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Redesigning Home Appliances for a Circular Economy

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Redesigning Home Appliances for a Circular Economy

Utformning av hemelektronik för en cirkulär ekonomi

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Redesigning Home Appliances for a Circular Economy

(Master's Thesis)

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Abstract

This thesis presents a case study on the redesign of an electric percolator with the aim of adapting it to a circular economy. The primary objective was to enhance the percolator's design in accordance with a Slowing the Loop strategy, focusing on longer product life and resistance toward obsolescence. A literature study was performed to identify sets of Design for X (DfX) rules for this purpose, resulting in five major areas of design: Design for Physical Durability/Reliability, Design for Emotional Durability, Design for Maintenance, Design for Modularity/Upgradeability and Design for Dematerialization.

Ideas were generated through structured brainstorming and concepts were illustrated through renders in Creo Parametrics. One concept was developed to be easily implemented and two concepts were developed for a more well developed circular product system. The realistic design case focused on an improved handle design while the advanced concepts considered more drastic design overhauls. Two evaluation tools, CirCit Evaluation Tool and Circular Concept Evaluation Tool, were used to confirm the improvements.

The results concluded that the products improved in circularity, mostly in areas connected to maintenance, repairability and robustness. Improvements were also made through the material selection, rendering the products more suitable for recycling. There is a lot more work to be done concerning these concepts, with testing and prototyping and further development and therefore, the main takeaway from this project should be a first showcase of how circular product design can look.

Den här rapporten dokumenterar omutformnignen utav en perkolator med målet att anpassa den för den cirkulära ekonomin. Den huvudsakliga uppgiften var att förbättra perkolatorns design enligt strategin 'Slowing the Loop' som fokuserar på att förlänga produktens levnadstid och på att göra produkten mer resistent mot åldrande. En litteraturstudie utfördes för att identifiera relevanta Design for X-regler (DfX) vilket resulterade i fem huvudsakliga designområden: Design for Physical Durability/Reliability, Design for Emotional Durability, Design for Maintenance, Design for Modularity/Upgradeability och Design for Dematerialization.

Idéer genererades genom strukturerad brainstorming och koncepten formgavs i Creo Parametrics. Ett koncept utvecklades med målet att vara realistiskt att förverkliga i rådande dagsläge och två koncept utvecklades för mer avancerade circkulära system. Det realistiska designfallet fokuserade på att förbättra handtaget på perkolatorn medan de avancerade koncepten genomgick heltäckande omdesign. Två stycken utvärderingsverktyg, CirCit Evaluation Tool och Circular Concept Evaluation Tool, användes för att utvärdera förbättringarna.

Projektet resulterade i förbättrad circularitet i alla tre design-fallen. Huvudsakligen rörde det sig om förbättringar inom produktvård, reparation och produktens fysiska hållbarhet. Förbättringar gjordes också genom materialval som gjorde produkten mer lämplig för återvinning. Mycket arbete kvarstår, där ibland att skapa prototyper och verifiera förbättringarna, och således ligger de huvudsakliga resultaten i att demonstrera hur framtagandet av cirkulära produkter kan se ut.

Keywords: MSc, Circular Design, Percolator, DfX, CEAP, Mechanical Design

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Contents

Chapter 1
Introduction

This chapter describes the background of the thesis, where the goals and research questions of the project are presented.

1.1 Background

The European Green Deal is the European Union's initiative to become the first climate neutral continent in the world [EU, 2024b]. Part of the deal involves the transition to a circular economy, as defined originally in 2015 and now updated in 2020 in the Circular Economy Action Plan (CEAP). According to CEAP, more than 50% of emissions and 90% of biodiversity/water loss comes from virgin resource extraction [EU, 2020]. To counteract this and to reduce end waste, circular economy and the recapture of used material is integral. Part of CEAP's focus is on consumer electronics, as less than 40% of the waste in that category is recovered. It is therefore important that companies take part in the change, to save the planet but also to realize the potential of untapped business models. The European Union expects both customers and companies to capitalize on the change, creating jobs and products for the future. One of the companies interested in this change is Order Nordic AB.

1.2 Order Nordic and the Circular Economy

This study is performed in collaboration with Order Nordic AB, a leading supplier to retailers of home appliances in the nordic countries. The company originated as an off-shoot from Resurs Radio och TV AB in 1980. That company later became Order Hemelektronik with the aim of being suppliers and service providers of electronics. Order Nordic got its new name in 2011 and today they operate in three business areas: high quality distribution to retailers, brand owners and as a third party logistics company. Order Nordic has focused

on being a leading supplier of electronics through a well developed warehouse management system. Today they operate an advanced warehouse in Helsingborg, Väla. Products are provided from different price ranges and brands including Melitta, Oral B, Philips and many more. More recently Order Nordic has focused on their own brands of products and how to make them circular.

The desire for sustainability has been a serious company goal since 2009, when the company became ISO 14001 certified and has since worked with sustainable development and growth. Order Nordic has worked to remove perfluoroalkoxy alkane (PFA) out of products. In Order Nordic's published their sustainability report in which they explained their desire in the change to circular business models, leveraging services, second hand markets and buy backs to break out of the linear economy [OrderNordic, 2023]. Their strategic goals are framed by the Planetary Boundaries and United Nations's goals for sustainable development. In particular this work will relate to Sustainable Development Goal 12, of sustainable consumption. As a logistics company they have a strong chance of affecting all stages of the value chain and plan to launch 3 circular product offers by 2025.

To allow this change, two brands which Order Nordic own themselves have been in focus for redesign. The brands are called C3 and Champion. Champion and C3 focuses on home appliances, such as vacuum cleaners, coffee makers, kettles and baking machines. Both brands have served as flagships to focus on sustainable home electronics. As such, the original pool of appliances investigated for the suitability of circular design, was limited to the two. In particular Order Nordic was interested in the redesign of a hand held vacuum cleaner and a percolator. Later, a clothes iron also was considered.

1.3 Understanding the Product and Order Nordic's Current Situation

A goal of this project is to investigate how product development can be used to design for circular business cases. Hence, it is important to consider what freedom of design Order Nordic has in their current state. Through meetings with Order Nordic's product developer some insight was gathered. As of now Manufacturing is located in China and product development is mostly related to finding suitable manufactures. Designs can be negotiated to some degree, but soon Order Nordic will have more power over the production. Due to Order Nordic having purchased the brand fully they will soon be able to alter the production to a more specific product blueprint. They will get increased control over casting, drawing and injection molding. From the company's point of view the goal with new designs was to mainly minimize the use of plastic, but any improvements regarding circularity were sought after.

Order Nordic is also currently working on developing a digital pass for their products. This will come in the form a QR-code sticker which is put on their product. By scanning this QR-code the user will be taken to a website meant to assist them with issues they might encounter. The development of this product is outsourced to another company and progress in the development of the digital pass would not be shared with this project. That is why this project will put no focus into that kind of a solution, because it would only be a waste of time and resources.

1.4 Project Goal

This is a project about the redesign of a home appliance product for the circular economy. A literature study about circular product design will be the basis for the redesign of an existing product. The Design for X (DfX)- strategy will be used for the designing. As Order Nordic does not currently have full control over their production which puts a limit on the design choices. The goal of this project is therefore to develop a collection of new concepts with different levels of alteration to the original product to fit the short and long term of the company.

1.5 Research Questions

Research questions were formulated in the beginning of the project to guide the academic work. They were formulated with regards to the project goal of producing three concept designs which in extension was formulated from Order Nordics interest in an investigation of the possibility of a circular design for their products.

- Which DfX strategies relate to slowing the loop in the context of circular economy?
- How does one match product types to circular design strategies?
- What is needed for a percolator design to become circular and long lasting?
- How does an easy-to-implement design look in contrast to a perfect circular design?
- What conflicts arise within the design framework when focusing on one set of DfX rules?

1.6 Delimitations

The time-frame of this project demanded some demarcation of what to include and as one product was chosen for the case study from the original three. The project was also limited by which aspects of the circular economy were to be considered. The major two ways of thinking of the circular economy is slowing and closing the loop and for this project the idea of "closing" was discarded. As for the evaluation of the results, only qualitative tools were used as there was a lack of material and emission data from the products investigated.

1.7 Structure of this Report

The report begins with a *Theory* chapter in which the term Circular Economy, the 10 sustainable strategies (10Rs), the different DfX perspectives and the evaluation tools are presented. Afterwards, the *Method* is explained in which the structure of the literature study and the work process of the Double Diamond. In the *Development Process* chapter the application of DfX rules is described. Following that, the *Results* present the final concepts and the results from the evaluation tools to confirm if there were improvements made in regards to circularity. Results are then discussed in the *Discussion* where also design conflicts and future work is presented. Lastly, the *Conclusions* from the work are given.

Chapter 2
Theory

This chapter establishes the theoretical basis of the project and a description of the current product.

2.1 Defining the Circular Economy

Circular economy (CE) is the adaptation of the economic system to follow circular material flows in a sustainable way. It is a systematic change from the linear industry, in which products are discarded as waste, to a complete overhaul where the waste becomes new potential and economic value. While the concept is now being widely adapted, its origins are not new. In the 90s, theories of industrial metabolism were presented which likened the material flow of resources and energy in our industry to the biological circular systems of the natural world [Ayres, 1994]. For the industry to be workable long term, material dissipation must be stopped and a holistic approach adopted on how to stop degradation of material. The metabolism of industry must be turned into a circular steady state system to continue long term.

The exact modern definition of circular economy varies, but the most common definitions all include the holistic repositioning of the role of material and energy in a product loop [Kirchherr et al., 2017]. The fundamental principle falls back on eliminating the concept of waste and instead striving for a 100% reuse of post-use material. The resources are kept useful through several strategies to reduce pollution and waste, to recirculate material and to regenerate nature [EllenMacArthurFoundation, 2013]. Within the system regenerative materials and stock materials can be considered. Stock includes materials such as plastic and steel and are kept in the loop through the maintenance, collection and reusing of products at different stages. The regenerative materials are typically more easily re-introduced into their original biological cycles. The three main benefits are less dependency on fresh rare materials, less resources spent on counteracting exhaust and economic benefits due to material recovery [Lieder and Rashid, 2016].

The Ellen MacArthur Foundation has created four principles for improved circularity. The first principle states that the closer the material and shape can be returned to original condition, the more energy and money is saved. The second principle involves using the same material as many times as possible in each loop. The third is the idea of cascading, using spent material in other product streams. Lastly, the fourth principle states that it is better to have as clean material loops as possible to guarantee the highest quality.[EllenMacArthurFoundation, 2013]

What cannot be neglected is the attachment of sustainable working business models to the circular and regenerative material flows. From the CEAP report it is expected that there will be a net positive of generated capital in the European Union from this transition. Even so, challenges naturally arise when companies have to design for end of life, create new business systems to monetize a desired longevity of products. This means there must be innovation on both the product level and the business level, typically uniting in a Product Service System and a mindset that the companies now are selling the usage of products, rather than the product itself. In this report the primary focus will be on the circular design aspect, altering a physical product to make it fit in the greater circular system. Hence, circular design goes hand in hand with circular business models.

2.2 The Building Blocks of the Circular Economy

For the system to function as a circular process, four main building blocks have been identified by the Ellen MacArthur Foundation [EllenMacArthurFoundation, 2013]. The first building block is the one that will primarily be touched upon in this report, namely the product design, that is further elaborated on below. The second piece is the development of the circular business model. Third and fourth building blocks are reverse cycle skills and cross cycle skills respectively. The business model step is about finding ways to keep adding value to material and waste. Reverse cycle skills means to adapt industry and services to keep regenerate value for the material in each distinct loop. Cross cycle skills care about moving material to increase value between the cycles, something typically called cascading. All four parts must work together for the CE to reach its full potential.

2.3 Defining Circular Design

In this report, the product design is the main building block in focus. When talking about circular product design it is important to first make the distinction from eco-design and how this relates to the current linear economy. The linear economy is a system of producing products that are used until the end of life and then thrown away, without regard to material in- and output. Den Hollander, et al, 2017 argues that eco-design is flawed from the beginning because this approach assumes that waste is inevitable [den Hollander et al., 2017]. Instead of

the ideal way of thinking where waste should be eliminated completely according to the circular economy, eco-design handles waste in a prioritized hierarchy of possible improvements. Of course waste will in some degree be inevitable even if the circular economy is applied and optimized, but the mindset differs from eco-design by not completely accepting waste as a part of the life-cycle of products. Circular product design applies two main approaches, slowing and closing the loop, which in general refers to increasing the life-time of the material input and controlling the output of material. The aim of this way of thinking is to solve the problem from the root instead of making small improvements based on the current situation.

2.4 Slowing and Closing the Loop

The slowing of resource loops is valuable since more usage can be garnered from already treated material before having to recover and reuse it. Such processes cost energy, money and more often than not degrade materials and components. In this report the focus will be on the following strategies contained within slowing the loop: Rethink, Reduce, Repair, Reuse, Refurbish, Remanufacture [Morseletto, 2020]. It is still worth mentioning the Closing aspect as it is still necessary for a product to be circular. As stated above, closing focuses on the output of material from the product's life cycle. Closing the loop treats the strategies of Remanufacture, Repurpose, Recycle and ultimately Recovery of energy. It saves energy, resources and money by reintroducing already treated materials and components into the value chain. Below the 10 Rs are defined according to CirCit Nord's definitions [Shahbazi, 2020]. These ten strategies became the targets the project aimed to achieve through the means of applying the rules of DfX.

2.4.1 Refuse and Rethink

The first strategy typically investigated in the circular economy is to 'Rethink'. From an innovation standpoint it targets the surrounding and holistic institutions, functions and services that the product provides. It does not necessarily mean to rethink the product, but primarily the surrounding systems to achieve a new type of value proposition. Things like how the product is delivered to the customer, in what way it is owned or procured are questioned and developed to create and close resource loops. Often new ideas of distribution and support are good ways to reduce waste and emission. However, even before Rethinking, one should consider Refusing: "The most environmentally conscious product is one that does not exist". While this may not be an option for a company, it helps to guide the thought into a service & function first mindset.

2.4.2 Reduce

The next step to consider is the Reduce strategy. It aims to minimize consumed resources in product manufacturing but also in the user phase. Whatever resources are spent should be regenerative to make a lasting loop and just by reducing the resource wasted, emissions and costs can be saved. The product should be designed so that processes use as little toxic material as possible. A product that has consumables bound to it should try to reduce this reliance.

2.4.3 Reuse

Since many products fall into obsolescence before they break, reusing is one of the most important ways to slow the resource loops. Any product in the loop should be designed to have multiple owners, stay relevant for a long time and to be resilient enough to survive. It also means to design with the intent of appealing to as many customers as possible. This saves both production costs, emissions, and limits virgin material needed. Materials can be reused several times without being recycled and downgraded, the loop can last longer. If the product can be sold on the second hand market it will also generate extra value.

2.4.4 Repair

When the product breaks, the next step in the process is to repair it and return it to the loop. Typically this manifests in one of three ways: 1 The company in question collects and performs the repairs, 2 a third party company collects the product and repairs it, 3 domestic repairs. In domestic repair it has been made possible for consumers to care for and repair their own products at home in accordance to the 'Right to Repair' legislation [EU, 2024a]. This can reduce the emissions from transports and collections but relies on a steady stream of components to repair with.

2.4.5 Refurbish and Remanufacture

Refurbishing is the act of bringing a deteriorated product up to good shape again. It is brought back and worn components are replaced, repainted and cleaned. It involves less processes than a complete remanufacture of the product itself. Some components have to be replaced even before breaking due to safety reasons and the uncertainty brought in by previous usage. Just like the repair, this can be performed by the original manufacturer but also other third party companies involved in the circular economy.

A complete remanufactured means taking in, disassembling, testing, repairing and possibly upgrading a product with the intent of reselling. It can be sold back to the original customer or on a new market. It is possible for new value to be added to the product via upgrading of components and functions. This also brings in another benefit, where old technology that may not be as resource effective in usage, can be updated with modern technology

to become less wasteful while maintaining the original bulk of the product. Like repairing and refurbishing, material and energy is saved in the reduced manufacturing and transportation of new products.

2.4.6 Re-purpose, Recycle and Recovery

When the product no longer is able to fulfill its original purpose there are still ways to keep it in the loop. Repurposing involves finding direct new usage for the product. It can also be that some parts of the product are meant to be used for a different purpose beyond the original life cycle. Finally if there is no other usage for the components they are to be collected and recycled for materials. By recycling energy and virgin material is saved, but there is usually a minimum amount that must be treated for the process to become profitable. Sometimes the material has the potential to become upgraded, sometimes it is downgraded but can be cascaded into other loops in the system.

The flow of material is one of the most important aspects of a circular economy and in the end any non-recycled material simply becomes lost value. The final option becomes to try and recover some of the energy bound to the material via combustion. This is only an option when it is safe to do so, when there is little toxic exhaust from the process and thus it is also something that products must be designed to have in mind. It should be seen as a final resort and is never ideal.

2.5 The DfX Tools for Slowing the Loop

Design for X is a design tool and perspective in which specific product attributes are prioritized through all stages of the product development process. Typically the characteristics optimized for are meant to result in cost savings for a product [Boothroyd et al., 2002]. The most common DfXs are: Design for Assembly and Design for Manufacture which improves resource cost in the production of the ware and Design for Cost contains strategies to push down manufacturing prices. Design for Environment is also an established theory, containing some relevant ideas such as reducing the use of material, ease of recycling and so on.

In this report the focus is put on a new set of DfX areas which have been compiled in many literature studies and collectively will be called Design for Circularity [le Moreno et al., 2016]. Reviews have already been made to establish the importance of the investigation of such tools in relation to circularity [Cappelletti et al., 2022]. This is an umbrella term containing substrategies to the prolonging of the resource loop. Different ways of categorizing the exact tools exist, but five main groups are presented to increase the lifetime of a product that are inspired by Bakker et al,. 2019 [Bakker et al., 2019]. Hence, the DfX selected in this work is meant to focus on prolonging product life. For each category, application examples and a summarized list of design guidelines are provided.

2.5.1 Design for Physical Durability and Reliability

Design for physical durability stands as the foundation for the longevity of the product. The direct connection to the slowing of the loop is clear, the more times the product can be used before being discarded the more resource efficient it becomes [Bocken et al., 2016]. The design rules have been developed since the 1990s and today most developments in physical durability are tied to simulation work [Mesa et al., 2022]. In the case of a percolator, durability means resistance to scratches, from stains of coffee, from physical destruction and manhandling and electronics that do not wear out. Each of the choices come from what materials to use, making sure that it lasts long without losing mechanical or aesthetic integrity [Bocken et al., 2016]. Durability also means that the components of the product are kept in as good a condition as possible when being returned to the circular resource streams which takes the larger circular perspective into account [le Moreno et al., 2016].

Reliability is measured as the probability of the product no longer functioning properly with each use [Bakker et al., 2019]. The product must be designed to practically fulfill its purpose without degradation to as large of an extent as possible as even some degradation can irritate or drive away users which means they will discard the product prematurely. Reliability also decreases the chance of maintenance work having to be performed, lowers the risk of components breaking and the allowance from rough handling [T.F. Go and Hishamuddin, 2016].

Below some of the design rules from literature is summarized: [T.F. Go and Hishamuddin, 2016], [Bovea and Pérez-Belis, 2018], [Mesa, 2023], [Shahbazi, 2020]

- Design with simplicity to reduce the amount of things that can break
- Performance of failure mode and effect analysis
- Implement parts with known history
- Simplicity in manufacturability makes for more reliable products
- Effective understanding of the requirements and the rules
- Mathematical confirmation of design to as large of an extent as possible
- Allowances for rough handling, use abuse, and transportation
- Proper material selection
- Use wear proof materials that last the expected life cycles
- Minimize numbers of joints and connections
- Minimize the use of toxic or dangerous materials
- Do not combine components with different lifespans
- Avoid sharp edges and corners, and reduce, if possible, stress concentrators
- Design joints and surfaces between joints using materials with high mechanical and chemical durability to face multiple disassembly and reassembly cycles

- Estimate product behavior in the use phase, i.e., components' strength and stiffness.
- Select quality, strong, robust and durable materials and components that do not degenerate during multiple lifecycles.
- Avoid materials that might lose strength, become brittle, or become discolored.
- Use as few materials as possible; i.e., minimize the number of different incompatible or dissimilar materials. The homogeneity of products with similar materials is vital for end-of-life management.
- When selecting correct and compatible materials and avoiding multi-materials and composites, consider also the durability of the materials.

2.5.2 Design for Product Care

The Design for Product Care primarily focuses on activities and design choices that allow the user to extend the product's life. In short it is the design that allows the user to easily access and replace parts that break before they make the product obsolete. By informing the customer of how to maintain their products to allow parts that are quickly worn out to be easily removed and replaced, the product life can be extended. It becomes important to design the product so that the maintenance is easy and accessible for the user.

Bovea, et al, 2018 proposes a framework for designers with guidelines on how to design for circularity [Bovea and Pérez-Belis, 2018]. In general, products should be designed to be as accessible to the user as possible to make repair and maintenance easy. By decreasing the amount and variation of joints and standardizing the type and using non-fixed joints, it becomes easier for users to disassemble the product. The product should also be designed to resist dirt build-up and exclude parts or components that require frequent repair. By designing a system for monitoring failing parts the care of the product can become more predictable. Additionally, Mesa, 2023 argues that joints and surfaces between joints are designed to endure multiple disassembly and reassembly cycles. A guide for troubleshooting and information about where to acquire spare parts should also be available.

Design rules [Mesa, 2023], [Shahbazi, 2020]:

- Utilization of light components to facilitate disassembly and extraction of failed parts
- Design joints and surfaces between joints using materials with high mechanical and chemical durability to face multiple disassembly and reassembly cycles
- Facilitate the identification of parts
- Generate a troubleshooting guide regarding potential product failures
- Include detailed information to get spare parts from the manufacturer and repair shops
- Make it easy to clean the product and components.
- The surfaces to be cleaned should be smooth and wear resistant.

- Reshape the interior surface to make it easier to clean.
- Make heavily stained surfaces able to withstand mechanical cleaning
- Avoid making areas where dirt might collect and are hard to clean properly; e.g., avoid small holes, nooks, grooves, sharp edges and thresholds that capture dirt.
- Avoid unnecessary coating procedures.
- Avoid non removable coating materials.
- Prioritize dyeing internal polymers over surface painting.
- Make it easy to inspect the product and components.
- Accurate inspection for reuse is essential to keep the product functional.
- Design should enable early identification of stress, wear or breakdown.
- Inspection points and testing components should be marked and easily accessed.
- The product must be safe to inspect and not include hazardous materials.

2.5.3 Design for Modularity and Upgradability

Modularity is the idea that parts and sections of the product can be exchanged to create permutations and options. In regards to longevity this allows for the combating of both physical deterioration (replacement of broken parts), emotional obsolescence (updated parts with new meaning) and technical obsolescence (improved function through new modules). Combined, this modularity becomes a way for customers to interact with the product and to personalize it, involving a stronger product identity. In turn this may lead to the consumer taking greater care of the product and increased willingness to repair it rather than replacing it. Modularity also allows for a diversification of the product application which in itself creates more inherent value, but also increases the odds of the consumer finding the product useful for a longer time.

Modularity and upgradability in the design can be achieved by considering modularity at the core of the design [Bovea and Pérez-Belis, 2018]. Minimizing the amount of parts and variations will help the user both upgrade and exchange parts with ease. It is also important to make the disassembly easy for the user which can be achieved by standardizing, decreasing the amount and variation of joints and connectors used in the assembly of the product [Ackermann et al., 2021]. It makes a point to design additional modules to the product for an option to upgrade the products for a more personalized and satisfactory experience.

Design rules [Bovea and Pérez-Belis, 2018], [Mesa, 2023], [Shahbazi, 2020]

- Create a modular base design
- Assure the fewest possible technicians are needed to perform repairs

- Use standardized components & joints parts
- Simplify Product Structure
- Minimize types of connectors
- Use simple and standardized tools
- Standardize components and parts across a range of brands and products.
- Design core components with higher safety factors and reliability to enable future use cycles
- Design additional modules that can serve as upgrades or personalization functionalities
- Include detailed information to get spare parts from the manufacturer and repair shops
- Divide product into different modules, and put all the parts that need to be exchanged or upgraded into one single module, thus lowering the effort needed to refurbish the product.
- Avoid cross-dependencies between modules; otherwise, we might be forced to update a working module simply as a consequence of updating an outdated one.
- Make a "kit" with all the elements required for an update.
- Design simple modular structures and design the product to change modules without damage.

2.5.4 Design for Emotional Durability and Attachment

Emotional Durability and Attachment are design goals that tie into the relationship between the customer's perceived value of the product and its actual functional value. It is a means of resisting premature obsolescence when a consumer may be tempted to replace the product early. Items that tell a story with their wear and tear are examples of products with good emotional durability. For example, cast iron pans that supposedly perform better after generations of use and seasoning or high quality jeans that start to fade and age with the user giving it a personalized fit and look for each individual user[Chapman, 2005].

Although we have begun to think more about our impact on the environment in the last decades, Chapman, 2005 [Chapman, 2005], points out that we are only dealing with the symptoms of our consumption instead of the core problem. They make the analogy between western medicine and how we usually take painkillers for a headache instead of proactively drinking more water. The painkillers usually eliminate the unpleasant symptoms we experience for the moment but it does not get rid of the health problem indicated by the headache. In the same way we can not become truly sustainable by managing the waste of production and consumption, we, as users, need to change our behavior. Designers do not have control

of how users behave or what they do with products after purchasing them but they can influence and nudge them in different directions. By designing products in a way that can create the opportunity for users to get an emotional connection to them, hopefully, the lifetime of the product can be extended. Instead of the throw-away behavior we employ at the moment, an emotional connection to our products can create a bond which makes users more willing to keep and care for their products.

Design rules [Bovea and Pérez-Belis, 2018], [Mesa, 2023], [Shahbazi, 2020] :

- Design for allowing the user to personalize the product appearance (i.e., the user can paint its product or include a logo, tattoo, or text)
- Generate a troubleshooting guide regarding potential product failures
- Include detail of secondary functionalities in the case of repurposing
- Employ timeless design to avoid outdated fashion.
- Simplicity and functionality often help a product remain attractive for a longer time.
- Compatibility and adaptability can be a means of giving a product longevity in the information technologies field, e.g., the USB or flash drive.
- The ability to change appearance, i.e., the exterior, can be a means of giving a product longevity.
- Think about product attachment and trust between customers/users and products.
- Think about the effect time and fashion will have on your product and about how specific is the function your product is aiming to fulfill.
- In addition to emotional attachment, reliability is also crucial; even if it is not the latest functional model, users still prefer to utilize rather than replace it.

2.5.5 Design for Dematerialization and Product Service Systems

Taking the entire redesign approach into account combined with the holistic perspective, design for dematerialisation means to design for service solutions rather than product solutions. In turn the business strategy affects the physical design of the product. In many ways this is part of the longevity project as a way to create an economic model. By offering a washing machine service where the owner only pays per wash instead of actually buying the machine, the company secures income while still having an incentive to keep the product alive for as long as possible. In turn stock resources are kept and the user of the product does not have to worry about selling it if they have to move.

Sumter et al, 2018 conducted a case-study of leasing baby strollers and how the product as well as their business model had to be redesigned [Sumter et al., 2018]. The main takeaway was that the business model had to be considered in parallel to the product design. There is a big logistical problem that needs to be solved when moving from a linear business model to a circular one, in this case leasing of products. The products seem to be treated differently when leased instead of owned which is one thing needed to be considered in the product development phase. This way of designing a product is therefore very different from those previously mentioned and would need a totally different narrative in the design phases which makes it not as compatible with the others. The motivation for leasing a product is also very different between product categories because most people might think leasing a car feels viable but not as much when it comes to cheaper home appliances.

2.6 Concept Evaluation Tools

At two moments in the work procedure concept evaluation tools were used. The initial application related to the choice of what product (vacuum cleaner or percolator) to re-design and was done with the Circular Pathfinder. Later in the project, two other tools were used to evaluate the improvement in circularity. Below, all these tools are introduced.

2.6.1 The Circular Pathfinder

The Circular Pathfinder is a tool developed based on case studies by companies that already have implemented circular strategies to screen circularity strategies [van Dam et al., 2017]. The tool provides questions to be answered in order to determine which circular strategies have most potential for a chosen product. The tool is a good way to quickly help companies find out where to start out, but due to the small amount of data input it should not rule out any strategies or completely guide the decision making. The tool provides branching questions depending on answers about the products, but there are a core set of variables that are considered. Table 2.1 lists these underlying variables which the tool is based upon. In the end, one or more circular strategies are recommended. Strategies that the Circular Pathfinder can recommend are: Prolong, Upgrade, Reuse, Repair, Refurbish, Remanufacture, Recycle and Biodegrade.

Table 2.1: The 6 Variables used by Circular Pathfinder

Nr	Case
1	Whether the parts or materials of the product could be collected.
2	The reason for discarding the product.
3	Whether the product could be used again after the first use cycle (as a whole).
4	Whether parts of the product are still useful to the company when the product is replaced or discarded.
5	Whether users are interested to acquire the used product (in good condition).
6	Whether users demand a warranty to assure that the used product works well.

2.6.2 The CirCit Nord Evaluation Tool

CiritNord was a circularity-research project between the Nordic countries involving 70+ companies throughout, spanning 3.5 years in total. The results of the project were presented in a series of reports and tools for different areas of the full process [Kravchenko et al., 2020]. One of the tools made was the Circit Nord Evaluation Tool. It is based on the discovered design principles which are rated in terms of importance for the concept and then how well that aspect is implemented. The tool also provides a matrix indicating connections between the design guidelines and the circular strategies. The strategies were those developed by CirCit-

Nord during the project and can be seen in Appendix B.1 and figure 3.3.

In practice, the tool was a spreadsheet that allows the comparison of three concepts in regards to circular potential compared to the 28 design rules of Circit Nord. These rules as presented in detail later in the report in figure 3.2. Every rule is ranked on the importance to developing the product. A scale of 0 to 3 is used where 3 is most important and 0 means that the rule is not applicable or desired at all. In this report the same rating as the concepts compared were all of very similar sort. Every concept is then evaluated for every rule with either a 1, 3 or 5 where a 1 means that the rule is fulfilled and a 5 means it is not fulfilled at all. In the end every importance rating and fulfillment rating is multiplied, giving a circularity score ranging between 0 to 15. A low score means that circularity has been implemented as there is little need for improvement.

2.6.3 The Concept Circularity Evaluation Tool

The Concept Circularity Evaluation Tool (CCET) is a tool developed to help companies evaluate the potential for circularity in the early stage of product development. The tool was developed from a literature study and then tested and verified by 4 case studies and proved to be helpful in deciding which concepts had the most potential for the circular economy and what primary strategies to focus on [Albeak et al., 2020]. The tool works by answering two questionnaires about the product type and circularity strategy goals and then rating the performance of the different concepts. This results in a visual representation of the circularity score which helps the company decide which concept has most potential and where to focus when further developing the product.

The CCET is also a downloadable spreadsheet tool with similar functionality to CirCit Nord's model, but with a different starting point. The sheet asks a set of questions about the product that is about to be developed. These questions are described below the paragraph in a list. The tool then asks for feedback relating to strategies in four categories: Materials, Parts and Products (new user), Products (same user) and Manufacturing. Every strategy is then rated if it is in focus or not. This leads to every concept being scored between 0 to 6 [Albeak et al., 2020] with a high number meaning high relevance. Lastly, the spreadsheet recommends the most relevant strategies and every concept is ranked on a scale 0 to 3 for each instance. The results are given as % circularity where a higher % means a better fulfillment.

The different questions about the product:

- What is the approximate lifetime of the product?
- What is the primary reason the user disposes of the product?
- Are there any other reasons that users dispose of the product?
- After the initial use, is the product still usable, or can return to usable condition?
- Are there large impacts in the use of the product?
- Does energy efficiency or functional capability change significantly between generations of products?
- Could there be a market for second hand/reused or repaired of these products?
- Can the product or its parts be used for something else
- Does the product typically contain high impact, rare materials or toxic materials?
- Does the production of this product often include processes which are high impacting?
- Could the product lifetime be improved if specific components are replaced?
- Is the product typically heavily packaged and transported?
- Is recycling of most of the product possible?
- Is there a risk that some of the products or parts will be cascaded or recovered?

2.7 Consumer Behavior

As previously mentioned in the DfX presentation of the report, products have a risk of reaching obsolescence before the actual end of life of the product. A lasting product must not only be technically sophisticated but also perform well and bond with the user. When obsolescence is reached, it is guided by three factors, the product characteristics (technical side of the product), the situational influences (media and market development) as well as the consumer behavior (replacement morality) [Ceschin and Gaziulusoy, 2019]. The first factor is what can be targeted with specific design, the others require more social innovation. At some level Order Nordic will be able to help with the second part by using marketing and branding to create a circular image for the products. Before that is possible, it is still the technical side that can be affected, possibly in the ways explained below.

2.7.1 Consumer Communication

While it has already been touched upon, product communication is an important part in guiding the user but also to build a bond with the item to guarantee emotional durability. Emotion centered design is one approach developed by Haines-Gadd et al 2018 through nine different strategies [Haines-Gadd et al., 2018]. The design can focus on creating a Relationship between product and user through mechanisms that create habitual rituals and participation through creative activities. It can focus on communicating Narratives through the product, making wear tell a story or to create nostalgia which allows the user to have it for longer without growing tired of it. Identity is the third focus, where personal expression becomes art of using and customizing the product. A certain level of Mystery helps spark the imagination parameter, where some processes should surprise the user. Interaction with the product in a pleasant way is also important. By bringing in the illusion of Consciousness in the product it can get its own identity. Integrity in structural and functional design, an honest product easily becomes more reliable and easy to enjoy. The second last concept is Materiality, how does the materiality of the product develop and change over time through use? Lastly designers must consider Evolvability, how can the product be customized and change through use with the consumer.

2.7.2 Inspiring maintenance

The emotional durability must also be complemented by design to communicate and inspire the user to repair and maintain the product at hand. This becomes extra important in Product Service System where the consumer borrows equipment or in systems where the product must be refurbished with minimum effort. There are many different ways of viewing behavior interference, scaling from a focus on the individual to a more contextual approach [Ceschin and Gaziulusoy, 2019]). It is also possible to take a mixed stand and combine both contextual and individual theories. Even so, the general rules can be summarized as: Make it easier for people to adopt the desired behavior and make it harder for people to perform the undesired; Make people want to perform the desired behaviour and

make people not want to perform the undesired. Eight main design strategies are presented below[Ackermann et al., 2021]

- Information: Inform the user through text, screens, manuals etc.
- Awareness: Make the user aware with push message, shift in look, shift in performance when it needs maintenance
- Consequences: Maintaining the product gives clear improved enjoyment, not gives a clear indication of failure.
- Social Connections: The consumer has support from clubs, shared tips or shared ownership of a product.
- Enabling: Flexibility, make it easy to repair, repair service.
- Appropriation: Allow the user to personalize the product, changing the product.
- Reflecting: Product makes meaningful memories, showing the story in the visual appearance, product care is fun!
- Control: Product takes initiative, self healing product, unconscious take over, forced product care.

2.8 The Circular Business Model

The design of a product can play a role in shifting to a circular economy, but due to products inevitably becoming obsolete the only other efforts a company can take is altering the business model. In some cases it might be possible to design products to become truly biodegradable or in some way make them reintegrated into the ecosystem in a completely healthy way after the end of life, but in general companies will need to take care of obsolete products or waste to become circular. The current business model for most companies is to produce and sell products without any concern to what happens after they become obsolete, e.i the linear economy.

There are many ways to alter the business model in accordance with the circular economy, but one common idea has been to create a leasing system or a subscription model of products. As previously mentioned Sumter et al 2018 conducted a case study on baby strollers to be leased and refurbished and found that both the product design and business model played a big part in the success of the company [Sumter et al., 2018]. By changing to a subscription model they found that the design of the product had to be much more robust and modular, but major parts of the business also had to be reformed. Due to large input of products and material to work with, the product development had to be continuous and anticipatory to be able to use old parts for new versions. This also put a stress on the logistics of the company which would have to be considered. This is only an example of a somewhat circular business model, but it showcases the importance of developing the products and business models in a coordinated way.

2.9 Material Considerations for the Circular Economy

Above, the design of the product has been discussed and several times the material choices have come up as a parameter to consider for circularity. Materials must be sourced and treated, they are a leading factor in determining product life time and how easy it is to recycle the product at the end of life. Immediately it becomes a complex task of comparing initial costs and emission in relation to an expected longer lifetime or possibility of refurbishing the materials for even longer usage. The Ellen MacArthur foundation also states that one must consider the toxicity of the material as well as if it belongs to the biological cycles or the technical cycles, can they be broken down biologically or is technical treatment necessary. Circular products never exist in a vacuum. The following lists what one must consider when selecting material compiled from Ellen MacArthur foundation and RiSE[Nyström et al., 2024]:

- The initial emissions and energy consumptions needed to make the material.
- Lifetime of the material in the product in a specific solution before needing treatment.
- Toxicity in production and usage.

- Emissions and energy needed for refurbishment to prolong lifetime.
- Defining if the material belongs to the biological or technical loop.
- Sustainable sourcing/ renewable material.
- Resources and emissions for recycling the material.
- Cascading or degrading.
- Other practical benefits of one material over another (Mechanical strength, water absorption, heat conductivity etc).

Some of the evaluation will always have to be qualitative, as in what is more valuable for this specific product. If a product does not feel nice to use, the customer will not become emotionally attached to it and throw it away earlier. Some materials last long if they are treated properly which is often the case for biocycle materials (leather, wood, fabric). In some cases this instead is a benefit as it can increase the emotional attachment and bring a level of pride in taking care of the product. As such things are hard to quantify before data can be gathered from sold products, these early stages of circular design are limited to speculation in some regard.

Chapter 3
Method

This chapter describes the general workflow of the project. The brainstorming process is described here as well as the tools used for evaluating the concepts.

3.1 Literature Search

The basis for this project was mainly a literature research in the field of circular economy and sustainable design. The study was based on searches using Google Scholar and Science Direct as sources. There were four major areas of interest: DfX rules and their correlation to Slowing the Loop, the 10 sustainability strategies, information about evaluation tools and lastly information about consumer psychology.

For the first type of searches, words like "Design for x", 'Circular Design', 'Lengthen product life', 'Sustainable product design' were used. Later the searched were refined to find information about the relevant strategies, 'DfDurability', 'DfReliability', 'DfModularity' etc. To make sure that theory was relevant, most articles were chosen if they were published within the last ten years and in instances where they specifically focused on home appliances. Often times the articles reached were studies compiling information and comparing design rules from several sources, in which case some of the sources themselves were investigated in a snowball-like manner.

The searches for sustainability strategies, evaluation tools and consumer psychology followed in similar ways. In the case of sustainability strategy choices, selection mostly related finding the most inclusive set of 'R' principles. In the search for evaluation tools, "circular evaluation tools" many different types of tools and aid from supervisors was helpful in finding a good compilation. For consumer psychology, the search words were focused around "Consumer behavior", Designing for emotional attachment" and "Emotionally durable design", hoping to find practical cases and examples. Ultimately the study was helpful and

generated guidelines on how to conduct the rest of the project along with various tools and methods for concepts development and evaluation.

3.2 Product Selection

This project aimed to apply the circular economy mindset of slowing the loop to a specific product from Order Nordics existing product catalog. The first step, besides the literature analysis, was to choose a product fit for this task. Due to the lack of research and actual efforts in similar cases the product was chosen based on the greatest potential for improvements. One of the biggest challenges in this field were thought to be the real world applications of the circular economy, which demands more case studies that exemplify how this could be done. Therefore, the choice of a less complex product with more potential for improvement was preferred.

The Circular Pathfinder is a tool developed based on case studies by companies that already have implemented circular strategies [van Dam et al., 2017]. The tool provides a maximum of 10 questions to be answered in order to determine which circular strategies have most potential for the chosen product. The tool is a good way to quickly help companies find out where to start out, but due to the small amount of data input it should not rule out any strategies or completely guide the decision making. The three product categories chosen for evaluation according to the tools were vacuum cleaners, percolators and clothing irons. These three were intuitively selected for evaluation due to their assumed popularity among customers and potential for improvements. Most of the other products in Order Nordics product catalog were considered to be too expendable with short lifetimes, too cheap for customers to engage in sustainable activities or too low in demand.

After evaluating the product categories with the Circular Pathfinder, the only product excluded was the clothing irons. This product category showed the least amount of potential compared to the other two which ended up with very similar results. For the vacuum cleaner the recommended strategies were 'Prolong', 'Repair', Remanufacture', 'Recycle' and 'Biodegradable'. The Percolator had similar strategies recommended: 'Prolong', 'Upgrade', 'Refurbish', 'Recycle' and 'Biodegradable'. The Clothing iron had 'Prolong', 'Repair' and 'Recycle'. The vacuum cleaner and the percolator were also closer to the original suggestions for products to develop from Order Nordic.

The final decision was based on discussions in the group about which product would be most fit for the project. The final decision for the case study was the percolator and the main reasoning was the relatively low complexity of the product. It fits the time frame better than a very complex product. It was also reasoned that customers care more for a percolator and are more willing to engage in activities that are beneficial for the circular economy like repairs and maintenance among others, which seemed to give it a slight advantage.

The percolator itself has other inherent technical qualities that renders it suitable for a focus on longer product life and a greater resistance to obsolescence. As a product on its mar-

ket it is definitely positioned in maturity and declining sales faces which means it can utilize most of the DfX posted above. Coffee brewing capacity has peaked and the risk of radical innovation in this product category that would spur sudden obsolescence is relatively low. As a means of making coffee, the machine does not use filters which saves some material compared to a traditional coffee maker. People will not stop drinking coffee anytime soon either and the customer base of this product seems to be very specific in their choice of coffee maker.

3.3 The Percolator

The Circular Pathfinder resulted in the percolator being chosen as the product type to continue with. The structure of the percolator was then dissected and analyzed.

3.3.1 Product Architecture

The C3 Percolator is a stainless steel electrical percolator meant to brew coffee with more intense flavor than regular coffee makers. It comes in several different sizes depending on the needed amount of coffee, 8-12 cups in size with varying price between 799 to 1099 sek. The Percolator is powered through a polymer cased bottom with a classic 230V wire and power switch. The resistance heater is placed in the bottom of a casing connected to the actual stainless steel jug. A plastic handle and see through glass is attached to the main body as well. Internally the percolator has a water circling pipe, a container for the coffee grounds. Lastly the top is of stainless steel with a plastic knob on the top [OrderNordic, 2025b].

To understand the current product a bit better, it was disassembled into the main parts of the percolator, while leaving the electronics fairly intact. In Figure 3.1 the different groups of components are displayed, which are as follows:

- Metal lid with a see-through plastic knob.
- Plastic handle, with a plastic tube indicating the amount of liquid in the jug as well as some small connectors.
- The main jug of the percolator.
- What is needed for a percolator design to become circular and long lasting?
- The electronics of the percolator which consists of two thermostats, one resistance heater and some wires and fasteners. The thermostats are connected to the underside of the jug and the resistance heater.
- The bottom plate which connects to a power source and the percolator.

Figure 3.1: The current percolator model from C3 when disassembled.

3.3.2 The Electronics

The percolator operates by a classic heating element attached to the bottom of the jug in a plastic casing. The heater is made out of an aluminium lump and shaped to accommodate for the end of the circulation straw to rest in a cavity. Two thermometers are attached to the circuit, one to the heating element and one to the bottom of the jug. Power is supplied via an external charging plate which also contains the on/off button which is connected to a 230 V power outlet. The plate holds the jug while the rest of the electronics get power. An on-switch allows electricity through to the resistance heater. A thermometer helps control and turn off the system.

3.3.3 The Customers

From Order Nordics own customer understanding, their percolator has an existing customer base characterized by being older people used to this specific type of coffee brewing. They tend to prefer a more intense coffee flavor and when they make coffee they want to make a lot at the same time. Customers tend to be more interested in environmentally conscious purchases as a percolator saves on filters and thus has one less consumption stream to take care of. When it comes to pricing the C3 percolators are a somewhat premium product, more expensive than many cheaper alternatives. They must have disposable income to afford the product and the expected lifetime, based on guarantees, is 5 years.

3.3.4 The Intended Product Use

The product design must reinforce the usage patterns that are expected of the customer for the product to work as well as possible. From the manual the customer gets instructions on normal usage, maintenance and end of life treatment [OrderNordic, 2025a]. As product designers these patterns are essential to understand.

Brewing Coffee

To brew coffee with the current model percolator, one fills the jug with water (minimum 2 cups). Ground coffee is measured up and poured into the steel container. With the lid the container is placed on top of the pipe and spring which are then inserted into the jug. The lid of the percolator is then put on, the contact to the power plate is then inserted to the power outlet. Brewing starts after pressing the Order Nordic button and activation is displayed through a red light. The product also has a heating mode that lasts up to 40 minutes.

Maintenance

After each use the percolator is to be cleaned according to instruction. Specifically the pipe and the holder for the coffee grounds has to be removed and washed out thoroughly. Additionally, the nut on the inside of the jug as well as the dimple at the bottom has to be carefully cleaned to avoid formation of calcification that could affect the flavor of the coffee. The outside is to be cleaned with wipes and not with chemical cleaners.

3.3.5 Flow of Material

The percolator is a relevant product for circular design as it is used regularly, for a long period of time and consumes both power as well as coffee grounds and water when used. As of now the products are shipped to Germany for repairs and at the end of life it is up to the consumer to bring the electronics to the recycling station and to clean and prepare for recycling. The current situation therefore poses some problems but also opportunities for redesigning of the percolator.

3.4 Scope

The main concern of the project was how to extend the life of the percolator. To serve both Order Nordic and the idea of a circular economy the best way the question of how realistic or idealistic the final concept should be was also relevant. By compromising too much there could have been risk of creating an inadequate concept from both viewpoints which resulted in a plan to create 3 versions of the redesign.

One case was done to act as a more approachable bridge while the two other concepts were more ideal. The first one was meant to be realized in a shorter time frame, with systems close to Order Nordic's current set-up. The more developed solutions, termed the ideal versions, are cases for the future where greater systematic changes would have been made. An evaluation was then made to find the weaknesses and strengths in circularity using the CirCit and CCET tool. The results were discussed in relation to how the designs affected the different scores to see which design rules worked better.

Labeling one concept as "realistic", implies that Order Nordic should be able realize the changes with their current mode of production. Currently, changes made to their products rely on negotiating with the factory they outsource their production to. Based on conversations with our contact at Order Nordic there was no clear way of knowing if any suggested changes to the product could be realized. Without any knowledge of the actual restrictions to comply with it was decided, with recommendations from Order Nordic, that the handle would be the component to focus on. The reason for this was the desire to eliminate plastic components due to issues with refurbishing, repairing, remanufacturing, and recycling. The handle was also deemed to be the only major part that could be replaced without the use of new or altering any other components. With this said, any changes to the product heavily rely on what the production company would agree to. The production company is limited in making changes to any products due to other companies than Order Nordic utilizing the same factories.

3.5 Double Diamond Method

The project followed the classic design pattern of the double diamond method, as described by the British Design Council. The method describes the movement of the project through two diverging/converging phases, starting off with the exploration and discovery phase. In this case it meant breaking down how the percolator was used and what circular problems with its current design had to be tackled. This widened the understanding of the problem. From the understanding of cause and effects and internal parameters, the actual design problem at hand could be formulated, the diamond converged. The ultimate design question became: 'How do we get people to use the product for longer?' From the defined problem the process diverged again when all potential solutions and developments were created. Concepts and specific solutions for functions were gathered and they were then analyzed and selected to create the final convergence.

3.6 Ideation and Brainstorming

According to the double diamond method, the first steps taken should be discovering all options and alternate solutions available. For the first sessions of idea generation the main focus was to create as broad of a sample as possible with every idea included no matter how unrealistic or implausible. To help with the brainstorming, specific questions of how to solve certain issues were presented as a starting point. The questions varied in how specific they were to the selected product but the goal was to keep an open mind when answering them and generating ideas. See Appendix A for a list of questions and prompts used in the brainstorming.

Starting with a very broad way of brainstorming was helpful to think more freely, but later it was decided to also conduct a brainstorming session in a structured way. This was done according to table 3.1, with every box in the grid containing at least one idea for the combination of the DfX strategies and circular design strategies, i.e DfX and 10R. This helped us generate a larger quantity of ideas by forcing a very specific set of goals for each idea. For example, by only considering Upgradability and Reduce which intuitively seem irrelevant to each other you get forced to think outside of the box which could be very helpful. A lot of ideas might turn out very similar, but the most important part of this exercise was to force idea generation even if the ideas turned out completely useless. One important thing to mention is that this "ideation matrix" was used only as an alternate ideation exercise. During the project, the 10R strategies are used as targeted requirements to uphold while the DfX strategies are means to achieve this. For this exercise however, it was decided to blur the lines between these strategies a bit to use both of them as sources of inspiration instead. The reason for this was to force the generation of a large quantity of ideas and to ideate in new way to open up for completely novel ideas.

Table 3.1: Matrix for brainstorming

10R/DFX	Phys. dur.	Reliable	Product care	Modularity	Upgrade	Emot. dur.	PSS
Refuse							
Rethink							
Reduce							
Reuse							
Repair							
Refurbish							
Remanufacture							
Repurpose							
Recover							
Recycle							

3.7 Defining the Problem

After the ideation phase a big variety of ideas were accumulated without any clear purpose for their application or relevance. The next step became to further narrow and define the scope of the project. Due to the time frame of the project it was decided to synthesize three concepts. The first concept was intended to fit Order Nordics current business model with relatively small changes to the design to make it easier for implementation in a shorter term. The second two concepts were intended to fit a more developed business model according to the CE with drastic changes to the design. The first concept was therefore called the realistic concept and the later two were called the idealistic concepts.

The three concepts were included to give Order Nordic reasonable alternatives to consider while also considering how the product could be developed further alongside the business model. As mentioned previously the ideal concepts were meant to fit a more developed business model. Developing this business model was out of scope for this project, but based on other cases and studies the general idea was that Order Nordic had more control of the product after the use phase. The ideal concepts were therefore based on the assumption that Order Nordic either implemented a resale model or in some way displaced the ownership of their products from the users to the company. This assumption further cemented some design strategies, such as robustness and modularity, which were considered due to previous case studies.

3.8 Concept Choice

After narrowing the scope and defining how to approach the problem, three concepts were synthesized from the ideation phase and the solutions generated through it. After concept generation there was a need to evaluate and compare the results to the current product. Due to the scope of the project, the concepts could not be tested in any way, but the design choices were based on literature and were partly validated by comparison to similar products. The lack of testing made physical prototypes less relevant, but CAD-models were still used to

visualize the concepts to show the changes made. Models were made and rendered in Creo Parametrics and helped in the next step of the process where qualitative analysis tools were employed to investigate potential improvements.

3.9 Prototyping

To evaluate concepts within circular development and the concept design phases, several tools have been developed by researchers. The tools either evaluate quantitative properties or use relative evaluation to compare concepts through ratings on the different principles of circularity. For a good assessment the two tools, the CirCit Nord Evaluation Tool and the Circular Concept Evaluation Tool were applied. There could be more fitting tools, but after scanning through over 60 tools these were chosen [Rexfelt and Selvefors, 2024].

3.10 Evaluation Tools

3.10.1 Screening of Evaluation Tools

The main source of evaluation tools were provided by Rexfelt and Selvefors (2024) where a screening of 65 tools was conducted [Rexfelt and Selvefors, 2024]. A list of the tools was provided accompanied with a brief description. The purpose and the expected outcome of each tool were described in the list which was the basis for the first screening where tools designed for anything but concept evaluation were discarded. The goal was to find tools designed to rate or in some way evaluate current products and new concepts based on circular requirements. Some tools were designed for a specific type of product, like apparel and furniture, and others focused on developing new ideas and concepts for either products or business models which was not in focus for this search. The first screening resulted in 10 tools listed in table 3.2. The second screening consisted of reviewing and testing the 10 remaining tools more closely, where the reason for discarding a tool can be seen in table 3.2 in the far right column. Mostly the tools were excluded from the project because it required payments or sign-ups that were outdated, required data that was unavailable or focused on irrelevant outcomes. Following the second screening CirCit Nord Evaluation Tool was the only remaining tool selected to be used for evaluating the developed concepts.

A general search as part of the literature study was conducted to find other evaluation tools to verify the results of the CirCit Nord Evaluation Tool and this produced the Circular Concept Evaluation Tool. The structure of the tool is very similar and is based on somewhat the same principles as the CirCit Nord. By evaluating the concepts through two similar tools it was thought that some bias could be eliminated. If the first tool would have been used a couple of times then the result would depend on what the user remembered they answered. By using a slightly different tool with similar questions that slightly vary in the phrasing the hope was that the user would disassociate the questions and answers from what they previously answered. This was done to remove some margin of error. During this search other tools were found through articles in the literature study, but the Circular Concept evaluation tool was the only one fit for this project. The other tools were tested, but deemed irrelevant due to wrong focus or requirement of unavailable data.

During the first part of the project one product had to be chosen without spending too much time on this. This choice was partly based on the evaluation of three products with the Circular Pathfinder. Due to the limited time assigned to this part of the project there was no extensive search conducted for an evaluation tool fit for this task. The general literature search supplied the project with the Circular Pathfinder which was the only tool found with right level of difficulty for this part of the project.

Table 3.2: Collection of potential evaluation tools following the first screening.

Tool Name	Purpose	Expected Outcome	Reason for Exclusion
Circular design radar chart	To reflect on how circular a product is in relation to 11 aspects using a radar chart.	Designs assessed; Strategies/guidelines prioritised; Visual representation created	Not available
Circular design toolkit: Ecodesign Assessment Product	To assess a current product, benchmark products, or compare ideas and concepts against a current product using a radar chart.	Designs assessed; Visual representation created	Data input unavailable
CIRCit Nord: Circularity assessment tool	To evaluate developed concepts based how well they fulfil key guidelines, resulting in a Circularity Score for each concept.	Designs assessed	-
Circularity calculator	To assess, optimise, and visualise the circularity of your products based on material flows.	Designs assessed; Visual representation created	Data input unavailable
Circularity check	To assess and score the circularity of products and operations across certain circular indicators using a checklist.	Designs assessed	Not available
A Design for Remanufacture toolkit	To assess an existing product based on remanufacturing guidelines, or design a new one.	Designs assessed; Ideas/concepts created	Not available
Disassembly map (FRI adapted)	To assess, score, and improve product repairability	Designs assessed; Visual representation created	Irrelevant focus and outcome
Nike circularity guide	To assesss current designs and explore circular and sustainable opportunities.	Designs assessed; Ideas/concepts created	Irrelevant focus and outcome
A Screening tool for Future Adaptive Design	To assess how well an existing design can resist obsolescence and to identify opportunities to make a design adaptable to future requirements to reduce risks of premature obsolescence.	Designs assessed	Irrelevant focus and outcome
The Use2Use Design Toolkit: Circular Designs Evaluation Pack	To assess and compare circular ideas and concepts.	Designs assessed	Irrelevant focus and outcome

3.10.2 CirCit Nord Evaluation Tool

The concepts had to be evaluated and compared to the current product to see if there had been any improvements and the first tool used was CirCitNord. To use the tool the user first had to study which circularity strategies were important for the project and then select which were relevant. The tool provided a guide for how to rate the importance of the circular design guidelines, seen in Appendix B.1. This guide provided the opportunity to avoid some bias and to make the evaluation in a structured way. After the rating of both importance and level of fulfillment the concepts received a score of the level of circularity of the design. The tool provided some charts and graphs to visualize where the concepts both needed improvement and where they excelled. The design guidelines included in the tool are seen in figure 3.2.

This project considered the DfX as the main basis of ideation and the 10R strategies as targeted requirements to fulfil. When looking at the CirCit Nord tool there is a clear resemblance between the structure of the CirCit Nord tool and this project. In the same way as the DfX correlates to the 10R in this project, the design guidelines correlate to the circularity strategies in the tool, seen in table 3.3. The circularity strategies represent the goals to achieve with the design guidelines as the tools. It was believed that even though the design guidelines and circularity strategies in this tool are represented in a different manner, they have identified the same areas of interest and problems to be solved. It was therefore believed that the tool could give a reasonable representation of the level of circularity of the developed concepts. It was also reasoned that if the purpose and the desired outcome of the tool was the same as for the project it was deemed to give a relevant perspective and evaluation of the concepts. The same reasoning was made for the Circular Concept Evaluation Tool.

CirCit Nord Design Guidelines

1. Focus mainly on functionality and quality performance.	16. Treat production (pre-consumer) wastes appropriately.
2. Think about activity supports in the operational stage.	17. Design for reduced energy consumption and usage of renewable energy.
3. Focus to fulfill the customer's requirements and value creation.	18. Design standardized components across different products and models.
4. Try to use digitalization, ICT and IoT solutions.	19. Design standardized tools required across different products and models.
5. Make it easy to inspect the product and components	20. Use durable and robust components and materials.
6. Make it easy to clean the product and components	21. Design in modular construction.
7. Make exchanging of faulty components easily accessible.	22. Provide manuals and documentation.
8. Make it easy to dismantle the product nondestructively.	23. Make spare parts and exchanging components easily available.
9. Think about boundary management.	24. Consider timeless design, emotional attachment and compatibility.
10. Think about incumbent configuration.	25. Investigate current and upcoming laws and regulations.
11. Think about complementary capabilities.	26. Use joints and connectors that can be easily opened and closed multiple times.
12. Design using renewable materials.	27. Minimize the number of different incompatible or dissimilar materials.
13. Design using recyclable and secondary (recycled) materials.	28. Make it easy to identify the materials and relevant information.
14. Consider toxicity and other environmental aspects of materials.	
15. Favor cleaner production, processes, machines and equipment	

Figure 3.2: List of the design guidelines included in the CirCit Nord evaluation tool [Shahbazi, 2020]

In figure C.1 the entire table of ratings of both importance of guidelines and results is being shown. The ratings have been done according to the prescribed rules of the tools. Originally, both authors evaluated the concepts independently, and then discussion led to consensus in the evaluation. It was found that strategies 9, 10 and 11 could not be covered by this project as they involved systemic changes to Order Nordic's company structure. It is believed that the rating would be similar enough between concepts to discard them.

Table 3.3: CirCit Nord Circularity Strategies

1. Rethink and reconfigure
2. Reinvent
3. Raw Materials and sourcing
4. Manufacturing
5. Product use and operation
6. Logistics and packaging
7. Upgrade
8. Repair and maintenance
9. Reuse
10. Refurbishment
11. Remanufacture
12. Repurpose
13. Recycle
14. Cascade
15. Recover

3.10.3 Circular Concept Evaluation Tool

The CCET tool worked by first answering a questions about the product type and the relevance of certain circular strategies. The questionnaire determined the level of importance of each circular strategy. The concepts were then graded on the level of performance which generated a relative circularity score, where the highest score indicated a more circular product design. The criteria which the level of performance was graded on is seen in figure 3.3.

Due to the nature of the Circular Concept Evaluation Tool, the evaluation had to be performed in two parts as can be seen in figures C.2 and C.3. The exact same input was used for the importance of each strategy and for the product describing part, but the Ideal Design 1 and Design 2 had to be put in separately. This was due to the fact that the tool only handles 3 concepts at the time. What is interesting to notice is the recommended Strategies: Raw materials and sourcing, Manufacturing, Logistics and Packaging, Upgrade, Repair and Maintain, Reuse, Refurbish and Cascade. Specifically Upgrade, Repair and maintain, Reuse and Refurbish were in line with the expected important strategies. In the Logistics and packaging the different versions were rated equally as to avoid unnecessary speculation in how distinct supply lines would be shaped, as this was considered outside the scope of the report.

Criteria of circular design strategies

1. Good environmental profile of materials
2. Minimization of material
3. Low impacting processes
4. Efficiency in production
5. Optimized logistics
6. Optimized packaging for purpose
7. Access to and availability of upgrading parts
8. Durability and timelessness of upgrading parts
9. Ease of diagnosis and repair of worn parts
10. Products longevity and maintainability
11. Durability and robustness of product
12. Ease of cleaning
13. Availability and compatibility of spare parts
14. Reversibility of assembly/disassembly process
15. Seperatability of materials
16. Material selection for cascading

Figure 3.3: List of the design guidelines included in the Circular Concept Evaluation Tool.

3.11 The Involvement of Order Nordic

During the project there was fairly little contact and collaboration with the people at Order Nordic. During the introduction of the project Order Nordic had some input on the choice of product and the general context of the project from their point of view. Later in the project when more specific questions had arisen and the better part of the three concepts had been compiled, a meeting was set up to discuss the following 6 questions. The starting point of the meeting were these questions, but the general structure of the meeting was more of a conversation and discussion surrounding the questions or any other points of interest.

Questions from meeting with Order Nordic:

1. Do you have any data on emissions concerning the production of the C3 Percolator? And is there data available of the environmental impact of specific materials or components?
2. How do you calculate CO2 emissions? And is this data available?
3. How much of the material is recycled?
4. Is it possible to make components out of wood instead? Or any other materials?

5. Biggest challenge with the “Ideal concepts”?
6. Do the concepts seem plausible?

Answers from meeting with Order Nordic:

1. When it comes to data on emissions and environmental impact, Order Nordic does not have access to specific data points concerning any individual product, material or component. The only data they have access to is on a much larger scale. They had calculated the emissions of Order Nordic as a whole and somewhat divided by brands, but it was concluded that the data they had available was irrelevant for this project. They did however say that they were going to investigate if this was actually the case, but did not get back to us on this. did not have this information available but would get back to us.

2. They did not have this information available but would get back to us.

3. The process of making any changes to products consisted of many discussions and negotiations with the production company, which made it hard to answer this question. Changing the handle from plastic to wood did however sound somewhat problematic, but not impossible.

4. The biggest challenge would be to alter the manufacturing method that they currently use. However, the plan is to gain control of the manufacturing of the C3 products in the future, which will enable them to make major changes. This would make the ideal concepts feasible, but because they did not yet know the conditions of this change, they were not able to point at specific problems or opportunities with the concepts.

5. As for the realistic concept, it would depend solely on conversations with the production company. The extended cable did however seem to be very plausible and of great interest. As mentioned during question 5, these concepts depend on the conditions of their new production, but at first glance they did not see any changes that would be impossible to achieve.

The general take away from the meeting was that most of the issues and questions put forward were hard to answer without direct contact with their production company. It was also clear that specific data on emissions and other environmental impacts caused by specific products were unavailable. This is not something to blame Order Nordic for because the acquisition of this kind of information can be challenging and Order Nordic is making efforts in making it more easily available. The digital pass product is one example of how this could be achieved. The questions they could not answer and would reply on at a later stage did unfortunately not happen due to the lack of time.

Chapter 4
Development Process

Here the steps of creating ideas and applying the DfX strategies to the percolator are presented.

4.1 Mind mapping Process

As presented in the Method chapter 3.6, after establishing the theory of DfX and what is needed realize the 10Rs, the projected proceeded into an ideation phase. The first step was the Free Brainstorming Process where the DfX and their design rules served as inspiration for prompts. The aim was to give specific shape and function to the more general design rules presented in the Theory chapter. In practice these Mind maps were drawn out on a white board, sometimes several prompts were connected to create larger contexts or combine solution categories.

4.2 Brainstorming Matrix Process

While the mind mapping process have many general ideas, a more structured way was then atempted. The brainstorming matrix was filled out individually by both authors and are presented in figures 4.1 and 4.2. Some fields were left empty, as no idea that seemed to bring in no apparent benefit was found. Many ideas were described in simple terms, some were more unrealistic than others. This was a result of deliberately accepting all types of ideas no matter how unrealistic. Afterwards the most promising ideas were highlighted in regards to how easy they were to implement and if they would have large or small impact. Worth mentioning is that the aim always was to apply the different DfX through the different rules presented in the theory chapter.

10R/DFX	Physical durability	Reliable	Product care	Modularity	Upgradability	Emotional durability	PSS
Refuse	One part, sous vide perc	Use what you have	Use disposable filter	Perc. attachment that works with the use a a container of any kind	Combine the function of the product with other home appliances	Potartable perc	Subscription for instant coffee that tastes like perc coffee
Rethink	Thermos. Non erosive inside	No electronics	Use excess heat for rinsing	Tea kettle function	Battery pack	Satisfying appearance change over time	Recycled coffee powder. share product with neighbors
Reduce	Mono-material, one part	External heat source	completely detachable inside in one part for easy cleaning	Coffee container handle + Kettle+ Heatsource+ cord	Parts critical for functionality are free to exchange if exchanged for old parts	One component. 3D printed for each user	Get money back for returning obsolete products
Reuse	Over dimensioned/ Over engineered	detachable electronics	accessible cleaning for dishwasher	Different handles	Big variety in handles. Second hand handle can feel like an upgrade if it looks different	Patina when used for long time	Second hand page on website
Repair	No threaded connections	Life-time repair guarantee. Detachable cord	QR-code with instructions for repair at home	No tools need for complete disassembly	Repairs = polish + "engraving" eg	Visible reparation	repair shop
Refurbish	Thicker walls, only metal	No electronics	No plastics, only steel and wood components to polish and sand components at home	No integrated electronics	personalization when refurbishing according to specific customer preferences	engravings	Tool kit for home-refurbish
Remanufacture	No plastics	Only steel			make a thermos of obsolete percolator	Create a completely new product of old obsolete product	Deposit for spare parts
Repurpose	No small connections	Function as a kettle if perc function stops working		Multi functional components. Wood stick for handle	components compatible with other brand	Create a new handle of an old product component found at home. Send in old product to be used in new product	Youtube channel or other media platform for exploring how to repurpose old products
Recover	Wood handle	Only steel and wood		Easy disassemble	Force to send back old components when upgrading		Home pickups of spare parts
Recycle	Only metal or clear plastics	Only steel	Instructions for maintenance and recycle on product	Mono material for each component	Clear PET handle		Collab with eg VASYD

Figure 4.1: Brainstorming matrix results

10R/DFX	Physical durability	Reliable	Product care	Modularity	Upgradability	Emotional durability	Attachment	PSS
Refuse	Home delivered aluminium can with coffe, heated on the stove	Dispenser built into a fridge with shared insurance	Collective care of one big machine, with tags and digital tracking of responsibility	Decentralize, brewing, boiling, grinding in different other appliances in the hoes	Subscription plan for parts and for increasing coffee bean quality	Coffee drinking club, make coffee together at set times and use a common machine	Barrista comes to your house with own equipment and makes it	Subscription to coffee shop in the block
Rethink	Massive welded steel handles to intensify use, never break	Stackable pots that boil at the same time	Removable heater to wash it off easily from coffee spots	Separate coffee holder module inside	Buy a centerpiece with more flow pipes	The dripping coffee adds to the aesthetics	Adjustable coffee filter strength	Rent or lease a percolator for a time
Reduce	Move the heater into the bottom of the jug to form one solid piece	Clear markings for amount of coffee and water needed to reduce waste	Easily removable parts to clean under, to reduce wear of each part	Increase or decrease the size of the pot when needed, stackable	Sell different heating plates for faster brewing times	Timeless visual design, the classic percolator	Aesthetic design, dents and wear adds to it	Rent and maintain broken parts for free
Reuse	The jug has a clean design that works as a water jug	A super wide pot that cannot topple	Spot for a decalcifying tablet in the holder for coffee	Power supply and lid match for different products, only they pot with the heater is exchanged	Aesthetic upgrades, new bottom, a cloth over the body	the product adapts to usage with a scalable indicator for coffee strength	Super intuitive non problematic mounting, no springperfect fit	Rent out clusters of products to collective living spaces
Repair	Every connection between parts is big, clear slide paths and interlocking	Matching symbols on parts and instruction manual	Clear colors show stains and imperfections to be cleaned	Easily detachable parts through snap fits and push in springs	Rented machines, hand in and get replacement while being repaired, able to try a different model	Make your own repair parts out of wood	biological look, looks hurt when not taken care of	Service place for repairing yourself
Refurbish	Made with a polishable steel surface to give a new look after each cycle	Heating element has an easy access point to be washed	Expanding top to reach down easily		Refurbish with higher quality components to offset value degradation	Refurbish cycle re establishes aesthetic identity with a new version	yearly check in with product, collect badges for doing so, claim badges for discount when buying new one	Comes with a digital counter to track usage
Remanufacture	The components have common shapes that appear in other products, like the kettle and jug	Collect and exchange parts regularly that customers cannot do themselves	Visible communication through the material choice, look windows	Only remanufacture lid and handle,	When you buy a new one, gain a discount for the parts you want to bring over from your old model	After remanufacture, the pot indicates that it has been used in this many cycles a sa selling point	Digital	QR codes on all parts for the post workers to track
Repurpose	The heating plate is compatible with other products, can be used as a mini stove	By being reliable the customer doesn't tamper with the electronics, easier to repurpose	An unscratchable surface lets the steel or plastic jug be used for something else	Flat bottom jug to boil coffee on stove, use heaters from kettles	Espresso attachment or the ability to make normal brewing coffee	Thermos only afterwards, remove handles	service online, check parts to be remade, free stl files	Resell between customers on a second hand app
Recover	Stackable shapes for easier recovery shipping		Complete disassembly for the customer, already		The parts that are replaced with upgrades are resold in other cheaper products	Wooden handle burn at home		Offer payment for material buyback
Recycle	A complete steel design of the same alloy	Separable electronics	Glass jug to recycle	Material group separation	The parts exchanged in the upgrade are easily recycled.			Wooden components are burned

Figure 4.2: Brainstorming matrix results

The most realistic ideas were gathered:

- (Rethink, Reliable): No Electronics
- (Rethink, Product Care): Removable heater to wash it off easily from coffee spots
- (Rethink, PSS): Satisfying appearance change over time
- (Rethink, Emotional Attach.): Adjustable coffee filter strength
- (Reduce, Physical Dur.): Move the heater into the bottom of the jug to form one solid piece
- (Reduce, Physical Dur.): Mono-material Parts
- (Reduce, Modularity): Separate Coffee Container+ Handle + Kettle + Heatsource + Cord
- (Reduce, Emotional Durability): Timelesss visual design, the classic percolator
- (Reuse, PSS): Second hand page on website
- (Reuse, Modulaity): Power supply and lid match for different proucts, only the part with the heater is exchanged
- (Repurpose, Reliable): Function as a kettle if perc function stops working
- (Repurpose, Emotional Durability): Create a new handle of an old product component found at home. Send in old product to be used in new product
- (Repair, Reliable): Matching symbols on parts and instruction manual
- (Recycle, Product Care): Instructions for maintenance and recycle on product
- (Recyle, PSS): Wooden components are burnt

The ideas above were the main ones being compiled into the three results presented below. The process was iterative, going through many changes and design variations before the final versions. As part of the development feedback was gathered from Order Nordic to make sure that the project was moving in the right direction.

4.3 Concept Development

When the brainstorming phase had generated a collection of ideas, the task was then to compose concepts of these. This was done by testing different configurations and discussing within the group how well the concept would perform. At one point, ideas were graded and scored according to their presumed improvement level, but this method was soon discarded. The highest graded ideas did not exclusively generate the best concepts and it was then decided that the composition of the ideas should also be based on the judgment of the designers. The work then consisted of compiling ideas and sketching the concepts which were briefly discussed and analyzed by the team to figure out the weaknesses and strengths. This process was iterated until a satisfactory concept was conceived.

4.4 Application of DfX

There are many ways to work with the DfX, especially when choosing how to prioritize and when to work with what aspect. While the first ideal design was conceived through a more iterative process, the second ideal concept followed a different structure. In this design, the work followed a linear path of application different DfX. This was used when designing the second ideal solution which aimed to be less functionally different to the original percolator design. The process started off with the specs and the sketch of the original percolator. It then proceeded to be redesigned according to Durability/Reliability, then Modularity/Upgradeability followed by Design for Product care and Lastly Emotional Attachment. Here the DfX were allowed to take more space directly in the design, however many of the ideas from the brainstorming was integrated.

The first redesign utilized the following rules from Design for Durability/Reliability

- Design with simplicity: A simpler shape was chosen for the spout and removed the see though knob from the lid.
- Simplicity in manufacturability: Welded simple steel handle
- Simplicity in manufacturability: The holes for the water-level reading was removed.
- Use wear proof materials: A thicker steel jug
- Allow for rough handling: Welded steel handle, wider bottom for balance.

The second redesign utilized the following rules from Design for Modularity/Upgradeability

- Create a modular base design: The handle returned to being screwed in place.
- Minimize types of connectors: Standardized M6 screws to fasten the handle
- Divide product into different modules, and put all the parts that need to be exchanged or upgraded into one single module: Collected the electronics of the power plate and heating element into one detachable container.
- Design core components with higher safety factors and reliability to enable future use: Welded on flanges for the handle to screw into.

The third redesign utilized the following rules from Design for Product Care

- Make it easy to clean the product and components: The jug was made to widen at the top.
- The surfaces to be cleaned should be smooth and wear resistant: Smooth steel and round shapes without cracks.
- The product must be safe to inspect and not include hazardous materials: The spring along the pipe was removed.

The fourth redesign utilized the following rules from Design for Emotional Attachment

- Consider timeless design, emotional attachment and compatibility: Redesigned shape to remind more of a classical cylindrical coffee press.
- Think about product attachment and trust between customers/users and products: The see through percolator top was reintroduced, but made out of glass to bring back a sense of wonder to the product.

Chapter 5
Results

Below the results of the work is presented. First the concept designs are presented in order of Realistic Design, Ideal Design 1 and Ideal Design 2. They are then followed by the scores from the CirCit and CCET tools are presented.

5.1 Realistic Design

The goal of the Realistic proposal was to keep the design and functionality very close to the original. Only the actual design changes to the original model are presented in isolation in this report. Any non-mentioned components are assumed to be left with the original design in place. This includes the jug, the heating system, the power system and the lid. As of now Order Nordic has limited control on the design, so by focusing on external design changes the ideas are left more easy to implement.

5.1.1 The Handle

Much focus was put into developing a new handle for the Realistic Design as it was deemed the easiest for alterations in the manufacturing. As per the request of Order Nordic it was investigated how plastic could be removed from the product and this remained the main driving factor in addition to the circular design principles. The two major parts made out of plastic were the electronic compartment and the handle. To redesign the bottom part, major alterations had to be made but the handle was connected with two simple connectors and easy to modularize. Below are three suggested solutions to the problem where wood and steel replace the plastic parts.

Screwed on Wooden Handle The first design combined wood and steel for a classic handle design and is displayed in figure 5.1. It is made from a thin steel sheet that has been cut and bent to form a handle shape. There are holes to allow anchoring with screws to the steel jug but also allow for the wooden handle parts to be fastened. The wood itself is attached akin to a knife handle, which makes it comfortable to grip and reduces heat transfer. Main benefits include great stability and simplicity in reparation as well as the avoidance of plastic.

(a) Assembled **(b)** Exploded

Figure 5.1: Screwed on wooden handle

Steel Bars Wooden Handle The second design was made to not utilize any screws and is displayed in figures 5.2. To do so two steel rods are bent and welded to the steel jug. The wood piece was designed with concave tracks on the sides to be slid down into position. This design too limits the amount of heat transfer from the jug. The thin metal rods aim to further reduce heat transfer. It also serves as a way to reduce the number of screws needed in the complete design at the cost of a more complex initial production. Another benefit by doing these changes is that the product receives a very specific look which may help it stand out on the market.

(a) Assembled **(b)** Exploded

Figure 5.2: Non-screwed on wooden handle

Steel Net Design This design, as displayed in figure 5.3, was made to be easy to manufacture and to use steel to replace the plastic. The common problem with a steel handle is the heat transfer increase which had to be dealt with. The design is anchored to the jug with two screws accompanied by two ceramic plates. The actual steel handle is made out of one sheet of metal. It is cut and bent into a handle shape and has several cut-outs to increase heat transfer through the metal. It would be possible to consider different patterns to manipulate

heat transfer, the comfort of the grip as well as the aesthetic design.

Figure 5.3: The steel net design with ceramic washers

5.1.2 Cable Alteration

Another consideration for improvement was to allow the cable to the charging plate to be detachable. This served several purposes including adapting the product to the user, some want shorter and others longer cables, making it easier to replace whenever it would break and also opening up potential for the cable to be used for other purposes.

5.2 Ideal Design 1

The Ideal Design 1 (ID1) concept was designed for a complete circular transition from Order Nordics perspective. It is based on several of the DfX areas focusing mainly on Durability, Product Care, Modularity and Emotional Attachment. The C3 percolator has been altered to a nonagonal shape reminiscent of a classic percolator design as shown in figure 5.4. Plastic has been minimized and the electronics have been removed and replaced by a multifunctional induction heat plate. The main design rules were robustness, modularity and ease of maintenance which resulted in completely modular design with no need for tools to disassemble the product. The amount of components were also minimized with a new internal mechanism and the number of materials used were reduced down to only two, excluding the heating plate. In figure 5.5 the complete exploded view is presented.

Figure 5.4: Ideal Design 1

5.2.1 The Jug

The jug was made of stainless steel, with a nonagon base and expanding top. The steel was selected for its durability, availability and the prospect of recycling. The steel will keep its shine, sustain decalcifying and is ultimately recyclable at the end of life. Attached to the base are two ears, welded in place to hold the handle. Each one has a hole for a standardized screw to make sure that anyone can repair the jug. To pour, an easy to clean spout has been designed without the closed tube. This means it is easier for all parts to be seen, inspect and clean when needed. Furthermore the choice of steel means the jug can be heated through induction. Markings to measure up water have instead been put on the inside of the jug, removing the window to reduce components and things that can break.

5.2.2 The Handle

The handle was changed to be made out of wood to tap into a completely renewable cycle of material. It was shaped into a hook configuration to allow maximum support for the hand. Common handle materials include oak and walnut for a premium feeling. Wood is preferable as a handle as it is heat isolating compared to steel and also softer to grip. To fasten the handle a bolt is screwed in place through the metal flanges welded to the steel jug. By making the handles easily removable they can be replaced or repaired by anyone and it would be possible to craft your own solution in case of need. When the product is collected for refurbishment this part can be replaced and made with a new specific design to indicate the last time it was collected and refurbished. Aesthetically the handle has a rough clear geometric design to appear as neutral as possible.

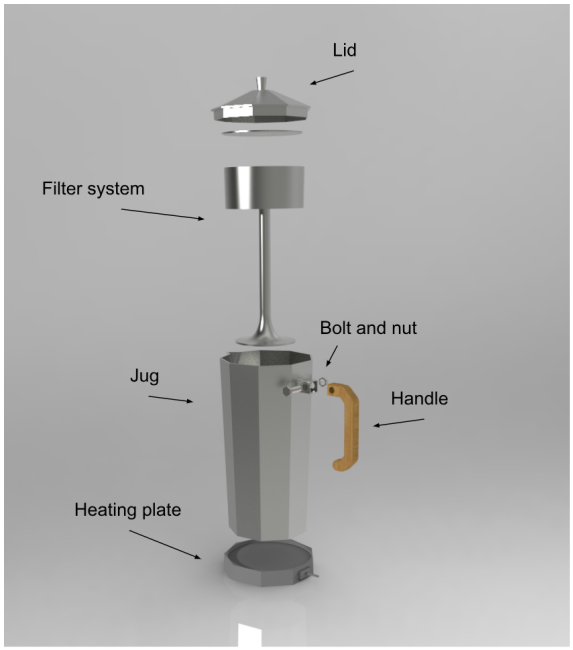


Figure 5.5: Ideal Design 1 Exploded View

5.2.3 The Lid

To match the nonagon shaped jug the lid has been made into a similar shape with converging plates moving toward a tip. A small cut had to be made on the side that pours the drink to allow coffee to pass unhindered. Primarily the lid has been redesigned to give a more interesting aesthetic impression. From the original design, the top knob made of transparent plastic has been removed and the knob is now a part of the body of the entire lid.

5.2.4 The Coffee Filter System

To make the percolator coffee there must be a circulation pipe and a container for the coffee grounds. Due to the expanding top of the jug shape, the container for the coffee ground was remade to have a slightly expanding shape. This means it can rest securely on the sides of the percolator. It also means that there is reduced risk of spilling coffee grounds outside of the container. The expanding shape also makes it slightly easier to clean out the container between uses.

5.2.5 The Heating Plate

The most radical change in this solution is to completely separate the electronics from the percolator jug. The main idea is for the jug to become a usable independent container post life to tap into the reuse and repurpose strategies. By having the plate separate it too can function as a separate application. Due to the pot not having any easy way of telling when the coffee is finished the changes have a risk of deterring customers due to the slightly less

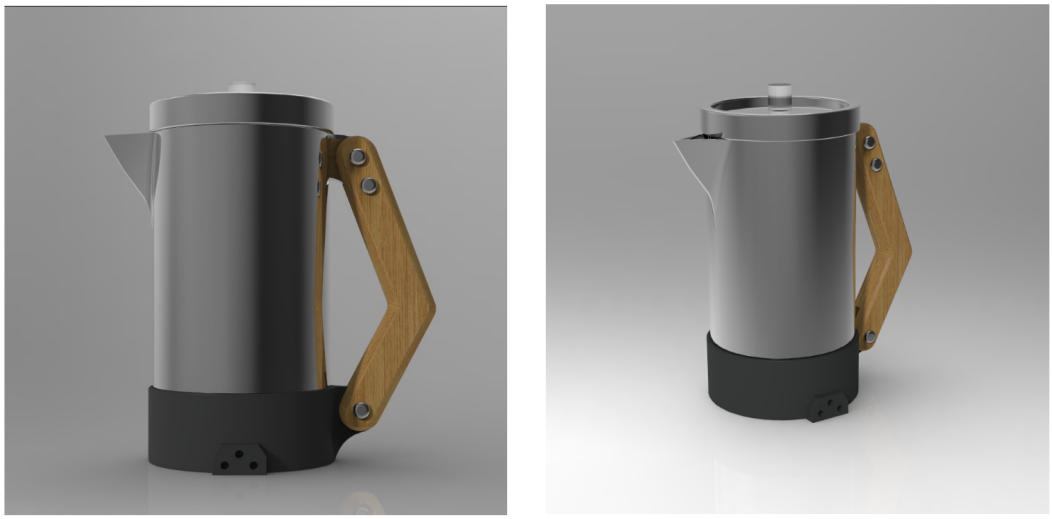
user friendly system.

5.2.6 The Bolt and Nut

The handle and the jug are connected by a bolt and a nut. They are supposed to be relatively big to make it easy to disconnect the handle from the jug without the use of any other tools than your hands. The bolt and nut are standardized and if lost or broken they can be purchased at most hardware stores, which incentivizes the users to repair the percolator on their own.

5.3 Ideal Design 2

The Ideal Design 2 (ID2) aspired to retain the original functionality of the percolator on a closer level. In this concept, a cylindrical steel jug was designed with indents to allow for the anchoring of a complete electronic/heating package at the bottom. Akin to the original design, all the electronics and heating is performed ”within” the percolator. At the same time the idea was to contain all electronics together and to create a module that could easily be replaced. To enhance the mechanical stability the handle was made to connect to the bottom plastic part with a screw as there otherwise there could be a risk of the resistance heater being exposed. This also gave the percolator a distinct design and identity. The knob is made out of glass, instead of the original plastics. The final design is presented in figure 5.6.



(a) View 1 **(b)** View 2

Figure 5.6: Ideal Design 2

5.3.1 The Jug

ID2 has a cylindrical jug containing 2 liters of water. It was designed to be made out of 2 mm thick stainless steel and to be punched from a metal disc in manufacturing.The spout was small and close to the top to be easily made by stretching the metal there, open to easily be washed as well. The jug has an attached metal ear at a 20º angle to allow the fastening of a handle via 2 M6 holes, fastened by welding so as to drill as few holes into the jug as possible. Two other important features of the jug were punched indents for water measurements (as to avoid holes) and also punched tracks for the locking mechanism connecting the electronic compartment to the steel jug.

5.3.2 The Handle

The handle has a bent design in wood and is screwed in place at the top at the steel jug and at the bottom in the heating component. Two screws were used at the top and one at the bottom into the electronic holding part. A main focus of the handle was to make it easily exchangeable, to communicate clearly to the user how it is connected but also to allow for increased stability; ideally easily replaceable screws could be used from any source such as a hardware store.

5.3.3 The Lid

The lid was designed to be a simple disc, easy to clean and to follow the general theme of cylindricity. Once again stainless steel was to be used to guarantee resistance to corrosion and wear. The top knop is also to be made out of a glass to give a good indication of when the coffee is brewing and attached via tracks to easily be replaceable when remanufactured. It is assumed that this is an important part of the product usage and something that consumers use to see if the product is working properly. To enhance the gripping experience, the knob is ribbed.

5.3.4 The Coffee Filter System

The percolator coffee filter system would be made out of stainless steel to survive for long periods of time and be slightly larger in size to fit the wider diameter of the jug, but also to become sturdier. Like in ideal concept 1 the components are made into one piece and do not use the extra spring from the original design.

5.3.5 The Bottom

The main design focus of this solution was to provide an easily removable electronics module to be sent in to repair, but still be able to attach to the percolator to work as close to a normal electric percolator as possible. To do so the original solution with an extra black charging plate was replaced by directly sticking the cable into the bottom of the jug. The bottom contains many pieces but was made to have an ABS case made from injection molding, matching the outer circumference of the jug. It would be molded with an ear to attach the handle to. The case also holds the power switch and a plug for the power cord. Two protruding edges matched the indents on the jug to create a slide and twist lock to lock the component in place. To be able to serve the coffee from the percolator, the power cord is detachable and this also serves as a modular design option. It is possible to sell different lengths of cable and to exchange it easily if it is broken.

The original design has the aluminum clad heating element in direct contact with the inside of the jug through a hole, but in this redesign the bottom of the steel jug is dented but

kept intact. The aluminum element is in contact with the outside of the convex shape. The bottom also has a plastic ear going up on the backside of the steel jug to which the handle can be attached with the M6 screw.

5.4 Evaluation of Concepts

5.4.1 The CirCit Evaluation Tool

The evaluation of each concept according to the CirCit evaluation tool produced the results seen in figure 5.7 and 5.8. The relatively high score of the original percolator indicates a lack of circularity in the design, whereas the descending score of the other concepts indicate an improvement towards a circular design. Figure 5.7 shows the score of the design guidelines individually for each concept. The score is based on the importance of the design guidelines and the level of fulfillment and the chart, in figure 5.7, displays what areas need more work. According to CirCit Nord the individual score of each design guideline corresponds to the following recommendations, seen in table 5.1.

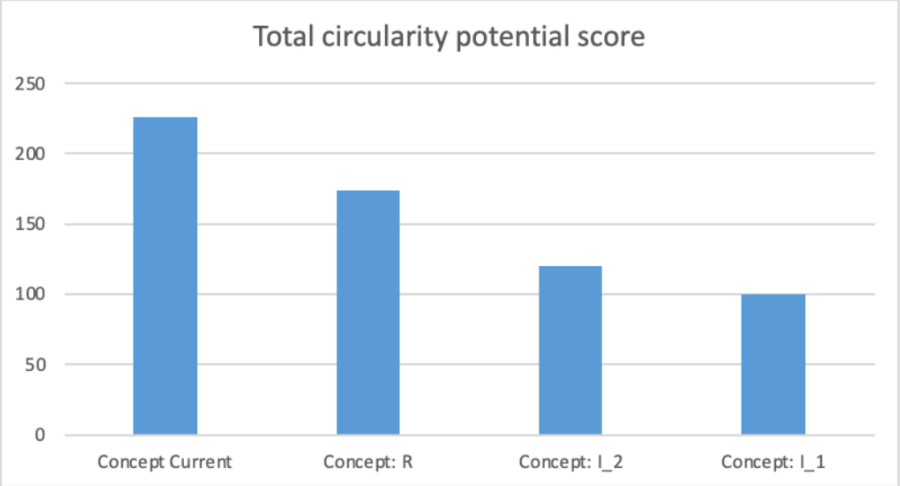


Figure 5.7: The score of potential for circularity for each concept.

Table 5.1: Advised action to take according to CirCit Nord for the respectives scores

Potential circularity score of design guideline	Recommendation
15	Improvement is vital and imperative
9-10	Improvement is necessary
5-6	Potential for improvements
1-3	No change required
0	Not a concern

In figure 5.8 it can be seen the chart generated by the CirCit tool which shows the specific score of the design guidelines. The y-axis shows the score with the corresponding design guideline on the x-axis, which are in the same order as in figure 4. Some notable things we can see in the chart is that there was no change in the value of design guideline nr.4 (try to use digitalization, ICT and IoT solutions), otherwise a gradual improvement across the new concepts with concept I_2 performing the best. Another thing to consider when looking at the chart is that design guidelines 9-11 are examples of guidelines that were considered irrelevant and that is the reason for the low score. The score of design guideline nr.22 was considered to be very important with a high level of fulfillment which also resulted in a very low score. Therefore, the only points of interest are those with high scores which can help understand where further improvements are necessary. Considering this we now see that the design guideline nr.4 is the main area to focus on for continued work in the future. A deeper breakdown of the results are provided below.

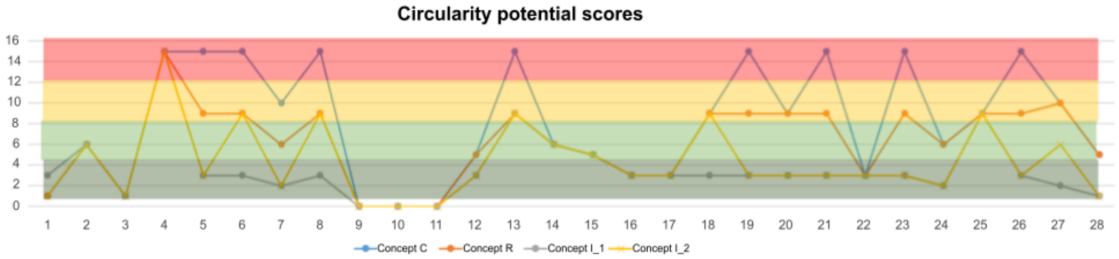


Figure 5.8: Score of potential for circularity of each design guideline.

Current Design

The current design was included to be the benchmark of the evaluation. It had overall higher scores, and sometimes equal scores compared to the improved alternatives. As per the function of the tool this means that there is a lot of room for improvement in areas deemed very important by the design strategies. The most important areas of improvement were nr.4, 5, 6, 8, 13, 19, 21, 23, 26 in which it received the maximum score of 15. nr.4-8 relates to disassembly and maintenance of the product. nr.21 had to do with designing in a modular fashion and nr.23 the exchange of spare parts.

Realistic Design

The initial improvements in the realistic redesign, by which the handle had been modified, saw the largest improvements in nr.5-8 and nr.18-19. Number 5 and 6 was the ability to clean the product and inspect it. Nr.7-8 related to the disassembly and access to faulty components rated at nr.6 and nr.8 respectively. Nr 14 (Consider toxicity …) and 20 (use durable and robust components …) were things that did not improve drastically. Nr.14-17 were not improved in this design, which were the same for the other concepts.

Ideal Design 1

Ideal Design 1 was considered to have a few greater improvements in areas 5-8 scoring 3, 3, 2,3 respectively. For nr, 18, 19, 20, 21, 22 and 23 an overall score of 3 was reached which means a large improvement in those areas. The improvement on aesthetics is noteworthy. In 14, 14 and 16 the designs were considered still on the same level as the original and realistic design with scores 6, 5, 4 respectively.

Ideal Design 2

The second ideal design showed similar trends to the first with improvements in areas relating to modularity 5-8 but to a lesser extent in some cases. The slight advantage found was in case nr 1 relating to functionality and quality. As the design was made to be close to an original percolator. Like the other designs it performed well at nr.3 (focus on fulfilling the customer's requirements and value creation).

5.4.2 The Circular Concept Evaluation Tool

The CCET presented the results of circularity as % achieved rating in the different strategies as well as a final relative circularity score. Due to the nature of the tool the Ideal 1 and Ideal 2 concepts had to be separately compared to the Current and Realistic design concepts. It was found that the Current Design had a 13% score, the Realistic Design had an 18% score, Ideal Design 1 a 36% score and the Ideal Design 2 a 30% score. Results are summarized in Table 5.2. tagit bort referens

Table 5.2: Results from the CCET evaluation.

Concept:	Current	Realistic	Idealistic 1	Idealistic 2
Relative circularity score:	13%	18%	36%	30%

Current Design

The original concept ended up with a low Circularity Score of 13%. This is a measurement of captured circularity in relation to the strategies that were inputted as the most important. It got scored higher in the Repair and maintain strategy, 50%, in which the ease of preparation and the longevity was the main things analysed. The tool found the greatest weaknesses to be in relation to Cascading, usage of degraded material, in the refurbishment and in the upgrade strategies 17%.

Realistic Design

Following the first improvements inside of the Realistic Concept, there was a slight improvement in the Relative Circularity Score from 13 to 18%. Most improvements were judged to be in the Repair and Maintain, Reuse and Refurbish strategies indicating that strategies for Slowing the Loop were working. Specifically it was rated higher on the ability to judge and inspect damages, and the ease of cleaning. However, 18% is still a relatively low score for the tool indicating that there was more work to be done.

Ideal Design 1

As for the Ideal Design 1 there was a general increase in all fields outside of Manufacturing and Logistics. It had a final score of 36%, more than double of the original 13%. It made great progress in using better materials, indicated by the higher rating in 'Raw materials and sourcing' with an 83% achieved potential score. The greatest improvements were in relation to Repair, Reuse and Refurbish reaching 100% of the potential rating in each case. The cascading improved somewhat as it was judged that the new design made it easier to separate materials.

Ideal Design 2

For the idealistic concept a total relative score of 30% was given. The final concept also saw improvements in regards to Repair, Maintain, Reuse but was said to have a lower rating on the reversibility of the assembly/manufacturing. In regards to the raw materials it was judged to be on par with concept 1 as in the case of manufacturing and the logistics/packaging rating.

Chapter 6

Discussion

This chapter discusses the results and methodology of the thesis. The achievements and flaws of the project are discussed along with areas where further investigation is needed.

6.1 Evaluation Tools

6.1.1 Circular Pathfinder

In the early stages of the project, selecting the right product to develop was integral. This was a choice that had to be made with relatively little knowledge of CE-strategies and thus a simple tool was very useful. IDEAL&CO are behind the development of the Circular Pathfinder as part of a European FP7Rescom [IdealCO, 2024]. FP7Rescom is a project to help companies with similar evaluation of their own products. What made this tool special was that it also was developed by company and not academia possibly making it more industry accurate. The main critique of it lies in the simplicity, as the method only uses 6 variables (see table 2.1) even with the 10 questions and that the terms are defined somewhat unscientifically [van Dam et al., 2017]. However, the need for accuracy in the first selection was not necessarily that high, as the products chosen between were endorsed by the company and the results are still very generic strategies. From the results, all the products could benefit from 'prolonged life', which was the main focus of the project. The most interesting difference was that the vacuum cleaner was recommended to be 'Repaired' while the Percolator was not. This was probably due to one question regarding if components wear out in which the percolator experiences less friction and abrasion compared to the vacuum cleaner.

6.1.2 CirCit Evaluation Tool

When evaluating concepts developed by yourself there is always a confirmation bias but certain mechanisms of the tool enables the user to exclude some of that. The tool forces you to do research beforehand and choose what areas are most relevant and important for your product. The tool then instructs you on how those choices correspond to the scoring of each design guideline. This erases some bias by not basing the scoring on intuition and feeling, which makes it a bit more trustworthy even if the evaluation is done by the same team that developed the concepts.

Compared to other tools developed for the same or similar purpose this tool was very fitting for this project and aligned very well with the research we had already done. It was one of the few tools found that were applicable for both the old product that had been on the market for a while, and for completely new concepts. Considering that it was desirable to compare an old product with our newly developed concepts, it was possible to find some commonality to base our comparison and evaluation on through this tool. In general, the tool was based on the same design guidelines and strategies as we had considered when developing our concepts.

6.1.3 Circular Concept Evaluation Tool

The Circular Concept Evaluation Tool is a practical tool to use to get a quick and brief understanding of how concepts compare against each other from a sustainability point of view. It does not require extensive research or data on the products to use, but the grading system is fairly limited. The benefits of being quick and easy comes with the clear drawback of shallow and somewhat unreliable results. For this project the products were designed to specifically achieve circularity goals and by using this tool to grade the new concepts it really gave a sense of confirmation bias. Even though the result is the same as for the CirCit Nord tool we reason that this tool should only be used as a starting point or a supplement in combination with other evaluation tools or methods.

6.2 Further Ideation

After evaluating the concepts it was realized that there was one area which we had completely ignored, which was digitalization. The reason it was overlooked the first time ideating was probably due to the relatively low tech product that was considered. When we got the results from the evaluation tool it helped us realize that we probably should have considered digitalization too. This is a clear example of the benefits of evaluating your concepts with similar tools as were used, because it helps you look at your progress from a different perspective.

The time frame again limited us from completely pursuing a new ideation phase and creating new concepts, but it is clear that this should be done in the future if the work continues. We did however conduct one short session to ideate with the idea of how we could digitalize

our new concepts, which resulted in a fair amount of new ideas to investigate if we would have had the time. This consisted mainly of ideas regarding digitalization of the product and systems surrounding it, which are listed in Appendix A, figure A.8.

6.3 Challenges with Implementation of Changes

After developing the concepts they were presented to Order Nordic to discuss how viable the implementation is in relation to their current situation. The changes suggested mainly relied on changing the design of most components which would require Order Nordic to have an influence in the manufacturing of their products. Currently they can negotiate and demand certain changes but the manufacturing company has the final say in if the changes would be possible. The answer from Order Nordic was that some changes might be possible in the near future, but that it depends on what the manufacturing company can manage. However, Order Nordic explained that in a couple of years they would have more control over the manufacturing and that remodeling would become a more viable option.

There has also been a desire to calculate the environmental impact of the different components and materials, but the specific data needed to do these calculations were not available through Order Nordic. The most basic assumption that could be made was that the elimination of plastic and replacing it with steel and/or wood would have a positive impact on the environment. Order Nordic agreed and saw this a desirable direction to move in.

In this project there has been limited focus on the concept of creating a product as a service, but in the interview held with Order Nordic this was touched upon and it was agreed that for this kind of product it would be hard to accomplish in an efficient way. The main reasoning was that the product is not expensive enough for people to feel they want a subscription instead of a direct purchase.

6.4 Concept Analysis Realistic Design

When designing this concept the intention was to make the changes as easy as possible for Order Nordic to adopt and implement. We figured that the part which required the least amount of manufacturing control to alter, besides the cable, was the handle. The bottom part of the jug and power supply of the percolator would need major intervention in the design and manufacturing to alter, which made changes to this part implausible for this concept. The handle, on the other hand, was connected with two bolts which made it relatively easy to exchange for a different version without having to alter any other part of the percolator. This led us to design three versions of a new handle where the main focus was to make it more robust, consist of less plastic and enable easy assembly.

The second alteration made to the original design was to make the cable detachable and available with different lengths. Cables usually have a much shorter expected lifetime and by allowing customers to replace a broken cable instead of the entire power supply unit we reduce the amount of resources needed to prolong the lifetime of the percolator. The ability to purchase different lengths of the cable falls in line with designing for upgradability which could increase the customers perceived value and postpone obsolescence.

6.5 Concept Analysis Ideal Design 1

When designing the Ideal Design 1 version, the main design strategies were robustness, modularity, emotional attachment and easy maintenance, but there was no rigid system to decide what parts were designed with what design strategy in mind. Design choices had to make sense and we tried to take everything into consideration when deciding if our ideas were plausible or not. The parts have been designed with either one or many different design strategies in mind, but every part has been thought through and serves a clear purpose. It is still unclear in some regards if any of the ideas are as effective as they are supposed to be, but this concept is only an example of what circular product design might end up like. Testing this concept with customers is absolutely necessary to see how viable it is and if it would help Order Nordic in becoming more fit for a circular economy.

The jug is designed to make it possible to stack many jugs within themselves to make shipping more efficient. The nonagonal shape of the percolator is inspired by a classic percolator to create a more timeless design. A hollow square shaped extrusion is supposed to be welded on the side for connecting the handle with a fairly large and standardized bolt and nut. Larger bolts and nuts create a sturdy construction while also enabling the customer to remove the handle with common tools or by hand. By using standardized bolts and nuts customers will be able to replace them by purchasing new ones from common hardware stores.

In the old design the heating mechanism and electronics are integrated into the jug itself which makes it nearly impossible for the customer to disassemble it in a safe way or without destroying the inner mechanisms of the percolator. The thermostats are connected with some kind of paste which was compromised the moment we disassembled the percolator, which makes it clear to us that it is not meant to be taken apart. If the customer would have any problem with just the metal jug or just the bottom part with all the electronics then they would have to send in the entire product to get fixed, but with our concept the heating mechanism is completely disconnected from the jug. The idea is to isolate components and make them more modular and independent from each other. Instead the percolator would use a common heating plate for the brewing which creates a few inconveniences, but the new system is based on models from other brands which confirms its viability. Testing with prototypes is still necessary, but due to the simple nature of the concept we can assume that it is possible.

One goal was to minimize the amount of different materials and especially the amount of plastic that was used. The idea of using almost no plastic in the design was something that

Order Nordic agreed with which resulted in a design which only utilized steel and wood for the percolator itself. The design of the heating plate is still not solved which could result in need for plastic in that design, but since that part would be separated from the rest of the product it could still be seen as an improvement. By only using two types of materials which are easily separated when disassembling we enable both Order Nordic and their customer to reuse, remanufacture or recycle the materials.

We wanted to create a product that was both easy to use and maintain for the customer. The first thing we knew would help was to create a modular design so that individual parts could be exchanged or repaired instead of the whole product. The first thing we wanted to change was the handle because it required specific tools to remove and it consisted of many small components which we felt were unnecessary. Instead we designed a handle from one part that could be mounted with a standardized nut and bolt without the use of any tools. The simple shape of the handle and the connection point was meant to incentivize customers to replace it with whatever they wanted, a completely new handle or a home made one if the first broke. Personalization of products has proven to increase the emotional attachment to them which in turn often increases the lifetime of products and we wanted to give users that option. Secondly, the separated heating plate makes it possible for the user to wash the percolator in the dishwasher.

6.6 Concept Analysis Ideal Design 2

As was the main directive of the report, longevity and stability stood as the driving factors in the design of Ideal Design 2. The strategies of Reuse, Repair, Refurbish and Remanufacture were the main guiding principles. Reduce was reached through the increased durability and the choices of materials. In regards to the theory discussion it was found that steel as the main body already was a good solution here as well. It is recyclable, has reasonable emission to life time values and is not harmful to humans.

Ease of reparation was reached through modularization of the handle, top knob and the electronics components in the bottom. Due to the complications of stocking specific electronics to send out to customers (as Order Nordic's Manufacturers will not allow it), being able to separate the bottom means it can be shipped with reduced weight and volume. Encapsulating the electronics also increases the safety for the next consumer as the chance is reduced for someone to have interfered with the wiring.

Starting off with the jug, the Design for Durability & Reliability was the most clear DfX to follow, as the jug is the main structural component in the percolator. The guidelines from the literature study that were implemented were to design with simplicity, for simplicity in manufacturability, minimize toxic materials and proper material selections. A general attempt was made to reduce the amount of fasteners, but a conflict arose with modularity. The rules not followed were related to minimizing the variety of materials, a result of striving to minimize plastic. As for modularity the jug with its M6 connection point is modifiable with different handles. As no holes have been made in it, the jug can also be repurposed as

other types of containers. Reliability has been thought of with the wide spout and the angle of which the handle is fastened to the percolator. Not being able to pour properly would quickly lead to customers growing tired of the product.

As the product was intended to work for a long time, Design for Product Care also became important. It meant designing both to make it easy and rewarding to care for the percolator. The most simple rule "Easy to Clean" was implemented through the ability to remove all electronics before washing. The metal jug is smooth without crevasses in which coffee grounds can get stuck. Another important aspect was the ease of dismounting the handle to be able to clean and oil the wood. Choosing wood as a material was also a careful consideration, as it will have to be maintained and polished to continue to look good. There would however be a problem with keeping the seal between the jug and the electronics container free from water and dirt.

Modularity has primarily been implemented in the localization of all electronics into one bottom compartment. This was a type of simplification of the product structure, as per the DfX recommendations. By removing the button and the power transmitter base plate to the percolator itself things are both concentrated and spread out. It allows for upgradeability. Modularity was also in mind with the handle design due to the simple anchoring with bolts. What Ideal Design 2 struggles with is its inability to function partially without some components. An ideal development would be to shape the handle and the connection point of the plastic bottom to connect higher up, so the jug could stand flat without the electronics compartment attached.

The emotional attachment aspect was also considered. Tying back to the Literature Study, different design theories to invoke Product Care behavior and creating long lasting bonds were studied. Those realized in the actual design pertained to seeing the machine work. Concepts like materiality and integrity which were introduced under customer behavior were considered. Percolators have a robust image already and the wooden handle was chosen to increase the nice feeling. There is also already a built in narrative in how the percolator functions with a see through knob which gives both wonder and clarity to the one observing the process.

6.7 The Circular Breakdown of Ideal Design 1 and 2

As discussed in the theory, a circular product is only partially its design, but also the business model, the upstream and its cascading capabilities. While this project primarily focuses on the exact product design, which developers can impact the most, none of these changes exist in a vacuum. Below the expected compatible models are explained for this design.

6.7.1 Up Stream Paths and Cascading

ID1 and ID2 have been created with longevity in mind, starting with the innermost up-stream path, repairing at home. By using standard M6-screws for the fastening of the handle together with clear guides for placement it becomes easy to do. Order Nordic can keep their own supply together with extra knobs for the lid and more wooden handles to replace old ones. This is the first step of home reparations that the product has been designed for. When it comes to communication there has to be clear instructions in the manual for where to go for new parts.

As was the main point of ID2, the electronics compartment can be separated and sent in itself to a repair shop for closer inspection and repartition on a level not available to people at home. The same goes for the induction plate in ID1 which means transport costs and emissions are reduced by minimizing the mass that has to be shipped. This also means newer updated electronics can be shipped when more energy efficient solutions have been found. If needed an entire new bottom can be sent out to the customers, or alternatively an already repaired second hand one. This would reduce the time of waiting for the customer. If the plastic casing is broken the heating element could be saved and re-installed.

After a set amount of years the product is repurchased to be refurbished and resold. Primarily this would involve collecting and cleaning out the stainless steel jugs. Remanufacturing will have to be performed on the wooden handles to give off a fresh feeling, either grinding and repolishing of complete replacement. A potential way to increase this with the idea being that a new color signifies a new recycled generation. This is also a chance to investigate and test the bottom electronics and replacing heating elements and so on. When shipping the metal jugs they can be stacked on top of each other easily due to draft angles from the manufacturing process.

Components will degrade, some break without being repairable. For the wooden handles they will be collected and incinerated or alternatively broken down for repurposing. Wood belongs to the biocycle together with the coffee grounds. The tip of the jugs can be cut off to create simple steel cups without any holes and these can be used to manufacture new smaller percolators of similar models used to send. When it is too stained the metal of the jugs are to be collected and recycled for new steel. The most complex waste is the electronic components in the bottom of the percolator.

6.7.2 Business Model

From the archetypes of CE business proposed by CirCit, the matching model idea was to sell a high value product that lives for a long time. In this report a system of circularity is proposed to be achieved by offering easy access to spare parts at discounted prices if the broken parts are returned to the manufacturer. The customer then has the ability to sell back the product to Order Nordic in exchange for a newer model or discount in the shop. Collection happens through certified electronics shops or direct shipping to Order Nordic, using their already established logistics network. Order Nordic would then evaluate and refurbish the product for reselling on a second-hand market.

6.8 Considerations of the DfX System and Conflicts of Design

This project has followed a united set of circularity and design frameworks, taking the first steps from the Ellen MacArthur Foundation definitions of Circularity, honing in on Slowing the Loop design and then finding the DfX supported by literature that is used to get the results of prolonged life of the product. Five major DfX were applied and compared with the different circularity strategies. Below the process and effectiveness of each rule-set is discussed and evaluated to help future designers apply them more efficiently. Not all DfX are useful in all cases and in this work it has been discovered that defining the specific circularity goals of the product is integral, even from an early stage in product design.

6.8.1 Design for Durability and Reliability

The literature proposing these DfX as useful for Slowing the Loop argued that physical durability would be a main component. Stronger components with a reduced chance of breaking would lead to less waste and less reparations. In the design of percolators the implementation typically manifested through material choice (designing with steel over plastic), but also through product architecture. When generating concepts in relation to the 10R, the trend was either to design with over dimensioned handles and connections, to suggest usage of extra amounts of material and non-corrosive materials. The common trade-off was more intense costs/resources in production and transports compared to the saved materials from additional use cycles. Overall it was easy to implement these rules in the design. Reliability from the perspective of making good coffee has been hard to design for, as taste is subjective and this paper does not dive into the intricacies of making good coffee. The main idea has therefore been to keep the functionality as close as possible to the original model.

6.8.2 Design for Upgradeability and Modularity

Modularity became one of the most driving DfX for this product. By moving components with similar life spans into the same modules, making them easily removable they can be replaced and shipped for remanufacturing. For the percolator the steel jug became the central long living product, while modularized handles and heating systems became common trends in the design work. Modularity often caused reduced durability in the joints as well as the increasing amount of connecting components. Upgradeability became less relevant in a performance sense as percolators have been around for a long while and do not run the risk of becoming obsolete. As for future circular design, modularity and upgradeability will be important aspects for these very reasons.

6.8.3 Design for Product Care

The product care DfX takes into account the psychology of the user and was an interesting point to investigate. General rules dictated that crevasses and cracks were to be avoided, to make areas easily reachable to clean and to use materials that could withstand the chemicals of cleaning. This project found that designing for accessibility was easily done, but implementing more advanced psychology to make users maintain their wares, as the one proposed in the literature study the was harder. This has to do with the rules not having concrete design rules but rather being goals of design. Information and Enabling were the two main principles that actually were successfully implemented.

6.8.4 Design for Emotional Attachment

Similarly to the Product care development DfX, emotional attachment is focused on customer perception and bonding. This was challenging to implement as there is less of a clear way to check if the product actually became attachable. It was difficult to come up with ways for customers to adapt the products visually, but by using simple designs the intention made it possible to present a timeless feel. There was a conflict between designing more extravagant solutions and ways of making coffee, as they would risk falling out of style faster and also appealing to less people. When planning for the product to be resold several times this is not ideal. At the same time it was considered to use a specific design to symbolize or communicate that this is a special circularity focused product.

6.8.5 Design for Dematerialisation and PSS

A common thing in Circular design is to rethink the product itself, working to transform it into a dematerialized service. In the brainstorming phase such ideas were considered briefly, but in this project the objective was still to produce a percolator. Instead the concepts of Internet of Things and using electronic services, apps were considered. The trade off became that of making an electronically advanced product adds components and also increases the cost of maintenance as some sort of software would have to be developed and maintained. Generally it has proven more interesting to move toward simpler solutions that work more reliably for longer periods.

6.9 Evaluating Research Questions

In the beginning of the report the research questions that the projected aimed to answer were defined. Below, the different questions are answered and discussed based on the findings of this report.

6.9.1 DfX relationship to Slowing the Loop

In the initial phases of the work, the question "Which DfX strategies relate to slowing the loop in the context of circular economy?" had to be answered. Through the literature study it was realized that there were several perspectives, but most agreed that the Design for Durability, Design fore Reliability, Design for Maintenance, Design for Modularity, Design for Ugradeability, Design for Emotional Attachment, and Design for Dematerilization. They either focused on making the physical product serviceable for as along as possible, or to fight obsolesce by creating relationships. Through the practical design work and evaluation it was then realized that aspects relating to Design for Durability, Design for Maintenance and Design for Modularity were the main drivers in improving circularity for this product. When it comes to Design for Emotional Attachment it is still unclear if any improvement has been made.

6.9.2 DfX Conflicts

As part of the work there was an idea to document potential conflicts in the discovered DfX perspectives ("What conflicts arise within the design framework when focusing on one set of DfX rules?"). This has already been elaborated upon earlier in the text, but conflicts mainly arose between Designing for Durability versus Designing for Modularity. By introducing new interfaces or making the section detachable, the general structural strength was reduced in the percolator.

6.9.3 Matching Circular Strategies to Products

Question three in the report,"How does one match product types to circular design strategies?" also had to be answered early in the work. It was found that the easiest way to match strategies is to use design tools that take the current product's expected lifetime and reusability into account. In this case it meant using the Circular Pathfinder tool.

6.9.4 Circular Percolator Design

For the question of "What is needed for a percolator design to become circular and long lasting?" the design study gave the following general answers: The percolator as a product would primarily benefit from increased lifetime and the Slowing the Loop strategy. To make this possible the percolator has to be reshaped to have a more durable design. Brittle plastic in the handle is replaced with wood that also integrates into the bio-loop. Modularity is applied to sensitive components that greatly impact the performance of the product, focusing on the heating system and the handle. By making the electronic components separable they are

easier to ship to reparation firms and the modularity means that consumers can re-assemble without knowing anything about electronics.

6.9.5 Realistic and Ideal Designs

Lastly, the report set out to answer: "How does an easy-to-implement design look in contrast to a perfect circular design?". The answer relates to how much the product architecture and use pattern can be changed and how easy the changes would be to implement. Earlier in the report it was established that Order Nordic desires to transition into circular product strategies, but only have limited control of production possibilities when it comes to specific designs. As a result, a realistic circular design ended up targeting specific components that had affect on the total lifetime, but could easily be mounted on the original jug design. More ideal designs focused on separating the electronics into one module and to change the way the product is used as part of the circularity improvement. Ideal Design 1 worked more similarly to an older model of percolator with separate heat source. Ideal Design 2 kept the heating tied to the jug and removed the separate power plate completely. These were larger steps away from Order Nordic's design and gave completely.

6.10 Future Work

6.10.1 Detail Design and Prototype

In its current state the project is still highly conceptual and future work would focus on realizing the design, taking steps towards an actual prototype. A natural continuation would be to focus on making a detailed CAD-design with a complete bill of materials and tolerances. It would have to be made with the rules of EU home electronics in mind. An actual prototype could then be tested to verify if the usability and the aesthetics of the original percolator has been kept/improved even with the circularity features added. Such an evaluation would help confirm qualitative elements of design as well.

6.10.2 Material Investigation

A problem with handling circularity by prolonging the loop is the consideration that has to be made in regards to environmental pay-off in the material choice. As explained in the theory chapter, oftentimes more advanced and optimal materials require more energy to manufacture, but such costs may be offset by having the product endure several life cycles. There are several questions to have in mind when choosing materials. A more thorough investigation of actual life time/use cycles compared to energy and resource costs/emissions in production would be necessary. Especially interesting is the incorporation of wood in the handles and to see how each individual user's experience and willingness to care affects the first and second hand value. Wood being a bio-material, degradation and decomposition is not necessarily that problematic, but creating new handles for each sale is not a solution and thus not necessarily an improvement.

6.10.3 Business Case Development

It would be possible to define an even better business case for Order Nordic with more information in hand about the percolator such as its production difficulties and expected lifetime. Ideally, a complete circularity business method, like CirCit's tool, would be employed to define value capture and generation. In this report the major focus has been on product design and not business models, but complementing the work would be necessary. In such a case, CirCit proposes starting off with generating the circularity goals for the company. Some of those are already known to Order Nordic, and then set up a system describing the value capture and the evaluation parameters for success. It is the hope of the authors that this report could serve as an aid when planning these circular strategies.

6.10.4 Production Logistics

From a circular perspective, planning production/refurbishment factories, places of sourcing for base materials, and all the circular post-life treatments is the final step. In this work the designs have been made to utilize materials that could be sourced in Sweden/Nordic countries. Our hope is for the possibility of completely local production and sourcing the wood and steel from northern Europe would also fall in line with the Order Nordic image and allow for interesting marketing capabilities.

A problem right now is acquiring spare parts from the Chinese manufacturers, such troubles could be avoided with a more local production. If a full move seems implausible, the focus might have to shift to only setting up a refurbishment/reparation workshop responsible for facilitating a second hand market. To summarize, the benefits of localized production are easier circular re-treatments, reduction of transport emissions, localized knowhow, and the drawbacks would be the increased costs.

6.10.5 Digitization

Order Nordic is currently working on implementing a so-called "digipass" for their products which will come in the form of a QR–code sticker that is put on every product. Scanning the QR-code will take you to a page meant to help customers with any product-specific issues like ordering spare parts or accessing manuals. The benefits of this system is that it can be continuously developed according to the customer needs. The idea is to enable customers to take care of their products to a greater extent instead of cascading entire products at the first sign of obsolescence.

The hardest part of becoming circular is the involvement of the consumers and the best way to increase consumer engagement in the sustainability efforts is to decrease the effort they have to put in. People are very lazy and to facilitate easy solutions that require minimum effort is key to slowing and closing the loop of material. The digipass has the opportunity to give customers the easy access they need to engage with products in a sustainable way and

should therefore be further developed and perfected in our opinion.

The knowledge of this system was there right from the start of this project, which is part of the reason other circular strategies were prioritized at first. To put in a lot of work in developing this system while Order Nordic has a partner doing the same felt like potentially wasting resources. As mentioned earlier, the project did however conduct a short session ideating with this idea in mind to not completely ignore this circular strategy, but this did not generate any ideas worth pursuing in this project.

6.11 Project Planning and Work Distirbution

Over all, the project has been able to follow the format of the original plan presented in a Gantt chart in appendix D, figure D.1. The main problem with the original plan was that too little time was allocated to the product development and brainstorming phases, which became the main part of the practical work. Generally speaking, some project phases had to be extended or delayed, primarily the Writing of literature study, the Evaluation of the redesigns and the writing of those respective chapters. Ultimately this was the result of the product development and the many design changes and pathways that were explored. The exact changes can be seen in figure D.2 in appendix D. Making the prototypes ended up taking less time than expected as these only had to be produced in CAD, no physical models were necessary.

This master's thesis describes the work of two students. The aim was to split the work equally between the two participants within each area of work in the plan. Both authors participated in the literature study, focusing both on finding design theory and evaluation tools. When producing the CAD models Pontus Pauli was in charge of producing Ideal design 1 and Sebastian Månsson was in charge of producing Ideal Design 2. In the brainstorming and evaluation activities, tools were filled in and analyzed by both writers. The same goes for the writing of the report where effort has been split equally.

Chapter 7
Conclusion

This chapter addresses the conclusions that can be drawn from this thesis and to what degree the goal of the project was reached.

This project was a case study done in collaboration with Order Nordic to investigate how circular product design could be applied on a C3 Percolator. During the design process a large collection of circular design strategies, i.e the "10Rs" and DfX, were gathered and used to generate many ideas, which posed the challenge of composing an optimal concept. Afterwards two evaluation tools were used to verify the improvements. The main insight gained was that Designing for Durability and Modularity had the greatest impact on the percolator. In the case of a realistic design, changes were mostly related to improving the design of specific components. More ideal designs instead required changes to the product architecture to fit in more complex circular systems. It was also found that it was more effective to independently chosen strategy for each component to create the biggest impact. The developed concepts are still in need testing, but it is important that companies do not limit themselves to a couple of design strategies from the start.

This project also set out to investigate what products could benefit from the slowing-strategy and if focusing on only one such strategy could be beneficial. Ultimately it was found that the usage of strategy tools like the Circular Pathfinder led to a successful match of the slowing approach to the product type, in this case the percolator. The work also found that the division was not always strict, as many choices that slowed the loop also made it easier to close it. In choices where conflict arose it was effective to focus on the main strategy matched to the product type.

As for consideration for Order Nordic when working with circular design, this report displays a way of working with general circularity strategies before the final logistics and supply capabilities are known. In the report it is explained that product design is only one of the four parts of a circular business, yet an approach of circular design principles could be applied for improvements guided by a general business idea.

There is a lot more work to be done concerning these concepts with testing and development of the surrounding business to accommodate for the production of these new products. Therefore, the main takeaway from this project should not be to see these concepts as finished products, but rather a first showcase of how circular product design can look. This case study is only a first draft of the large scale efforts that needs to be done. It should be taken as an introduction or a source of inspiration to how circular product design can be conducted. The redesign of parts and components is a good way to show how the design guidelines were applied but the general workflow of the project is just as important to recognize.

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Appendices

Appendix A
Collection of Ideas

- Combine the function of the current product with how a classic percolator works. Water and coffee containers on the bottom which screws on to the container that fills up with coffee.
- Handle is designed like a harness for the coffee container. Snug fit without any other connectors.
- The handle slides into place without any connectors for easy assembling and reassembling.
- Snap fitted handle. “Lego hand” connection.
- Removable handle that fastens on the edge of the container. See figure A.1 below.
- Capsules/ separate modules for each functional component of the percolator. See figure A.2.

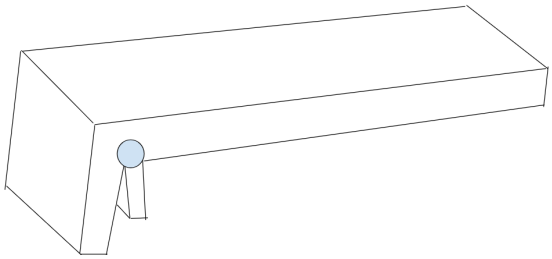


Figure A.1: Sketch of modular handle

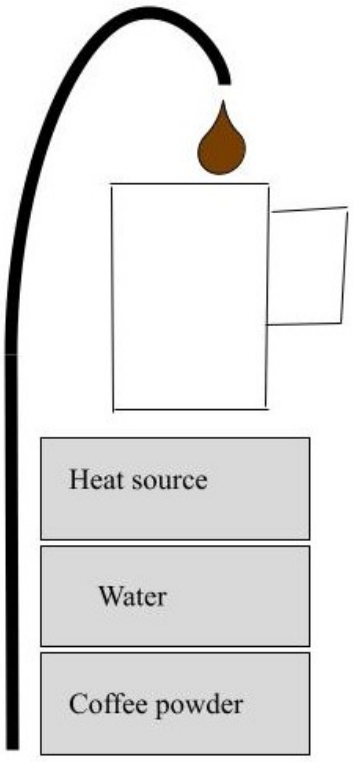


Figure A.2: Sketch of modular percolator.

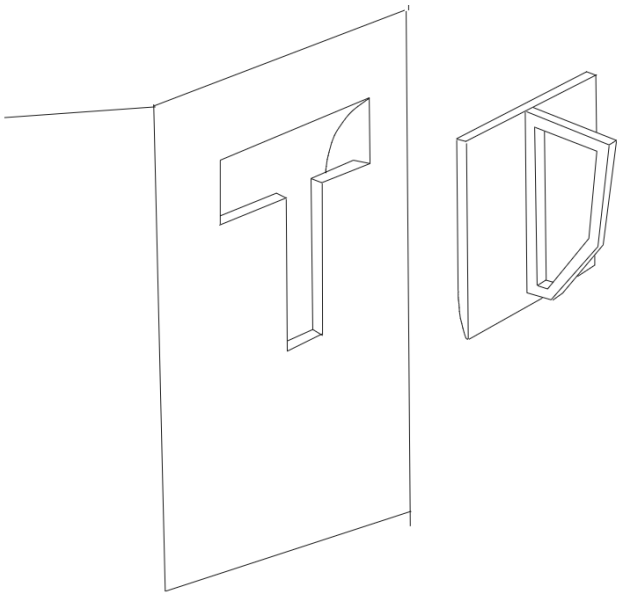


Figure A.3: Handle slides into place via rail.

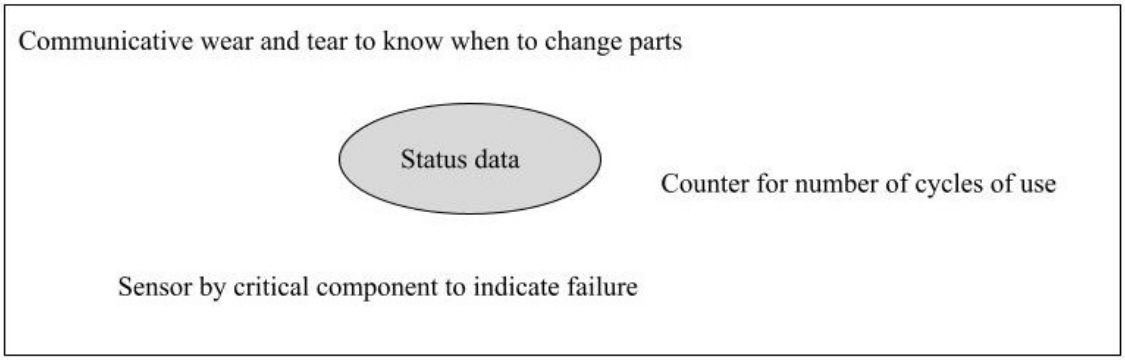


Figure A.4: Mapping ideas for communication

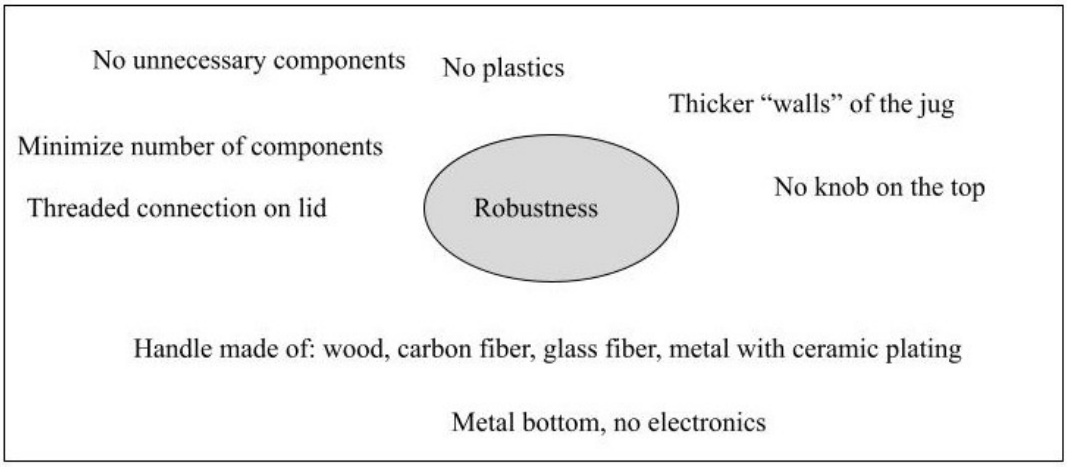


Figure A.5: Mapping ideas for robustness

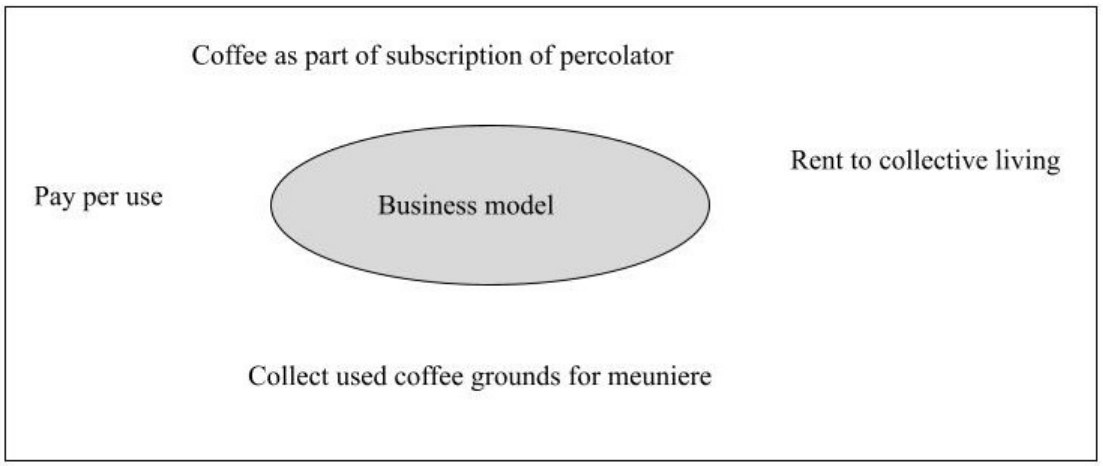


Figure A.6: Mapping ideas for business

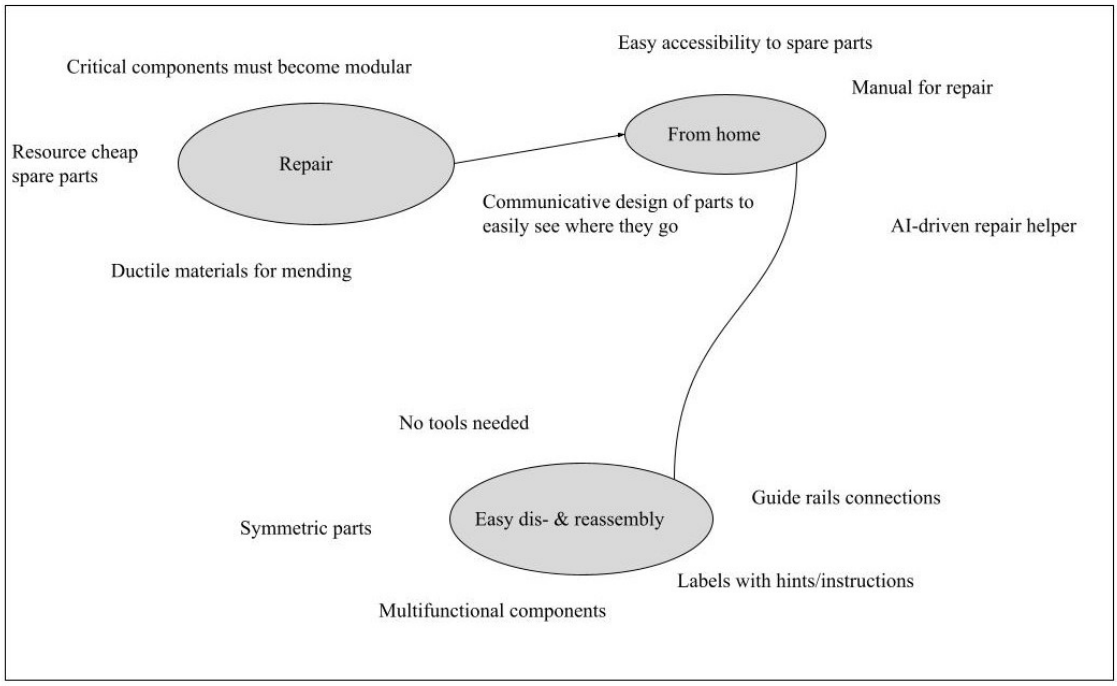


Figure A.7: Mapping ideas for maintenance

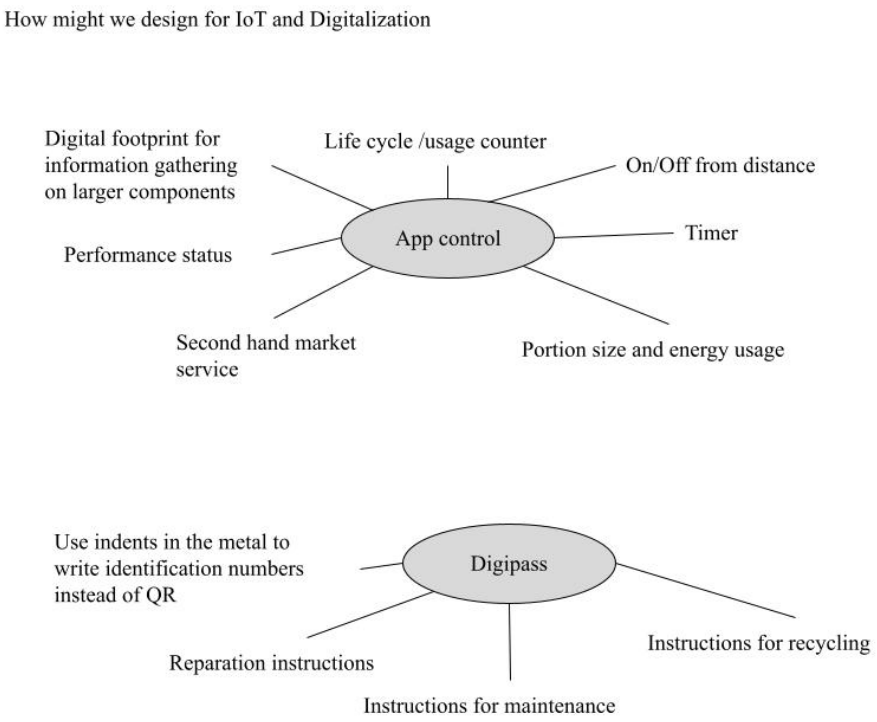


Figure A.8: Mapping ideas for PSS

Figure A.9: Concept sketches in ink.

Appendix B

Guidelines for Rating with the Circit Nord Evaluation Tool

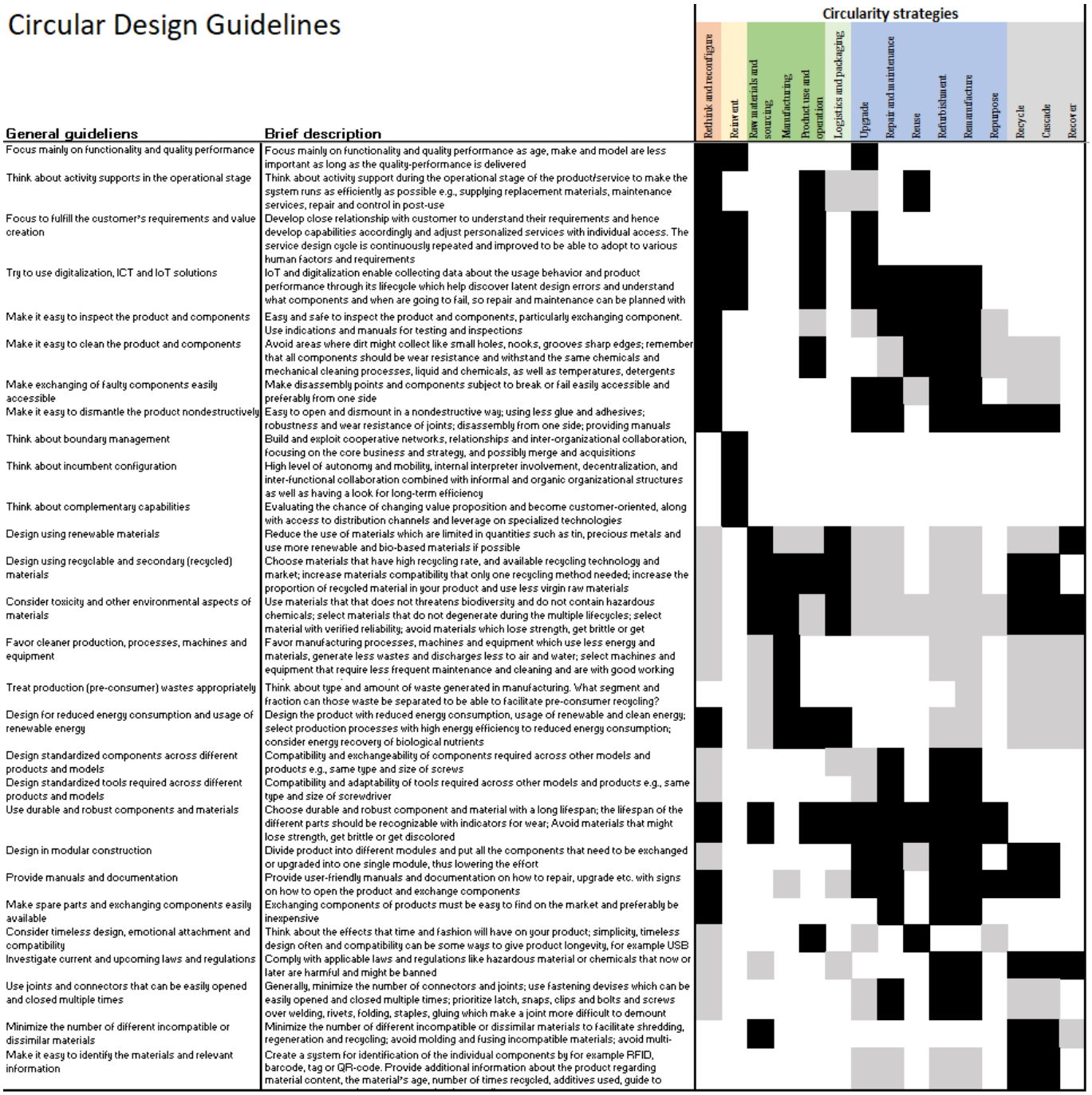


Figure B.1: Guidelines for rating with the Circit Nord Evaluation Tool.

Appendix C
Ratings of the Different Evaluation Tools

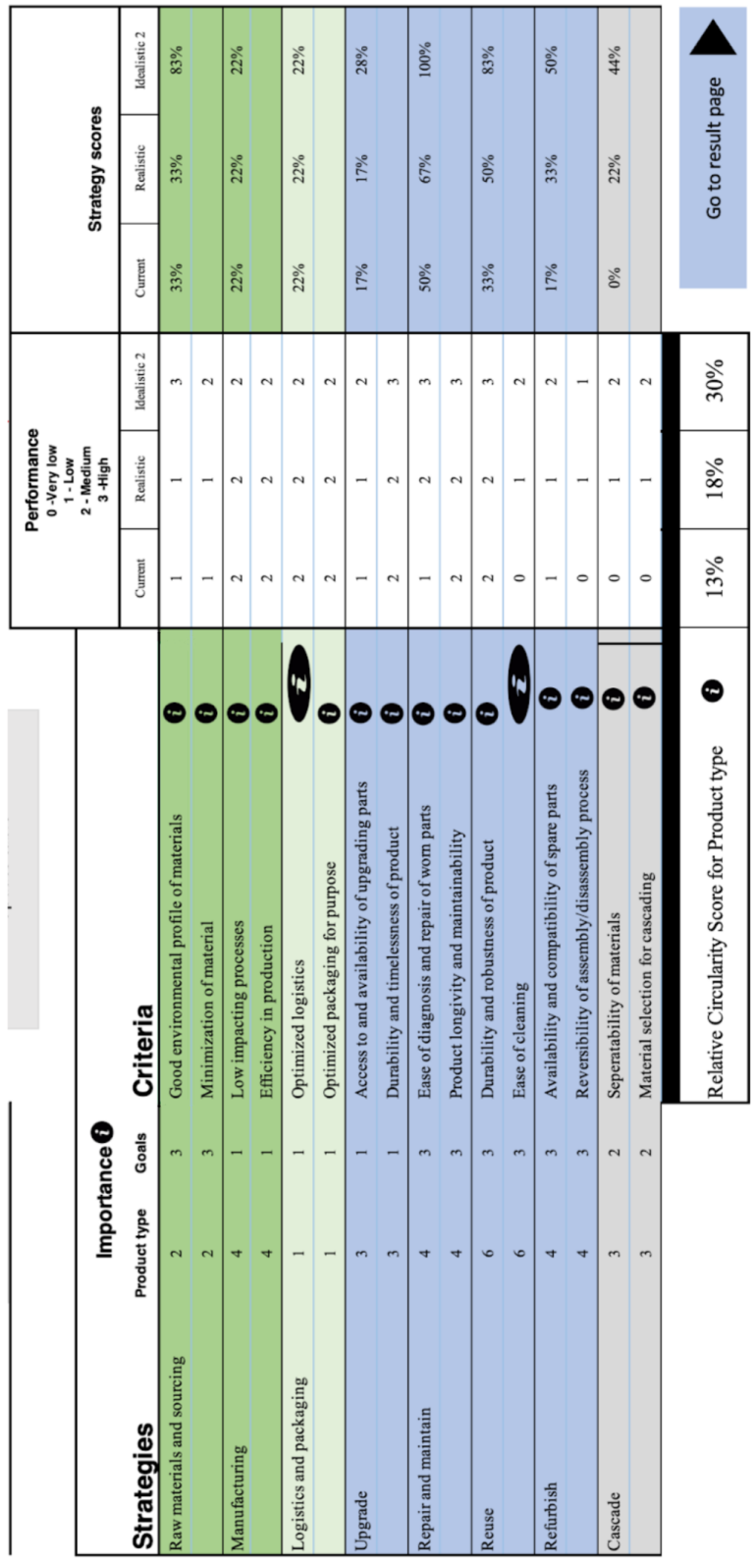
General design guidelines	Improtance to developing the product Really important (3) Moderately important (2) Slightly important (1) Not important (0)				Level of fulfillment (1) yes, the guideline has been completely fulfilled by this concept (3) somehow but can be improved (5) no, the guideline has not been fulfilled by this concept and it has to be				Circularity Potential Scores 15: Vital and imperative 10 and 9: Improvement are necessary 6 and 5: Potential circularity improvements 3, 2 and 1: No change required 0: Not a concern			
	Concept: Current	Concept: R	Concept: I_1	Concept: I_2	Concept: Current	Concept: R	Concept: I_2	Concept: I_1	Concept Current	Concept: R	Concept: !_2	Concept: I_1
Focus mainly on functionality and quality performance	1	1	1	1	1	1	1	3	1	1	1	3
Think about activity supports in the operational stage	2	2	2	2	3	3	3	3	6	6	6	6
Focus to fulfill the customer's requirements and value creation	1	1	1	1	1	1	1	1	1	1	1	1
Try to use digitalization, ICT and IoT solutions	3	3	3	3	5	5	5	5	15	15	15	15
Make it easy to inspect the product and components	3	3	3	3	5	3	1	1	15	9	3	3
Make it easy to clean the product and components	3	3	3	3	5	3	3	1	15	9	9	3
Make exchanging of faulty components easily accessible	2	2	2	2	5	3	1	1	10	6	2	2
Make it easy to dismantle the product nondestructively	3	3	3	3	5	3	3	1	15	9	9	3
Think about boundary management	0	0	0	0	3	3	3	3	0	0	0	0
Think about incumbent configuration	0	0	0	0	3	3	3	3	0	0	0	0
Think about complementary capabilities	0	0	0	0	3	3	3	1	0	0	0	0
Design using renewable materials	1	1	1	1	5	5	3	3	5	5	3	3
Design using recyclable and secondary (recycled) materials	3	3	3	3	5	3	3	3	15	9	9	9
Consider toxicity and other environmental aspects of materials	2	2	2	2	3	3	3	3	6	6	6	6
Favor cleaner production, processes, machines and equipment	1	1	1	1	5	5	5	5	5	5	5	5
Treat production (pre-consumer) wastes appropriately	1	1	1	1	3	3	3	3	3	3	3	3
Design for reduced energy consumption and usage of renewable energy	1	1	1	1	3	3	3	3	3	3	3	3
Design standardized components across different products and models	3	3	3	3	3	3	3	1	9	9	9	3
Design standardized tools required across different products and models	3	3	3	3	5	3	1	1	15	9	3	3
Use durable and robust components and materials	3	3	3	3	3	3	1	1	9	9	3	3
Design in modular construction	3	3	3	3	5	3	1	1	15	9	3	3
Provide manuals and documentation	3	3	3	3	1	1	1	4	3	3	3	12
Make spare parts and exchanging components easily available	3	3	3	3	5	3	1	1	15	9	3	3
Consider timeless design, emotional attachment and compatibility	2	2	2	2	3	3	1	1	6	6	2	2
Investigate current and upcoming laws and regulations	3	3	3	3	3	3	3	3	9	9	9	9
Use joints and connectors that can be easily opened and closed multiple times	3	3	3	3	5	3	1	1	15	9	3	3
Minimize the number of different incompatible or dissimilar materials	2	2	2	2	5	5	3	1	10	10	6	2
Make it easy to identify the materials and relevant information	1	1	1	1	5	5	1	1	5	5	1	1
Total Circularity potential Score with inclusion of the effect (the smaller the better)									**226**	**174**	**120**	**109**

Figure C.1: Full evaluation of concepts using CirCit Nord Evaluation Tool

Strategies	Importance: Product type	Importance: Goals	Criteria	Performance (0 -Very low, 1 - Low, 2 - Medium, 3 -High): Current	Performance: Realistic	Performance: Idealistic 1	Strategy scores: Current	Strategy scores: Realistic	Strategy scores: Idealistic 1
Raw materials and sourcing	2	3	Good environmental profile of materials	1	1	3	33%	33%	83%
	2	3	Minimization of material	1	1	2			
Manufacturing	4	1	Low impacting processes	2	2	2	22%	22%	22%
	4	1	Efficiency in production	2	2	2			
Logistics and packaging	1	1	Optimized logistics	2	2	2	22%	22%	22%
	1	1	Optimized packaging for purpose	2	2	2			
Upgrade	3	1	Access to and availability of upgrading parts	1	1	2	17%	17%	28%
	3	1	Durability and timelessness of product	2	2	3			
Repair and maintain	4	3	Ease of diagnosis and repair of worn parts	1	2	3	50%	67%	100%
	4	3	Product longivity and maintainability	2	2	3			
Reuse	6	3	Durability and robustness of product	2	2	3	33%	50%	100%
	6	3	Ease of cleaning	0	1	3			
Refurbish	4	3	Availability and compatibility of spare parts	1	1	3	17%	33%	100%
	4	3	Reversibility of assembly/disassembly process	0	1	3			
Cascade	3	2	Seperatability of materials	0	1	3	0%	22%	56%
	3	2	Material selection for cascading	0	1	2			
			Relative Circularity Score for Product type	13%	18%	36%			

Go to result page

Figure C.2: Full evaluation of Ideal Concept 1 using CirCit Nord Evaluation Tool



Strategies	Importance		Criteria	Performance 0 -Very low 1 - Low 2 - Medium 3 -High			Strategy scores		
	Product type	Goals		Current	Realistic	Idealistic 2	Current	Realistic	Idealistic 2
Raw materials and sourcing	2	3	Good environmental profile of materials	1	1	3	33%	33%	83%
	2	3	Minimization of material	1	1	2			
Manufacturing	4	1	Low impacting processes	2	2	2	22%	22%	22%
	4	1	Efficiency in production	2	2	2			
Logistics and packaging	1	1	Optimized logistics	2	2	2	22%	22%	22%
	1	1	Optimized packaging for purpose	2	2	2			
Upgrade	3	1	Access to and availability of upgrading parts	1	1	2	17%	17%	28%
	3	1	Durability and timelessness of product	2	2	3			
Repair and maintain	4	3	Ease of diagnosis and repair of worn parts	1	2	3	50%	67%	100%
	4	3	Product longivity and maintainability	2	2	3			
Reuse	6	3	Durability and robustness of product	2	2	3	33%	50%	83%
	6	3	Ease of cleaning	0	1	2			
Refurbish	4	3	Availability and compatibility of spare parts	1	1	2	17%	33%	50%
	4	3	Reversibility of assembly/disassembly process	0	1	1			
Cascade	3	2	Seperatability of materials	0	1	2	0%	22%	44%
	3	2	Material selection for cascading	0	1	2			
			Relative Circularity Score for Product type		13%	18%	30%		

Figure C.3: Full evaluation of Ideal Concept 2 using Circular Concept Evaluation Tool

Appendix D
Gantt Charts

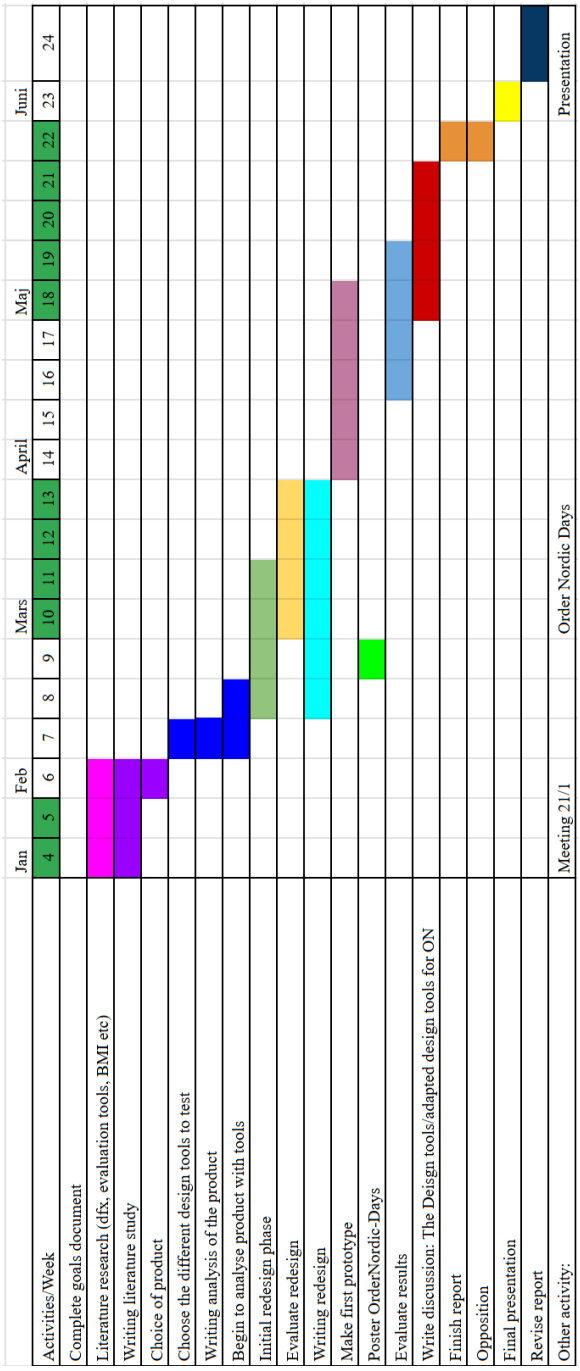


Figure D.1: The Gantt chart of the project in the beginning.

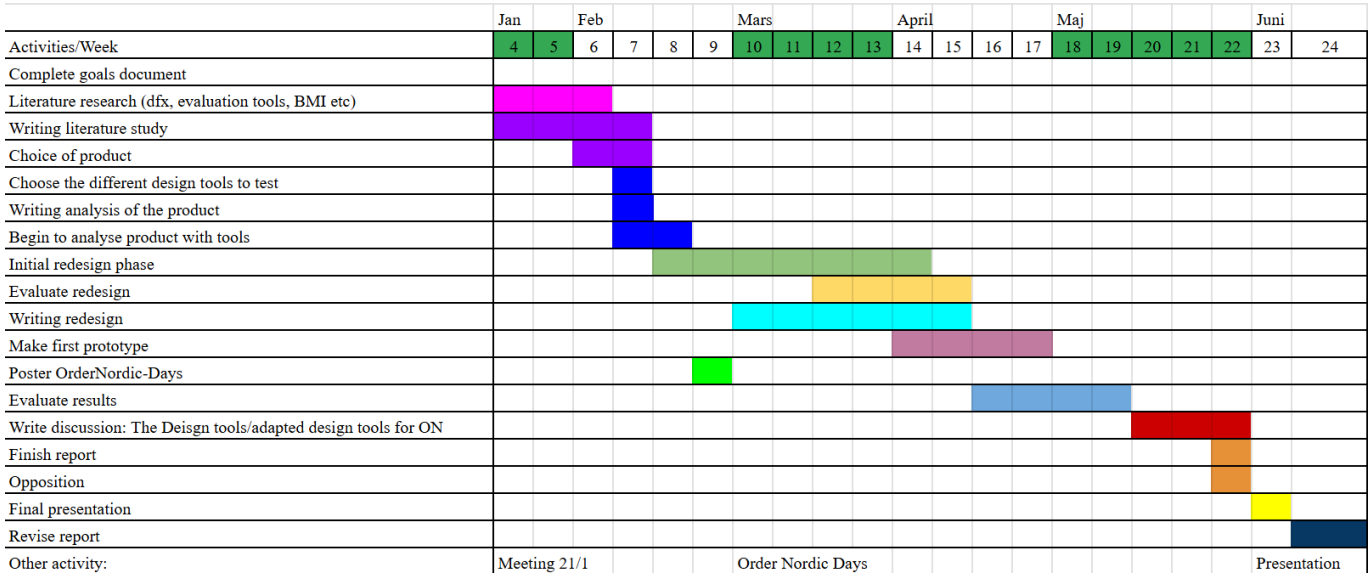


Figure D.2: The Gantt chart of the project.