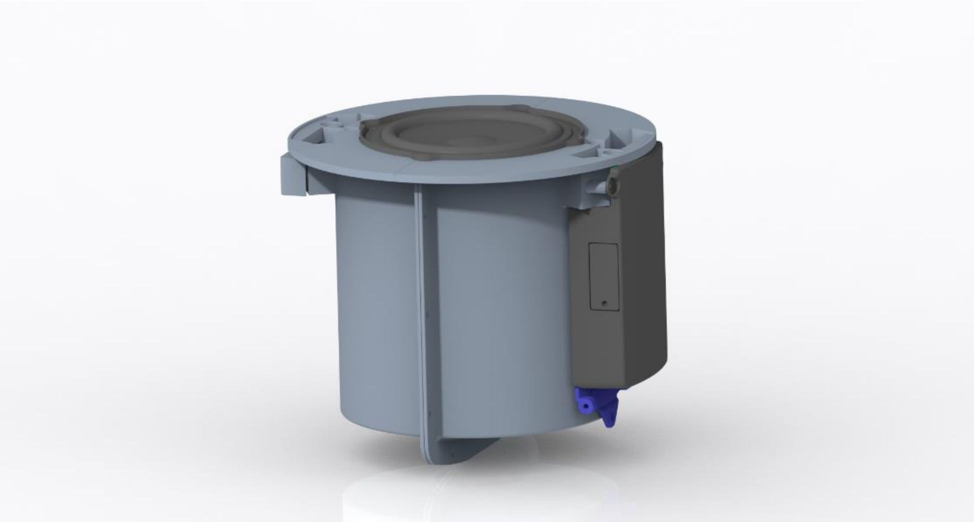


Figure 4.16. First CAD of the small Snobben.

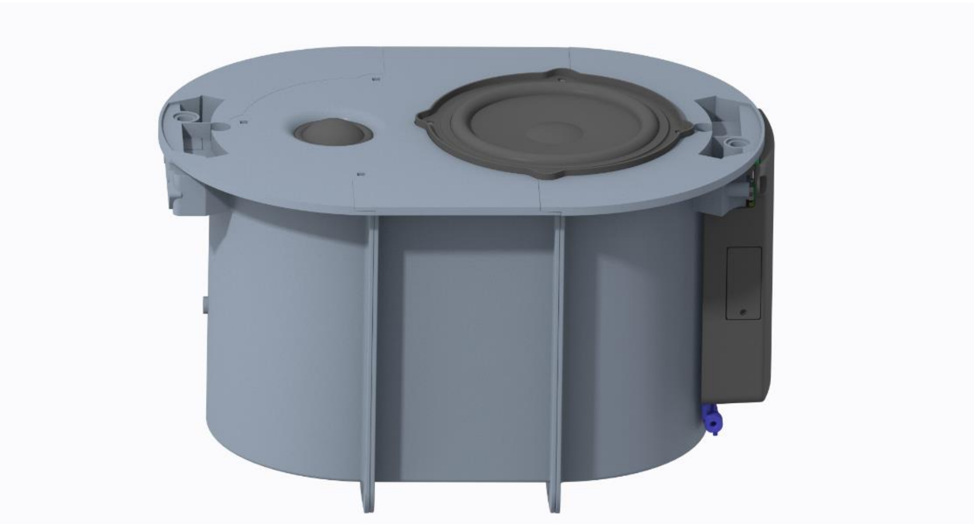


Figure 4.17. First CAD of the big Snobben.

To upgrade the smaller speaker to the larger one, the team designed the connecting sides in a way that they could connect to both a half-rounded side and the middle side when upgraded. Since it would be beneficial to have standardised components in the speaker, following Shahbazi and Jönbrink (2020) and Shahbazi (2020), the team worked a lot with symmetry in the model. The desire was to create two identical sides that together make up the back cover of the smaller speaker whilst can also be used as the edge sides to the bigger one. See Figure 4.18 for the symmetrical connections.

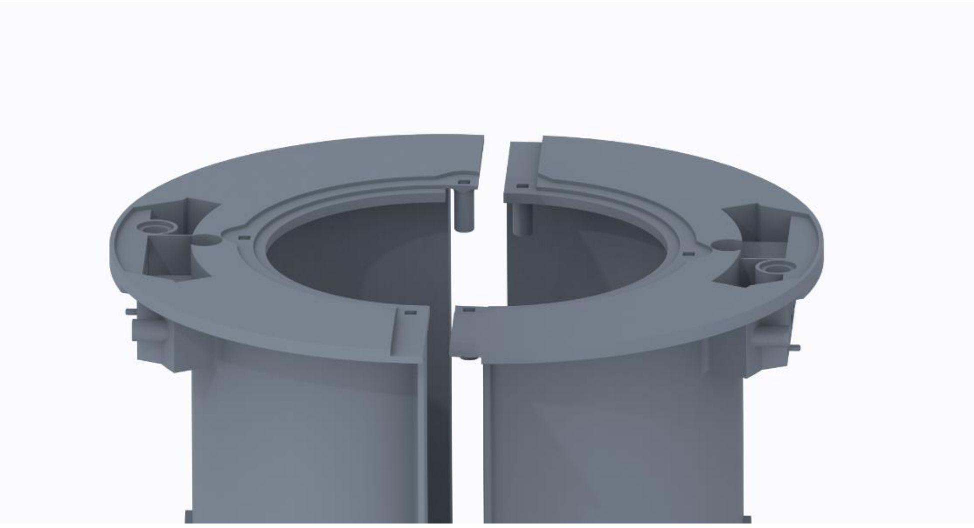


Figure 4.18. CAD showing the symmetrical connections.

Additionally, a pattern matching the speaker driver was incorporated in the design to be used as a guide in the assembly step in accordance with Ahonen and Nurmi (2004) and interviewee O, see Figure 4.19**.**

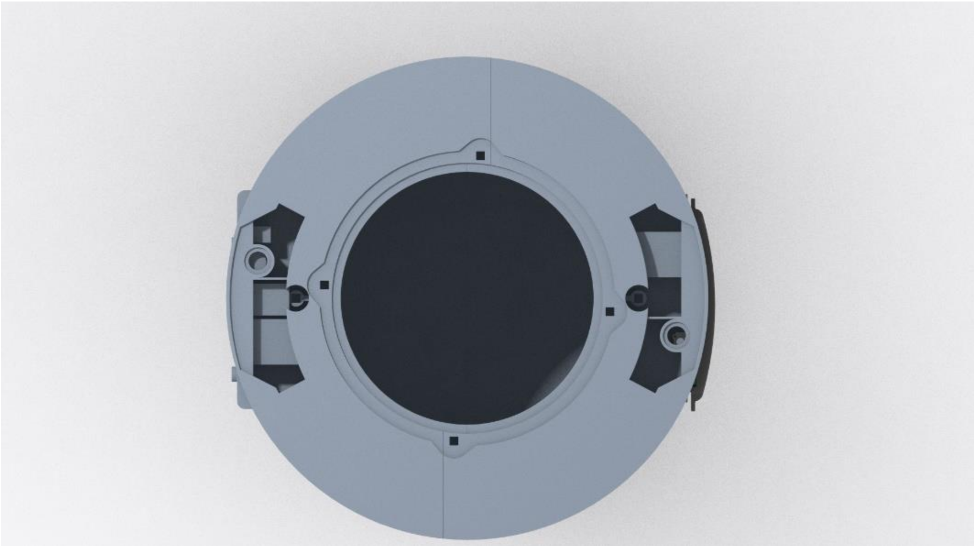


Figure 4.19. The smaller redesign from above, showing the pattern for the speaker driver.

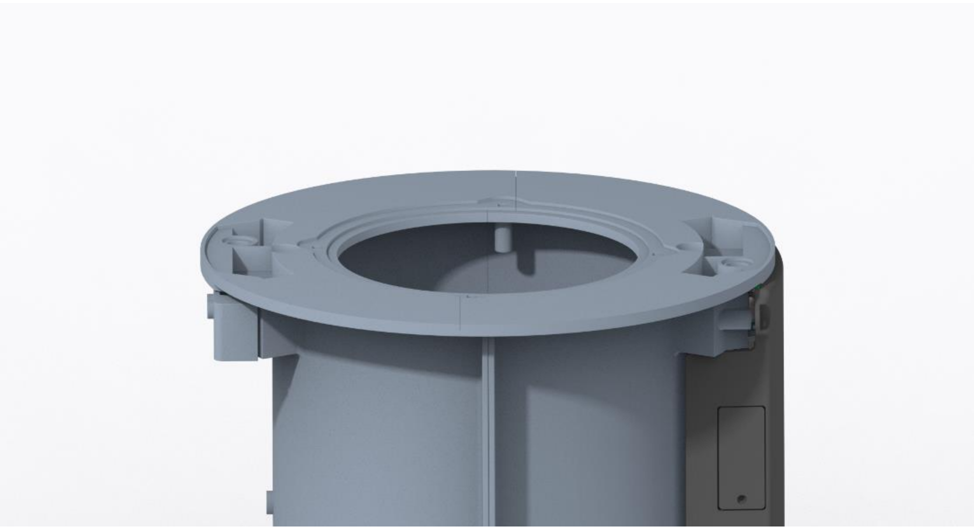


Figure 4.20. The small Snobben, showing the cords on both sides.

To keep both sides of the back cover symmetrical, the interfaces for the cords are on both sides of the speaker but only utilised on one of the sides, see Figure 4.20. This resulted in the creation of a lid for the interfaces. The lid is added to keep the speaker fully airtight. See Figure 4.21 and Figure 4.22.

Figure 4.21. Close up on the lid, covering the extra interface.

Figure 4.22. The lid.

Some ideas discussed and iterated were related to the consequences of having symmetrical sides of the back cover. The two symmetrical sides mean that some details would appear in doubles, adding more material and decreasing the aesthetics of the speaker. It was therefore discussed to place the interface connectors and the PCB-box in a cross-section, which means that half the connectors would be on one half and the rest on the other, see Figure 4.23**.** By placing critical features in a cross-section, minor assembly errors could significantly impact the overall product, which the team assessed to be too risky. Additionally, it would be hard to keep these areas airtight since no joint could be placed there. The team decided that the best solution was to try to cover one interface side with the lid, as can be seen in Figure 4.21**.**

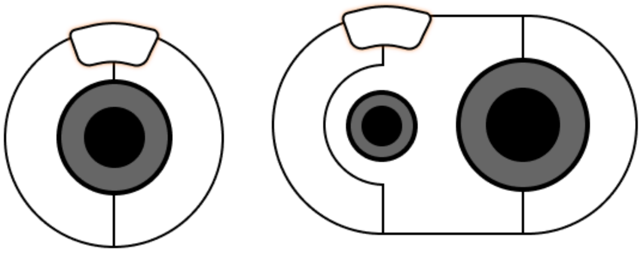


Figure 4.23. Sketches showing the interface in the cross section.

As interviewee Q mentions, the PCB is updated from one version to another and is a high-risk component regarding failure. Therefore, the team felt, in correlation with Shahbazi and Jönbrink (2020) and Shahbazi (2020), that the PCB should be isolated from the product, like in the original design whilst, as opposed to now, the attachment should enable easy disassembly and reassembly and scalability of the PCB. The team explored different solutions. The overall solution was to use the rail feature from the lightbulb concept. This could mean that the PCB could be changed in size without altering the joint on the back cover, in turn having to discard the previous back cover. One option was to slide the whole PCB-box, already assembled, onto the rail and then connect the wires from the inside. Then one wall in the interface would have to be removed to enable assembly from the inside. The team feared that with this solution, the cords would detach from the connector pins on the PCB and fall into the back cover during assembly. There would also be a cut in the connection interface to leave room for the connector pins to slide through, see Figure 4.24. The second solution was to connect the cords from the outside, like in the current design, and then slide the back of the PCB-box onto the rail. This would mean that no hole would have to be cut for the connector pins on the PCB. On the other hand, the assembly would be more difficult since PCB would have to be screwed onto the attached backside and then, secondly, the lid. The team chose to therefore go with the first alternative, which can be seen in Figure 4.24.

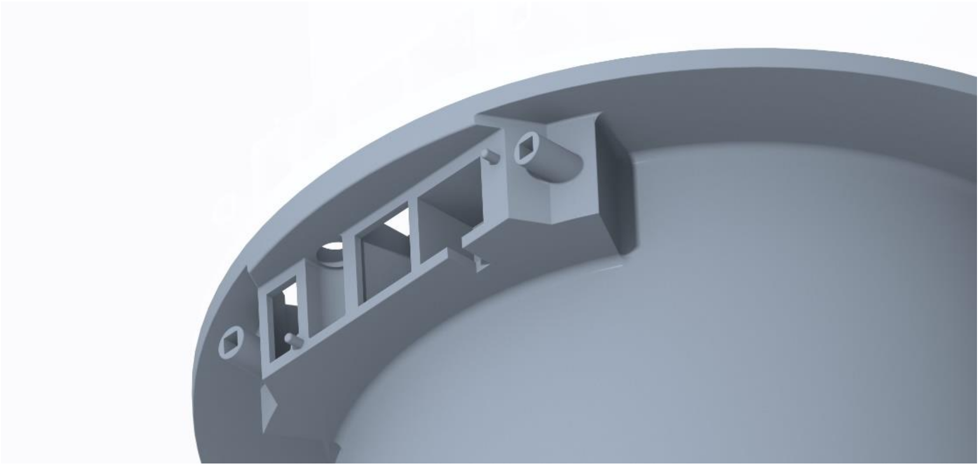


Figure 4.24. Close up on the cut, to leave room for the connector pins.

The middle part design for the bigger version has matching connections, and where the speaker driver is usually placed, the geometry perfectly matches the empty half of the half cone. The port for the speaker was dimensioned through WinISD. When designing a speaker, the cone extrusion is one crucial factor to consider to not break the speaker, according to interviewee B. For the current speaker driver, the xmax equals 2.9 mm, symbolised by the red line in Figure 4.25. As seen in Figure 4.25, the redesign fulfils the limit of having an xmax below 2.9 mm.

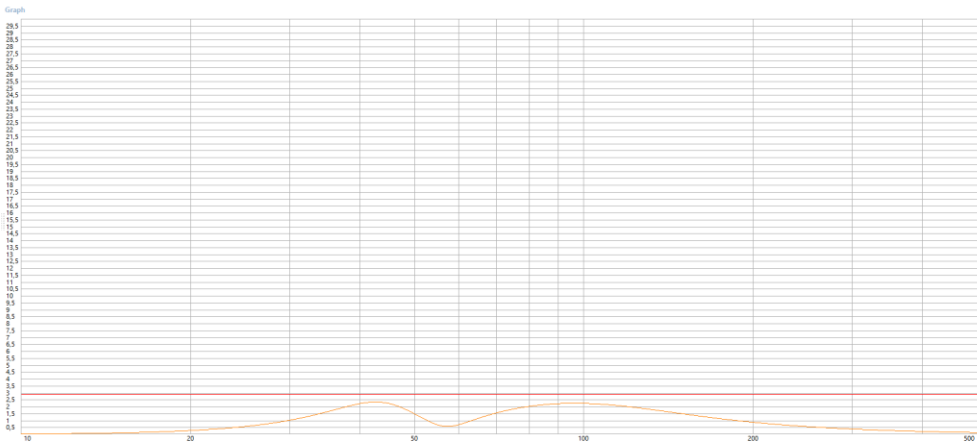


Figure 4.25. Cone excursion. Cone excursion (mm) on the y-axis and Hertz (Hz) on the x-axis.

Moreover, when adding a port, the air velocity is important to keep below 10 m/s. A higher number will lead to a wheezing sound. The result for the air velocity in the redesign can be seen in Figure 4.26.

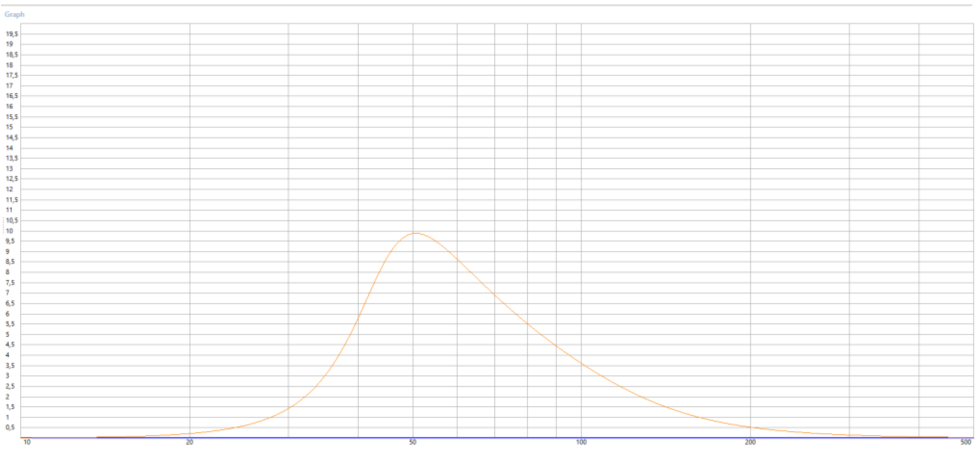


Figure 4.26. Air velocity for the redesign. Air velocity (m/s) on the y-axis and Hertz (Hz) on the x-axis.

In accordance with interviewee T, the team chose to round the edges of the port to decrease unwanted port noise (wheezing sounds) from the speaker. The rounded edges decrease air turbulence at the edge of the bas port, otherwise resulting in this type of sound. The port length was dimensioned to 230 mm in WinISD, which would not fit the dimensions of the back cover. On the other hand, interviewee T explains that the port length can be decreased by increasing the tuning frequency. However, an increase in tuning frequency will worsen the base response. Additionally, troelsgravesen.dk. (n.d.) decreases the recommended port lengths by 30 % compared to the audio program when designing a port to achieve the same results. Therefore, the team minimised the port length to better fit the dimensions of the back cover.

Following the discussions with interviewees B and M, the team desired a design to enhance the sound waves' dispersion angle. For example, mounting the speaker driver from the exterior and having it above the front baffle should result in a better sound spread. Likewise, flatting the front baffle instead of having pits should contribute to a better spread of the sound waves.

4.4.2 Prototypes

As mentioned in the method, 3D printers were used to create prototypes in plastic. The first print result can be seen below, Figure 4.27 and Figure 4.28 show the smaller design and Figure 4.29, and Figure 4.30 show the bigger design.

Figure 4.27. The 3D-printed prototype of the smaller redesign.

Figure 4.28. The mounted PCB-box on the smaller redesign and the redesign from above.

Figure 4.29. The 3D-printed prototype of the bigger redesign.

Figure 4.30. The bigger redesign from the side.

From the prototypes and the assembly of the components, it was discovered that the screws on the wings needed a screw tower to avoid nuts securing the screws and making the assembly sequence shorter. This was changed to the final concept, see Figure 5.6.

Moreover, the connectors for the speaker driver to the PCB are too wide to lower the speaker driver into the back cover smoothly. To fix this, it was decided to change the direction of the connectors to be aimed downwards instead of sideways, minimising the spread of the connectors. Another solution discussed to solve the problem was to mount the speaker driver on one side of the back cover and then assemble the two halves. However, this solution creates a challenging assembly sequence. It also puts a lot of force on the edge that needs to carry the heavy speaker driver and requires relocation of the screws for attaching the speaker driver.

The air tightening was mentioned in a discussion with interviewee M. A lot of areas require air tightening, which is not a problem but needs to be considered. On the other hand, the thin material thickness of the front baffle might need to be changed to ensure airtight sealing. As well as the overlapping gaskets in the design, this could be more optimal and will need to be investigated. Having an airtight solution is of high importance.

Most likely, the side covers will be produced in plastic, which requires greater thickness, for best results up to 6 millimetres or 2 millimetres and then add extra ribs, mentioned by interviewee M. However, a thin front baffle in plastic might be too weak, leading to the spread of vibrations and thus creating dissonance. If the back cover will be produced in metal instead, the thickness can be two millimetres, stated by interviewee M.

Another concern was how to fasten the mesh and mount the product in the sealing since these are development areas that were down-prioritised by the team and have yet to be investigated further. The solution for the mesh requires an attachment solution which will function for both a circular and an oval construction (compared to the current circular construction where the mesh is twisted on for fastening).

Last, the production of the side covers was discussed, and the two screw towers inside the BC were mentioned as problematic. The form must be released and removed in one direction, creating problems with the screw towers. One solution is to make the front baffle as thick as needed to fit a screw and avoid the need of screw towers. This also leads to a stiffer front baffle, which is good. Another solution is to make the front baffle slightly thicker, keeping the screw tower but making it shorter due to the thicker front baffle, and design a track behind the tower to enable manufacturing. The screws are usually unnecessarily long and could be shortened in this case. However, the choice of gasket will affect the length of the screws, whereas a silicon gasket requires longer screws than a foam gasket.

In addition, a suggestion about long screws was discussed. Instead of several smaller screws on the flange, it might be possible to have fewer screws inserted through the halves.

Furthermore, a mingle with Axis employees at New Business resulted in more feedback. One idea presented was the option to slide the two sides together, which probably would give an airtight solution and avoid all the screws. It was also mentioned that screws cost a lot, and a question about the production cost was raised. Additionally, CO_2 emission calculations for both designs was asked about. To test the sound quality on the redesign, the current design could be 3D printed to compare the sound quality on equal terms with the same material and setting as the redesign. Due to the short time frame, the team did not prioritise this.

5 Final Concept

Here the final concept is presented, as well as a small comparison between the redesign and the current design of Snobben.

5.1 Final Concept

The final concept can be seen in Figure 5.1 and Figure 5.2. The final concept is a modular design with the same speaker driver in both models. The design of the speaker is cut in half, creating two side covers. These sides are identical, and together with a speaker driver, a PCB, a PCB-box and a lid, the speaker is complete (see Table 5.1 and Figure 5.3 for name references for the components). To construct the bigger speaker, a middle piece is added with a tweeter and a port while keeping the other components, see Figure 5.4.

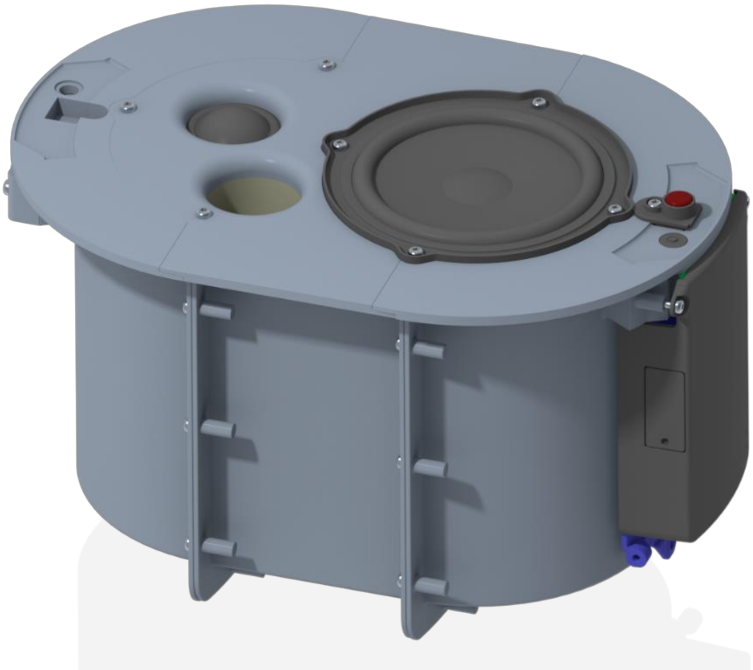


Figure 5.1. Final 3D-model for the bigger redesign.

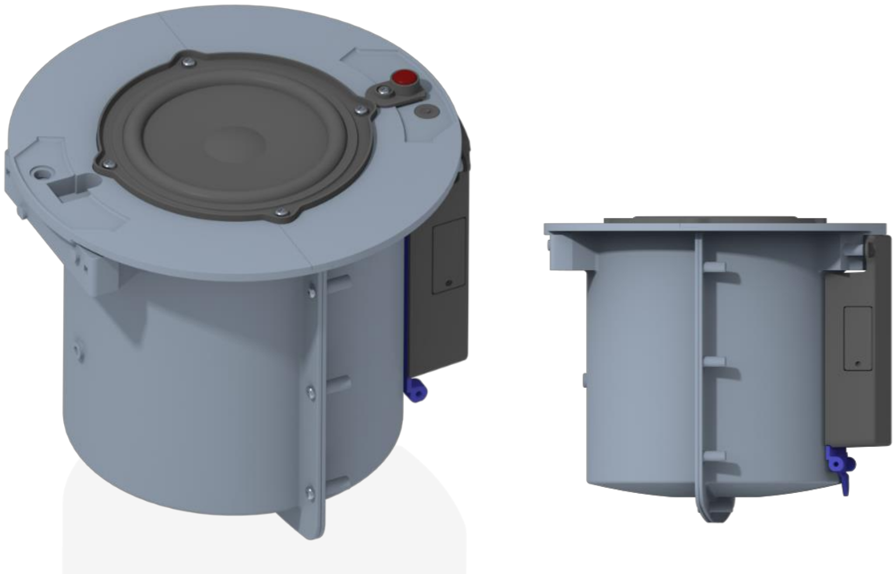


Figure 5.2. Final concept for the smaller redesign.

Table 5.1. Component references for the redsign.

Component	***Component Letter***
Tweeter	A
Clamp	B
PCB – attaching screw	C
Lid	D
Side cover	E
Port	F
Speaker driver	G
Extendable part	H
Gasket	I
Light guide	J
PCB – attachment	K
PCB-box	L

Figure 5.3. Exploded view of the bigger speaker.

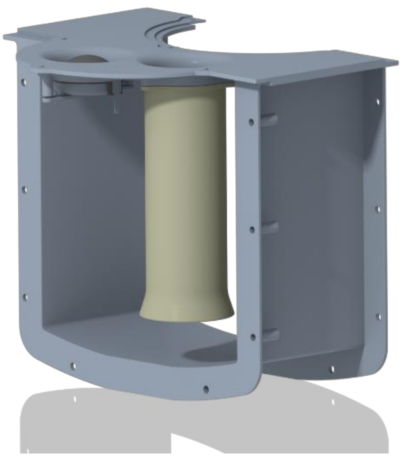


Figure 5.4. Middle part of the bigger speaker with visible port.

The changes made from the previous version were that the team incorporated the feedback given in 4.4.2. To make the speaker more easily manufactured a track was created behind the screw tower, see Figure 5.5. A redesign of the screw towers in the front baffle was also created following the feedback, see Figure 5.6 and Figure 5.7. The port was added to generate a better frequency span, see Figure 5.8. The port and tweeter are mounted on the inside of the middle part, see Figure 5.9. Finally, the PCB attachment was developed and designed. The attachment can be seen in Figure 5.10 and Figure 5.11.

Figure 5.5. Redesign of screw towers for manufacturing purposes.

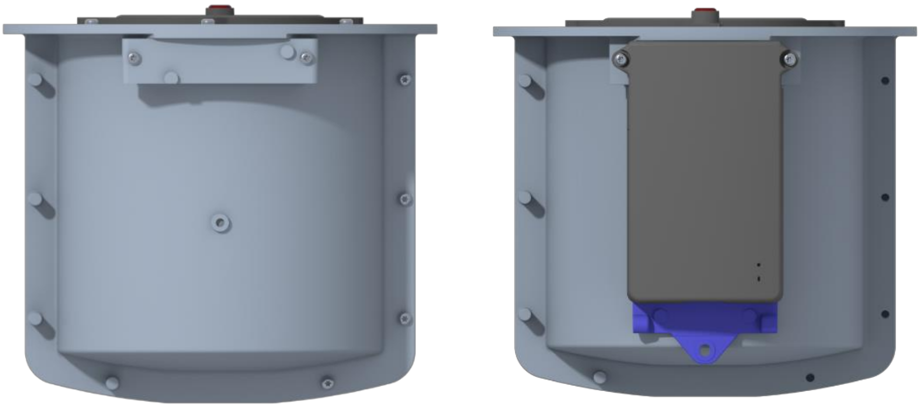


Figure 5.6. Back and front of the final concept, showing PCB-box and lid for interfaces and the screw towers on one of the sides.

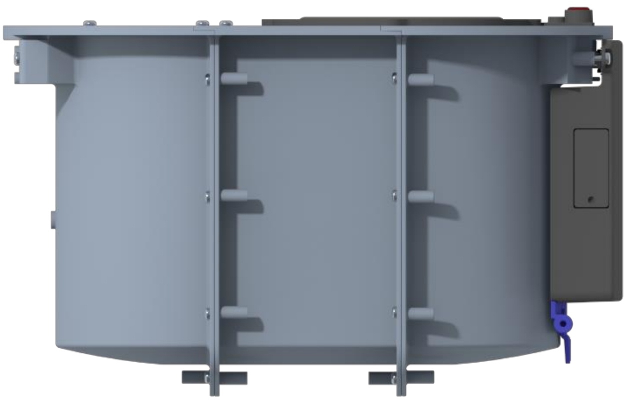


Figure 5.7. The side of the final concept, showing the screw towers.

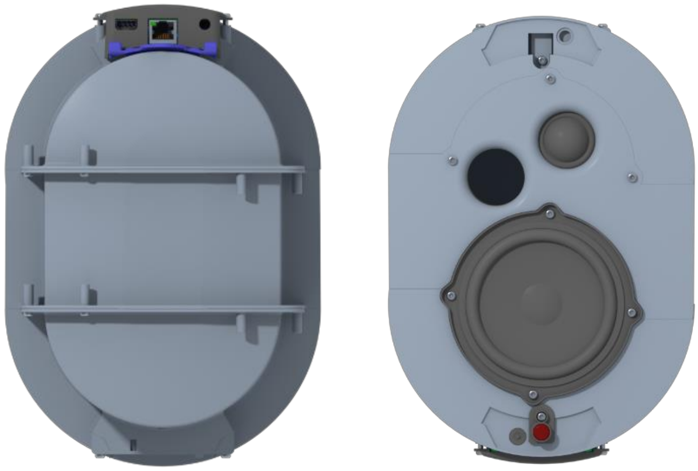


Figure 5.8. Top and bottom view of the final concept, showing the placement of the port and the tweeter.

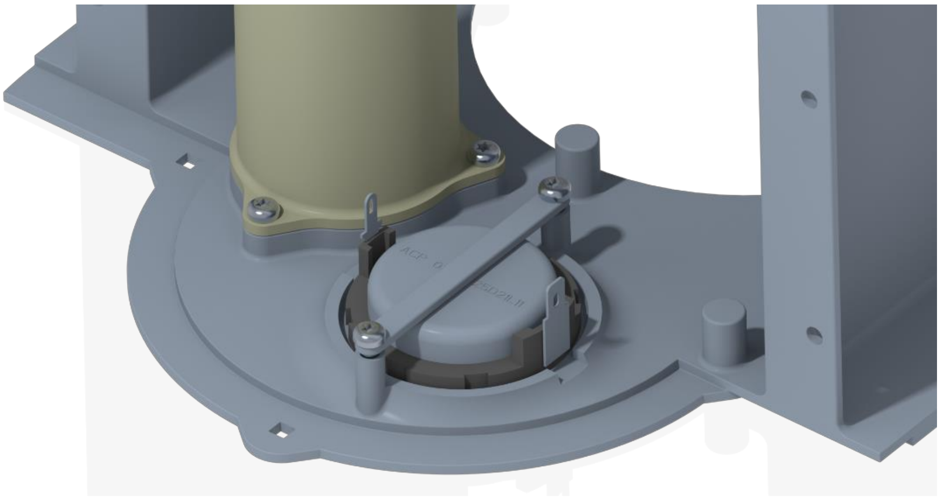


Figure 5.9. Close up on how the tweeter and the port is fasten.

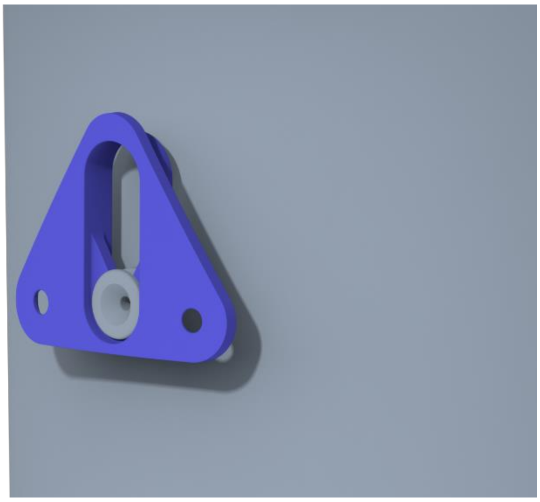


Figure 5.10. Display of modular attachment when attached to the side cover, with the screw (in grey) placed on the side cover.

Figure 5.11. PCB-box with modular attachment.

Figure 5.12. Exploded view of the smaller speaker.

Figure 5.12 shows an exploded view of the smaller speaker and all the included components. A general assembly sequence for the smaller concept follows:

1. The PCB-box is assembled separately. The screw connector is screwed to the side of one side cover. The connecting attachment is then attached onto the back of the PCB-box, see Figure 5.11.
2. The PCB-box slides onto the side of the side cover, and the connector pins run through the gap of the interface area. The box is then mounted with two screws at the top edge.
3. The cables are connected to the PCB connector pins from the inside of the side cover.
4. The two sides are then connected with screws.
5. The speaker driver is mounted onto the front of the assembled side covers with a screw from the front.
6. The lid is mounted on the unused interface.

Figure 5.3 presents the included components for the bigger speaker, and the assembly sequence is similar to the smaller speaker, with some added steps. For the bigger one:

1. The same steps as in the sequence for the smaller design are being done. Then the tweeter and the port are mounted on the middle part, see Figure 5.9.
2. The side with the PCB-box is connected to the middle part with screws. The other side is then connected to the middle part with screws.

5.2 Compare current Snobben vs Circular Snobben

For the small version of Snobben and the smaller redesign, it is assumed that due to the same volume and speaker driver, they will perform equally in WinISD and, therefore, were not tested in the program.

The sound quality and experience were, as mentioned in Section 3.1.5.3, compared in WinISD for the two bigger speakers, and the following presents the result. The aspect being compared between the current and the new design was the Sound Pressure Level. The result can be seen in Figure 5.13, with a belonging explanation in Table 5.2.

Table 5.2. Information regarding Figure 5.13.

Design	*Color*	*Port*	*Volume*	*High pass*
Current Design (big speaker)	Blue	No	4 L	-
Redesign (big speaker)	Orange	3,4 cm	3,2 L	Order = 3 Fc = 52 Hz

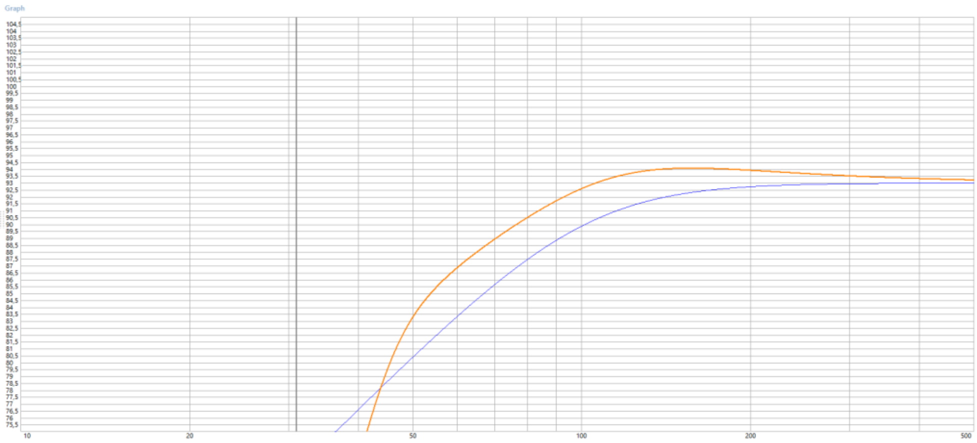


Figure 5.13. Sound Pressure Level.

Figure 5.13 shows a lower and better frequency for the redesigned speaker. The redesign reaches approximately 53 Hz at lowest frequency, compared to the current 60 Hz.

The current and new design air volumes are stated below in Table 5.3 for each size. The table shows that the air volume in the redesign has decreased for the bigger speaker, which is good for transportation reasons while maintaining the same sound quality as the current speaker.

Table 5.3. Approximate volume definition.

Design \ Size	***Small speaker***	***Big Speaker***
Current Design	1,6 l	4 l
Redesign	1,6 l	3.2 l

With the team's redesign, there are more standardised components. In addition, the redesign allows for a decrease in air volume, facilitating lighter transportation. The team believes the design will allow for cheaper production costs due to the identical sides used in all four models. By mounting the speaker element from the outside and having a flatter front baffle, the sound is spread in a more optimal way thus creating a better sound experience. Compared to the current design, the downside to the final concept is that each speaker model consists of more components, for instance, the added lid and, in the bigger speaker, the added port, tweeter, and middle component. More components might also affect the cost and the assembly time, as mentioned during the mingle at Axis.

6 Conclusion and discussion

This chapter presents the main insights and findings from the projects. In addition, a discussion about difficulties and trade-offs are presented, as well as recommendations for Axis and further work necessary for this project to be further developed.

6.1 Findings

Findings regarding the two research questions are presented in the following section.

6.1.1 RQ1: How can a network speaker be designed to support circular material flows?

There are several design options to acknowledge when designing to support circular material flows. One opportunity is to reduce material consumption in production to decrease carbon emissions and create a more sustainable production process (Mangla et al., 2023). Another option is to design with standardised components, minimising the number of parts (Bovea and Pérez-Belis, 2018) and enabling easy maintenance and cleaning of the product (Plumeyer and Würl, 2019). Moreover, traceability and modularity are factors to consider (Conti and Orcioni, 2020). Designing for easy disassembly and reassembly is also one way to support circular material flows (De Fazio et al., 2021) which enables identification and separation of materials (Bovea and Pérez-Belis, 2018). To facilitate upgrades and make the component likely of update accessible is another aspect which supports circular material flows (Shahbazi and Jönbrink, 2020; Shahbazi, 2020). Likewise, designing without glue and with a timeless design along with a durable and robust platform to endure several life cycles is also a perspective to consider (Shahbazi and Jönbrink, 2020; Shahbazi, 2020).

The team's solution was to design the network speaker modularly to support circular material flows (Conti and Orcioni, 2020). A thought-out, modular design contributes to the isolation of modules most plausible for an update and will, therefore, utilise components for several life cycles. In this project, to design in a modular way was similar to designing with focus on upgradability. Looking at Snobben, with background highlighted by interviewee Q and interviewee P, and with regard to upgradeability and modularity, isolating the electrical components, like the PCB-box, is a good focus area. Other components, such as the speaker driver and the back cover will manage several life cycles without significant design updates, according to interviewee M. They should, therefore, also be considered by the audio teams at Axis.

Moreover, this modular design enables the usage of the same components in several models and sizes, with a few added components. In our case, the side covers, the speaker driver, the PCB, and the PCB-box are used for all four variants and by adding a middle part, a port, and a tweeter, the bigger model is created. This solution accomplishes an increase of standardized components, leading to more significant ordering volumes of each component. In addition, increased order volumes reduce manufacturing costs. The modular design also creates a more flexible and customized solution, where the product can be adjusted for the individual need of the customer. This can be achieved by adding components, creating different levels of speaker quality. Eliminating the bigger speaker element and having a smaller back cover for the bigger speaker, should lead to a lighter speaker design. Furthermore, isolating the PCB-box on the side of the side covers is also beneficial from a recycling point of view, motivating easier separation before recycling (Bovea and Pérez-Belis, 2018). Another benefit is that the isolated box is easy to disassemble and reassemble, which benefits any PCB reparations (De Fazio et al., 2021) – a component with high plausibility of failure during use, according to interviewee U. The flat front baffle with the speaker assembled from the outside creates a better sound experience, by spreading the sound in a more desirable way.

6.1.2 RQ2: What design guidelines are applicable?

Three of the guidelines used in our checklist were applicable directly in the Reuse concept phase:

- The product is designed in modular construction.
- It is possible to change the exterior of the outer shell.
- There are no adhesives or glue in the product.

The following guidelines needed assumptions to be able to interpret:

- The product is easy to upgrade.
- It is easy to dismantle the product non-destructively.
- The platform (components that do not change through all generations of products) is designed to be durable, robust and reliable for several lifecycles and withstand several upgrades.
- The modules/subsystems most likely to need an upgrade or exchange are easily accessible.
- The product is easy to repair at RMA.
- Joints are standardised.
- The product consists of joints and connectors that can easily be opened and closed multiple times.
- The product consists of some standardised components across different products and models.
- Components with a high plausibility of change are modular and isolated.
- Components are easily accessible and have reachable directions.
- The design is timeless and compatible.

With this said, three guidelines are applicable immediately, and 11 guidelines can be applied if the Department of Audio makes assumptions that suit and reflect them as a business. The assumptions made in this thesis are biased, based on our knowledge, and can be seen in section 4.2.5. With other assumptions, another concept might score higher, leading to a different result.

6.2 Recommendations

As mentioned, 80% of a product's environmental impact is decided in the design phase (Ulrich and Eppinger, 2012). Therefore, we recommend that Axis early on incorporate guidelines of circularity in their projects. The guidelines determined to be instantly applicable, Section 6.1.2, should be used as a foundation in all projects on Axis, especially when designing new additions to the product family. With the information and knowledge from previous projects, assumptions could be determined to utilise the remaining Guidelines of Reuse as well.

Moreover, we recommend that the project groups take inspiration from this project and use the data gathered by the team. The team brings a broad perspective from insight gathered in discussions with several different departments at Axis. From the team's understanding, discussions with other departments have not been prioritised due to the project time limit, and therefore, the team might provide an otherwise unfamiliar perspective.

As technology keeps advancing and changing, Axis could benefit from a modular approach to its development process. Modularity could imply flexibility in their product portfolio and more adaptable products that can change when technology advances, or when the needs of the customers change.

It is therefore also strongly recommended that Axis extend project times and budget to yield innovative and sustainable solutions from their development team. This would enable thoughtful design choices, which in the long run, contribute to the company's environmental footprint and long-term financial sustainability. For example, instead of focusing on COGS, Axis could take a larger perspective and look at a product's sustainable and financial cost in several aspects of its life cycle, like during transportation, manufacturing, and end-of-life. Hopefully, this would spark the reuse of components and a more standardised product portfolio that would be kinder to the planet.

With its current business model, Axis could benefit from incorporating traceability. Traceability could provide increased product knowledge and yield solutions designed more optimised and energy efficient. They would also be aware of what happens at end-of-life.

Transport logistics and placement of repair- and production sites compared to where Axis mainly sell its products are recommended to be looked at and optimised to limit the company's environmental footprint. Axis could also develop stand-by product features to minimise energy consumption during the use phase to minimise environmental impact. Energy consumption during the use phase has been mentioned a lot during the project, among others by interviewee Q, interviewee N and during the workshop, but was outside the scope.

The team mainly recommends initiating more projects focusing on Designing for Circularity to help employees gather knowledge and experience in using circular guidelines in development processes (since they have seen it to be difficult and time-consuming to get started with). Furthermore, to collaborate more over departments and roles - so much knowledge exists within Axis but needs to be shared between each other. The knowledge is needed both to be able to innovate but also to not repeatedly invent the wheel. Since Axis is located on the first step in the Circular Design Ladder (Motalli, 2022), collaboration and directions from the management are required for Axis to take one or two steps up the ladder.

Implementing a more circular business model is vital to be ready when laws take effect and customers start stating new expectations for Axis to keep a competitive market position. The Canons sustainability report from 2021 highlights the possibility of damaging the corporate image if it does not transition to a circular economy fast (Canon Inc, 2021).

6.3 Project discussion

The downside with modularity is the adjustment for several use cases. To use the components in a handful of speakers, some design features were added due to symmetrical reasons, even though not necessary. For instance, since the side covers in the final concept are designed identically, both sides have outlets for PCB interfaces but are only needed on one. A trade-off which led to the creation of an extra part to manufacture and assemble. This also leads to extra material and decreased user-friendliness, possibly negatively affecting product design perception.

Secondly, it was noticed that to Design for Reusability; the product had to be reparable and easy to assemble/disassemble, which led to using more screws which are both costly to manufacture and assemble. Another trade-off was correlated to isolating components in need of updates, like the PCB-box in the final concept. A separate PCB-box was understood as a good design feature, but on the contrary, it causes the pendulum to tilt, highlighting another trade-off with each decision.

Furthermore, designing for all 10 Rs is hard since guidelines are conflicting and insufficient. Which guidelines to priorities are hard to know since there needs to be data or Life Cycle Assessment (LCA) to base the decisions on. Moreover, the extensive and complex list of guidelines makes it impossible to implement all of them. It requires a lot of research and time, which is not reasonable in terms of project budgets. This is underlined by both the experience of the team and the interviewees. First, the team believed that problems concerning sustainability and circularity would be clear from the start but soon realised that it was not the case without LCA and actual data. Second, the team recognised the broadness of the circular guidelines and the difficulty in deciding which guideline to focus on.

The estimated weaknesses of our analysis are, first, the lack of data. The team needed more time to evaluate the concept and properly compare it to the original design. To say that this concept is better than the existing product requires calculations regarding durability and strength, energy consumption in production and cost of manufacturing. Second, since the guidelines were used as criteria during evaluation and not applied as guidelines, the generated concept could look different if used as proper guidelines. A better solution might have been produced if the guidelines were applied right at the start of the generation.

The strength of this thesis work is that the teams have a broad insight into the subject and of Axis, which is preferable when making thought out design choices. Furthermore, the project has been unrestricted in terms of requirements from Axis side, this has led to a different design, incorporating a lot of innovation.

Additionally, the team were not limited by budget, which is good from an environmental perspective since this could be of full focus.

Overall, it can be seen in Appendix D Project Plan and Outcome, that the team kept to the time schedule. Some segments took longer than expected, like the prototyping whilst others were incorrectly estimated. The comparison of the final concept to the explored speaker was conducted in a quicker manner than expected and therefore more time could be put on development. To write the report also took longer than expected and therefore it can be seen that more time was put there than on presentation preparations.

6.4 General discussion

The main problem with sustainability and circular material flows are the vague guidelines and the lack of right or wrong. No case is the same, and finding a "one size, fits all" solution is impossible. Design choices differ, for example, if the product is recycled in Malta, Sweden or the USA design regarding to recycling could still look different. Additionally, design choices change depending on where the product is sold– if manufactured in Asia and sold in the USA, one significant impact is the weight since the product is transported by flight with significant CO_2 emissions (Axis Communications, 2023). Hence, it is a complex topic which will need time, innovation, data, tools, and long-term commitment to be able to transit and see results.

The perception of the teams is that because of the complexity of the area, the transit towards circular material flows will not happen by itself. To make it happen, laws and the economic factor will play a role. One concern is the types of laws that need to be implemented; they must be clear, or else nothing will happen, but they cannot be too precise since not one solution is the best for all cases.

Moreover, many of the products on the market are over-dimensioned. They are designed to cope with several exceptional use cases that only occur for a minority of the products during their life cycle. For instance, the IP classification of speakers decreases the sound quality, according to interviewee B, and increases the complexity in production, according to interviewee O, even though only being used by a few customers. This results in the average customer requiring more material and complexity (and paying a higher price) for something they do not need.

Even though mechanical engineers can act by incorporating circularity from the early stages of the design process, insufficient data and tools to determine environmental impacts per design decision make the evaluation process problematic. Adding the increase time and cost required to develop these solutions, the circular transition is even more complicated. Hence, corporate profits beat global responsibilities, meaning the Cost of Goods Sold (COGS) is prioritised above the product's environmental impact, and the short time frame to maintain a competitive market share decreases the time spent on creating innovative circular solutions. Therefore, one challenge to designing for circular material flows is cost.

In addition, it is hard to predict the future. Product projects take about 2-3 years to develop at Axis Audio department, making it hard to know the future technology trends. Designing for Circularity can be contradicting when it comes to new laws and regulations as well. For example, new substances can be added to REACH, forcing products off the market, or forcing them to be redesigned when initially designed to last several life cycles.

6.5 Further work

The team has scraped the surface of this exciting topic to design a circular network speaker, but there is still a lot to investigate further to realising it into a working product which can be manufactured. Design features such as gaskets to ensure an airtight sealing, the thickness of the front baffle to avoid vibrations, the fastening of the mesh, placement of the vent and the mounting construction for the ceiling speaker are still to be investigated further. About the gasket, both guides/tracks, design, and choice of material are areas left to explore. On the other hand, the team discussed the topic, and desirably, the gasket will be without adhesives, possibly in silicon.

The screws need to be investigated further regarding size and quantity. However, the team wishes for as few screws as possible while ensuring an airtight design, good sound quality, and a uniform screw throughout the design.

The overall material is still undecided due to the time limit. The side cover will likely be in plastic or aluminium, but this must be reviewed. Aluminium might be desirable from a reuse point of view, but it also increases the complexity of manufacturing. Aluminium is, for now, easier to recycle and maintains the same mechanical properties compared to recycling plastic, as mentioned by El-Kretsen (2021b). The design needs to be inspected and probably adjusted for either choice of material. For aluminium, release angles need to be added, and the thickness needs to be increased for the plastic. Following the design guidelines, the design needs to be timeless, and therefore, the material chosen also needs to age well.

Beyond that, it would be beneficial to conduct a LCA to understand where in the speaker's life cycle the product is affecting the planet the most, to be able to design for most environmental improvements. Furthermore, a finite element method (FEM)-analysis would give more information about stresses during use and how to efficiently design without adding unnecessary material. FEM-analysis can also indicate wear and tear, and product- and component lifetimes. An important aspect of Design for Reuse, but not included in this project.

The current speaker driver is used together with a tweeter accessible at the office. This match might not be optimal, and for the best sound performance and frequency span, this would need a closer examination and evaluation to choose a good match. In the same term, the port will also need to be tested to decide which design would be the best solution for the use case.

The whole speaker driver will need to be tested, both audio tests and IP and IK tests, to ensure the right quality. Exploration of the circuit board is necessary because of the added tweeter, leading to needing an extra pin connector to capture the frequency from the tweeter. The tweeter will also require about 10% extra power, which is not a problem according to interviewee V. There are solutions for this, adding extra connector pins or an analogue filter – but this has not been investigated further.

In addition, it would be interesting to calculate the production costs to see if the modular design is financially beneficial compared to the current design.

Finally, there are several exciting aspects to look further into regarding designing circular material flows since this is constantly evolving subject with a lot of room for innovation there will always be areas of improvements to consider.

References

Ahonen, T. and Nurmi, J. (2004). *Design reuse and design for reuse, a case study on HDSL2*. 2004 International Symposium on System-on-Chip, 2004. Proceedings. doi: https://doi.org/10.1109/issoc.2004.1411165.

Amend, C., Revellio, F., Tenner, I. and Schaltegger, S. (2022). *The potential of modular product design on repair behavior and user experience – Evidence from the smartphone industry*. Journal of Cleaner Production, 367, 132770. doi:https: //doi.org/10.1016/j.jclepro.2022.132770.

Atlassian (n.d.). *How To Use Mindmapping for Effective Brainstorming*. [online] Atlassian. Available at: https://www.atlassian.com/team-playbook/plays/mind-mapping [Accessed 13 Apr. 2023].

Axis Communications. (2023). Internal website.

Axis Communications. (2022). *Sustainability Report 2021.* [online] Available at: https://www.axis.com/dam/public/e7/10/58/axis-sustainability-report-2021-en-US-359983.pdf

Axis Communications. (n.d.-a). *About Axis*. [online] Available at: https://www.axis.com/about-axis [Accessed 30 Jan. 2023].

Axis Communications. (n.d.-b). *Network audio*. [online] Available at: https://www.axis.com/products/network-audio [Accessed 30 Jan. 2023].

Axis Communications. (n.d.-c). *Sustainability.* [online] Available at: https://www.axis.com/about-axis/sustainability.

Bosch. (2022) *Sustainability report 2021 factbook*. Stuttgart, Germany. Available at: https://assets.bosch.com/media/global/sustainability/reporting_and_data/2021/bosch-sustainability-report-2021.pdf.

Bosch. (n.d.). *Sustainable products and new paths.* [online] Available at: https://www.bosch.de/en/news-and-stories/isabelle-gola/ [Accessed 14 Apr. 2023].

Bourguignon, D. (2016). *Closing the loop New circular economy package.* [online] Available at: https://www.europarl.europa.eu/RegData/etudes/BRIE/2016/573899/EPRS_BRI%282016%29573899_EN.pdf.

Bovea, M.D. and Pérez-Belis, V. (2018). Identifying design guidelines to meet the circular economy principles: A case study on electric and electronic equipment. Journal of Environmental Management, 228, pp.483–494. doi: https://doi.org/10.1016/j.jenvman.2018.08.014.

Brorsson, N. Repair Development Engineer, Axis Communication, Lund, Sweden. Personal conversation (2023, 25 January and 2 February).

Canon Inc. (2021). *CANON SUSTAINABILITY REPORT 2021 Kyosei Good Corporate Citizen Creating New Value -An Integrated Report for Realizing Kyosei.* Available at: https://global.canon/en/csr/report/pdf/canon-sus-2021-e.pdf.

Canon Global. (n.d.). *Contributing to a Circular Economy*. [online] Available at: https://global.canon/en/environment/circulation.html.

Circularity Gap. (2021). *CGR 2021*. [online] Available at: https://www.circularity-gap.world/2021.

Circularity Gap. (n.d.). *CGR 2023*. [online] Available at: https://www.circularity-gap.world/2023.

Conti, M. and Orcioni, S. (2020). *Modeling of Failure Probability for Reliability and Component Reuse of Electric and Electronic Equipment*. Energies, 13(11). doi: https://doi.org/10.3390/en13112843.

Danish Design Center. (n.d.). *The Design Ladder: Four steps of design in use.* [PDF Document]. [online] Available at: https://vdocuments.net/the-design-ladder-four-steps-of-design-use.html?page=1 [Accessed 24 Feb. 2023].

Dazer, M., Ostertag, A., Herzig, T., Borschewski, D., Albrecht, S. and Bertsche, B. (2022). *Consideration of reliability and sustainability in mechanical and civil engineering design to reduce oversizing without risking disasters*. *E3S Web of Conferences*, [online] 349, p.11004. doi:https://doi.org/10.1051/e3sconf/202234911004.

De Fazio, F., Bakker, C., Flipsen, B. and Balkenende, R. (2021). *The Disassembly Map: A new method to enhance design for product repairability*. Journal of Cleaner Production, [online] 320, p.128552. doi:https://doi.org/10.1016/j.jclepro.2021.128552.

Design Council. (2019). *Framework for Innovation: Design Council's evolved Double Diamond*. [online] Available at: https://www.designcouncil.org.uk/our-work/skills-learning/tools-frameworks/framework-for-innovation-design-councils-evolved-double-diamond/.

Electrolux Sverige. (n.d.-a). *Better Living Program*. [online] Available at: https://www.electrolux.se/about-us/better-living-program/#716836 [Accessed 17 Feb. 2023].

El-Kretsen. (2021a). *Så förlänger du livet på dina elprylar*. [online] Available at: https://kunskapsrummet.com/artiklar/sa-forlanger-du-livet-pa-dina-elprylar/ [Accessed 27 Feb. 2023].

El-Kretsen. (2021b). *Elektronikbranschens utmaningar – så kan vi skapa slutna kretslopp*. [online] Available at: https://kunskapsrummet.com/artiklar/elektronikbranschens-utmaningar-sa-kan-vi-skapa-slutna-kretslopp/ [Accessed 27 Feb. 2023].

El-Kretsen. (2021c). *Samarbete för plaståtervinning*. [online] Available at: https://kunskapsrummet.com/artiklar/stena-recycling/ [Accessed 27 Feb. 2023].

El-Kretsen. (2021d). *Framtiden för sällsynta metaller*. [online] Available at: https://kunskapsrummet.com/artiklar/framtiden-for-sallsynta-metaller-2/ [Accessed 27 Feb. 2023].

El-Kretsen. (2021e). *Nya initiativ för att skapa spårbarhet hos elektronik*. [online] Available at: https://kunskapsrummet.com/artiklar/nya-initiativ-for-att-skapa-sparbarhet-hos-elektronik/ [Accessed 27 Mar. 2023].

Ellen MacArthur Foundation. (2019). *What Is a Circular Economy?* [online] Ellen MacArthur Foundation. Available at: https://ellenmacarthurfoundation.org/topics/circular-economy-introduction/overview.

Elmansy, Dr. R. (2021). *The Double Diamond Design Thinking Process and How to Use it*. [online] Available at: https://www.designorate.com/the-double-diamond-design-thinking-process-and-how-to-use-it/#:~:text=The%20Double%20Diamond%20design%20process%2C%20developed%20by%20the.

European Commission (EUROPEISKA KOMISSIONEN). (2020) *En ny handlingsplan för den cirkulära ekonomin för ett renare och mer konkurrenskraftigt Europa*. Available at: A new Circular Economy Action Plan (sharepoint.com) [Accessed 20 Jan. 2023]. Interact. (n.d.).

European Commission. (2023). *Corporate Sustainability Reporting*. [online] finance.ec.europa.eu. Available at: https://finance.ec.europa.eu/capital-markets-union-and-financial-markets/company-reporting-and-auditing/company-reporting/corporate-sustainability-reporting_en.

European Commission. (n.d.-a). *Ecodesign for sustainable products*. [online] Available at: https://commission.europa.eu/energy-climate-change-environment/standards-tools-and-labels/products-labelling-rules-and-requirements/sustainable-products/ecodesign-sustainable-products_en.

European Commission. (n.d.-b). *RoHS Directive*. [online] Available at: https://environment.ec.europa.eu/topics/waste-and-recycling/rohs-directive_en#:~:text=The%20RoHS%20Directive%20aims%20to%20prevent%20the%20risks [Accessed 22 Mar. 2023].

European Parliament. (2020). *E-waste in the EU: facts and figures (infographic).* [online] Available at: https://www.europarl.europa.eu/news/en/headlines/society/20201208STO93325/e-waste-in-the-eu-facts-and-figures-infographic.

European Parliament (2021). *How the EU wants to achieve a circular economy by 2050* [online] Available at: https://www.europarl.europa.eu/news/en/headlines/society/20210128STO96607/how-the-eu-wants-to-achieve-a-circular-economy-by-2050 [Accessed 20 May. 2023].

Galan, J.J.P. (2020*). Green Controlling (5): The 10 R's of circular economy (no, they are not 3)*. [online] Available at: https://www.linkedin.com/pulse/green-controlling-5-10-rs-circular-economy-3-juan-jose-piedra-galan/.

Hallack, E., Peris, N.M., Lindahl, M. and Sundin, E. (2022). Systematic Design for Recycling Approach – Automotive Exterior Plastics. Procedia CIRP, 105, pp.204–209. doi: https://doi.org/10.1016/j.procir.2022.02.034.

Höst, M., Regnell, B. and Runeson, P. (2006) *Att genomföra examensarbete.* (1:2) Författarna och Studentlitteratur, Lund.

Johansson, G., Sundin, E. and Wiktorsson, M. (2019). *Sustainable Manufacturing.* Studentlitteratur, Lund.

Jonsson, G. PMT Project Manager, New Business, Axis Communication, Lund. Sweden. Personal conversation (2023, 8 February).

Lombard Odier. (2020). *The 10 principles of circular economy*. [online] Available at: https://www.lombardodier.com/contents/corporate-news/responsible-capital/2020/september/the-10-steps-to-a-circular-econo.html.

Ltd, S.W.P. (2022). *Chapter 5: The Circular Economy: The 10R's Model*. [online] The Circular Economy Journey. Available at: https://thecejourney.org.au/research/chapter-5-the-circular-economy-the-10rs-model.

Luttropp, C. and Lagerstedt, J. (2006). *EcoDesign and The Ten Golden Rules: generic advice for merging environmental aspects into product development.* Journal of Cleaner Production, 14(15-16), pp.1396–1408. doi:https://doi.org/10.1016/j.jclepro.2005.11.022.

Mangla, S.K., Kazancoglu, Y., Sezer, M.D., Top, N. and Sahin, I. (2023). *Optimizing fused deposition modelling parameters based on the design for additive manufacturing to enhance product sustainability.* Computers in Industry, 145, p.103833. doi: https://doi.org/10.1016/j.compind.2022.103833.

McAloone, TC & Bey, N. (2009). *Environmental improvement through product development: A guide.* Danish Environmental Protection Agency, Copenhagen.

Motalli, E. (2022) *What does the maturity look like for organizations transitioning towards a #circulareconomy?* [online] Available at: https://www.linkedin.com/posts/elise-motalli_circulareconomy-optimisation-innovation-activity-6995248726202085376-O8yB?utm_source=share&utm_medium=member_desktop [Accessed 4 Apr. 2023].

Motte, D. and Bjärnemo, R. (2022). Product Innovation - Product renewal. [PowerPoint-slides]. Division of Product Development, Department for Design Science, Faculty of Engineering LTH, Lund University, Lund, Sweden.

Neutel, K. 2023. Internal material Axis Communications.

Philips. (n.d.-a). *Circular economy*. [online] Available at: https://www.philips.com/a-w/about/environmental-social-governance/environmental/circular-economy.html.

Plumeyer, M. and Würl, H. (2019). *Waste Electrical and Electronic Equipment (WEEE) Handbook*. [online] United Kingdom. Elsevier. pp.619–646. doi: https://doi.org/10.1016/B978-0-08-102158-3.00023-9.

Potting, J., Hekkert, M., Worrell, E. and Hanemaaijer, A. (2017). *Circular Economy: Measuring innovation in the product chain.* PBL Netherlands Environmental Assessment Agency, The Hague.

Reike, D., Vermeulen, W.J.V. and Witjes, S. (2018). *The circular economy: New or Refurbished as CE 3.0? — Exploring Controversies in the Conceptualization of the Circular Economy through a Focus on History and Resource Value Retention Options*. Resources, Conservation and Recycling, 135(135), pp.246–264. doi: https://doi.org/10.1016/j.resconrec.2017.08.027.

Renner, A., Muller, J. and Theissler, A. (2022). *State-of-the-art on writing a literature review: An overview of types and components*. 2022 IEEE Global Engineering Education Conference (EDUCON). doi: https://doi.org/10.1109/educon52537.2022.9766503.

Shahbazi, A. (2020). *Guidelines for circular product design and development.* CIRCit Norden. Technical University of Denmark. Available at: https://circitnord.com/wp-content/uploads/2020/04/Guidelines-for-circular-product-design-and-development.pdf

Shahbazi, S. and Jönbrink, A.K. (2020). *Design Guidelines to Develop Circular Products: Action Research on Nordic Industry*. Sustainability, [online] 12(9), p.3679. doi:https://doi.org/10.3390/su12093679.

Shin, J. (2020). *What is E-Waste?* [online] Earth.org. Available at: https://earth.org/e-waste/.

Skärin, F., Rösiö, C. and Andersen, A.-L. (2022) *An Explorative Study of up Practices in Swedish Manufacturing Companies*. Sustainability 2022, 14, 7246. Doi: https:// doi.org/10.3390/su14127246

Skärin, F., Rösiö, C. and Andersen, A.-L. (2022). *An Explorative Study of Circularity Practices in Swedish Manufacturing Companies*. Sustainability, 14(12), p.7246. doi: https://doi.org/10.3390/su14127246.

Svenskt Näringsliv. (2022). Skapa goda marknadsförutsättningar för den cirkulära ekonomins framväxt.

Stena Recycling Sverige. (2020). *Electrolux presenterar dammsugare av 100% återvunnet och återanvänt material*. [online] Available at: https://www.stenarecycling.se/nyheter/electrolux-presenterar-dammsugare-av-100-atervunnet-och-ateranvant-material/ [Accessed 17 Feb. 2023].

Transpa.rent. (n.d.). *Award-winning transparent speakers with high end sound quality*. [online] Available at: https://transpa.rent/en/circularity [Accessed 3 Apr. 2023].

troelsgravesen.dk. (n.d.). *PORTS*. [online] Available at: http://troelsgravesen.dk/ports.htm [Accessed 23 May 2023].

Ulrich, K.T. and Eppinger, S.D. (2012) *Product Design and Development.* 5 ed. New York. McGraw-Hill.

United Nations. (n.d.). *The Paris Agreement*. [online] United Nations. Available at: https://www.un.org/en/climatechange/paris-agreement.

Vanegas, P., Peeters, J.R., Cattrysse, D., Tecchio, P., Ardente, F., Mathieux, F., Dewulf, W. and Duflou, J.R. (2018). *Ease of disassembly of products to support circular economy strategies*. Resources, Conservation and Recycling, [online] 135(135), pp.323–334. doi: https://doi.org/10.1016/j.resconrec.2017.06.022.

Världsnaturfonden WWF. (2022). *Klimatförändringar - Vad är det?* [online] Available at: https://www.wwf.se/klimat/klimatforandringar/#:~:text=Den%20globala%20uppv%C3%A4rmningen%20och%20klimatf%C3%B6r%C3%A4ndringarna%20f%C3%A5r%20katastrofala%20f%C3%B6ljder%2C [Accessed 6 Feb. 2023].

Weinert, J. (n.d.). *How LaaS helps the bottom line — and the planet*. Interact. [online] Available at: https://www.interact-lighting.com/global/iot-insights/laas-in-the-industry [Accessed 6 Mar. 2023].

Zenit Design. (2020-06-11). *Omställning och skalbarhet.* [PowerPoint-slides]. Lund, Sweden.

Wykes, A. (2020). *How Do Speakers work?* [online] Available at: https://www.soundguys.com/how-speakers-work-29860/.

www.europarl.europa.eu. (2020). *Green Deal: key to a climate-neutral and sustainable EU*. [online] Available at: https://www.europarl.europa.eu/news/en/headlines/society/20200618STO81513/green-deal-key-to-a-climate-neutral-and-sustainable-eu.

www.europarl.europa.eu. (2021). *How the EU wants to achieve a circular economy by 2050*. [online] Available at: https://www.europarl.europa.eu/news/en/headlines/priorities/circular-economy/20210128STO96607/how-the-eu-wants-to-achieve-a-circular-economy-by-2050.

www.europarl.europa.eu. (2022). *Why is the EU's right to repair legislation important?*. [online] Available at: https://www.europarl.europa.eu/news/en/headlines/society/20220331STO26410/why-is-the-eu-s-right-to-repair-legislation-important.

Appendices

Appendix A Interview Questions

Interview Questions

The interviews were conducted in Swedish, but the interview guide has been translated for the report. The following shows two different interview guides. In total, seven different interview guides were conducted for different departments.

Introduction

Our names are Emma and Lovisa and we study mechanical engineering at LTH, specializing in product development. We are doing our master thesis at Axis, where we focus on circular design of a network speaker (Snobben). The aim with the thesis is to find the optimal design for a sustainable speaker, without taking cost into consideration. Therefore, this might be more of an alternative design than a design that is realistic. Moreover, we will not focus on the logistics around the speaker nor the during phase. The focus will be on the development phase and the end of life.

As of now, the focus is broad and we are still in the discovering phase where we try to collect as much information and knowledge as possible about repair, reduce, recycle, reuse etc. Later, the scope will be narrowed down to focus on one area or part, depending on what we discover.

We are trying to understand how Axis works as a company, what the development process of the products looks like, what problems and challenges exists, and which are the compromises that are made. That is why we will ask a lot of questions and have a lot of wonderings. Important to keep in mind, we are not here to question or criticize you as a person or what you as a team are doing, we are just trying to figure out how a products lifecycle looks like at Axis.

Please, do share your knowledge, your thoughts and your opinions. We are new here at Axis and here at Audio, so we want to hear your insights and learnings from problematic areas and potential improvements. We want to focus our time where it will have the most effect.

Standard questions

What do you work with? Can you describe your daily tasks?

Do you work with circularity/sustainability at your department? If so, how?

What is the core value with the product Snobben that differs the speaker from other speakers, according to you?

Questions for Repair

How does a repair work for Axis products? Can you please explain.

What does RMA stand for?

What do you mean and refer to with RMA?

Who decides which product that will be possible to repair at RMA?

Do you work together with the RMA in USA?

Are you involved in the design and development process of new products to make sure the repair aspect is taken into consideration?

Is there any guidelines the teams needs to/can follow to have repair in mind in the development of new products?

How many of Axis products are repaired?

What is a common reason for repairment of a product?

What kind of problems do RMA/repair experience?

What is the reason for not repairing all products?

Do you have any thoughts how the repairment might be improved from a sustainability perspective?

Would it be possible to repair Snobben in a smooth way?

What is the cost for repairment of a product? Is it cheaper to send a new product?

Would maintenance of the products contribute to a longer lifetime for the products? If so, why is that not the case?

Do you think Axis could benefit from another business model?

For how long period are the products used by the customers?

What is the average length of Axis products?

For how much longer will the products be usable, if repaired?

Where does the products end up after usage?

Questions for Audio

How does a speaker work?

How does sound work?

Can you please have a walk thought about each part in Snobben and their function.

How is it possible to collect different frequencies at the same time in one speaker?

Where is the microphone located and how does a microphone work?

Which parts affects the sound experience? What is important to think about when designing a speaker?

How would you like to re-design the speaker if the sound experience would be optimal?

What compromises are usually made?

Why is the air volume so important?

Is there any material that does not working in a speaker?

How does the mesh affect the sound? Why does a mech look like it does?

Appendix B Scenario Posters

The created scenario posters for the workshop can be seen below.

REUSE

Axis behåller ägandeskap för produkterna och erbjuder sina produkter som en service – leasing. Det ger högre incitament till att designa produkten hållbart och Axis får möjlighet att påverka högre upp i R-modellen, genom att återanvända produkter eller komponenter. Potentiella utfall för detta skulle kunna förlänga livslängden på produkterna genom att ha olika nivåer på leasing-kontrakt, där använda men fungerande och uppfräschade produkter går ut till en lägre nivå av leasing-kunder för att användas en längre tid. Axis befinner sig högt upp i hållbarhetstriangeln och kan därmed behålla produkterna i ett högre värdestadie.

VÄRDETILLFÖRSEL

- Långsiktiga kundrelationer
- Uppgraderbarhet
- Tidlös design
- Hållbara produkter
- Axis får äganderoll över produkterna (i och med leasing) vilket leder till kontakt med slutkunden & ökad kunskap om kundbehov.
    - Verklighetsbaserad/verklighetsgrundad design. Design baserad på "äkta" kundbehov snarare än dagens situation där man designar på det man tror utan vidare kontakt med slutkunden.
- Intäkter från högkvalitativa produkter eller service på hög nivå, kundlojalitet
- Kontinuerligt intäktsflöde genom prenumerationer
- Ökade intäkter från prenumerationsbaserade priser
- Nya kundsammarbeten
    - Mindre startkostnad för kunderna
- Ökat resursutnyttjande
- Minskad e-waste
- Ökad motståndskraft
    - Begränsade resurstillgångar av bland annat jordartsmetaller i framtiden

AXIS

- Ny säljmodell
    - Nya avtal med distributörer och installatörer
- Krav på bevisning av återställandet av produkter/raderingen av känslig information
- Nya designkrav på produkterna
- Införande/utökande av retursystem

VÅRA UTFORSKNINGSOMRÅDEN

- Definiera styrkor och svagheter i den nuvarande produktdesignen ur återanvändningssynpunkt
- Välja material som åldras väl
- Skapa en tidlös design
- Designa för att underlätta uppgradering
    - Designa för att kunna separera delar
- Möjliggöra lättillgänglighet av PCB:t genom den mekaniska designen

REPAIR

Axis utökar sitt partnerskap med framför allt RMA men även EMS för att kunna erbjuda underhåll och reparation av produkter även efter garantin för de kunder som önskar. Reparation ska inte innebära att en produkt ersätts av en ny, utan att produkten ska repareras genom att delar bytas ut och produkten fräschas upp. *17 000 fall har inkommit till Axis där kunderna har varit villiga att betala för att få sin produkt reparerad även efter att garantitiden gått ut.* Axis befinner sig längre ner på hållbarhetstriangeln men jobbar mot lagkraven som Right to Repair.

VÄRDETILLFÖRSEL

- Konkurrensfördel på marknaden
- Nöjda och mer hållbara kunder
  - Slipper köpa nya produkter efter att garantin har gått ut
- Minskad e-waste
- Ökad motståndskraft
  - Right 2 Repair rörelsen – Mer än hälften av amerikanska stater överväger laginföringar som främjar möjligheten att kunna få sina produkter reparerade
  - Begränsade resurstillgångar av bland annat jordartsmetaller i framtiden
- Underlättar arbetet för RMAs verksamhet
  - Produkter som är designade för reparation kommer göra reparations processen snabbare och enklare
- Ökat resursutnyttjande

AXIS

- Utökande av återtagningssystem
- Minska specifikationer och krav på produkter
  - Förenkla testsituationen
- Köpa in testverktyg/material så att RMA kan utföra tester på plats
  - Inte möjligt i dagsläget att utföra de tester som är specificerade
- Utökar samarbetet mellan R&D och repair tidigt i produktutvecklingsprocessen

VÅRA UTFORSKNINGSOMRÅDEN

- Definiera styrkor och svagheter i den nuvarande produktdesignen ur reparationssynpunkt
- Granska befintliga reparationsmanualer
- Minimera specialverktyg för utförandet av reparation
- Designad för att vara lättåtkomlig att reparera
- Reparationsmanualer finns tillgängliga
- Designa för att följa "Right to Repair" lagar
- Utforska möjligheten att designa standardiserade delar och komponenter

RECYCLING

Axis etablerar nya partnerskap med återvinningscentraler för att säkerställa att deras produkter tas om hand om och återvinns på ett kontrollerat sätt och därmed sluter kretsloppet. Detta för att eliminera risken att Axis produkter deponeras/hamnar på soptipp. Axis befinner sig längre ner i hållbarhetstriangeln.

VÄRDETILLFÖRSEL

- Ökad motståndskraft
    - Lagändringar producentansvar till individuellt producentansvar
- Minskar hälsoriskerna i samband med okontrollerad återvinning i tredjevärlds länder
    - Återvinningsbar design innebär ofta att farliga material används i mindre utsträckning
- Minskad miljöpåverkan vid deponering
- Ökad transparens gentemot kunder
- Nya kundsammarbeten
    - Axis har och riskerar att förlora samarbeten genom att inte erbjuda återvinning
- Nya marknadsföringsmöjligheter som ett grönt företag
- Framtidsmöjligheter att återanvända och återvinna materialen till nyproducerade Axis produkter
    - Spara energiresurser
    - Minskad utvinning av råmaterial

AXIS

- Logistiklösningar för insamling
- Avtal med återvinningscentraler i varje region
- Definiera tydliga guidelines gällande återvinning till R&D och etablera en kontinuerlig dialog med återvinningscentralerna så att dessa guidelines hålls uppdaterade

VÅRA UTFORSKNINGSOMRÅDEN

- Definiera styrkor och svagheter i den nuvarande produktdesignen ur en återvinningssynpunkt
- Välja material som går att återvinna
    - Till så stor grad som möjligt välja monomaterial
    - Undersöka hur material är kombinerade och sammanbundna och hur det påverkar återvinningsprocessen
- Eliminera farliga material
- Designa för separerbarhet
    - Designa för enkel separering av farliga material
    - Designa för enkel separering av elektriska komponenter
- Designa för enkel identifiering av ingående material
- Undvika permanenta kopplingar mellan komponenter via ex. lim
- Undvika ytbehandlingar som sänker återvinningsbarheten hos materialen

REDUCE

Axis minimerar energiförbrukningen i deras logistikkedjor genom att optimera produktdesignen efter tillverkningens och produktionens geografiska placering och produktens marknad. Axis optimerar produktdesignen för att underlätta och effektivisera tillverkning och montering i fabrikerna. Genom en medveten tillverkningsprocess där scrapping minimeras bidrar Axis till en bättre användning av materialresurser. Axis jobbar i toppen av hållbarhetstriangeln men möjliggör fortfarande inte en cirkulär affärsmodell enligt EU kommissionens mål 2050.

VÄRDETILLFÖRSEL

- Lägre COGS
  - Större produktionsvolymer av enskilda material
- Lägre transportkostnader
  - Lättare produkter
- Minskade koldioxidutsläpp i logistikkedjan
- Minskade koldioxidutsläpp i produktion
- Enklare montering i produktion
  - Möjligtvis minskar assembly-tiden
- Ökat resursutnyttjande
- Mer lätthanterliga produkter i logistikkedjan
  - Lättare viktmässigt att montera

AXIS

- Kartlägger vad som skapar scrapping i sina fabriker
- Kartlägger problem och möjligheter i produktion
- Utökar samarbetet mellan R&D och produktionen tidigt i produktutvecklingsprocessen
- Sänka kraven på produkterna så att dom inte blir större och större - vänder utvecklingen som råder idag

VÅRA UTFORSKNINGSOMRÅDEN

- Minimera materialanvändandet
- Minimera antalet olika material
- Minska vikten på produkten
- Minimera antalet komponenter
- Minska skrotning av material i produktion
- Minska farliga material

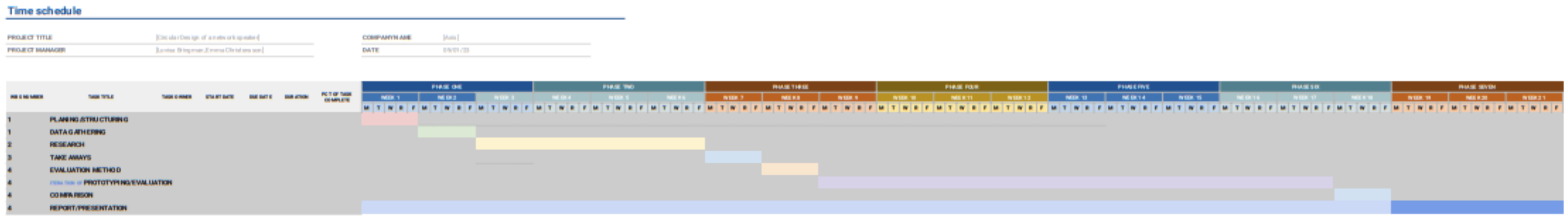
Appendix C Evaluation of Snobben

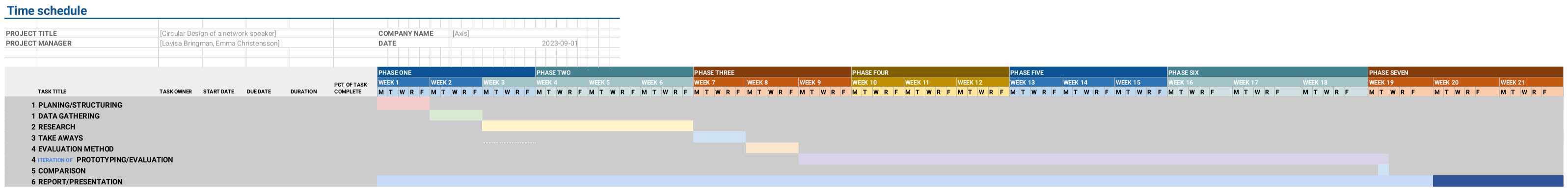
Kriterier	Grading Pendent	1 = Not at all	2 = To some extent	3 = Fulfils
Extended life				
The design aim to extend the value life of the product.	2		Many components are robust but lack information on lifetime for each part	
Future				
The product is aligned with current and upcoming laws and regulations.	2		It complies with REACH & ROHS but is not circular according to the European Greendeal	
The material and components in the product will be available in the future.	3			
Upgrade				
The product is easy to upgrade.	2		If you can increase the input power and the processor, you achive better sound. On the other hand it is difficult to change to a	
It is easy to dismantle the product nondestructivley.	2		Foam gaskets are destroyed after taking apart the back can and front baffle	
The platform (components that do not change throught all genereations of a products) is designed durable, robust and reliable for several lifecycles and can withstand several upgrades.	2		The threads break when you loosen the screws to the ceiling attachment, but otherwise the back can is robust	
The moduls/subsystems most likely to need an upgrade or exchange is easily accesseble.	3			The PCB is easily accessible outside the speaker
The product is easy to repair at RMA	1	The mesh is the only spare part. There is no manual and cannot perform the tests. Cannot be repaired beyond the mesh.		

The product is easy to repair by the installer themself.	1	Can change the mesh but nothing else.	
Standardized			
Joints are standardized.	2		6 different screws are used
The product consist of joints and connectors that easily can be opened and closed multiple times.	2		Går att skruva tillbaka skruvarna men gängorna till fästena i taket/kåpan kan lätt skadas
The product requires standardized tools across products and models.	2		The screws can be screwed back, but the threads for the fasteners in the roof/cover can be easily damaged
Assembling of the product requires one single type of tool (en och samma skruvdragare).	1	Not possible.	
The product consist of some standardized components across different products and models.	2		The PCB box, screws, lamp, interface are the same.
Modules			
The product is designed in modular construction.	2		Clear assembly sequence. But cannot reuse components for the different sizes of speakers.
No cross-dependecies exist between modules.	1	FB is based on HE. BC builds on FB. PCB is based on FB & BC. The cover is based on everything. Mesh is based on FB.	
Componenets with a high plausability of change are modular and isolated.	2		The PCB is isolated from the rest of the design.
Isolation			
Parts that wear out is easily accesable and isolated from other systems.	2		The processor often breaks and is isolated from the rest of the mechanics. The gasket must be replaced and the threads of the ceiling mounting screws are worn.

Componenets are easily accessable and have reachable directions.	2		The speaker element is difficult to access from the outside. This is mainly due to design.	
Design				
It is possible to change exterior of the outer shell.	3			Yes, the shell can be painted and replaced. The mesh can be replaced.
The design is timeless and compatable.	3			Minimalistic design and flexible coloring.
Wear and tear				
The product does not have components subjected to stress, wear, break or fail - In production	1	Risk of deformation of back can. No poka yoke solution, risk of failure de to destructive interferense. Screws can break, gasket break easily, thread of mouting screws.		
The product does not have components subjected to stress, wear, break or fail - During transportation	1	Frontbaffel can break during transport, due to wall thickness.		
The product does not have components subjected to stress, wear, break or fail - During use	1	PCB - processor fail		
The product does not have materials that easily are discolored.				
Componenets clearly indicate when they are worn out and need exchange.	1			
Exchanges componenets are marked or easy to recognize.	1	No markings		
Materials				
There are no adhesives and glue in the product.	1	Under all gaskets		

Appendix D Project Plan and Outcome


Time schedule


Time schedule
PROJECT TITLE
[Circular Design of a network speaker]
PROJECT MANAGER
[Lovisa Bringman, Emma Christensson]
COMPANY NAME
[Axis]
DATE
2023-09-01
TASK TITLE
TASK OWNER
START DATE
DUE DATE
DURATION
PCT OF TASK COMPLETE
PHASE ONE
PHASE TWO
PHASE THREE
PHASE FOUR
PHASE FIVE
PHASE SIX
PHASE SEVEN
WEEK 1
WEEK 2
WEEK 3
WEEK 4
WEEK 5
WEEK 6
WEEK 7
WEEK 8
WEEK 9
WEEK 10
WEEK 11
WEEK 12
WEEK 13
WEEK 14
WEEK 15
WEEK 16
WEEK 17
WEEK 18
WEEK 19
WEEK 20
WEEK 21
1 PLANING/STRUCTURING
1 DATA GATHERING
2 RESEARCH
3 TAKE AWAYS
4 EVALUATION METHOD
4 ITERATION OF PROTOTYPING/EVALUATION
5 COMPARISON
6 REPORT/PRESENTATION