Material Efficient Product Design

AALBORG UNIVERSITY
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Product report

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Abstract

Dette afgangsprojekt omhandler udviklingen af et produktkoncept for fremtidens Nilfisk støvsuger til B2C markedet med fokus på forøget materialeeffektivitet.

De hidtidige regler omkring bæredygtigt produktdesign omfattet af EU's Eco-Design direktiv har hovedsageligt fokuseret på energieffektivitet. I takt med øget fokus på cirkulær økonomi i EU, er materialeeffektivitet blevet et nyt fokusområde i Eco-design direktivet. Materialeeffektivitet omhandler et produkts miljømæssige belastning forårsaget af dets materialesammensætning og materialeforbrug i forhold til dets levetid. Sagt med andre ord, hvor effektivt anvendes disse materialer til at levere en funktion eller ydelse igennem et produkt over dets levetid. Elektriske produkter er defineret som et særligt fokusområde for EU's indsats for forøget materiale effektivitet. Det skyldtes at gængse elektroniske produkter typisk har en kort levetid i forhold til deres materialeforbrug, hvilket er medvirkende til at elektronikaffald er den hurtigst voksende affaldsstrøm i verden.

Nilfisk er en producent af elektroniske produkter som fx. støvsugere, og er dermed omfattet af de fremtidige krav til materialeeffektivitet. Nilfisks udviklingsafdeling for B2C produkter har medvirket som sparringspartner i projektet og projektet omhandler derfor udvikling af fremtidens Nilfisk støvsuger til B2C markedet

Resultatet af dette afgangsprojekt er produktkonceptet "Nilfisk Infinity". Nilfsik infinity er en ledningsfri håndholdt støvsuger der er designet med fokus på lang produktlevetid gennem mulighed for reparation samt effektiv genanvendelse af materialer ved produktets bortskaffelse.

Content

Introduction

Material efficiency is a term describing the level of efficiency of which materials and resources are used in products to deliver a certain function during its lifetime.

The topic of material efficiency is gaining momentum, and regulatory measures are soon to be implemented on European and national levels to increased material efficiency and sustainable consumption of materials on the European market.

The Danish production company Nilfisk has acted as a partner in this thesis project. Nilfisk produces electric products (e-Products) such as vacuum cleaners and high-pressure washer. Material efficiency is highly relevant to e-Product producers, such as Nilfisk, because the EU Commission has identified e-products as a key focus area to improve material efficiency within the union. Considering the work and investments needed to prepare entire product portfolios for the future regulations, the next few years are crucial to e-Product producers present on the European market.

The Nilfisk Infinity is a product concept designed for optimal material efficiency. The product concept outlines how Nilfisk can design their product for a nearby future of increased material efficiency.

Nilfisk
Infinity

E-waste

Waste from e-Products, called E-waste, has increased so massively in recent years, that it is now considered the fastest growing waste stream in the world.

Technological advances and a rising global middle class have made ordinary e-Products commercially available and affordable to the masses, increasing the amount of e-waste [Balde et al. 2017]. This development makes it increasingly important to use materials efficiently by designing for longer product lifetimes and proper recycling at EoL (End of Life). There are several barriers to improving material efficiency in e-products. Modern e-Products are designed for quick assembly and efficient manufacturing, which has reduced the cost of e-Products, but also reduced the repairability as products are extremely difficult to disassemble [Madsen et al., 2018]. As a result, consumers are unable to repair even minor faults at an acceptable cost. Thereby near-perfect products are disposed of as E-waste. The diversity of e-Products, complexity and the lack of design for disassembly means that material recovery (recycling) becomes the only economically feasible option at EoL [Parajuly 2017]. There will be no attempt to recover the actual product or its components, which means all the energy and resources gone into manufacturing will be lost and only the material value of successfully recovered materials will remain.

Growing global middle class

Common e-Products has become available and affordable to the masses as the global middle class has grown.

Fast product obsolescence

Rapid technological development results in products being outdated quickly, generating more E-waste.

Difficult disassembly

The lack of Design for disassembly means e-Products are difficult and expensive to repair.

Complex products

Different and complex product structures hinder effective product, component and material recovery at EoL.

Cheap products

Low cost of new e-products means the consumer has no incentive to pay for repairs of old products.

44.7
Mio. tons

Amount of E-waste generated every year.

16
kg

Amount of E-waste per inhabitant per year in Scandinavia.

170
%

Growth rate of E-waste from small household equipment, 2010-2020 (including vaccuum cleaners).

[Balde et al. 2017]

ill. 1

Future regulations

The environmental impact of a product is primarily decided by its material composition related to its lifetime [Montalvo, Carlos; Peck, David; Rietveld 2016]. Therefore prolonging of product lifetime and use of sustainable or recycled materials are key parameters to increase material efficiency.

1st March 2023 the EU will implement regulatory measures under the Ecodesign Directive to ensure products are designed for energy efficiency and durability, reparability, upgradability, maintenance, reuse and recycling [European Union 2020].

e-Products are identified as a priority sector for implementing a new "right to repair", increasing the access to repair through the availability of spare parts and relevant information [European Union 2020]. Furthermore, a repairability label, visible at the point of sale, will be implemented to guide consumers in making informed decisions, and pushing producers to compete on repairability and long product lifetime [Cordella et al. 2019].

As the majority of modern e-product, the current Nilfisk handheld unit, Nilfisk Easy, is not designed for disassembly. From the 1st March 2023 Nilfisk will no longer be able to sell the Nilfisk Easy, as it is not repairable with common tools without causing damage to the product.

Several nations, such as France and Germany, are working on their own parallel regulations to improve material efficiency through repair and use of recyclable materials. The French regulations are published, but they are not final laws. (listed on the timeline ill. 2). The specific product categories covered are not specified yet, but e-Products are mentioned. The German regulations are yet to be finalised but talk about improved durability, repairability, recycling and use of recycled materials.

From 1st March 2023

Cordless vacuum cleaners:

- Availability of spare parts for 6 years after end of sale
- Spare parts must be publicly available
- Spare parts must be replaceable with the use of common tools without any permanent damage to the vacuum cleaner.

Repairability label

A score will be calculated based on priority parts such as motor, battery, filter and PCB's, and parameters listed below.

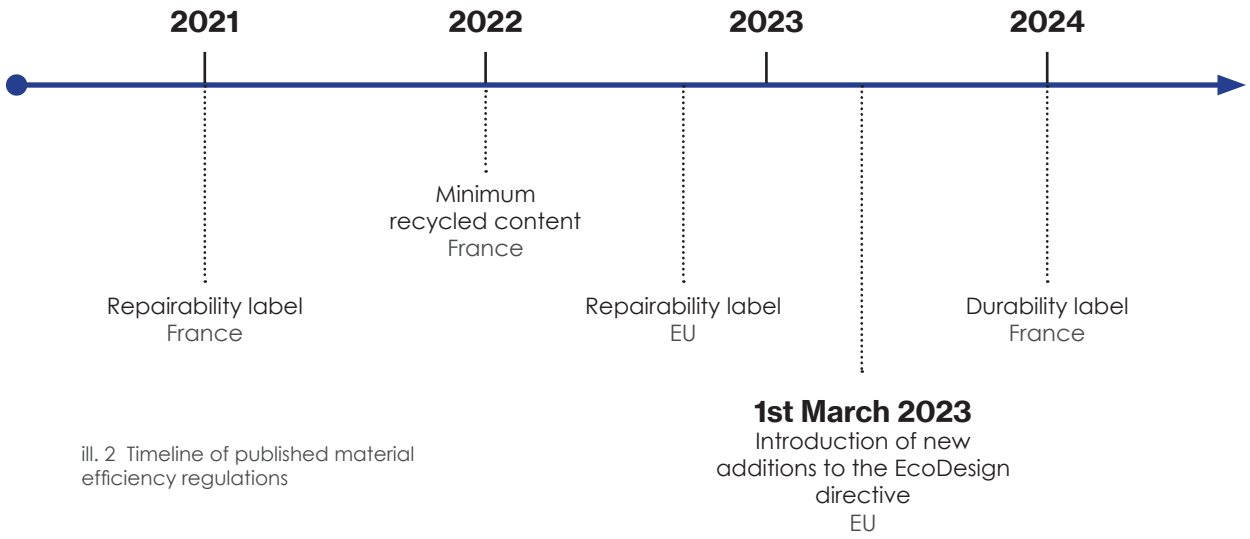
Product parameters:

- Disassembly depth/sequence
- Reuseabilityof fasteners
- Tool required
- Disassembly time

Other parameters:

- Spare parts availability, accessible repair information, diagnosis support.

[Cordella et al. 2019]

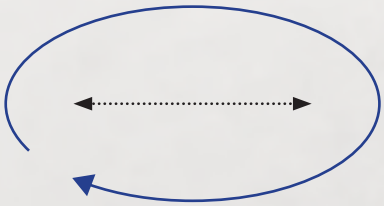


ill. 2 Timeline of published material efficiency regulations

* Information about the regulation are gathered from sources referenced in the text and talks with Charalambos Freed, *Technical Director - Head of standardisation & government relations at Nilfisk*

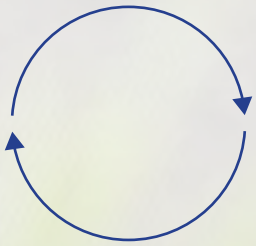
Nilfisk Infinity

The Nilfisk Easy is a handheld vacuum cleaner for the consumer market. The Nilfisk Infinity will comply with, and exceed the future regulations by being repairable by the consumer without any tools and considering the recyclability in the design.



1. Prolonged product lifetime

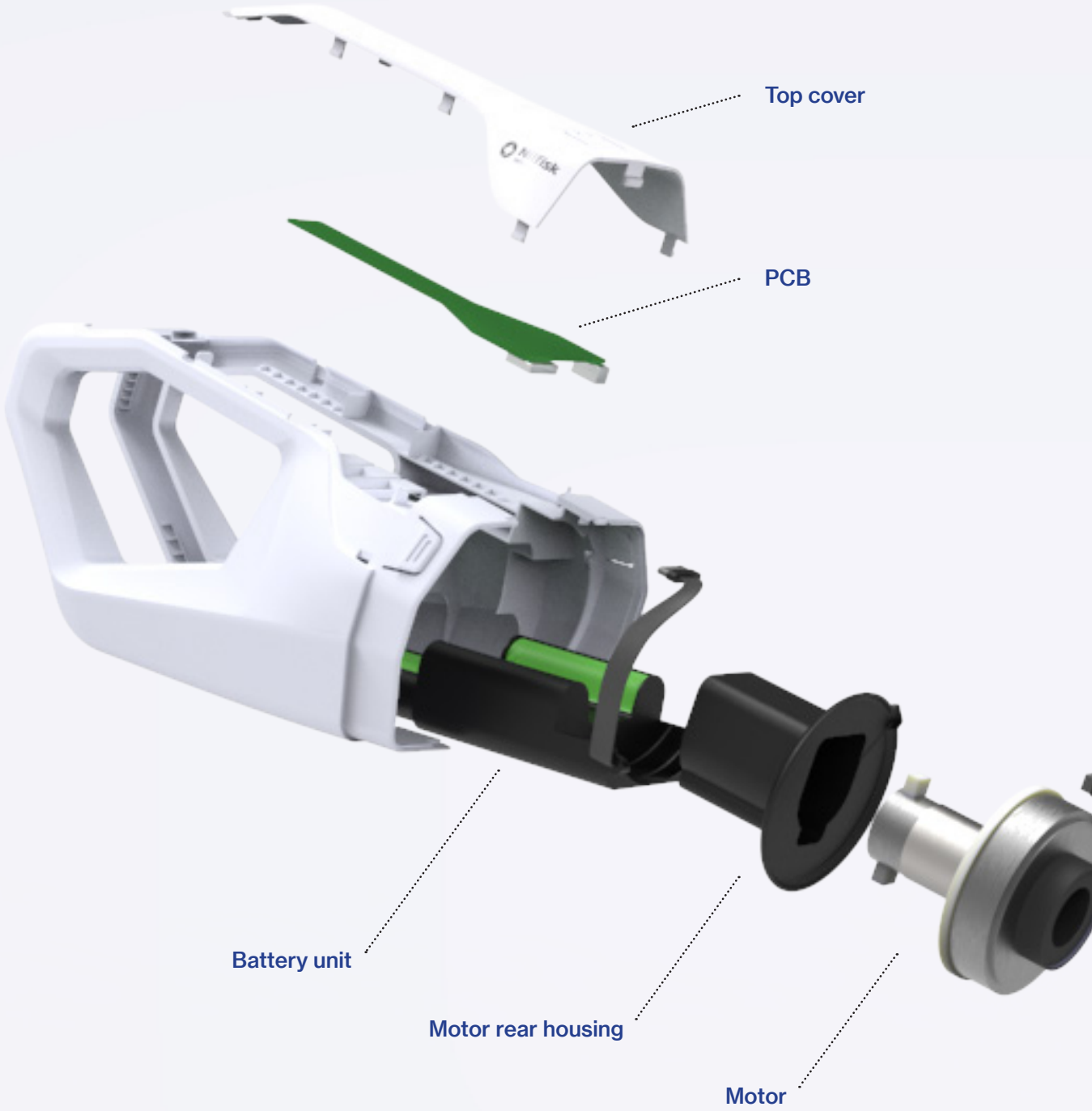
the Nilfisk Infinity is designed to prolong product lifetime by allowing for easy and cost-effective repair of priority parts such as the motor and battery.



2. Designed for recycling

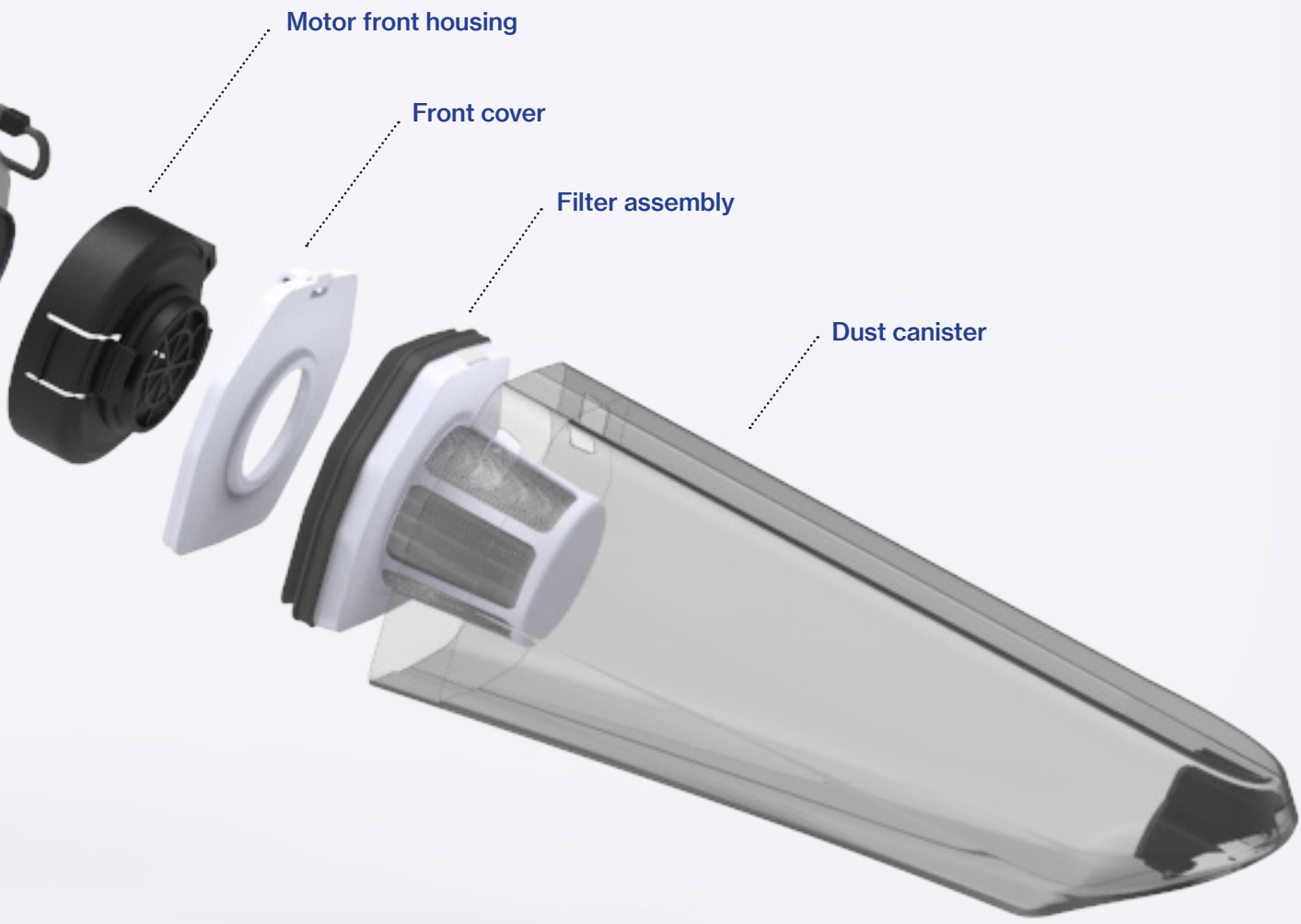
The design is optimized for recycling at EoL by ensuring components of different materials can easily separate from each other during the recycling process, which will increase the recovery percentage.

ill. 3


Top cover
PCB
Battery unit
Motor rear housing
Motor

Construction
Exploded view

The Nilfisk Infinity is constructed from injection moulded ABS plastic parts, which is very similar to current Nilfisk products. Thereby it is possible to draw on existing knowledge and partners in the production.



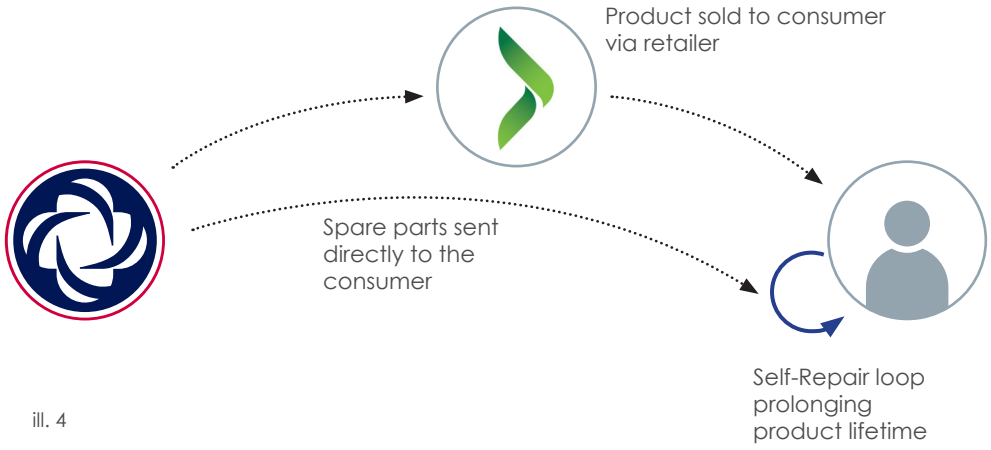
Nilfisk Infinity
Prolong product lifetime

To prolong lifetime via repair it is necessary to offer repair at a cost which is acceptable to the consumer. During this thesis project, a user survey was conducted to gain information about the consumers' thoughts of repair. It is clear that consumers will only consider repair if it is the repair cost is significantly lower than the cost of a new product. Furthermore, the hassle with arranging a repair was found to be a significant barrier. The acceptable repair cost was determined to be 24% of the new product cost, which corresponds to 466 DKK for the current handheld vacuum cleaner, Nilfisk Easy.

The Nilfisk Infinity is designed with user-replaceable priority parts, including the motor, battery, filter and PCB. By designing the product for self-repair by the consumer, the repair cost will be lower than the acceptable repair cost because the start-up cost and labour time cost normally paid at a professional repair shop are avoided. The spare part will simply be sent directly from Nilfisk to the consumer (ill. 4).

Replacement of spare parts in the Nilfisk Infinity can be done with very low disassembly depth within a short time. Furthermore, all spare parts are accessible without any tools. As a result, the Nilfisk Infinity will have a high score on the future repairability label, thereby it will be in a good position compared to competitors.

The ability to offer the consumers self-repair will open op sales of spare parts. If designed correctly, spare parts can be compatible with multiple different products within the product portfolio, which will reduce the cost of delivering spare parts.



ill. 4

Filter assembly

The filter is a vital component to ensure the vacuum cleaner is working properly. One of the most common faults in vacuum cleaners is suction deterioration during to blocked or broken filters [Cordella et al. 2019]. To prevent the risk of the product being disposed of based on this issue, the filter must be considered a wear part and needs to be easily replaceable by the consumer. In some modern vacuum cleaners, including the current Nilfisk Easy, the pursuit of lower production costs means the filter can only be changed by replacing the entire filter assembly, which is a waste of materials.

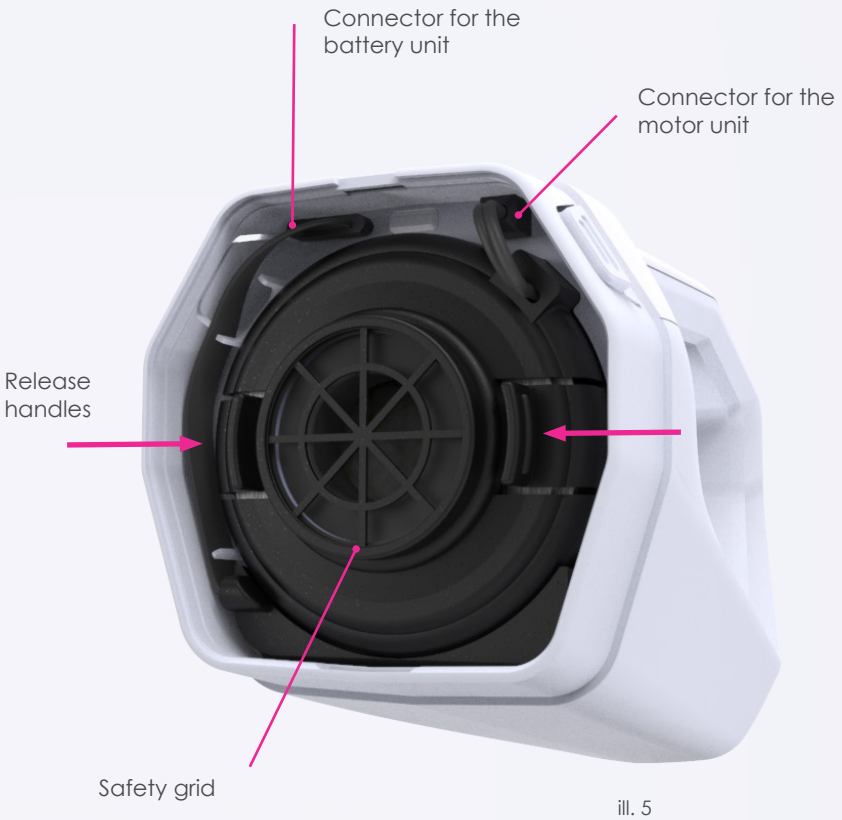
When disassembling the Nilfisk Infinity filter assembly for cleaning, it is possible to replace the filter and prolong the performance and lifetime of the product.

Motor and battery replacement

Removing the front cover will allow the consumer to replace the motor and battery units. The first step is to disconnect the connectors for each part seen in ill. x. Afterwards, the motor unit is removed by pushing the release handles and pulling it straight out of the vacuum cleaner. The battery, positioned behind the motor, can now be replaced as well.

The use of connectors which reassemble connectors you would find in common consumer electronics, e.g. USB cables mean the consumer will feel familiar with changing the parts, as connectors are universally understood.

Interfaces need to be of high quality to avoid any risks of failure when handled by the consumer. Furthermore, any safety hazards must be avoided. Therefore the air intake of the motor is covered by a safety grid.



ill. 5

The motor and battery unit can be removed when the front cover is detached.

ill. 6

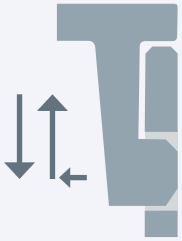
PCB replacement

The PCB must be replaceable to comply with future regulations.
The PCB in the Nilfisk Infinity can be replaced by removing the top cover.

The top cover is attached entirely with snap-fits to avoid complicating the material composition for recycling.

The top cover is released by pushing the release button marked in ill. 7. The button is, in reality, a snap-fit shaped as illustrated in ill. 8. The shape ensures it can only be released when pushed. The other snap-fits along the top cover edges are reversible snap-fits shaped as ill. 9.

ill. 7



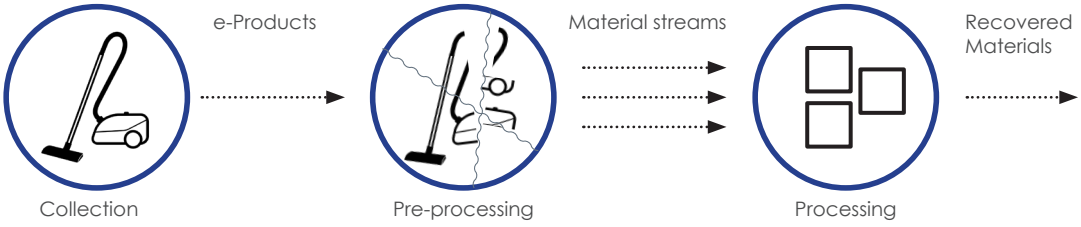
ill. 8

ill. 9

ill. 10

Nilfisk Infinity
Design for recycling

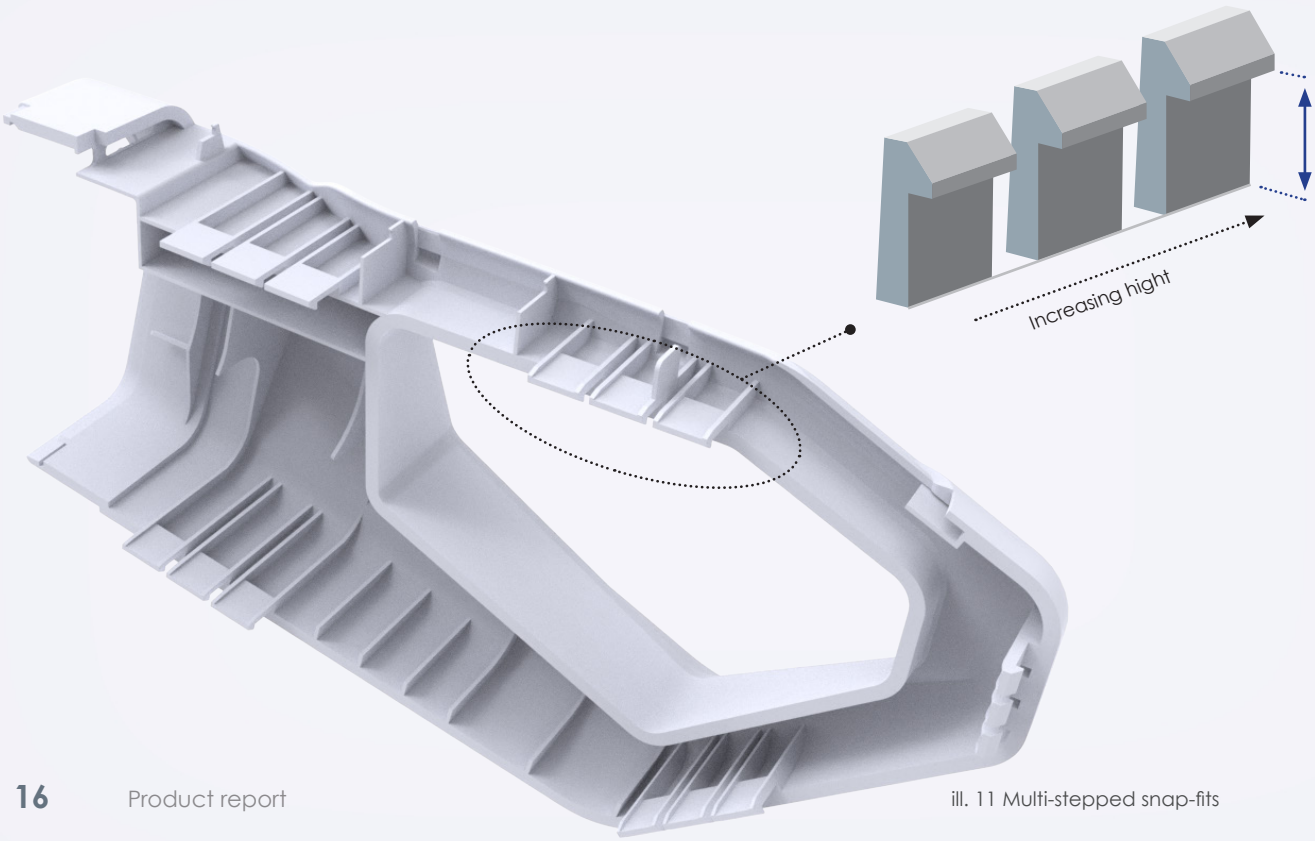
The recycling of E-waste is handled through a 3-step process of collection, preprocessing and processing. In Denmark, products are collected at municipally waste collection centres before they move to the preprocessing stage where products go through mechanical size reduction and are sorted into different material streams. Next materials are recovered from the material streams at highly specialized plants.
To increased the recyclability of a product it is key to ensure proper material liberation during the mechanical size reduction. Proper material liberation will create cleaner material streams for the processing stage. It is advisable to avoid screws or other assembly methods such as glue, that can prevent components of different material to separate. Therefore the Nilfisk Infinity is assembled entirely with snap-fits.
The Nilfisk Infinity is made from ABS plastic, which is a pure recyclable material. Because ABS is a high-volume plastic it is very suitable for recycling as existing specialized recycling processes already exists at the recycling companies for high-volume materials.



Design requirements for recycling

- Use pure recyclable materials. Preferably high volume plastics such as ABS.
- Use Snap-fits wherever possible
- Avoid screws
- Design assemblies between components of different materials to be breakable.

Consulting with Stena Recycling resulted in these product requirements for recycling.



ill. 11 Multi-stepped snap-fits

Extensive use of snap-fits

Nilfisk Infinity is designed in such a way that all components in the product is replaceable through the front and top cover. Thereby it is possible to use aggressively shaped, irreversibly snap-fits to join the two main shells of the vacuum cleaner, as they never have to be separated again. Snap-fits are normally not used as the primary assembly method, because it does not handle tolerances as well as screws. A new type of snap-fit has been invented for the Nilfisk Infinity to ensure proper assembly. The multi-stepped snap-fit (ill. 11) will be able to mimic the tightening of a screw and thereby be less sensitive to tolerances compared to traditional snap-fits. The multi-stepped snap-fits are in reality independent snap-fits positioned next to each other, featuring a slight difference in height. In this way, the snap-fits will snap into position one by one during assembly and ensuring the best possible fit for the specific parts.

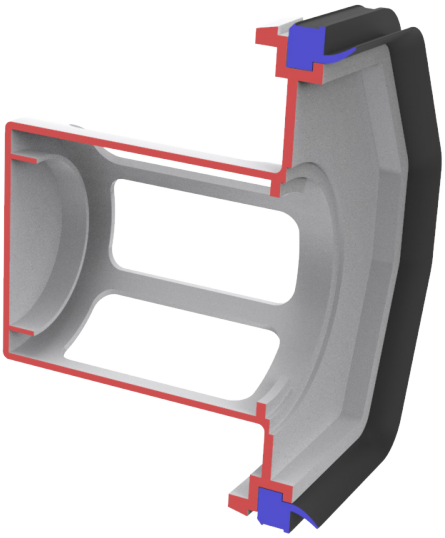
Snap-fits are used extensively throughout the construction, as seen in the top cover and motor unit, which means the entire construction is assembled with snap-fits. Furthermore, the dust canister release buttons are integrated into the outer shells (ill. 12). When pushed the buttons will flex and release the dust canister. This design avoids any metal springs in the construction and makes for a cleaner material composition.

The extensive use of snap-fits will also decrease the assembly time as snap-fits assemble quicker and are easier ta handle than screws.

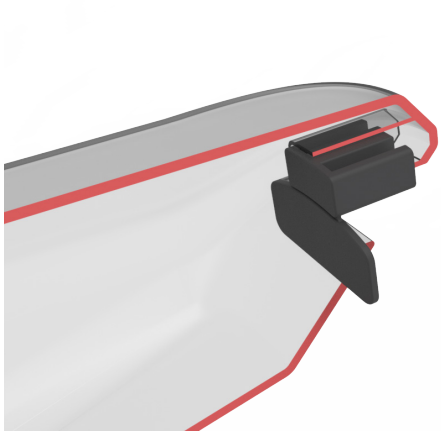
ill. 12 Dust canister release buttons

Material liberation

Nilfisk Infinity ensures proper material liberation during the recycling process by the use of simple joining methods. The key is to design assemblies which fix components in position as long as the components are intact, but releases when they are crushed in the recycling process. In the example of the inner filter housing assembly, the rubber seal is pushed into position behind an edge on the inner filter housing component. This will keep the seal stays in place until the components are crushed. A similar approach is used in the front of the dust canister. Here, the rubber stopper is squeezed into a rectangular slot, which will release the rubber stopper during the mechanical reduction process.



ill. 13 Section view. Assembly seal - inner filter housing



ill. 14 Section view. Assembly dust canister - rubber stopper

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Content:

1 / Understand

2 / Concept exploration

3 / Concept detailling

4 / Epilog

Reading guide

The project is presented in four documents: The product report, The process report, Technical drawings and Appendix.

This is the process report. This report is describing the development process during this thesis project. Content in the process report is presented the same chronologically order as the project has progressed.

To ease readability the following “sum up” boxes are applied throughout the report.

The task has given important insights to the solution that might need further investigation	▽
Project direction decision	□
Product requirement	○
The task has confirmed or validated a previous finding or hypothesis	✓
The task has dismissed or invalidated a previous finding or hypothesis	✕

Definitions

E-waste /	Waste from electronic and electrical equipment
e-Product /	Electronic product
EoL /	End-of-Life
Repair /	The process of returning a product to working order
Refurbishment /	The process of repairing and updating discarded products to be sold as a new product with new warranty.
Remanufacturing /	Waste from electronic and electrical equipment
Recycling /	The process of converting disposed materials to new raw materials
Material efficiency /	How efficient materials are used in products to deliver a function or service during its lifetime

Acknowledgement

Thanks to supervisor Christian Tollestrup for feedback during the project.
Special thanks to Kristian Bang Nielsen, Esben Graff and Charalambos Freed from Nilfisk for contributing to the project with information, material and great feedback along the way.

Introduction

This thesis project deals with the topic of material efficiency within product design. Material efficiency address how efficiently materials are used in products to deliver a function or service during its lifetime. The topic of material efficiency is unavoidable in the future of product design as both regulatory measures and increasingly environmentally conscious consumers will push for sustainable consumption of materials.

The Danish production company Nillfisk has acted as a partner in the project. The collaboration with Nilfisk provided an opportunity to understand the opportunities and challenges related to material efficiency as seen from a global company perspective. As a producer of electronic products (e-Products), material efficiency is particularly important for Nilfisk because e-Products are has been identified as a key focus area for improved material efficiency by the EU.

The topic is particularly interesting as seen from a design engineers perspective as it involves multiple overlapping parameters such as human, business, technologic and organisational factors, which must all be considered to successfully design a truly material-efficient product.

1

Understand

The foundation for understanding material efficiency in relation to e-Products is established in this chapter. Main topics such as handling of E-waste, future regulations and circular economy principles are explored in the chapter. The chapter finishes with a short project brief stating the direction for the next phases of the project.

The E-waste Problem

This section will create general understanding of the E-waste problem, how the problem has developed, what is contributing to the problem and how E-waste is handled.

The generation of E-waste is a direct consequence of the low material efficiency seen in modern e-Products which is caused by multiple overlapping parameters. The global information society is developing ever faster and is characterized by a rapidly growing user base and continued technological development which has helped drive innovation, social and economic development [Balde et al. 2017]. As technology has evolved and the global growing middle class is increasing, an increasing number of e-products has become commercially available and affordable to the masses, which predictably has produced an increasing amount of E-waste [Parajuly, 2017]. The amount of E-waste has accelerated to a point where E-waste is now considered to be the fastest-growing waste stream in the world [UNEP et al. 2019].

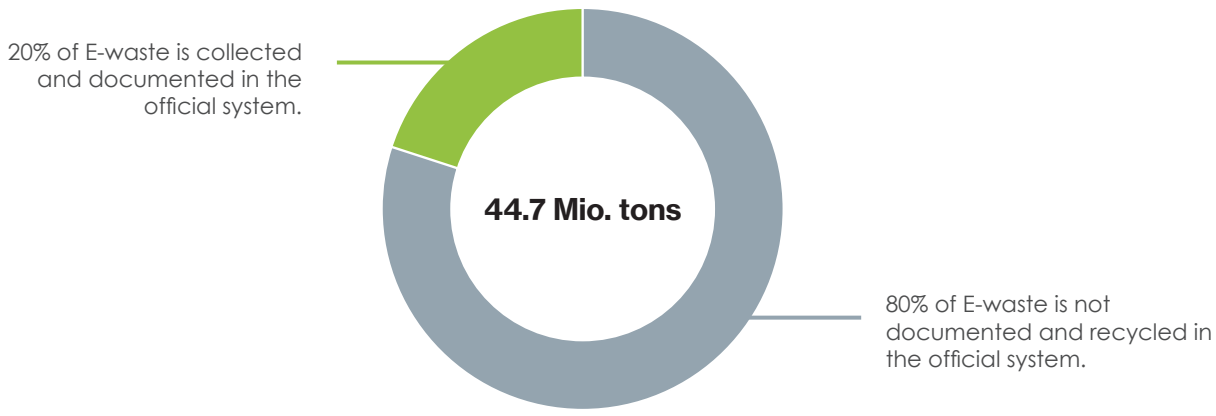
The rise in E-waste is further fueled by the short lifespan of e-products which is a consequence of the rapid technological development resulting in products being outdated in a short period of time. As a result, modern e-products are often discarded by the user despite still being functional [Parajuly, 2017]. Furthermore by continuous development within design for assembly and manufacturing the production cost of electronic consumer products has been successfully reduced to a minimum. Unfortunately, this development has also resulted in products being extremely difficult to disassemble and repair. As a consequence near-perfect products are discarded with only small insignificant defects, which would otherwise be repairable. Moreover, the reduced cost has massively increased the consumption and the amount of E-waste [Madsen et al., 2018]. The average expected lifetime of e-products such as smartphones and electric toothbrushes are only 1-2 years, while small household equipment such as vacuum cleaners and power tools are expected to be disposed of after 5-6 years [Montalvo, Carlos; Peck, David; Rietveld 2016].
In countries with established waste management systems, the rising quantity of E-waste may not be alarming in itself. The main challenge is the EoL (End of Life) management as the complexity that characterise e-products in regards to diverse product types and combination of materials, makes it difficult to design an effective system for material recovery.

It is estimated that 44,7 Mio. tons of E-waste is generated yearly, but only 20% of E-waste is documented to be collected and recycled through official systems (ill. 1). The remaining 80% is either thrown into household waste(4%) or dumped, traded or recycled under inferior conditions (76%) [v]. As e-products contain a significant amount of hazardous substances the increasing quantity of E-waste pose a significant risk to the environment and human health if the products are handled incorrectly at EoL. Incorrect disposal of E-waste is often done through disposal by open burning or disposed of in dumpsites causing the release of hazardous substances to the atmosphere and environment [Parajuly, 2017].

The lack of effective E-waste material recovery represents a huge loss of valuable raw materials as e-product contain high value and scares materials like gold, platinum, cobalt and large amounts of aluminium, tin and copper [UNEP et al. 2019]. It is estimated that the total value of raw materials present in E-waste equals 55 billion Euros in 2016. This amount is considered to be just a small fraction of the total value represented by its components or value as used appliances [Balde et al. 2017].

Rapid technological development results in products being outdated quickly, generating more E-waste. ▽

Low cost of e-products means the user has no incentive to attempt to repair broken products. ▽



ill. 1 Total amount of E-waste diagram

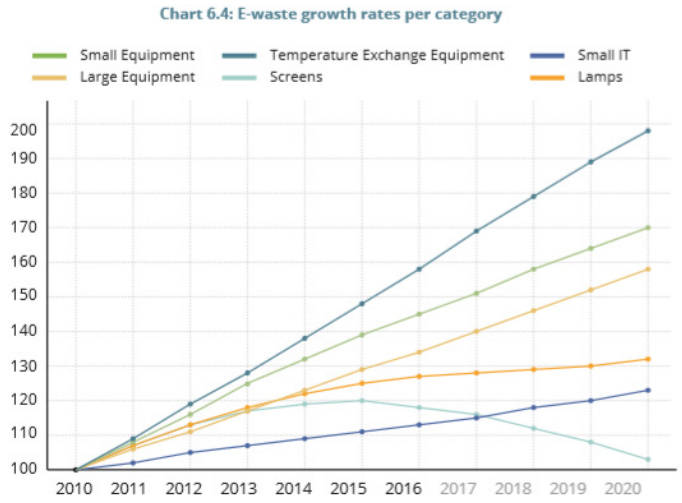
E-waste categories

In general, the amount of E-waste is expected to continue to grow in the future. It is expected that E-waste from small equipment, which includes vacuum cleaners, will continue to be one of the categories with the largest growth rate, as consumption increase with living standards in the developing world (ill. 2). The small equipment category is responsible for 16,8 Mio. tons. of E-waste a year (37,5% of total E-waste, ill. 3) [Balde et al. 2017]. Furthermore, a recent study by Erik Skov Madsen, SDU Center for Sustainable Supply Chain Engineering examining 2251 kg of E-waste, suggests that vacuum cleaners are the most common types of E-waste in Denmark measured by weight [Madsen et al., 2018], which all points to the importance of the E-waste problem in relation to Nilfisk.

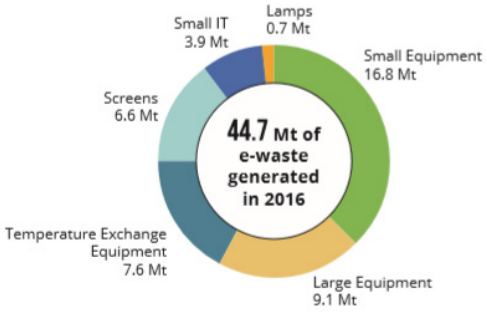
E-waste can be divided into six waste categories:

1. Temperature exchange equipment (Freezers, refrigerators, heat pumps).
2. Screens and monitors (Televisions, laptops, tablets, PC screens)
3. Light sources (Lamps)
4. Large household equipment (Washing machines, dish-washer, printers)
5. Small household equipment (**Vacuum cleaners**, microwaves, kettles, electric tools, radios)
6. Small IT and telecommunication equipment (Mobile phones, routers, GPS-devices)

E-waste from Small household equipment is expected to keep growing



ill. 2 E-waste growth rates per category [Balde et al. 2017]

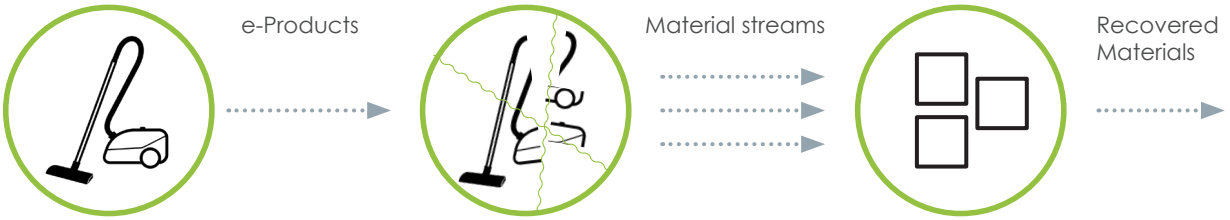


ill. 3 E-waste growth per category [Balde et al. 2017]

E-waste management in Denmark

In 2005 the EU introduced the WEEE directive (Waste Electrical and Electronic Equipment) which includes guidelines for an E-waste management system based on an extended producer responsibility (EPR) principle. According to the directive, EoL management of E-waste must be handled by a separate system from other solid waste. The WEEE directive states that the producer or importer of e-products has the responsibility to organise and finance the disposal of their products in a responsible way when they reach EoL [The danish environmental protection agency n.d.] E-waste management in Denmark is based on a collection schemes run by the local municipalities, which is finanzed by fees collected form the e-products producers or importers. The fees are collected by the Danish Producer Responsibility sytem (DPA-system) who calculated the fee based of the total weight of marketed products. The fee for small household equipment is 59,82 DKK pr. ton [DPA-system n.d.].

The process of E-waste management in Denmark can descriped in 3 steps: Collection, Preprocessing and Processing [Parajuly, 2017].



Collection:
Collection at the municipality recycled centres is the most practised model of E-waste collection in Denmark. At the recycling centres, the E-waste is collected in five different fractions, almost, but not exactly according to the general definition of E-waste categories mentioned earlier. The main difference being the lack of the Small IT category

Preprocessing:
During the preprocessing E-waste goes through manual and mechanical size reduction to create material streams suitable for the end processing stage. The exact method for size reduction depends on the specific input of E-waste and the target material for recovery. Vacuum cleaners and other products of the Small electrical equipment category are sent directly to large shredders where they are crushed to separate the components from each other. Afterwards, the shredded e-products are sorted into different material streams by manual, mechanical or electromagnetic sorting.

Processing:
In the final step material streams such as metals, non-metals and mixed fractions are processed for material or energy recovery at highly specialized plants. In general, metals are recovered through metallurgical processes. The plastic waste streams are recovered either by specialized facilities or sent for energy recovery at thermal plants where it is burned as fuel. To recover plastics from the shredder mixture is extremely difficult as it is necessary to sort it into the different plastic polymers for effective recycling. The plastic content is also sometimes used as fuel in the metal recycling process..

According to the WEEE directive, some parts of the product must be removed before shredding. This concerns, among other things, batteries and PCBs. Considering the diversity in e-products this must be a difficult process. No research confirmed exactly how is step is done but it is presumed to be done by manual sorting.

Challenges in the E-waste System

The current system of dealing with E-waste is focusing solely on material recovery (recycling). As previously described fully functional products are often discarded by the user, and as they are shredded immediately there is no attempt to recover the product for reuse or refurbishment. As a consequence, all the energy and resources that have gone into manufacturing these products and its parts are lost, and only the material value of successfully recovered materials remain. The current process of shredding is very good at producing waste streams suitable for recovery of base metals and features recovery rates of up to 92 % [Parajuly, 2017]. However large quantities of mixed waste streams which are difficult to extract materials from are generated. These material streams consist of different plastic polymers, precious metals and rare earth materials from components such as magnets and PCB's. As a consequence recovery rates of plastics is at best 45%. [Parajuly, 2017].

Modern e-products are designed for a linear economy of make-use-dispose which means a total lack of EoL (End-of-Life) considerations in the design phase. This means products are optimized for cost-efficient assembly and manufacturing, and they are not designed to be disassembled. As a consequence of the lack of design for disassembly, the diverse product types and complex product structure, the shredding procedure becomes the only financially feasible way to separate components and materials from each other. A major change in e-products design needs to be realized if components and materials are to be recovered more efficiently. This change, however, has to be adopted by the majority of e-products producers in order to change the system and is likely to happen only through regulations. A critique of the existing system points to the fee collected by the danish Producer Responsibility system. The fee is solely based on the weight of the product and does not create an incentive to create genuine prevention of E-waste through better product design [Jørgensen 2020].

The current E-waste system focus only on material recovery (recycling). ▽

The lack of Design for disassembly means shredding of E-waste is the only option in the official system. ▽

Nilfisk company description

At project start, a meeting was arranged with Nilfisk to discuss the scope in the project and gain general knowledge about Nilfisk as a company. Participating in the meeting was Kristian Bang Nielsen, head of R&D Consumer and Esben Graff, Vice President Portfolio Management Consumer.

Nilfisk is an old danish company founded in 1906. The company is best known for its long history of manufacturing and sales of cleaning equipment, especially vacuum cleaners. Today Nilfisk is a large global company which sells its products all around the world [Nilfisk n.d.].

Nilfisk largest business area is its B2B products, however, B2C products still represent a substantial part of the company. The business model of Nilfisk consumer products is based upon sales through large retailers such as Elgiganten and Power in Denmark. The consumer product portfolio consists of 10 different vacuum cleaners seen in ill. 4.

he Nilfisk organisation is divided between operations in Hadsund, Denmark and Shenzhen, China (ill. 4). Nilfisk has established a close collaboration with an OEM manufacturer also based in China, who is responsible for all production of products in the Nilfisk consumer product portfolio. The OEM manufacturer supplies multiple other producers than Nilfisk, thereby obtaining mass-production benefits. The Nilfisk products, therefore, consists of a selected number of parts exclusively produce for Nilfisk, and several common parts shared between the OEM manufacturers customers. For this reason, some components are more or less fixed and Nilfisk has limited power to change the specifications of these parts as it would introduce unwanted complexity at the OEM manufacturer. These parts are the electronic components such as the motor.

In regards to sustainability Nilfisk primary focus until now has been energy, water and emissions. Use of recycled materials is also on the agenda, however, no concrete examples of the use of recycled materials could be found [Nilfisk 2008].

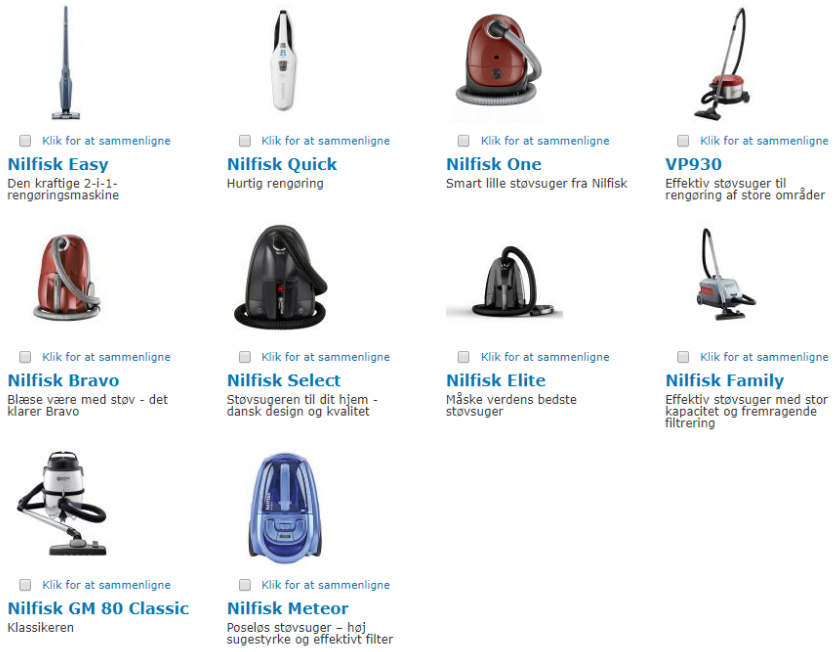
Findings from Project start meeting

As a global producer of electronic products, Nilfisk contributes to the E-waste problem. Nilfisk is fully aware that changes to reduce E-waste and increase material efficiency are necessary to secure the future of the company. Pressure from future regulations (described on page 22) as well as a new generation of environmentally conscious consumers are pushing for the change. All Nilfisk Consumer products are currently designed as make-use-dispose products, and there are no EoL considerations in the design phase.

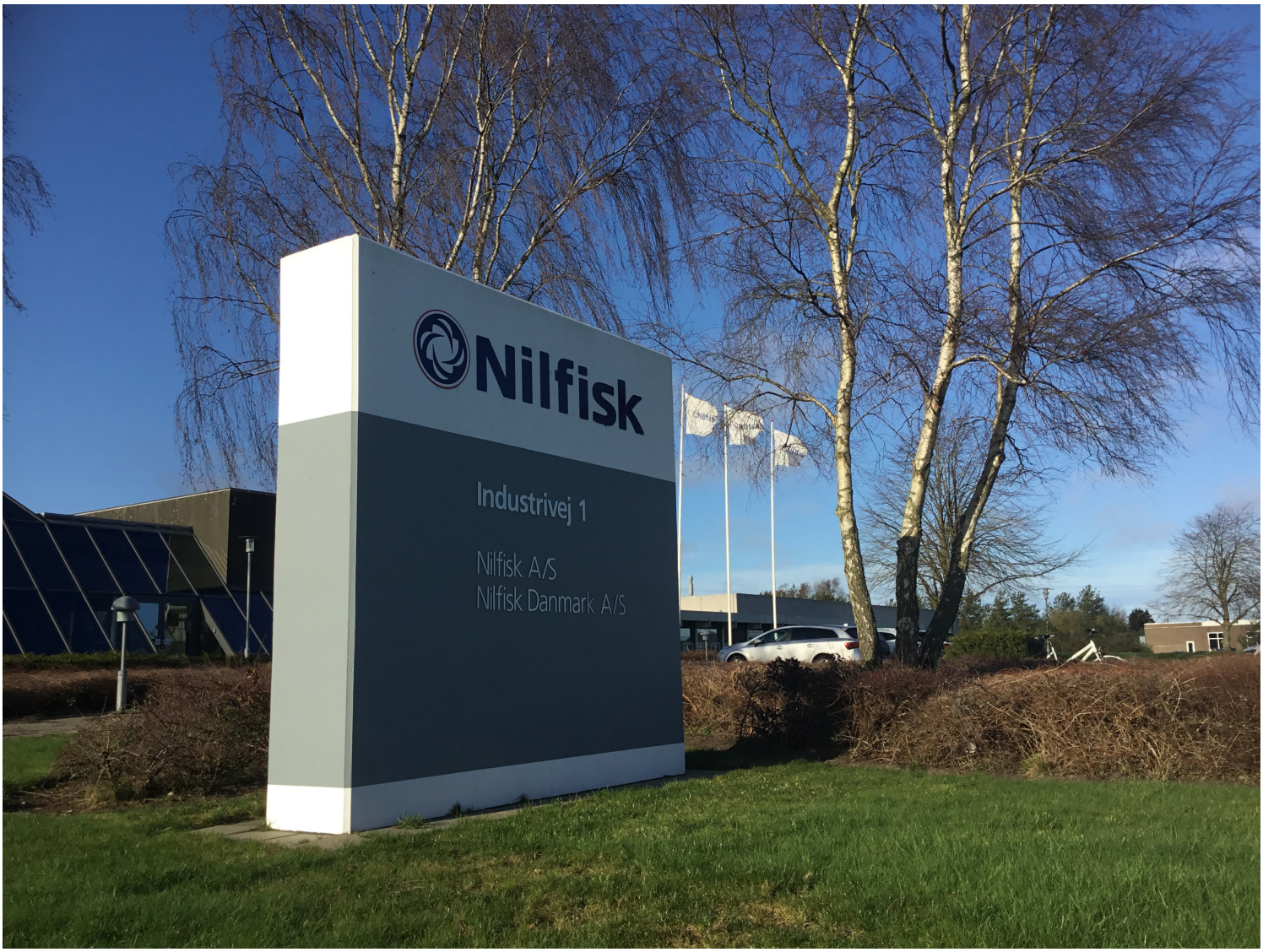
The consumer market is moving towards handheld stick vacuum cleaners. The main driver behind this shift is the easier handling of stick vacuum cleaners, which is further improved by being battery powered and cordless. As the project is focusing on developing a product concept for a future consumer vacuum cleaner, it makes sense to focus on the growing product category of stick vacuum cleaners.

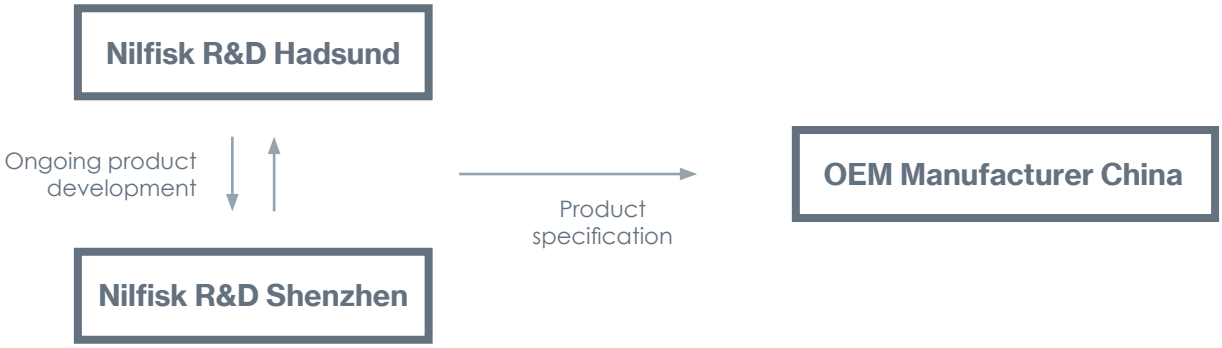
Influence of OEM manufacturer and existing organisation is important to consider. ▽

The project will focus on the stick vacuum cleaner category, which is a segment experiencing good growth. □



ill. 4 Nilfisk Consumer vacuum cleaners product portfolio





ill. 5 Nilfisk R&D organisation

Nilfisk Easy

Nilfisk's most popular stick vacuum cleaner is the Nilfisk Easy. The Nilfisk Easy is a 2-in-1 vacuum cleaner meaning it consists of a handheld unit and a stick unit, in where the handheld unit fits, for cleaning larger areas. The Nilfisk Easy is targeted towards smaller appartments or as an extra vacuum cleaner in large households. The complete target group description provided by Nilfisk can be seen in appendix 1. The Nilfisk easy comes in three different versions to compete in differen price segments, ranging from low-end to mid-end price segments.

The Nilfisk Easy features a modular construction consisting of 4 main modules; Handle, stick unit, handheld unit and mouthpiece (ill. 8). This allows for easy storage of the product in small appartments. The Interaction areas as the cover of the mouthpiece and dust canister are transparent which enables the user to observe when maintenance is needed. Also the mouthpiece has a holder for a cutting tool for maintenance of the rotating brush.

Specs: Nilfisk Easy 36V

Battery capacity	1950 mAh
Battery time	80min.
Charging time	4h
Max power	170W
Dimensions:	17x28x116
Weight:	3,62kg

List price

20V	145 EUR / 1087 DKK
28V	199 EUR / 1495 DKK
36V	259EUR / 1942 DKK

ill. 6 Nilfisk Easy

ill. 7 Removing handheld unit from Nilfisk Easy

1) Handle
With controls

2) Stick unit.
Internal storage for acces-sories

3) Handheld unit.
Electronics, motor, battery
Housing + Dust canistor

4) Mounthpiece
Including rotating brush and see through lid to ease main-tenance.

ill. 8 Nilfisk Easy modules

Handheld unit

Main body
Motor, battery and electrics
Controls
Battery indicater LEDs
Power connectors

Filters
Fine mesh filter filtering small particles
Large mesh filter filtering larger items

Dust canister
0,6L dust canistor

ill. 9 Nilfisk Easy handheld unit

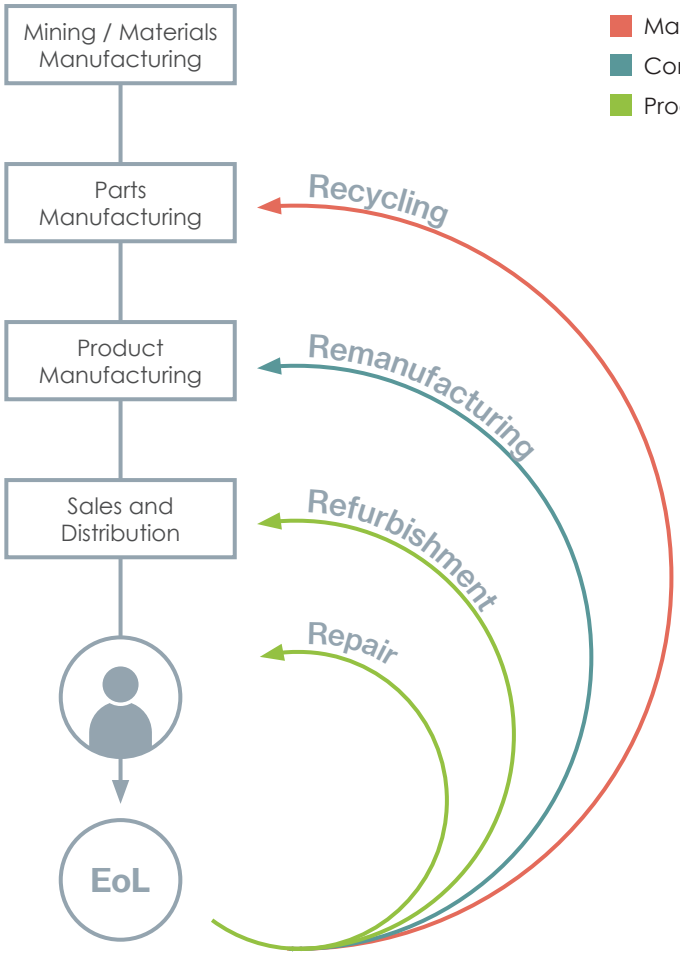
Circular economy

The current practice of e-products design focuses heavily on a linear business model of make-use-dispose, where products are designed to maximize sales numbers without any real EoL considerations. As described previously this is a very wasteful process, as all resources which have gone into manufacturing are lost the moment the product becomes waste.

The circular economy is a concept describing an industrial system which seeks to design out waste. The concept strives to accomplish this by achieving maximum material efficiency through optimized resource loops to preserve products, components and materials at its highest level of utility.

A products environmental impact is mainly determined by its material composition, as related to its lifetime [Montalvo, Carlos; Peck, David; Rietveld 2016]. In other words, the environmental impact is determined by how efficiently is the consumed resources and materials used to deliver a certain value in the products lifetime. Illustration ill. 10 describes a circular system where products, components and materials are circulated back into the system at EoL instead of being disposed of as waste. The feedback loops in the system are repair, refurbishment, remanufacturing and recycling (explained in the box, ill. 11). The inner loops of repair and refurbishment can be considered product recovery loops. In these loops, products are maintained, repaired and/or distributed to new users to prolong its lifetime. The remanufacturing loop is focused on the recovery of components at a time where the product itself is no longer functional. The final loop is the recycling loop which focuses only on material recovery. The further we move towards the outer loops, the more energy and resources are needed in order to produce a new functional product. Therefore it is, environmentally speaking, most efficient to prolong product lifetime by circulating in the inner loops.

The potential benefits, both environmentally and economically, of the circular economy concept in the e-products industry are huge and has been identified as a key focus area of the recent European Union Action Plan for Circular Economy [Parajuly 2017].



ill. 10 Circular economy "Butterfly"diagram"

Recycling
The process of converting disposed materials to new raw materials

Remanufacturing
The process of recovering, repairing and preparing used components to be used in new products.

Refurbishment
The proces of repairing and updating discarded products to be sold as a new product with new warranty.

Repair
The process of returning a product to working order

ill. 11 Circular economy definitions [Circular Economy Practitioner Guide n.d.]

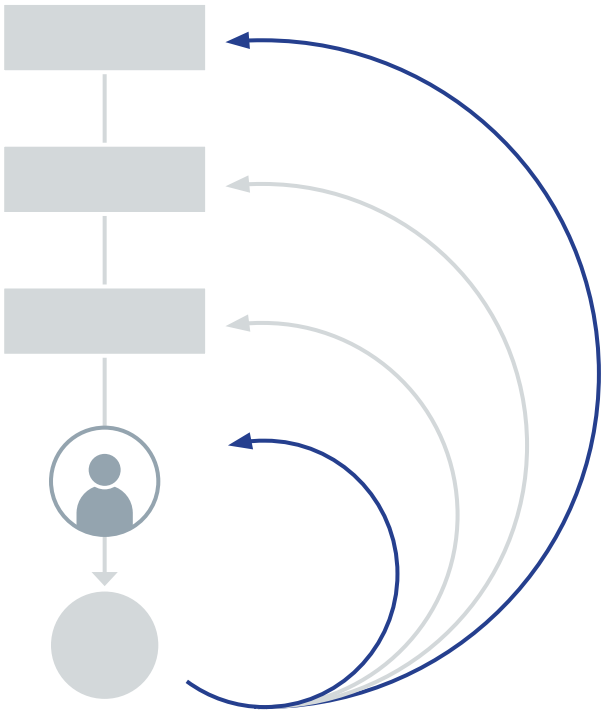
How to exploit the loops in circular economy ?

The inner loops of reuse, refurbishment and remanufacturing are the prefered EoL options in the circular economy. However it can be a challenge to unlock the economic potential and sustainability benefits of the inner loops as these activities tends to be more labour-intensive and logistically challenging than the conventional recycling loop [Parajuly, 2017].

The key challenge is the infrastructure needed to handle refurbishment and remanufacturing of recovered parts and products. This infrastructure would have to be highly specialized to ensure high quality and remain cost-effective [Accenture, 2014]. Nilfisk consumer products are sold over a large geographical area. Thereby the products end up in multiple different E-waste handling systems, none of which returns any products to Nilfisk. To carry out refurbishment and remanufacturing Nilfisk would have to set up their own reverse logistics infrastructure for each area, and it would have to be evaluated if the potential return flow of products justifies the investments in the necessary infrastructure.

In Denmark establishing individual take-bake schemes for consumer electronics is not possible as the national waste regulations (Affaldsbekendtgørelsen 2019, §43) [Miljø- og Fødevareministeriet 2019] prohibit take-back schemes for product categories which are already covered by extended producer responsibility schemes as is the case with consumer e-Products. Products handled as waste must go through the existing E-waste system.

Currently, the most realistic option for Nilfisk consumer products is considered to be focusing on the inner- and outermost loop ill.x. This would include prolonging product lifetime via durable product design and repair as well as optimizing the design for recycling at the official E-waste system. At a later stage, the focus can then be extended to include the feedback loops of refurbishment and remanufacturing. Moving towards new business models which prioritise access over ownership can be instrumental to exploit these remaining feedback loops. This business model and a more conventional long-life business model are briefly described on p. 18.



ill. 12 Repair and recycling loop

Business models

The long-life model

As mentioned earlier a product environmental impact is determined by the resources and materials used within its lifetime [Montalvo, Carlos; Peck, David; Rietveld 2016]. One way to reduce a products environmental impact is then to design for a long lifetime. The long-life model seeks to prolong lifetime by developing a product which is durable and easy to repair to preserve product functionality for as long as possible [Accenture, 2014]. Companies using this model is characterised by developing high-end products of good quality [Bakker et al. 2014], which fits well with the values the Nilfisk brand is already associated with. A long lifetime requires ongoing service and maintenance, which will enable profit generated by the sale of spare parts and repair services.

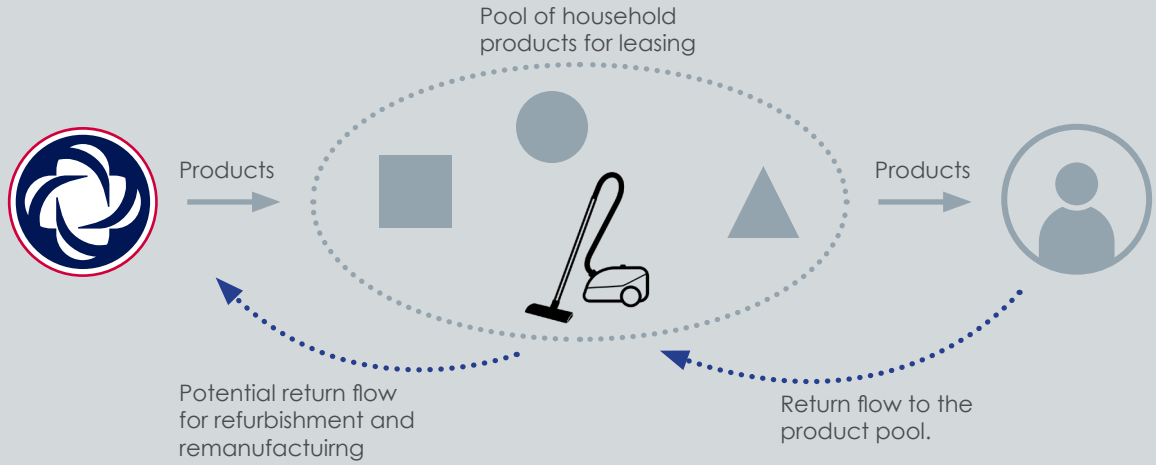
The long-life business model relies on conventional sales, thereby it is dependent on the current product being made obsolete or break to sell new products or spare parts. This means the company will always have the incentive to sell new products rather than keep products in use. With that said, a long product lifetime can be a good sales argument to gain new customers to compensate for the relative lower profit generated by existing customers. Furthermore good quality will help build healthy customer relationships.

The business model is suitable for B2C products competing in markets with limited performance gains over the previous generation of products, which can be said to be true for vacuum cleaners. Products in these markets are not rendered obsolete in a short time and therefore is worth maintaining [Accenture, 2014].

Product-as-a-service

In product-as-a-service business models, the producer sells access to the service or function a product provides rather than ownership of the product itself. This is typically done via leasing or pay-per-use deals [Accenture, 2014]. This business model will generate revenue over time as opposed to relying on single payments at the point of sale. This pay structure creates an incentive for durability and longer product life as the business model is no longer dependent on making a profit at the point of sale. With product-as-a-service, the producer retains ownership of the products and thereby has greater control of the product flows, which would make it easier to establish the infrastructure needed to enable refurbishment and remanufacturing.

In the B2B part of Nilfisk leasing is a well-known business model in which Nilfisk has extensive experience. The option of product-as-a-service does not exist on the consumer side of things. It is considered unrealistic to introduce this kind of business model for individual consumer products at the relatively low cost of the Nilfisk Easy. A more realistic option could be to include the future Nilfisk Easy in a pool of household products and marketing it as a combined leasing deal (ill. 13).

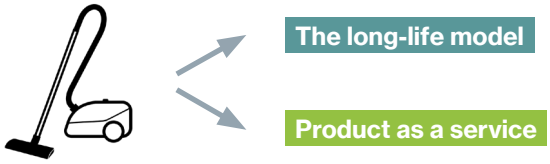


ill. 13 Product as a service

Product design

To effectively exploit the recovery loops and circulate products, components or materials back into the system the products needs to be designed to be handled effectively in the loops. In every case of repair, refurbishment and remanufacturing it will be necessary to dis- and reassemble the product easily to ensure cost-effective operations. It is vital that every part is easily accessible, independent and can be replaced without damaging other parts of the product [Bakker et al. 2014]. Further principles for dis- and reassembly is listed in ill. 16. Principles of modularity and standardisation can be adapted to ease replacement key components and make it possible to share components or complete modules across a product family. Thereby it is easier to offer repair/ refurbishment/ remanufacturing of the entire product portfolio. The product design should use as little material as possible and as few different materials as possible to ease the sorting process at EoL. Furthermore, the product should be made of pure materials, which are best suited for high-quality recycling at the end of life [Ellen MacArthur Foundation 2015]. The consumers' willingness to keep a product for a long period of time is just as essential as the product ability to function for a long time. Therefore products must be designed to induce trust and attachment.

The product design and the business model is mostly independent of each other (ill. 14), which means the same product can be used in multiple business models. A product could be sold with a long-life business model, to begin with, and afterwards, move to a product-as-a-service model to pursue higher circularity. As long as the product design allows for effective handling in the loops, by following the circular design principles mentioned, the producer can freely select which loops to focus on and develop the necessary infrastructure over time.



ill. 14

Conclusion

The long-life model is considered the most likely option as it requires the least organisational investment and is the least complex. The long-life model would also be the most logical place to start the material efficiency journey at Nilfisk to get the basic product design principles right, before potentially exploring product-as-a-service, refurbishment and remanufacturing.
From here the project direction will be developing the future Nilfisk stick vacuum cleaner with focus on extending product lifetime and designing the product to fit the existing recycling process by following the listed product design and dis-/reassembly principles.

Project direction

1. Follow the long-life model
2. Prolong lifetime via durable and repairable deisgn.
3. Deisgn for efficient material recovery

Circular product design principles

Design for long product life:
1. Durability
2. Trust and attachment

Deisgn for repair, refurbishment and remanufacturing:
3. Dis- and Reassembly
4. Modularity and standardisation
5. Adaptability and upgradability

Design for recyclability:
6. Pure materials with high recyclability
7. Few materials
8. No fused/merged materials
9. Minimize material usage

[Ellen MacArthur Foundation 2015]
[Bakker et al. 2014]

ill. 15 Circular product design principles

Dis- & reassembly principles

1. Easy access of key components
2. Visible interaction areas
3. Easy alignment of components
4. Durable connections
5. Standardized joint types
6. Minimize number of fasteners
7. Reorientate components as little as possible
8. Must be possible with few simple tools

ill. 16 Dis- & reassembly principles

Product Ecosystem

Mapping the flow of e-products and possible repair options was done be conducting two interviews. Michael Nielsen, Stock responsible at Elgiganten Aalborg, and Steen Larsen, service employe at CJ Hvidevare service.

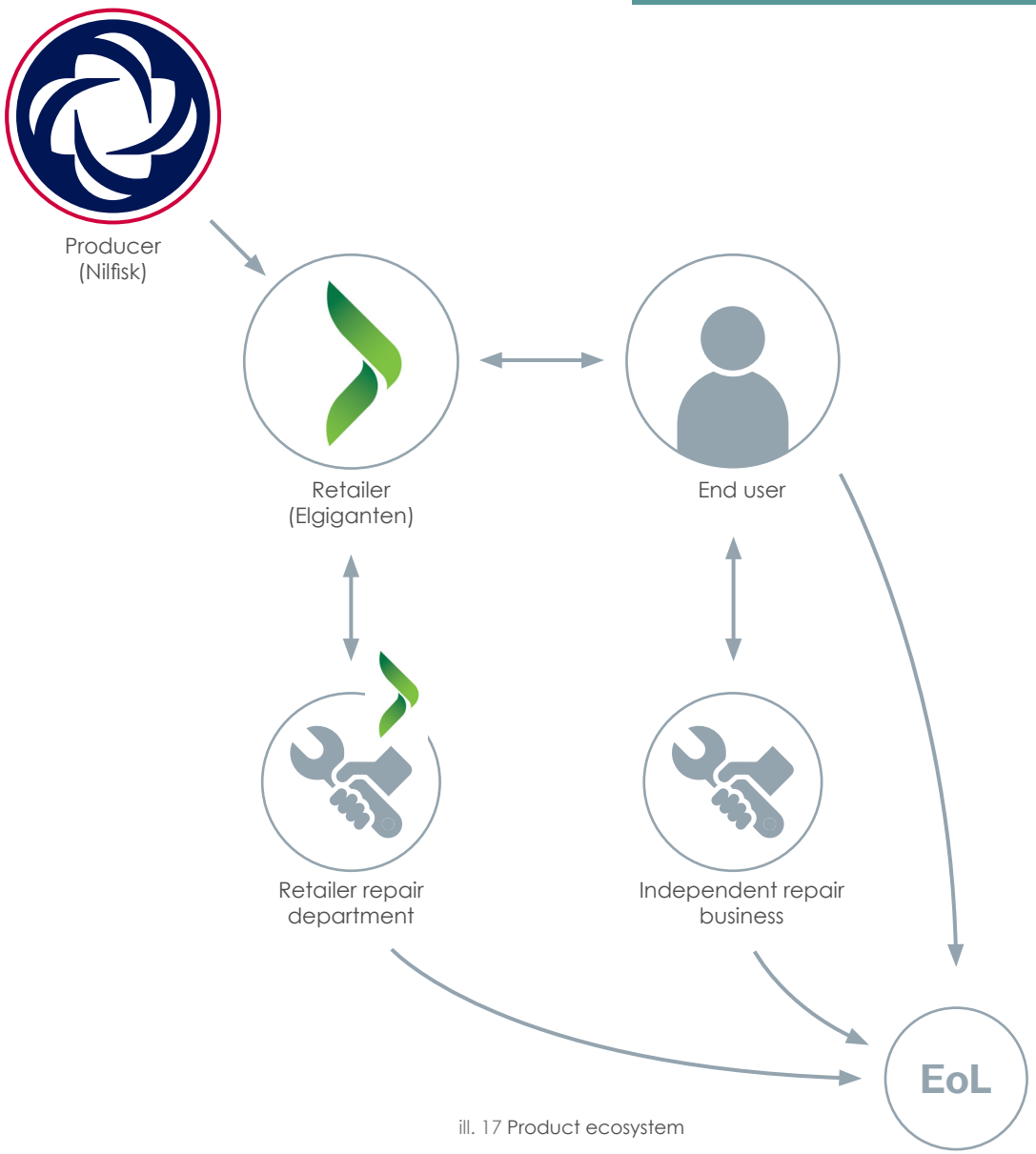
The Nilfisk consumer products are typically sold in retail stores such as Elgiganten in Scandinavia. If the product experiences any faults during its lifetime, the end-user can dispose of the product via the official E-waste system or use one of two repair options; Repair at retailer or repair at independent repair business

Repair at retailer

If a product fails within the warranty period the user can hand in the product for repair at the retail store (e.g. Elgiganten). Elgiganten, being a large retailer of electronics devices, has its own repair centres around Scandinavia. Prior to repair, Elgiganten will evaluate if a repair is feasible or the customer should be given a new product instead.
The Nilfisk Easy is already marked in the internal system as a "Low-cost" product without the option of repair, meaning no attempt to repair will be made. Instead, the product will be sent to a DOA centre (Dead On Arrival), where it will either be handed back to the producer or end up in the official E-waste system.
Rather interestingly employes at Elgiganten was able to carry out repairs of Dyson vacuum cleaners at the store in Aalborg without the need of sending it to the repair centre. This was possible because Dysons products are divided into modules, which can easily be replaced with common tools. Thereby the cost and logistics of a repair operation is reduced significantly

A moduler design, as seen in Dyson vacuum cleaners, allow quick repair at the retail store.

Possibility of using Elgigantens existing repair system for repair operations.



ill. 17 Product ecosystem

Repair at independent repair business

When the warranty period is over, the user can pay an independent repair business to repair the product. The challenge is the cost of repair related to the cost of a new product. CJ Hvidevare service confirms that the design of most low-cost e-products does not allow for efficient repair operations, as it can easily take up to 20 min. just to gain access to the motor in a common vacuum cleaner. Most of the common problems experienced by CJ Hvidevare service listed below could be solved by following previously the design for dis- & reassembly principles.

Common problems in repair of small electronics:

1. Exaggerated number of screws
2. Screws in different sizes and types
3. Combination of many different assembly methods in the same product.
4. Poor snap-fit designs. Sometimes snapfits break in disassembly and the company is liable for the damage

Common repair operations in vacuum cleaners:

5. Motor change. Often because of fine dust has been sucked into the motor, in some cases wall-dust. Evidens the vacuum cleaner have been used for more heavy duty work than intended for a consumer vacuum cleaner.
6. Cord winder system
7. Cleaning filters and removing stuck items, result of general lack of maintenance.
8. Battery change will be likely in new cordless vacuum cleaners.

In the case of a typical motor change, the cost of repair would be as follows. The start-up cost of repair is 300 DKK. If the vacuum cleaner is from a brand which CJ Hvidevare Service has a service contract with they will be able to buy spare parts at a relatively low price. In this case, the motor is approximately 150 DKK. Otherwise, the average motor cost is 405 DKK [Cordella et al. 2019]. The hourly rate is 480 DKK/h, which is billed per 15 min. Depending on the repair time the cost of repair is calculated in ill. 18.

Repair within 15 min is considered unlikely as the total repair time also include packaging and documentation. Under the assumption that the customer would prefer repair if the repair cost is less than 50% of a new products price, four cases marked with green is possible regarding the Nilfisk Easy. Repair of the lowest priced 20V version is not considered feasible in any scenario. To enable repair a product requirement of total repair time is set at 30 min. To allow for packaging and documentation the actual repair must be possible within max. 15 min.

The barrier to repair operations are the startup cost and the labour time cost. These costs can be excluded if the product features user replaceable modules as the dyson products. When discussing the possibility of user replaceable modules with Nilfisk the key take away was the balancing ease of serviceability and cost added by the moduels. The modular product will be more expensive to produce as the quality of interfaces must be higher. Furthermore there is a concern about warranty and safety hazards when allowing the user to perform repairs. For now it is decided to follow a strategy where repairs, such as motor and battery change, is to be done by a professional repair shop.

Change of priority parts max. 15 min. ○

Avoid many different assembly methods in the same product ○

Avoid an excessive amount of fasteners. Minimize the number of fasteners. ○

Repair time	**Cost of repair** (Service contract / No service contract)	**% of new product price** (Easy 20V, 1087 DKK)	**% of new product price** (Easy 28V, 1495 DKK)	**% of new product price** (Easy 36V, 1942 DKK)
15 min.	570 / 825 DKK	52,4% / 75,9%	38,2% / 55,3%	29,3% / 42,5%
30 min.	690 / 915 DKK	63,1% / 86,9%	46,2% / 63,3%	35,5% / 48,6%
45 min.	810 / 1065 DKK	74,5% / 97,9%	54,3% / 71,4%	41,7% / 54,8%
60 min.	930 / 1185 DKK	85,6% / 100,9%	62,3% / 79,4%	47,9% / 61,0%

ill. 18 Repair cost at CJ Hvidevarer service

Future regulations

To gain an overview of future EU regulations affecting material efficiency in e-products, and vacuum cleaners in particular, an interview with Charalambos Freed was conducted. Charalambos Freed is Technical Director - Head of standardisation & government relations at Nilfisk and works with the EU commission to form the future regulations of material efficiency

The EU Commission is soon to implement regulatory measures under the ecodesign directive to increase material efficiency and ensure products are designed for energy efficiency and durability, reparability, upgradability, maintenance, reuse and recycling [European Union 2020]. Producers of e-Products should take special note of the development within material efficiency as e-Products are considered a priority sector for implementing a new "right to repair", increasing the access to repair, availability of spare parts and relevant information [European Union 2020].

From 1st March 2023
Cordless vacuum cleaners:

- Availability of spare parts for 6 years after end of sale (may be limited to professional repairers)
- Following spare parts must be publicly available: Battery, hose, filters, handle, nozzles and tube extensions
- Spare parts must be replaceable with the use of common tools without any permanent damage to the vacuum cleaner. Common tools are e.g. screwdriver, full list in appendix 2.

Circular economy law, France

- Repairability label - 2021. Starting with washing machines, lawnmowers, smartphones, laptops. The list will be extended step by step.
- Minimum for recycled content in new products- 2022. Products covered still unclear, but law mentions e-products
- Durability label - 2024. Products covered still unclear, but law mentions e-products

Circular economy law, Germany
No specific regulations have been approved yet. However, three different topics are discussed as part of future circular economy laws about producer responsibility.

- "The development, manufacture and placing on the market of products, resource efficiency reusable, technically long-lasting, easily repairable and, after use, suitable for proper, harmless and high-quality recycling and environmentally compatible disposal".
- "The primary use of recyclable waste or secondary raw materials, in particular recyclates, in the manufacture of products".
- "The economical use of critical raw materials and the labelling of the critical raw materials contained in the products to prevent them from becoming waste and to ensure that the critical raw materials can be recovered from the products or waste generated after use of the products".

Recycled content
Both France and the EU commission are taking action to increase the use of recycled materials. France will introduce a minimum of recycled materials in 2022 and the EU is likely to follow the same direction if targets of recycled materials are not reached by other measures. When producers are obligated to use recycled materials in the production of new products it will be increasingly important to secure high quality recycled materials. One option to secure quality is If producers can take back their products at EoL, and use them for recycling. Then they will have an advantage in being able to control the quality of the recycled material. However this solution might be challenging in terms of infrastucture if products are not sold with a product-as-a-service business model.

Repairability label
As in the case of France, the EU commission is discussing the introduction of a repairability label which will communicate the ease of repair to the consumer. This label will be visible at the point of sale in retail stores, which will enable consumers to compare products against each other. The EU Commission seeks to introduce the label at roughly the same time as France.

The EU commission's JRC (Joint Research Centre) has conducted a study on a possible scoring system for the repairability label in different product groups including vacuum cleaners. Based on the parts risk of failure and the part's contribution to the products main functionality, the study has identifies 8 priority parts for cordless vacuum cleaners (ill. 19). The motor, motor brushes, filters and battery is given a weight of 3, while the wheels, switches/electronics, battery charger and brushes/nozzles are given a weight of 1 [Cordella et al. 2019].

The score on the repairability label for cordless vacuum cleaners will be calculated within 7 parameters, of which the first 4 is product specific. In terms of the product design, the main aspects are Disassembly depth/sequence, fasteners and tools needed to replace each priority part. The scoring system is not fully developed yet, and only the product parameters of fasteners and tools are possible to calculate at the moment (ill. 20).

As the first rules on material efficiency are already in effect as early as 2021, it is clear that Nilfisk must act now to be prepared.

Priority parts	Weight
Motor	3
Motor brushes	3
Filters	3
Battery	3
Wheels	1
Swithes / Electronic boards	1
Brushes / Nozzles	1
Battery charger / charging station	1

ill. 19 Priority parts for cordless vacuum cleaners

No.	Parameter	Rating	Weight	Notes
1	Disassembly depth/ sequence	*"No rating is proposed since data regarding disassembly depths has not been collected in this study"*	2	• Not specified yet • Low disassembly depth, short sequence and time of replacement of priority parts will be important.
2	Fasteners	A score is assigned for each priority part according to the reversibility and reusability of the fasteners used for its assembly. I) Reuseable = 1pt. II) Removeable = 0.5 pt. III) Non-removeable = 0 pt.	2	
3	Tools	A score is assigned for each priority part according to the complexity and availability of the tools needed for its repair/ upgrade: I) Basic Tools = 1pt. II) Commercially available tools = 0.5 pt. III)Proprietary tools = 0 pt.	2	
4	Disassembly time	-	-	• Not specifies yet. • May be calculated as the sum of #1 #2 #3
5	Diagnosis support and interfaces	-	-	
6	Type and availability of information	I) Public availability at no additional cost for consumers= 1 pt. II) Available only to registered professional repairers = 0.5 pt.	2	
7	Spare parts	(a) Availability: I) Spare parts to be available for at least 8 years = 1 pt. II) Spare parts to be available for at least 5 years = 0.5 pt. (b) Target group: I) The spare parts is available publicly= 1 pt. II) The spare parts is available to professional repairers = 0.5 pt. Score= (a) x (b)	2	

ill. 20 Repairability label scoring system

The product should achieve the maximum repairability label score

1. Access to priority parts must feature low disassembly depth and low disassembly time
2. Priority parts must be accessible with common tools
3. Any fasteners must be reusable

Nilfisk Easy
Disassembly study

To investigate how the current Nilfisk Easy compares to the product design and design for dis- & reassembly principles as well as the criteria set by the future repairability label a disassembly study was conducted.

The study focussed on accessibility of priority parts, dis- and reassembly sequence, materials and tools required. The disassembly study is assessed accordingly to each priority part relevant for cordless vacuum cleaners defined by the EU Commission Joint Research Center [Cordella et al. 2019]. See appendix 3 for further details about this study.

The study was conducted by disassembling a Nilfisk Easy vacuum cleaner. It was not possible to disassemble the vacuum cleaner completely, as some assemblies could not be separated. Furthermore, the electronic assemblies were treated as one part. The disassembly was possible with common tools, cross-slotted screwdrivers for loosening of screws and normal slot screwdriver for prying open snaplocks. However, the disassembly operation was not possible without leaving clearly visible damage as difficult snaplocks were opened with multiple screwdrivers. Multiple snaplocks also broke in the process. Each priority part is assessed in ill. 21. Additional parts not included in EU regulations, which arguably could be considered as priority parts as well is assessed in ill. 22.

Calculating the repairability score of the Nilfisk Easy results in a score of 24 of possible 64 points (ill. 23) (only parameters fasteners and tools can be calculated).

Materials

1. The dominant material is ABS
2. Different plastics (ABS/PC) was used without significantly differently requirements.
3. Few components of PP plastic
4. Components with merged materials
5. Filter assemblies. The seal was overmoulded to the plastic part and the filter bag was not possible to remove.
6. Top lid in mouthpiece. The seal was glued in place.

Priority part	Weight	Notes	Illustration no.
Motor	3	• Main body top cover had to be removed before opening the main body. • Extremely difficult snap locks fastening the top cover. High risk of breaking/ scratching/ damaging the product. • Visual damage and broken snap locks occurred	(ill. 24, ill. 25, ill. 26)
Motor brushes	3	• Not replaceable • Would require motor change	
Fiters	3	• Easily replaceable • However, the filter bag cannot be replaced without changing the whole component.	(ill. 27)
Battery	3	• Same as motor priority part	(ill. 24, ill. 25, ill. 26)
Wheels	1	• Easily replaceable	
Switches / electronic board	1	• Acces to electric components require high disassembly depth. • Most electric components are fitted to the PCB with connecters which makes then easy replaceale. • In the mouthpiece the wiring is soldered directly onto the PCB which makes for difficult replacement.	
Battery Charger	1		
Brushes / Nozzles	1		

ill. 21 Findings from Nilfisk Easy disassembly study

Priority part	Weight	Notes	Illustration no.
Rotating brush	3	• Tool for maintenance provided • User interaction could be improved further	
Brush motor and drive	3	• Excessive amount of screws (10) • Reassembly alignment problems, especially with switch. • Motor and lights were fastened in different parts (top and bottom) of mouthpiece leading risk of damage when they are pulled from each other during disassembly. Also leading to difficult cable handling during reassembly	ill. 28

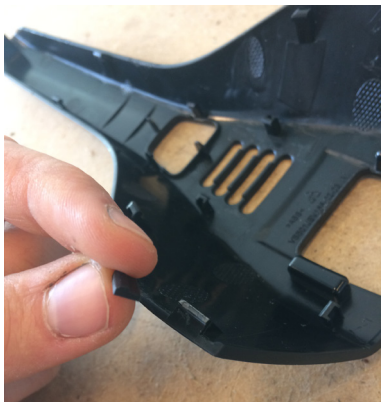
ill. 22 Additional priority parts

Parameter	Weight	Rating	Score	Notes
Disassembly depth	2	*"No rating is possible since data regarding disassembly depth has not been collected for this study"*	-	
Fasteners	3	A score is assigned for each priority part according to the reversibility and reuseability af fasteners used for its assembly. I) Reuseable: 1 pt. II) Removeable: 0,5 pt. II) Non-removeable: 0 pt.	12 pt.	Sum of: (pt. per. priority parts) x (priority part wegit) x (repairability lable parameter weight)
Tools	3	A score is assigned for each priority part according to the complexity and availability of the tools needed for its repair/ upgrade: I) Reuseable: 1 pt. II) Removeable: 0,5 pt. II) Non-removeable: 0 pt.	12 pt.	Sum of: (pt. per. priority parts) x (priority part wegit) x (repairability labal parameter weight)
Disassembly time	-	-	-	Not specified yet.
		Total score=	24 pt.	Max score: 64pt.

ill. 23 Repariability score calculation

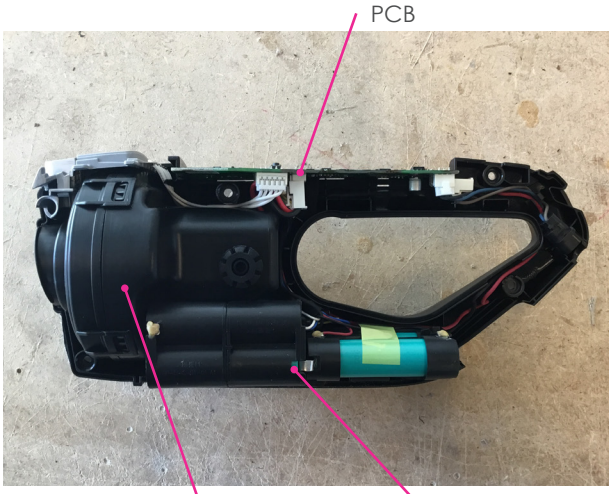
It is clear that the product was never intended to be disassembled. The main problem is the difficult assembly of the handheld unit top cover which hinders access to the priority parts (motor, battery and PCB) because scews are hidden behind it (ill. 24, ill. 25, ill. 26). As the top cover is not possible to remove without damaging the product, priority parts are not accessible. Thereby Nilfisk will not be able to sell the Nilfisk Easy on the European market beyond 1st March 2023.
In theory the mouthpiece and stick unit does comply with future regulations as all priority parts can be accessed with tools from the common tools list. However, repair operations of parts in the mouthpiece would be very complex because of the wiring through the rotation joint (ill. 29) and the wiring being soldered directly onto the PCB in the mouthpiece (ill. 28). Repair of the brush motor and PCB would require soldering and potential rewiring through the rotation joint, which would be very difficult.

The problem of inaccessible priority parts in the handheld unit could probably be solved by redesigning the top cover assembly, which would also improve the repairability score. However, the overall design would never achieve a very high score as disassembly depth and time is too high.



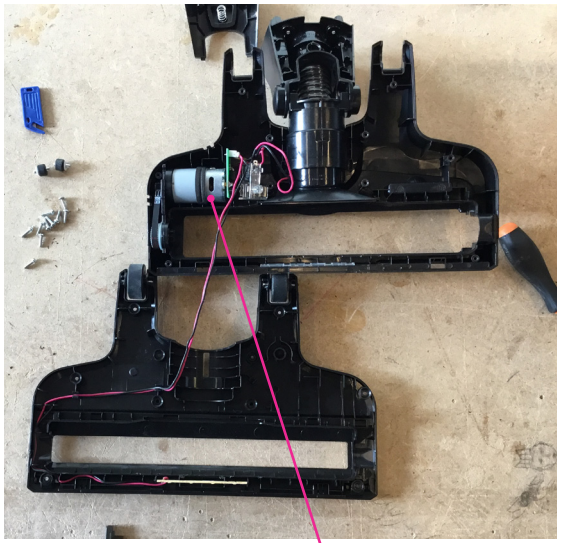
ill. 24 Top cover broken snap-fits

ill. 25 Side view handheld unit

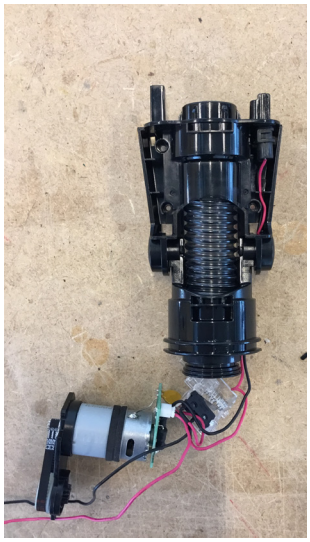


ill. 26 priority parts

ill. 27 Filter assembly



ill. 28 Mouthpiece



ill. 29 Rotation joint

Nilfisk VP600
Disassembly study

The Nilfisk VP600 is a vacuum cleaner from the B2B portfolio. The VP600 has been studied because of its modular construction. Key findings are listed below. Further information about the study can be seen in appendix 4.

The VP600 is without a doubt a very well designed machine, which allows for repair in most cases. The modularity of priority parts makes common repair or refurbishment operations less timeconsuming and cost-effective. The possibility of refurbishment could be further improved be less complex assemblies between body panels allowing for changing of individual body panels. The modular system also enables different configurations and future upgradeability of the machine.

The VP600 will still be very time consuming to separate into material fractions for effective material recovery as some complex assemblies remain, merged materials are still present and a lot of screws are used in the assembly. However, the use of only one type of plastic, PP, does improve recyclability.

The modularization of priority parts and use of connectors in modules made for easy repairability

Modules

1. Clear defined and easily replaced modules
2. The cable module is released by two half-turn fasteners. Good icons to make the user understand the half-turn locks (ill. 31)
3. The motor module, including HEPA-filter, could be removed and replaced by releasing two half-turn fasteners and four screws (ill. 32).
4. The electronics in each module has connectors which meant modules can be changed without fiddling with electronics (ill. 35).
5. All priority parts, apart from a few of the electronic connectors, are easy to change.

Disassembly/ reassembly

6. One tool disassembly, Torx tool provided.
7. Magnet solution is a very easy way to dis and reassemble the dust compartment cover.
8. Filter change in dust compartment is extremely easy as the filter snaps off without difficulties (ill. 34)
9. Good steerers and pins to easy alignment during reassembly of modules.
10. Power button lid had to be pried open to gain access to electronics. Risk of damage. (This was the correct way to do it according to the service manual).

Materials

11. All plastic parts are PP.
12. Merged materials. Magnets in the plastic casing are fitted in the lid's front and hinges.
13. Merged materials. The filter is sewed to the plastic parts. Rubber is insert moulded to the part.

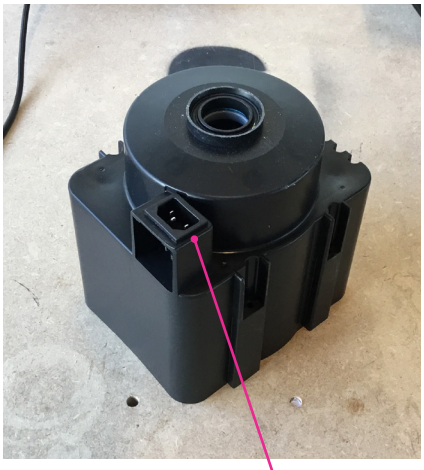
ill. 30 Nilfisk VP600


ill. 31 Cable module removed


ill. 32 Motor module removed


ill. 33 Nilfisk VP600 parts


ill. 34 Dust compartment filter change



ill. 35 Motor module

Project Brief

The ever-growing problem of E-waste calls for a change in the way producers design and manufacture e-Products to ensure sustainable consumption. This project aims to develop a product concept showcasing how future Nilfisk consumer products can be designed with material efficiency in mind. The project will focus on the stick vacuum cleaner category, but the principles explored in this project will likely apply to the majority of the future consumer product portfolio.

Aligning with future regulations

The EU Commission is working to secure a higher level of material efficiency in products sold on the European market. The increasing focus on circular economy and material efficiency in future environmental regulations will require companies to develop in this area to continue selling their product on the European market. The regulations will have a big impact on how the products are designed and manufactured as the requirements for access to priority parts means products can no longer be designed only for assembly. As it must be expected that the products will have to comply with higher and higher demands to material efficiency in the future, it will be important to be at the forefront of future regulations.

User perception:

The consumers' willingness to keep the product will ultimately decide the products lifetime. The product must be designed to induce trust and be perceived by the consumer as a trusted long-lasting durable product.

Material efficiency:

The most likely strategy to start improving material efficiency at Nilfisk is focusing on two main areas:

1: Prolong product lifetime through improved repairability.
The product concept must be able to be repaired at a reasonable cost at a professional repair shop. Multiple areas of improvement to the Nilfisk Easy was discovered during the disassembly analysis including the accessibility of priority parts. The product concept should strive to score the maximum points in the future repairability label.

2. Effective material recovery
The product concept should be designed to allow for high-quality recycling in the official E-waste system, and improve upon the current problems of merged materials which hinders the recycling process.

Interaction:

A professional repair shop should be able to repair the product at a reasonable cost compared to the new product cost. This requires the product to be intuitive to repair and easy to understand for the repair worker.

Vision

The vision of the project is to provide information about how future consumer products can be designed to improve material efficiency.

The solution should:

1. Be designed according to Dis- & reassembly principles. *p. 21*
2. Be designed according to Circular product design principles. *p. 21*
3. Enable the replacement of priority parts in less than 15 min. *p. 23*
4. Avoid many different assembly methods in the same product. *p.23*
5. Avoid an excessive amount of fasteners. Minimize the number of fasteners. *p.23*
6. Achieve the highest repairability label score. *p.25*
    - Access to priority parts must feature low disassembly depth and low disassembly time. *p.25*
    - Priority parts must be accessible with common tools. *p.25*
    - Any fasteners must be reusable. *p.25*

2

Concept Exploration

Building on the information gathered in the understand chapter, in this chapter, the project seeks to explore the consumers' behaviour in relation to material efficiency and generate ideas and principles for a product concept.

User perception theory

Increasing a products functional lifetime will not necessarily increase its actual lifetime as only there is no guarantee that the user will exploit the full functional lifetime. According to (Cox et al. 2013) products lifetime is the combined functional lifetime and lifetime in use. While the products functional lifetime is defined by its durability and repairability, the lifetime in use is determined by the user's perception of value which influences their "willingness to keep". Important parameters influencing the perceived value are price, information, social norms, updating(fashion), emotional attachment, functional utility (Cox et al. 2013).

Categories of product perceptions:

[Cox et al. 2013]

1. **Up-to-date.** Products defined by high technological development, fashion or other parameters which drive fast product obsolescence. Products are often discarded before their functional lifetime. (Clothing, mobile phones, small appliances)
2. **Workhorse.** Products that are valued primarily for their functionality. Expected to be durable in use and most often disposed of when they are broken.
3. **Investment.** Larger expensive appliances which are considered essential. (quality electronics, major appliances)

Main points from the study "Consumer understanding of product lifetime":

[Cox et al. 2013]

1. Lifetime expectations are greatly influenced by product price.
2. The brand is a key parameter to judge product lifetime.
3. Consumers accept cheap products will break and consider them semi-disposable.
4. Consumers have a general feeling that repair is difficult and expensive, which combined with the low cost of replacement means repair is not considered.
5. Extended warranty was interpreted by the consumer as a show fo faith in the product, thereby extending lifetime expectations. Especially when combined with a trusted brand.

Vacuum cleaners can arguably be considered a workhorse product. it's clearly a product which is bought mainly because of its functionality, meaning vacuum cleaners will most likely only be replaced if the break or the consumer has changed demands. With the introduction of the repairability label durable product design will be very visible to the consumer and the future Nilfisk consumer products will compete on long product lifetime. The Nilfisk brand is already well positioned as a trusted quality brand and there is a good oppotunity to design future products to work in with the brand to communicate durability to the consumer.

User perception survey

A test of user perception was conducted to uncover product features to enhance the expectation of product lifetime. Test participants were presented with product-cards showing a picture of the product and the brand of seven different products (ill. 36). Based on this material only the test participants were asked to assign a score between 1 and 5 for each product in three categories: Price, lifetime expectancy and performance/quality. The survey can be seen in appendix 5.

Three of the seven products was made-up product concepts designed to test specific aspects. The Nilfisk VP980 concept (product 2) was designed to test a direct translation of the well-known look of the Nilfisk VP930, as the VP930 is known for great durability. The Gerger concept (product 4) was designed to look like a simple tool with low complexity, almost like a garden tool. The Kemco concept (product 5) experimented with higher quality materials, as metal was the primary material for this concept.

Product 1

RYOBI

Model:
Ryobi Akku stick Vac.

Product 2

Nilfisk

Model:
Nilfisk VP980

Product 3

dyson

Model:
Dyson Cyclon V10

Product 4

Kemco.

Model:
Ruff B1

Product 5

Gerger

Model:
VX 117R

Product 6

Nilfisk

Model:
Nilfisk Easy

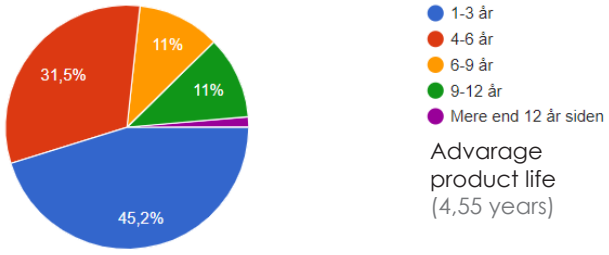
Product 7

point

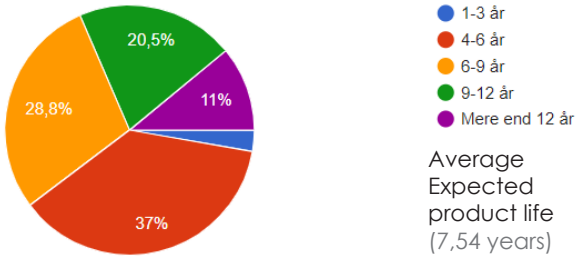
Model:
POV Stick Vac.

ill. 36 Product cards for user perception survey

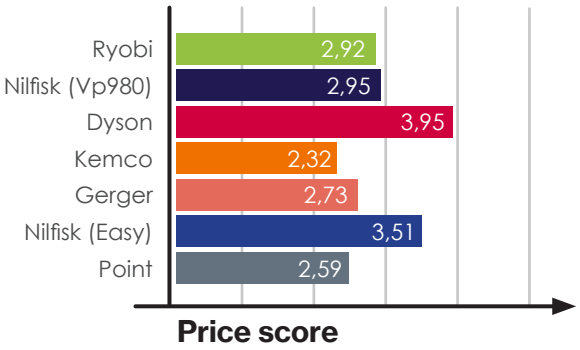
Results from user perception survey



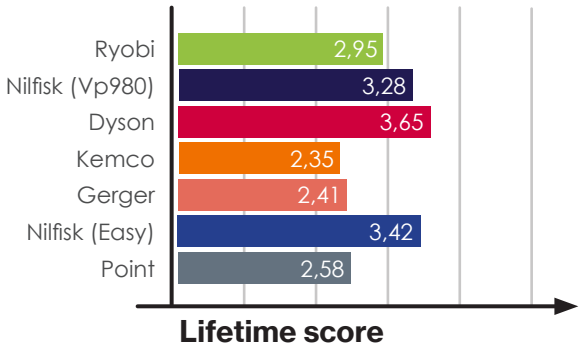
ill. 37 Current product age



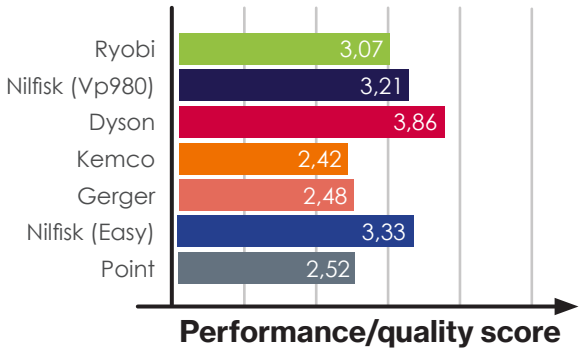
ill. 38 Expected product lifetime



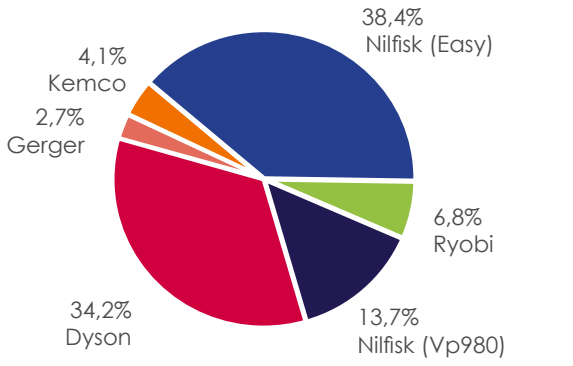
ill. 39



ill. 40



ill. 41



ill. 42

Why did you prefer this product?

Key themes based on the answers:

Brand loyalty and experience	**1.**	*Jeg har en opfattelse af, at Dyson er et rigtig godt mærke på grund af alle de fede og nytænkende produkter de laver, som altid ser seje og anderledes ud*
	2.	*(Dyson) Det er mit indtryk at de er kendt for at have produceret de første poseløse støvsugere og var nogen af de første til at udvikle de ledningsfrie støvsugere og har noget mere erfaring hvad dette angår*
	3.	*(Nilfisk Easy) Nilfisk er et anerkendt mærke, og min nuværende støvsuger, som jeg er meget tilfreds med, er Nilfisk*
	4.	*Jeg har kun hørt om Nilfisk og Dyson af mærkerne, så jeg ville ikke turde gå med nogen af de andre.*
	5.	*(Niilfisk Easy) Nilfisk er kvalitet og den ser god ud.*
Design	**1.**	*(Ryobi) Den ser gennemtænkt ud, og ligner en der virkelig kan suge snavs op*
	2.	*Ryobi'en ser mest "power"-agtig ud, som om at den har bedst sugeevne. Den ser også "tungest" ud, som sikkert afspejles i kvaliteten modsat Nilfisk's (begge to) som ser lette og plastikagtige ud.*
	3.	*(Nilfisk Easy) Den ser high tech ud, men uden for mange dikkedarer. Det sorte design får den også til at se ret stilet ud*
	4.	*(Nilfisk Easy) Designet er strømlinet og robust, men gjort på en meget mere nedtonet måde end f.eks. dyson. Den signalere robusthed og funktionalitet fordi den har volumen. Især fordi den har volumen ned hvor den skal suge.*
	5.	*(Nilfisk Easy) Designet virker meget tidsløst*

Evaluation

75 test participants took part in the test.

The survey reveals that participants expect a vacuum cleaner to last 7,54 years (ill. 38). However, the average current lifetime of the participants' vacuum cleaners was 4,55 years (ill. 37), which suggest that vacuum cleaners, in general, have a shorter lifetime than expected and desired by the consumer.

In general the scores on price, lifetime and performance/quality looked very similar as products kept roughly the same score and ranking. The top three scores in all three questions were Dyson, Nilfisk Easy and Nilfisk Vp980 (ill. 39, ill. 40, ill. 41). When asked to choose one of the products, the most desired model was the Nilfisk Easy followed by the Dyson and Nilfisk VP980 (ill. 42).

As expected the Brand has a great influence on the user perception. Nilfisk and Dyson's brand value is perceived as a clear quality stamp making the consumer trust in the product and appeared to have high customer loyalty.

Multiple participants described the Nilfisk Easy as the best looking, describing it as elegant, minimalistic, futuristic, well-proportioned. Furthermore, participants believed the product to be very stable and balanced as the "body" of the product is low to the ground. Participants valued a minimalistic look as it would allow them to store the vacuum cleaner in clear view, as they did not necessarily have room in any closets for it.

Other concepts

As expected the participants commented on the power-tool look of the Ryobi, describing it as a powerful and tough machine, but it did finish 4th in all questions. It suggests that the brand value of Nilfisk and Dyson means more than a tough look when consumers judge lifetime expectancy, quality and performance.

The Kemco concept which included "higher value materials"(metal) did not increase the test-participants perception of a lifetime/quality as was otherwise expected. This test is only considering the overall impression judged by a product picture, meaning the test persons were not able to get a feel for the quality of materials and interaction areas which might have influenced the results.

Ther Gerger concepts look was meant to be associated with a simple tool which is so simple it cannot break. However, the concept was second to last in the lifetime expectancy score, which indicates the participant doesn't notice the reference or the product simply looks too simple and too cheap to compete with the established brands.

It is worth noticing that the three concepts with unknown brands (Kemco, Gerger and Point) consistently scored the lowest points.

Nilfisk VP980 concept vs Nilfisk Easy

The Nilfisk Easy outscored the VP980 concept in all 3 main questions. The clear reference to Nilfisk VP930 did have an impact on multiple participants, as they mentioned it in the comments. The Nilfisk VP980 consistently scored better results than the Ryobi, but it did not match the Easy, as was otherwise expected considering the legacy of the VP930. The looks of the VP930 does not seem to be directly translatable to a stick vacuum cleaner. Or maybe the industrial look of the VP930 is not appealing to consumers.

Conclusion

The results imply that the most important parameter to assess product lifetime is the brand and previous experience. It is clear that the consumers trust in the Nilfisk brand and that the looks of the Nilfisk Easy is pleasing to the user.

As the Nilfisk Easy scored very well, the logical direction for the project is to follow the minimalistic aesthetics of the current Nilfisk Easy. Seen from a company strategic position this direction would also have the lowest risk, as the direction does not require large marketing efforts or new market positioning as other concepts might require. The Nilfisk Easy design has a very shiny front and wobbly plastic buttons which, in my opinion, does not match the perceived quality by the test participants. The wobbly buttons make the user interfaces feel like low quality which would probably have had an impact on the participants' perception of the Nilfisk Easy. Likewise, the other products in the survey would probably have been perceived slightly different if examined by the participants in real life.

Based on the results from the survey it is decided to follow the Nilfisk Easy looks in the future product concept.

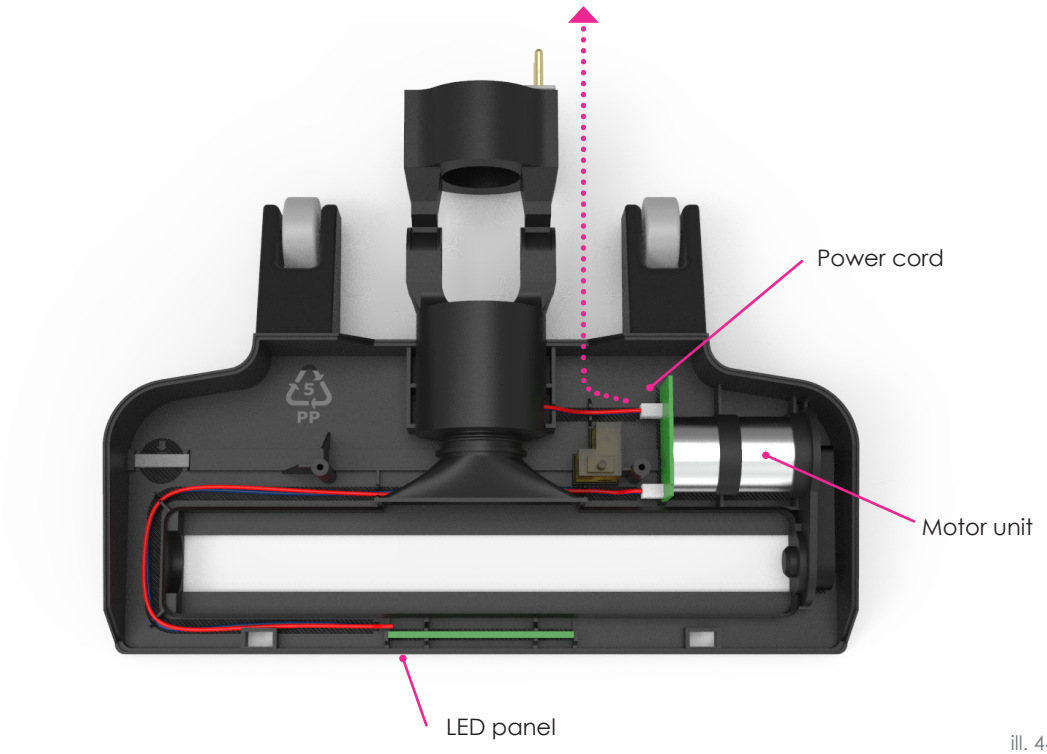
Brand value is the most important parameter in assessing lifetime, quality and performance	✓
The product concept will be aligned to existing looks of Nilfisk Easy,	☐

Mouthpiece
Concept

The next part of the report will dive deeper into the actual design of the future product concept, starting with the mouthpiece. The objective is to design a construction which enables easy and economically feasible repair of priority parts, in this case the brush motor. Furthermore, components must be able to be separated into clean material fractions at EoL.
The previously listed Design for dis- & reassembly principles (p. 19) has provided the ground rules for the design.

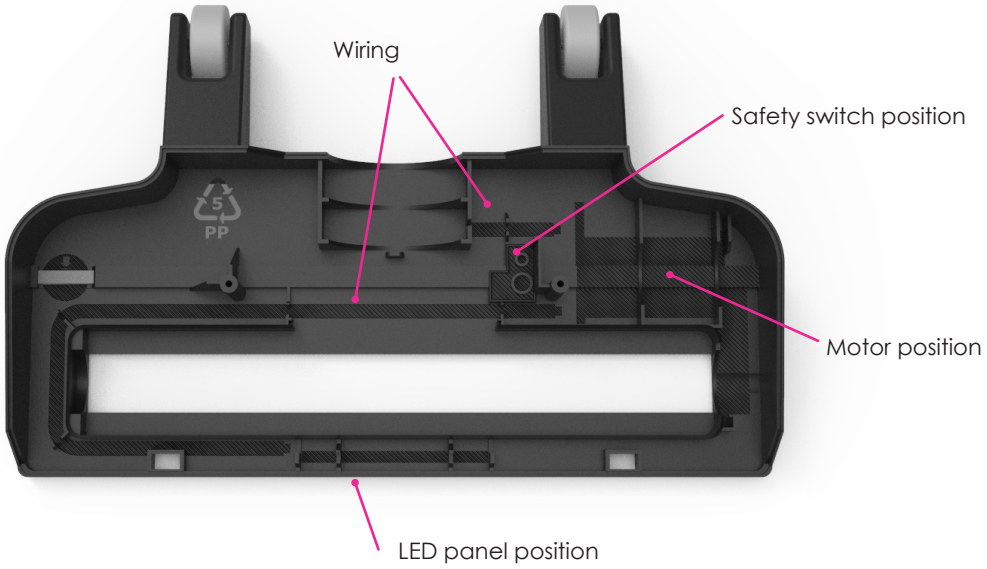
ill. 43 Mouthpice layering

1. The mouthpiece concept is designed with a layering principle. It results in a disassembly sequence from the top down, and means there will be no need for any reorientation during dis- or reassembly,
2. The fasteners are reduced to a minimum with only two screws keeping the mouthpiece together. This is achieved by "hook pins" at the top-parts front allowing the top-part to be tilted backwards and secured with the screws. The limited number of screws will reduce the repair time.



ill. 44

1. The electronics are connected to the PCB with two white connectors. Disconnecting the connectors the electrics can be separated into three parts; Motor unit, LED panel, Power cord, which can be changed independently.
2. When the power cord is unplugged it can be removed through a special designed rotation joint which features a hollow channel (Presented on p. 40).
3. The straight wiring will minimize difficult handling of wires and time in the repair operation

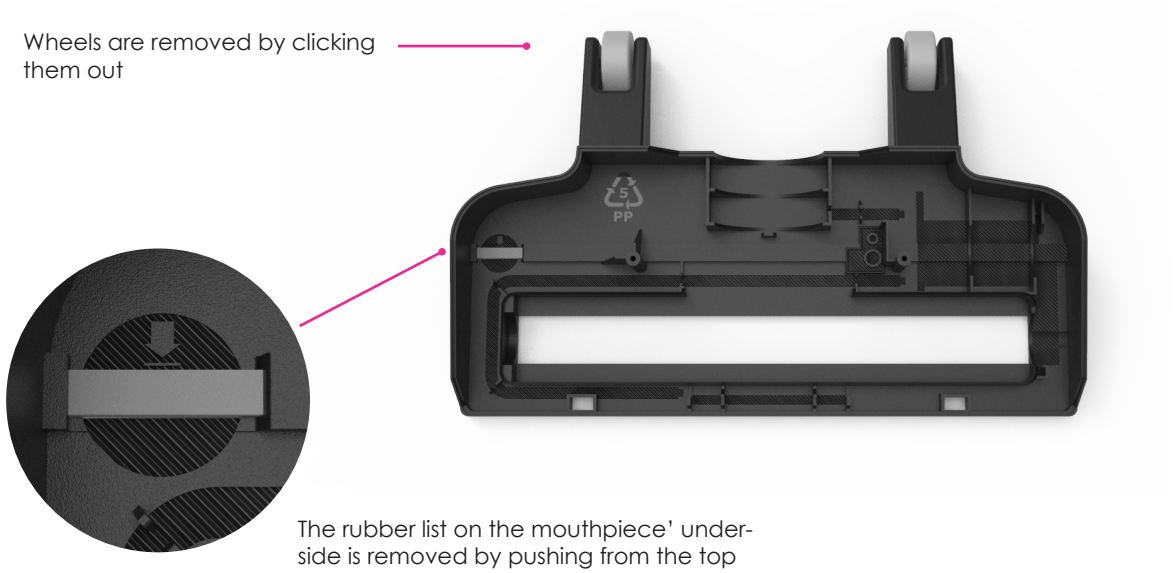


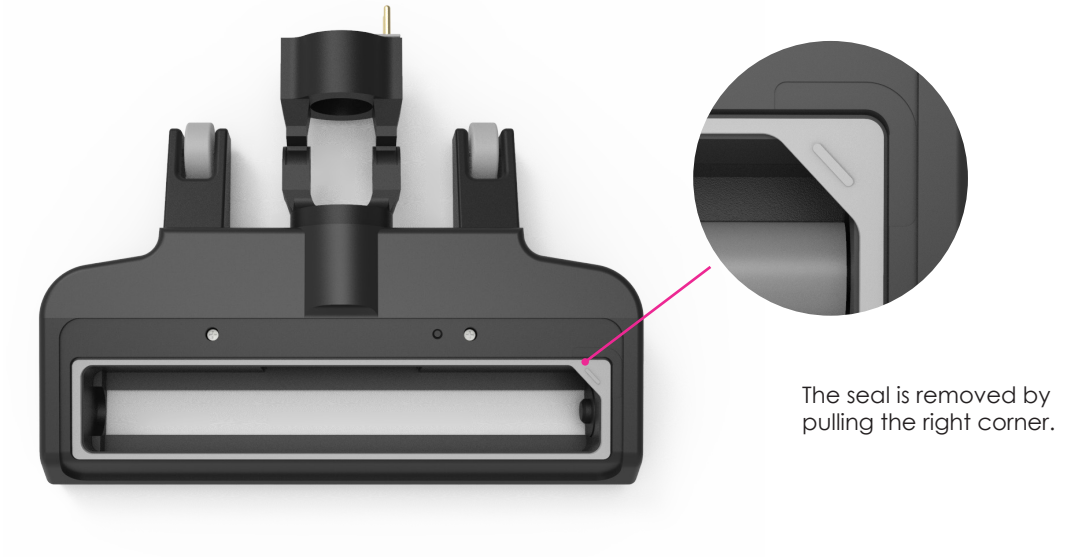
ill. 45

1. Textured surface areas will communicate the position of components and wires for reassembly.
2. The Textures areas indicate components shape and orientation, easily identifying which components fit where.
3. This approach will reduce the risk of errors and damage during repair, disassembly and reassembly.
4. The textured surface areas will be made in the injection moulding process hence no extra operations are needed.

Material recovery

As discovered in the Nilfisk Easy disassembly study multiple different materials are often used in e-Products, which introduce unnecessary complexity when the materials are sorted in the recycling process. As seen in the Nilfisk Vp600 case it is possible to design a product which uses the same type of plastic for all of the injection moulded parts. The components in the mouthpiece concept are color-coded to identify components of different materials from each other for intuitive sorting of materials. All black components are the main plastic material (ABS/PP, yet to be specified) and the grey components are the wheels, seal and a rubber list which has to be separated from the main plastic material.





1. Main components manufactures in the same material (for example PP-plastic)
2. Color coding
   - Black components are PP
   - Grey components must be sorted out
   - Electric components are sorted seperately

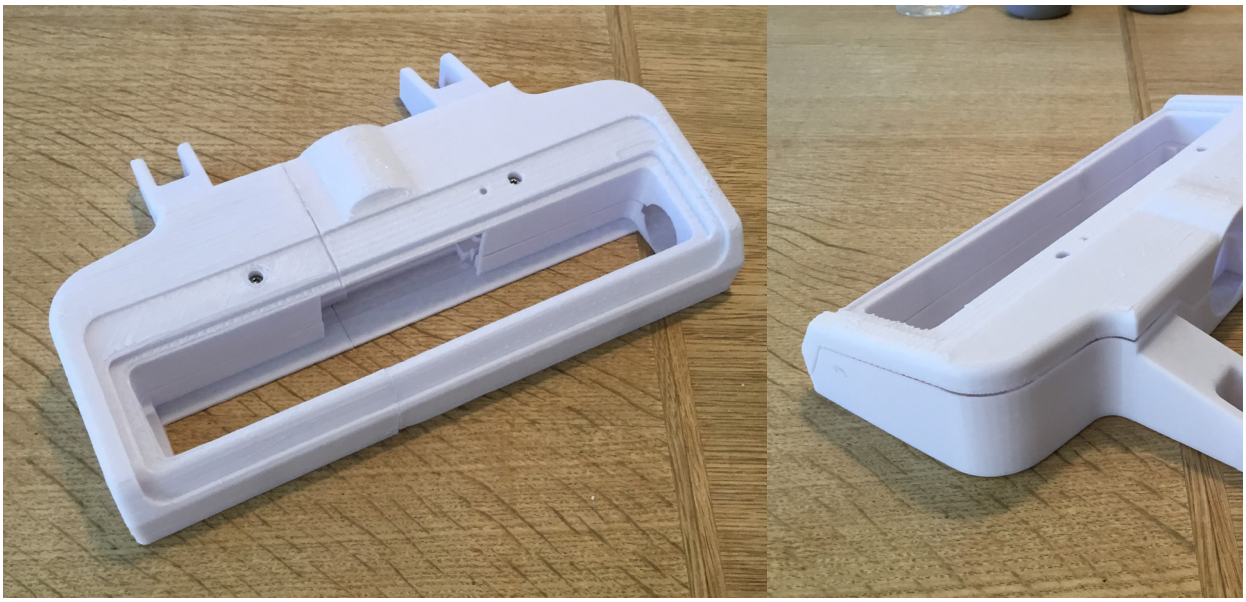
Evaluation

The mouthpiece concept was presented to CJ Hvidevare service for feedback. In general CJ Hvidevare service was very positive about the design. Especially the minimal number of fasteners, the layered construction and no need for reorientation was mentioned as improvements of the workflow. Furthermore, the textured areas indications of part position and orientation was deemed to reduce the risk of incorrect reassembly and make it easier to understand the product for new and inexperienced workers.

To evaluate the construction a 3D printed model was produced. The 3D printed model confirms that the front hook pins can be used to fasten the front part of the top cover. There was a little play in the assembly which could be solved by refining the shape and undercut of the hook pins.
It can be concluded that using only two screws is not enough to for the assembly, as there were gaps between the components at the edges furthest away from the screws (ill. 46). Furthermore, the use of only two screws raises a concern about whether the rotation joint is properly fastened. It is critical to avoid any play in the assembly between the mouthpiece and the rotation joint as the rotation joint will move during use of the product. The rotation joint is held in place by the ribs on the inside of the top and bottom part of the mouthpiece. To improve the assembly more screws positioned closer to the rotation joint is the most obvious solution, but this solution would have a negative impact on repair time and material recovery.

Because of the color-coding, the design can easily be sorted into material fractions by manual sorting. Evaluating the design it is questionable if this possibility of manual sorting of materials would ever be relevant. As the product will end up in the E-waste system it will go through a shredding process as explained on p. 10. Only the battery from the handheld unit will be removed manually. The recycling process must be investigated in greater detail to assess the true recyclability of the design and establish guidelines.

The design proved to ease repair by being intuative and less timeconsuming to disassemble	✓
Only two screws is not suficient to keep the top lid fastened properly.	✗
The recycling process must be investigated in greater detail to assess the recyclability of the design.	▽



ill. 46 3D printed mouthpiece model

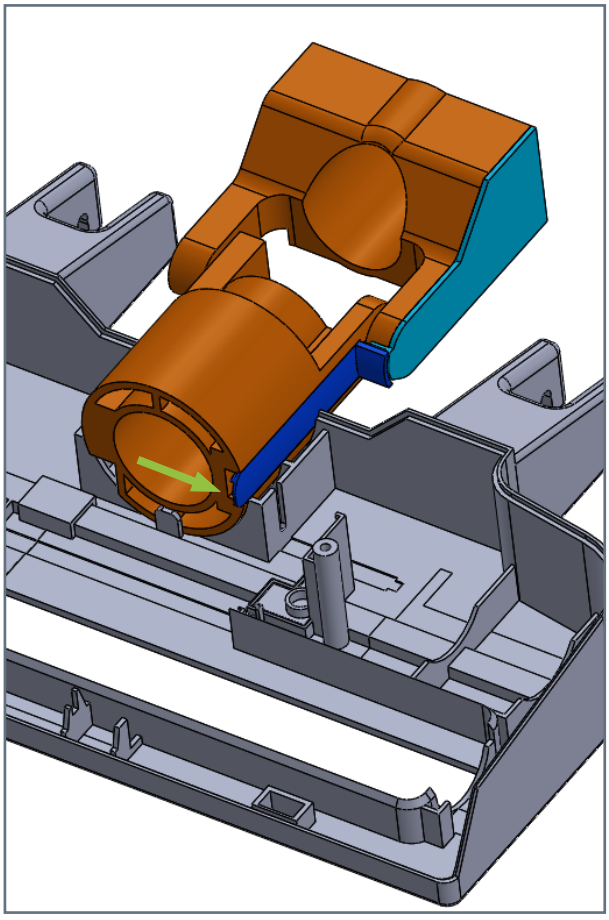
Rotation joint
Concept

What makes the rotation joint complex is that the power cord from the PCB in the mouthpiece has to pass through it. This is relatively easy if the product is designed as traditional e-Products without disassembly in mind. In this case, the wires can be passed through and afterwards electrical components can be soldered onto the ends, as it seems to be done in the Nilfisk Easy rotation joint (ill. 48). This solution makes a potential repair very complex as electrical components will have to be removed and soldered again after repair. The new rotation joint must allow for a better repair operation in order to make repair possible.

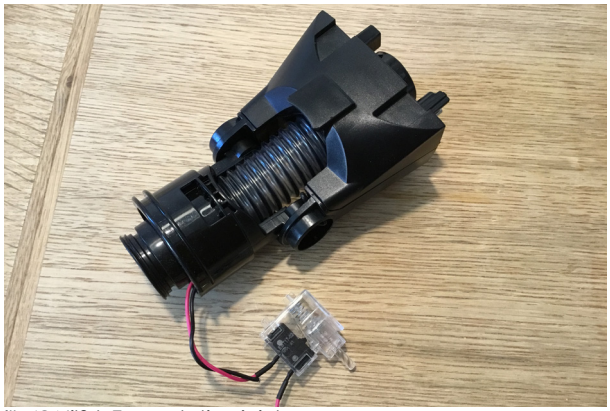
Removable covers concept

The initial idea of a rotation joint with a replaceable power cord featured removable covers hiding the power cord. (ill. 47, ill. 49). The lower cover (dark blue) would be removed by pushing the lip (green arrow), which would only be accessible when the top part of the mouthpiece had been removed during a repair operation. When the lower cover had been removed, the upper cover (light blue) could be removed in the same manner exposing the power cord.

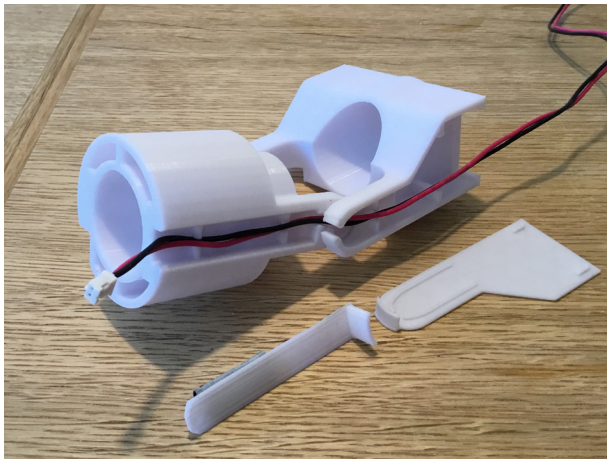
A mock-up was constructed in Solidworks and 3D printed. It was clear that is was not easy to insert the power cord in the side of the rotation joint. The shape it had to pass through made it difficult to position the power cord correctly. As the covers are loose parts there is a risk of losing them during a repair operation. It was decided not to continue with this concept.



ill. 47 Rotation joint removeable covers



ill. 48 Nilfisk Easy rotation joint



ill. 49 Rotation joint removeable covers 3D printed prototype

Concept “hollow channel”

The second concept of a rotation joint abandoned the idea of removable covers to gain access to the power cord. Instead, the design is featuring an internal channel for the power cord. The channel is big enough for the power cord, and the white connecter at the end, to pass through (ill. 50, ill. 51), which makes it very easy to replace the power cord. To remove the power cord, first, the grey connector has to be removed. The grey connector is intended to be snapped in place, and it can be removed with the tip of a screwdriver (ill. 52).

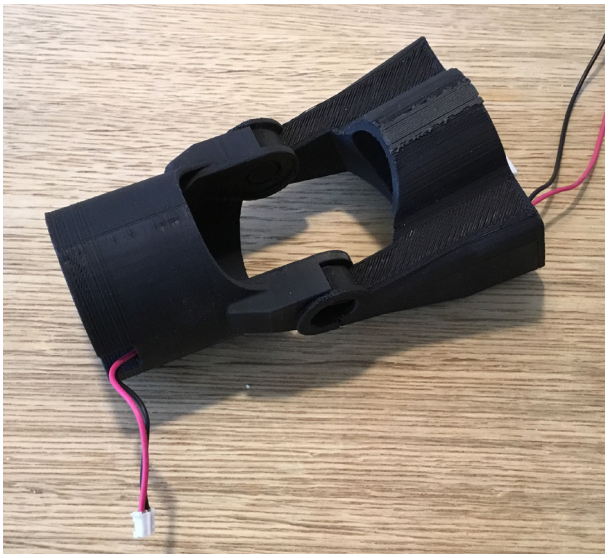
The 3d printed prototype (ill. 51) confirmed it is possible to pass the power cord through, but the channel has to be straightened out more. When the component is injection moulded the surface finish and friction will be lower, which would mean further improvements.

The possibility of removing the power cord will probably not be used very frequently, because the mouthpiece concept allows replacement of the brush motor without having to replace the power cord. This is possible because the power cord is connected to the PCB with a connector, as explained previously (ill. 44)

The upper part of the rotation joint features a “hook” which fasten the rotation joint to the stick unit. This hook is normally spring-loaded by a metal spring. The 3d printed prototype explored the possibility of using a plastic part with a flexible “leg” instead (ill. 53). This would make is cleaner construction in regards to material composition, and bring slight improvements to the assembly process. The solution is deemed possible, but changes have to be made to ensure that it is only the “leg” that flexes.

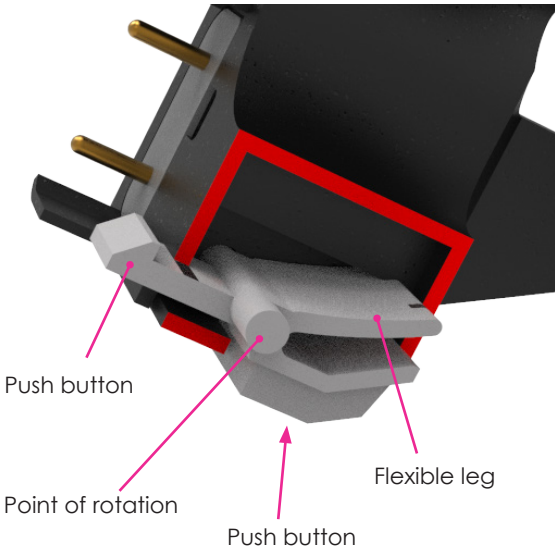
Internal cable channels makes it easy to replace internal wiring. ✓

ill. 50 Rotation joint hollow channel concept



ill. 51 Rotation joint hollow channel 3D printed prototype

ill. 52 Rotation joint hollow channel detail



ill. 53 Rotation joint hook detail

Material Recovery
Consulting with Stena Recycling

The large recycling firm Stena Recycling was contacted to gain more information about design for material recovery. Rikke Helstrup, Head of sustainable business, provided guidelines and agreed to review the product concept at a later stage in the project.

Stena Recycling is a major recycling company with operations in most of Scandinavia. Each year Stena Recycling recycles 6 Mio. tons of materials and products from both business and private customers. Stena Recycling is also handling E-waste from the official E-waste system in Denmark. [Stena Recycling n.d].

It was previously established that the exploitation of the inner loops of refurbishment and remanufacturing are difficult when dealing with consumer products as it requires large take-back schemes. According to Rikke Helstrup, Stena recycling would not recommend any form of takeback program for consumer products or its components. Stena recycling does, however, offer some sort of take-back solution on special occasions if the product contains especially valuable materials.

Stena recycling evaluates six parameters when assessing the recyclability of a product (ill. 54). To enable the highest possible recycling percentage the joining method should be designed in a way which liberates the different materials from each other when the product undergoes the shredding process. Assemblies with screws will not be able to liberate materials properly as the plastic mounting boss around the screw will remain. Glued assemblies and over-moulded parts, such as the filter assembly of the Nilfisk Easy (ill. 56), face the same liberation problems.

Stena's recycling parameters:

1. Materials (Preferably pure materials, no composites)
2. Material composition (As few different materials as possible)
3. Joining methods (Assemblies between different materials must be breakable by the shredder operation)
4. Recycling process (What specific process is suitable for the specific product/material stream)
5. Flow / volume (What is the expected volume and flow of products)
6. Handling (How well has the product been handled and collected before recycling)

ill. 54 Stena Recycling parameters

In general, products should consist of as few materials as possible, however, it is acceptable to use different kinds of common plastic types in the same product, as the processing facility is well designed to separate different types of plastic according to Rikke Helstrup.

Stena Recycling advises using high volume plastics, such as ABS and PP, as that would enable the products to contribute to the existing production of the new ABS/PP raw material.

Recycled ABS from Stena Recycling is already being sold to existing customers of electronic products. Rikke Helstrup confirms that the material their recycled material is both REACH (environmental and health risk posed by chemicals) and RoHS (Restriction of Hazardous Substances) certified, which they have to be, to be used in consumer products. Considering the chance of future regulations including a minimum of recycled content in new products it would be interesting for Nilfisk to evaluate the option of recycled materials from Stena Recycling.

The Stena Recycling parameters are translated into direct product requirements in ill. 55.

Review of current assemblies

ill. 56 to ill. 60 is showing examples of assemblies other than screw assemblies in the current Nilfisk Easy. These assemblies were discussed and review with Rikke Helstrup.

The product should be made of high volume plastics. The current ABS material is suitable. ✓

Design for material recovery principles for plastic constructions: ○

1. Use pure materials. Preferably high volume plastics such as ABS and PP.
2. Use snap fits wherever possible
3. Avoid screws
4. Ensure assemblies between different materials are breakable

ill. 55 Recycling product requirements

ill. 56 Filter assembly

Bad practice example

The silicone/rubber seal is over-moulded onto a plastic component, probably ABS. The large overlap and size of the seal mean the materials are very well fused together. The filter bag is believed to be heat shrunk or glued in place. It will also hinder proper material liberation

ill. 57 Seal

ill. 58 Seal inserted in plastic part

ill. 59 Filter housing

Medium practice example

ill. 57 is showing a rubber seal mounted in a plastic component ill. 58 in the bottom of the stick unit of the Nilfisk Easy. The seal is fitted by four rubber pins (marked with pink) which are pulled through holes in the plastic component. There is a risk each pin will retain small pieces of plastic around it after the shredding procedure.

The fine mesh of the filter housing in ill. 59 is glued in place and not able to separate properly. In this case, the mesh is such a small light-weight part that it will not contaminate the recycling much.

ill. 60 Rubber stopper

Good practice example

This assembly between the dust canister and the rubber stopper at the entry hole in the dust canister is a good example of how material liberation is possible. The rubber stopper is squeezed into the rectangular slot ill. 60. for assembly. When the part passes through the shredding process the plastic component will be crushed and the rubber stopper is no longer contained by the rectangular slot.

Stick unit
Concept

The original Nilfisk Easy stick unit consists of two main shells assembled with multiple snap fits and nine screws. In order the optimized the design for repair and material recovery, principles from the rotation joint and insight from Stena recycling was implemented.

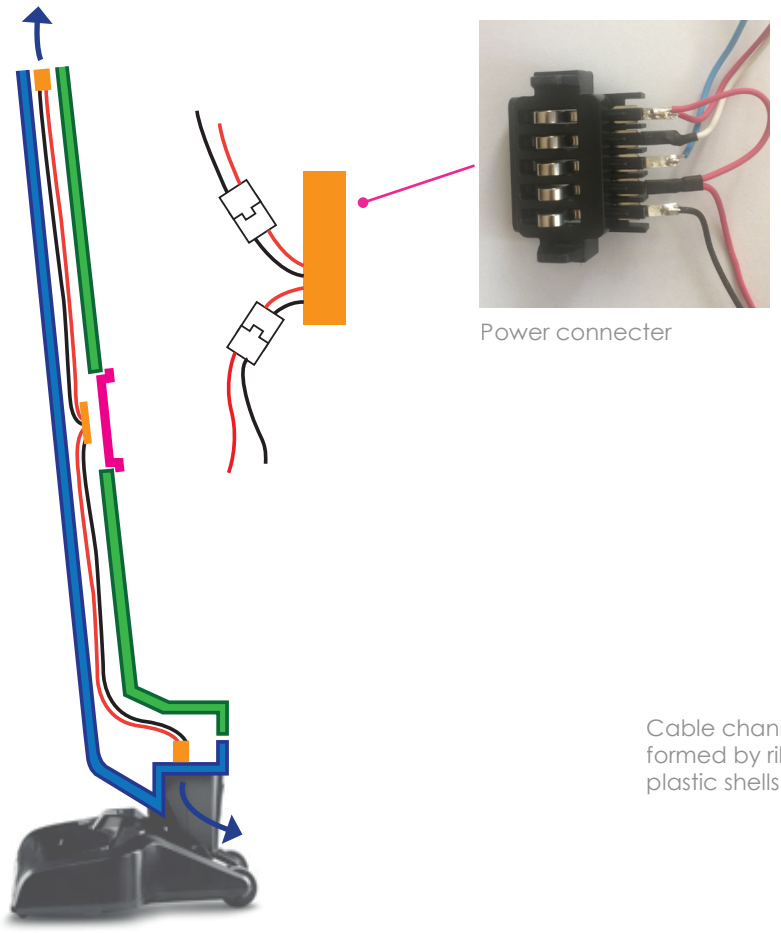
ill. 61 shows a stick unit concept consisting of two shells (green and blue). When assembled, the ribs on the inside of the shells form a channel in where the cables can run, as seen on the Solidworks mock-up (ill. 62). Much like the rotation joint, the cables can then be pulled out of each end (blue arrows, ill. 61) when the cables are disconnected from the power connector (orange). The power connector, which connects the stick unit and handheld unit, is accessible through a cover (pink) in the inner green shell. The cover can be opened with the tip of a screwdriver.

By using the same principle as in the rotation joint it will feel similar and intuitive to the repair worker. Furthermore, it will ensure very low disassembly depth when replacing electronics, which is a parameter in the future repairability label.

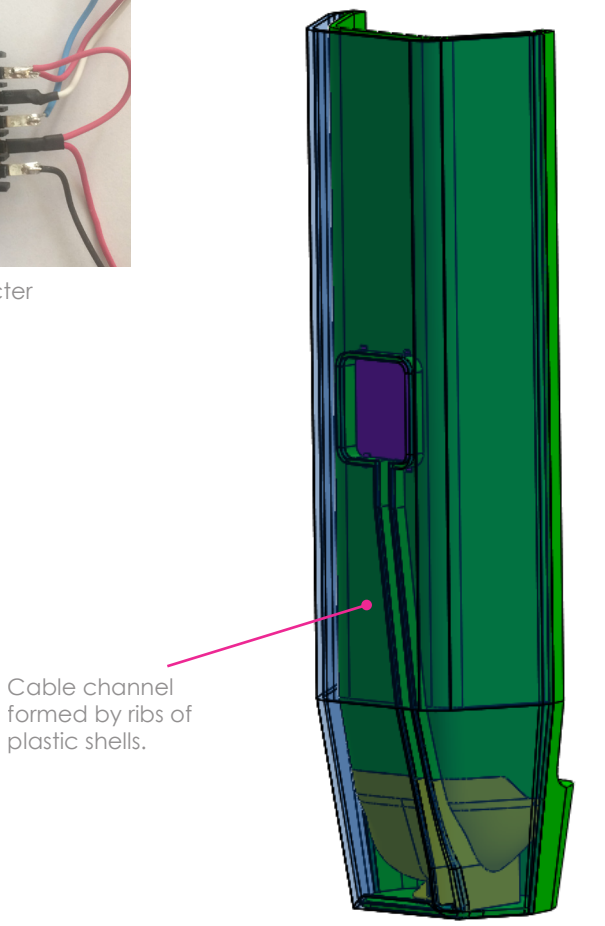
Snap-fit assembly method

By having the opportunity of replacing the electronics without disassembling the main shells of the product these parts never has to be disassembled. Thereby it is possible to assemble the product entirely with non-reversible snap-fits. This would optimize the product for material recovery by avoiding the screws which limit material liberation in the recycling process. Furthermore, it could optimize the assembly process as snap-fit assemblies are less timeconsuming than screw assemblies.

Nilfisk is already using snap-fits in their products, but they are mainly used to fasten non-critical components or meant to keep components in place until screws are added. Screws are normally used as the



ill. 61 Stick unit concept



ill. 62 Stick unit solidworks mock-up

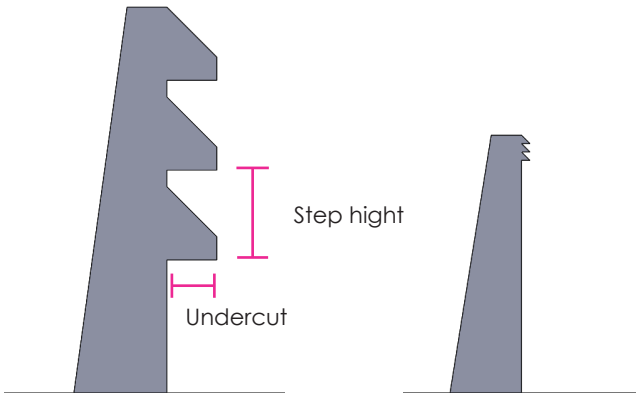
primary assembly method because it is a very secure assembly method. Furthermore, it handles tolerances well as the screws will pull the components together when tightened. Using traditional snap-fits as the primary assembly method would require more precision and smaller component tolerances. As Nilfisk has no prior experience in using snap-fits as the primary assembly method it would lead to increased development cost in order to get right according to Kristian Bang Nielsen and Esben Graff from Nilfisk.

Multi-stepped snap-fits

To lower the requirements to fine tolerances a multi-stepped snap-fit was developed. By introducing multiple steps, the snap-fit would be able to mimic the effect of tightening a screw and thereby by less sensitive to component tolerances. At first, the steps were intended to be on the same snap-fit (ill. 63, ill. 64). This would result in either a very small undercut or very high steps. The solution is to position multiple snap-fits next to each other instead, thereby each step is independent (ill. 65). The snap-fits will then snap in place one by one when components are mated and ensure the best possible assembly for the specific components. The snap-fit would be dimensioned in accordance with the material yield strength, and component tolerances would determine the step hight from snap-fit to snap-fit. As the components never have to be separated it would be possible to design a very aggressive snap-fit with a large undercut to make the assembly secure.

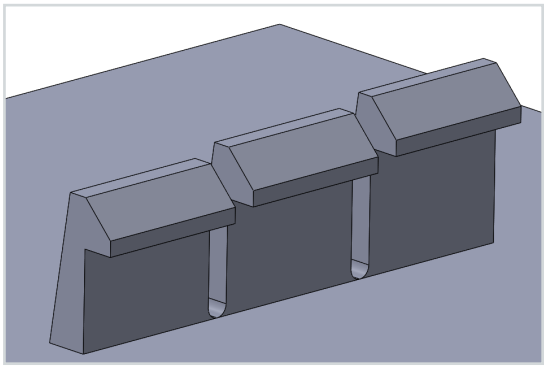
A section of the stick unit mock-up was 3D printed to prove the concept (ill. 66). The snap fits had an undercut of 1.5mm, similar to snap-fits in Nilfisk Easy, and a step-height of 0.3mm. Larger scale prototypes are needed to properly assess the concept, but initial indications are good.

Multi-stepped snap-fits can be used to replace screws in the construction ✓

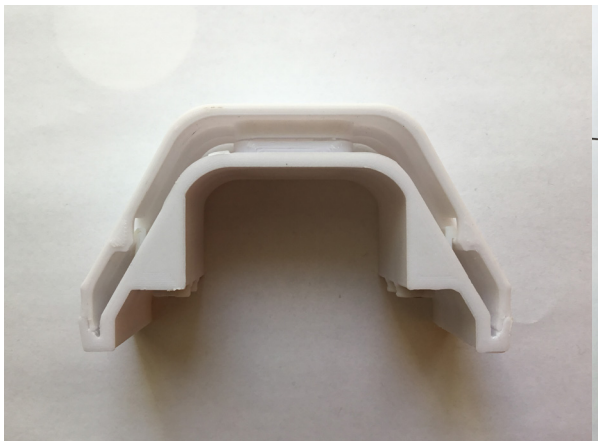


ill. 63 Correct undercut, Too large step hight

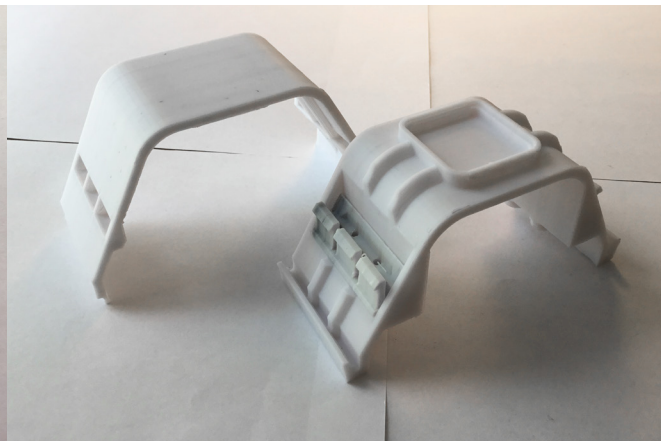
ill. 64 Correct step high, too small undercut



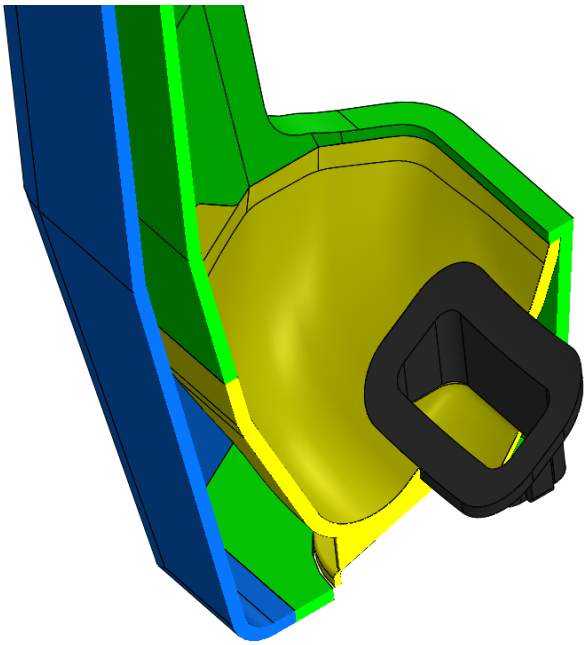
ill. 65 Multi-stepped snap-fit. Individual snap-fits.



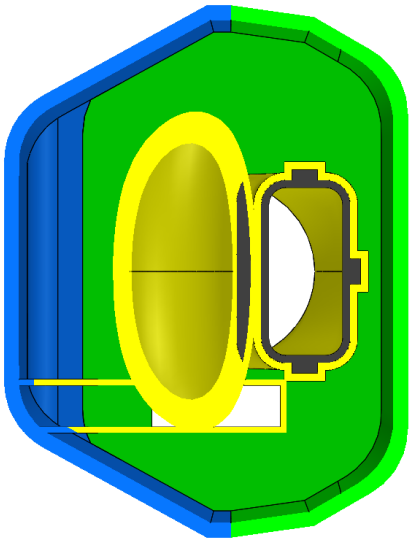
ill. 66 3D printed test of Multi-stepped snap-fits



Multi-stepped snap-fits



ill. 67 Seal assembly



ill. 68 Seal assembly section view

Optimized material liberation

Apart from the electronics, only the seal in the bottom of the stick unit has to be separated from the plastic shells. As explained previously on page 43 (ill. 57) the seal in the bottom of the Nilfisk Easy does not ensure proper material liberation during the material recovery process. To improve the material liberation the seal in the new product concept will follow the good practice example from ill. 60. The seal will be squeezed into a hole in the plastic component (yellow, ill. 67, ill. 68).

Thereby the two different materials will be separated when the yellow component is crushed in the material recovery process.

The construction principle for the mouthpiece, rotation joint and stick unit explored in this chapter will not be developed further in this project as the focus will now shift to the design of the new handheld unit.

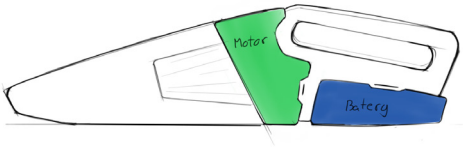
Self-repair

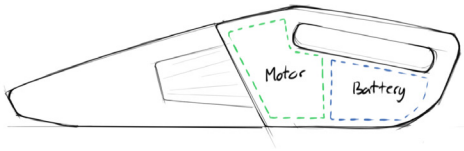
Earlier in the project, it was decided to follow a strategy of optimized repair for the professional repair shop. Thereby not allowing the users to repair the product themselves. This scenario is acceptable if professional repair services are available to an acceptable cost for the consumer or the producer provides extended warranty periods. A growing concern that this approach would not be good enough to promote repair and prolong lifetime lead to revisiting the subject to determine the acceptable repair cost and decide upon the possibility of self-repair.

When considering the option for self-repair modularization of priority parts are the obvious choice.
As seen in the Nilfisk VP600 disassembly study and the Dysons products, modularity of priority parts can have a great impact on repairability and serviceability of a product. Thereby consumers, or staff at the retail store, can easily service the products without the need of a professional repair shop ill. 69. The priority parts to consider for modularization would be the motor and the battery, as they are the most important components for functionality and are among the most likely to fail according to the EU Commissions repairability label research. [Cordella et al. 2019]. They are also the most expensive parts of the product. The point of allowing self-repair would be to prolong lifetime by lowering repair cost and thereby enhancing the chances that the consumer will invest in a repair. When deciding upon modules for self-repair multiple parameters have to be considered, some of which mentioned below.

Self-repair parameters

1. How much is the customer willing to pay for a repair?
2. What is the risk of each priority part failing?
3. What are the benefits of future upgradeility for each priority part?
4. What is the extra cost of a design made for self-repair?





User-accessible priority parts (possibly modules)

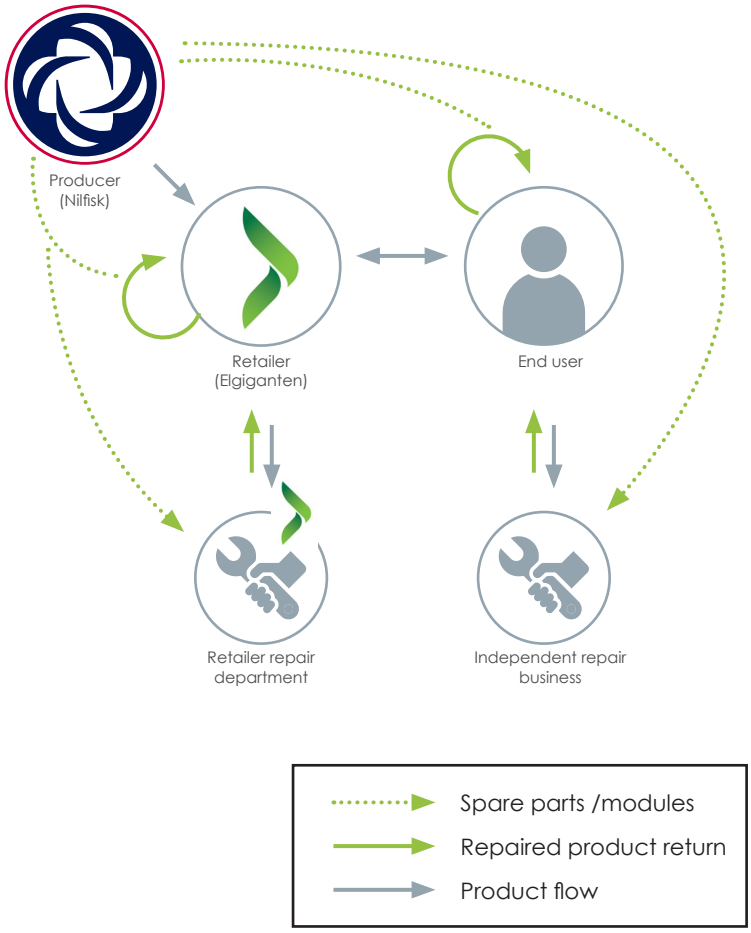
- **Lower cost** of repair as user-accessible motor and battery units provide the opportunity for self-repair by the user or sales store.
- Future **upgradability** for better performance would also be possible, either by purchase by the user or as a service provided by Nilfisk.
- The modular approach requires more space in the construction as each module must have its own exterior shell as no live electronics can be accessible to the user.

Conventional design

- **High cost** of repair as only professional repair is possible.
- No motor and battery module allows for tighter packaging and compact design and this is considered a **less complicated cheaper option**.
- External priority parts, as the filter assembly, will still be changeable by the user.

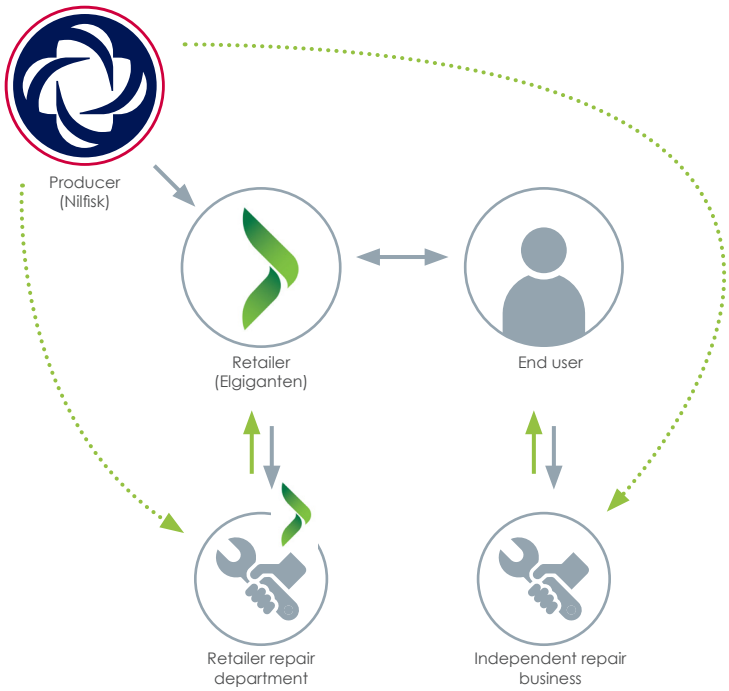
ill. 69 System possibilities user accessible priority parts

By having user-accessible priority parts it will be possible for the user or retail store to prolong product lifetime by repair or upgrade at priority part cost only. The logistics would be relatively easy as it only involves Nilfisk sending parts to different recipients.



ill. 70 System possibilities conventional design

A conventional design can only be repaired at the repair shops as the operation is too timecon-cuming or complex to carry out by the user or retail store.



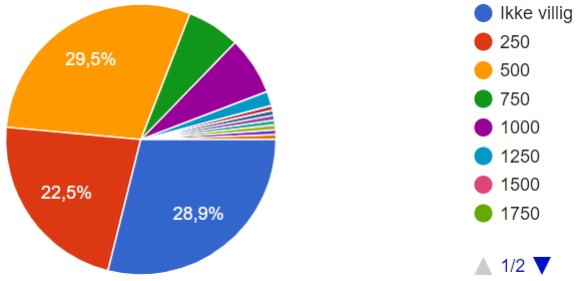
Acceptable repair cost

A survey with 185 participants was conducted to investigate the consumers' acceptable repair cost. The participants had an even distribution between age groups ranging from 18 to 65 years of age. 3/4 of participants was women. The full survey details can be seen in append 6.

Willingness to repair

The data indicate that a repair must not exceed 500 DKK. The average acceptable repair cost is 24% of a new product cost. However, if the 28,9% of participants(light blue region), who is not willing to repair, is excluded, the average acceptable repair cost is 33%.

If your vacuum cleaner broke today, how much would you be willing to pay for a repair? [DKK]



24%

Acceptable repair cost.
(% of new product cost)

All participants

33%

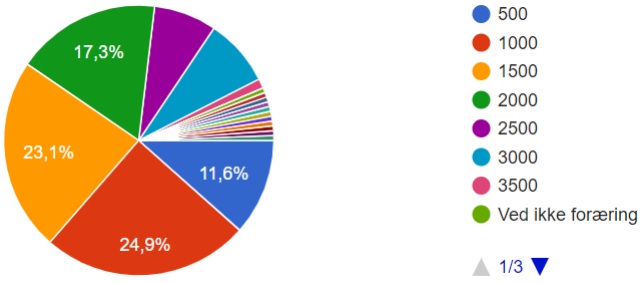
Acceptable repair cost.
(% of new product cost)

Excl. participants not wiling to repair

Price segments

Even distribution of price segments.
Unexpectedly, the willingness to repair seems to be highest at the 1000-1500 price segment and decreasing towards the highest price segments.

How much did you pay for your vacuum cleaner when you bought it? [DKK]

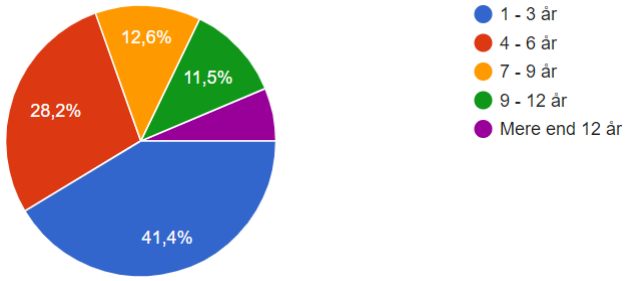


Acceptable repair cost. (% of new product cost)	**21%** **(80 DKK)**	**24%** **(300 DKK)**	**20%** **(427 DKK)**	**19%** **(780 DKK)**
Price segment	**[500 DKK]**	**[1000-1500 DKK]**	**[2000-2500 DKK]**	**[3000-4800 DKK]**

Product age

Predictably consumers are less likely to invest in repairs if the product is old. There seems to be a noticeable drop (-6%) in willingness to repair after 6 years product age.

How many years is it since you bought your vacuum cleaner? [DKK]



Acceptable repair cost. (% of new product cost)	**26%**	**24%**	**18%**	**17%**	**17%**
Product age segment	**[1-3 years]**	**[4-6 years]**	**[7-9 years]**	**[9-12 years]**	**[12 years <]**

Average product life (4,55 years)

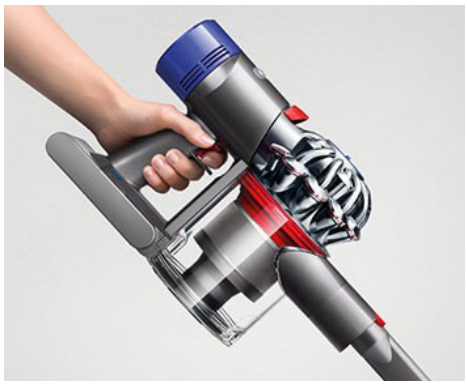
Average Expected product life (7,54 years)

Calculated from the results of the user perception survey and this, the acceptable repair cost survey.

What are your considerations when deciding upon repairing your existing vacuum cleaner or buiyng a new product?

Four topics were clearly visible in the answers to this question. The main concerns are the repair cost relative to the cost of a new product. The product age and the extra lifetime added by a repair was also considered among the majority of participants. The ease of repair or hassle with arranging a repair seemed to be just as important as the repair cost. Multiple participants commented that they would prefer to be able to repair the product themselves. Considerations about sustainability were mention by surprisingly many participants. This could indicate consumers are becoming more aware of the link between sustainability and consumption, but, as the participants knew the project theme when answering the question, it might have influenced the participants.

Key topics Arangend in order of frequency:	Hihghlighted answers:
Repair cost vs new product cost **&** **Product age and expected lifetime**	**1.** *Prisen i forhold til hvad en ny vil koste. Derudover vil det også være afgørende efter hvor mange år den går i stykker. Hvis der er få år gammel vil jeg være mere villig til at betale for det end hvis den er + 5 år gammel, da jeg da vil tænke over hvornår den næste gang vil gå i stykker.* **2.** *Prisen for en ny af god kvalitet er vigtig i forhold til værdien af rep. af den gamle, der skal være sikkerhed for at den gamle kan holde i mange år efter reparationen.* **3.** *Om det kan betale sig økonomisk, hvor længe reparationen vil holde.* **4.** *Hvis man i forvejen kun udskifter en del for nogle tusinde, hvor længe går der så før den skal repareres igen?. En ny støvsuger giver en garanti på 2 år som minimum, det skal altså være en billigere løsning i hele den tidsperiode.* **5.** *Kan det betale sig i forhold til prisen på en ny, kontra risikoen for at der opstår en ny fejl på den kort efter denne reparation, dens alder og brug taget i betragtning.* **6.** *Hvis der var mulighed for at få repareret sine ting, såsom støvsugere, vaskemaskiner osv. Så ville jeg sandsynligvis også investere i bedre kvalitet.*
Ease of repair service	**1.** *Det taler for reparation hvis det er nemt at indlevere til reparation, hvis der er garanti på reparationen.* **2.** *...derudover vil jeg også vurdere om jeg selv kan skifte den defekte komponent, da timelønnen til en reparatør ofte er det dyreste i forhold til komponenten* **3.** *For mig vil det være afgørende om den skal sendes til fabrikken eller om jeg kan reparere den selv med evt. reservedele.* **4.** *Om jeg selv kan lave den og evt. hvor meget reservedele vil koste og besværet ved at fremskaffe dem. Om der vil være samme funktionalitet efter reparationen.* **5.** *Omkostninger og besvær sammenholdt med priserne på en ny støvsuger i tilsvarende kvalitet.*
Sustainability (Might be influenced by knowing the theme for the project)	**1.** *...jeg går så langt jeg kan, for at reparere frem for at kassere og købe ny, principielle årsager om max bæredygtighed* **2.** *Jeg synes det er vigtigt, at bruge ens ting "op" i den forstand, at det kun kasseres, hvis det virkelig ikke fungerer længere. Derfor vil jeg gerne reparere og dermed spare både miljø og min samvittighed.* **3.** *Pris/ holdbarhed vs. Miljøbelastning* **4.** *Men jeg vil rigtig gerne reparere og dermed undgå produktion af en helt ny støvsuger, hvis den gamle kunne repareres, men det skal bare ikke blive for dyrt eller besværligt.* **5.** *Overvejelser mellem om det på den ene side kan betale sig og på den anden side konsekvenser i et bæredygtigt perspektiv*
Market development	**1.** *...hvordan markedet med nye modeller ser ud i forhold til mine behov* **2.** *Hvilke bedre modeller der er kommet på markedet, siden jeg købte den jeg har.*



ill. 71 Dyson V8

Comparison Dyson V8

New product cost:	2990 DKK	
Motor module cost:	499 DKK	(17%)
Battery modul cost:	449 DKK	(15%)

[Whiteparts.dk n.d.]
[AV-cables n.d.]

ill. 72 Dyson v8 table

Comparison Nilfisk Easy 36V

New product cost:	1942 DKK
(Motor/battery cost)	
Acceptable repair cost (24%):	**466 DKK**
Acceptable repair cost (17%):	330 DKK

ill. 73 Nilfisk Easy table

Evaluation

Previously in the report (p. 21) it was established that the lowest repair cost at a repair shop (CJ Hvidevare Service) was 35,5 % (48,6% if there is no service contract between the specific brand and the repair shop). This is under the condition that the total repair time is less than 30 min, all included.

According to the gathered data the consumers' acceptable repair cost is 24% of the new product cost, meaning repair at a traditional repair shop is not possible. The start-up cost and labour costs make the repair too expensive. To lower the repair cost and prolong lifetime through repair the consumers must be able to repair the product themselves. Being able to repair the products themselves would also contribute to the ease of repair desired by a significant proportion of the survey participants.

By comparison, the Dyson V8's motor and battery modules have a sales price of 499 DKK and 449 DKK, which is 17% and 15% of the new product cost (ill. 72). It is worth noticing that Dyson is 7-9% below the acceptable repair cost. This is equal to the acceptable repair cost of products with the highest product age (up to 12 years, p.50), meaning even very old Dysons could be repaired at an acceptable cost.

From the Dyson example, it is clear that it is possible to produce modules at a cost below 500 DKK, which corresponds well to the acceptable repair cost for the Nilfisk Easy 36V which would be 466 DKK (ill. 73).

Self-repair parameters
As mention earlier there are multiple parameters to consider when deciding on the option of self-repair. However, most parameters such as the risk of priority part failure and benefits of upgradeability are simply too complex to be assessed in this project.

The self-repair/modular design is expected to be more expensive, as it could be more cvomplex and use more material to box all priority parts, and require higher quality interfaces between parts. The extra cost is necessary if the future product concept should be a truly material-efficient design, which is able to prolong lifetime by repair at an acceptable cost.

To enable repair at a acceptable cost battery and motor priority parts will be replaceable by the consumer. □

The maximum repair cost is 24%. (Corosponding to 466 DKK at Nilfisk Easy price level) ○

3

Concept Detailing

In this chapter, the concept is refined and described in greater detail in regards to construction principles, materials and construction

Design for self-repair

To allow the consumer to repair the product themselves the product must be carefully designed to avoid any safety hazards. In the case of a cordless vacuum cleaner safety requirements are adressed in the *Low-voltage directive 2014-35,* Annex 1.

The directive states, among other things, the following:
(The full annex 1 of the Low-voltage directive can be seen in appendix x.)

1. *"the electrical equipment, together with its component parts, shall be made in such a way as to ensure that it can be safely and properly assembled and connected".*
2. *"persons and domestic animals are adequately protected against the danger of physical injury or other harm which might be caused by direct or indirect contact".*
3. *"meets the expected mechanical requirements in such a way that persons, domestic animals and property are not endangered".*

The directive and consulting with Charalambos Freed, Technical Director - Head of standardisation & government relations, lead to the following requirements:

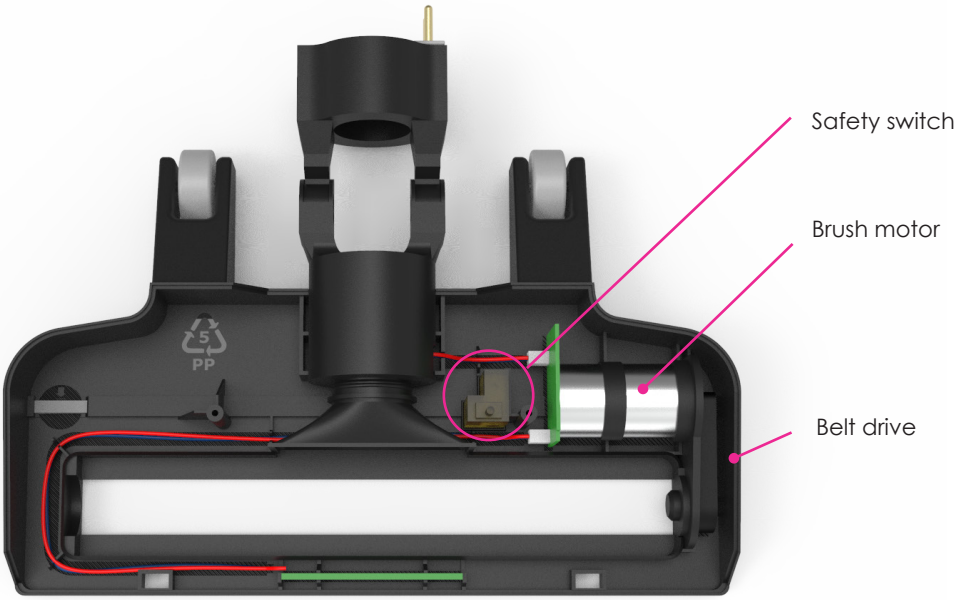
Safety hazard requirments

1. Mechanical moving components and live electronics must be safely covered
2. Interface design must be durable and intuative to acommondate all user.
3. Interfaces design must ensure correct assembly

Changes to mouthpiece design

To allow for consumers to carry out repairs of priority parts in the mouthpiece, certain safety improvements have to be made to the initial design to fulfil the safety hazards requirements. Two main areas need improving, the safety switch ill. 76 and the belt drive ill. 75. The safety switch ensures that the brush motor cannot turn when the top cover is removed from the mouthpiece. However, there is nothing to hinder the consumer in accidentally pushing down on the safety switch during a repair operation. This action would make it possible to activate the brush motor making the belt drive a safety hazard during repair operations. ill. 77 shows proposed changes to the safety switch in order to prevent accidental activation of the switch. By embedding the switch in such a way that it can only be activated by an associated pin in the top lid. The pin pushing down on the switch when the top lid is closed. To mitigate, the safety hazard from the belt drive itself the belt drive, a cover for the belt drive should be added.

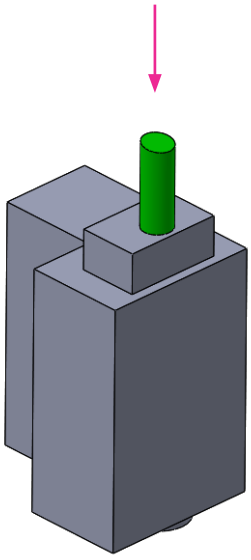
Other areas of improvement include the white connectors and the PCB. To ensure sufficient durability of interfaces the original white connectors (ill. 78) should be changed to connectors of higher quality. Furthermore, the connectors should be changed to feature different shapes compared to one another to avoid incorrect assembly. To lower the risk of consumers accidentally damaging the PCB during repair operations, it would be beneficial to cover up the PCB as well. It could be a possibility to combine the belt cover, PCB cover and safety switch into one part. The necessary changes in order to fulfil the safety hazard requirements will add to the production cost and cause slightly longer assembly time.



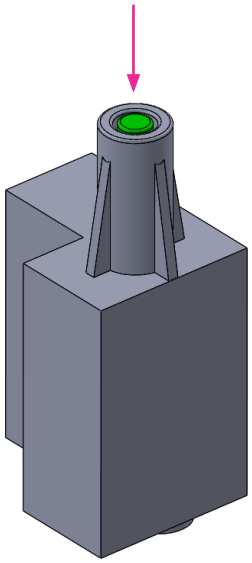
ill. 74 Mouthpiece

Picture of belt drive

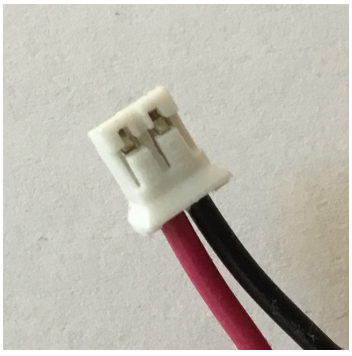
ill. 75 Belt drive



ill. 76 Original safety swich. Risk of accidental activation



ill. 77 Redesigned safety swich. Embedded switch to prevent accidental activation



ill. 78 White connecter detail

Updated requirements list

Updated list. The solution should:	
1.	Be designed according to Dis- & reassembly principles. *p. 21*
2.	Be designed according to Circular product design principles. *p. 21*
3.	Enable the replacement of priority parts in less than 15 min. *p. 23*
4.	Avoid many different assembly methods in the same product. *p.23*
5.	Avoid an excessive amount of fasteners. Minimize the number of fasteners. *p.23*
6.	Achieve the highest repairability label score. *p.25* • Access to priority parts must feature low disassembly depth and low disassembly time. *p.25* • Priority parts must be accessible with common tools. *p.25* • Any fasteners must be reusable. *p.25*
7.	The maximum repair cost is 24%. (Corosponding to 466 DKK at Nilfisk Easy price level) p.52
8.	Avoid any safety hazards p.54 • Mechanical moving components and live electronics must be safely covered • Interface design must be durable and intuative to acommondate all user. • Interfaces design must ensure correct assembly
9.	Enusre proper material recovery p. 42 • Use pure materials. Preferably high volume plastics such as ABS and PP. • Use snap fits wherever possible • Avoid screws • Ensure assemblies between different materials are breakable

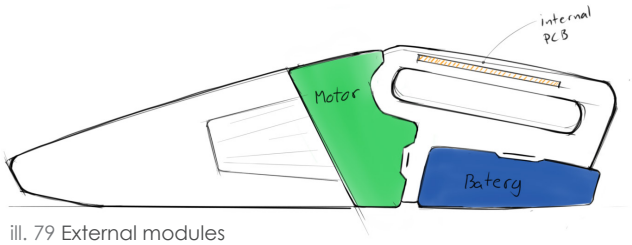
Handheld unit
Construction Priciples

The handheld unit contains the motor unit, the battery unit and the main PCB which are all considered priority parts.

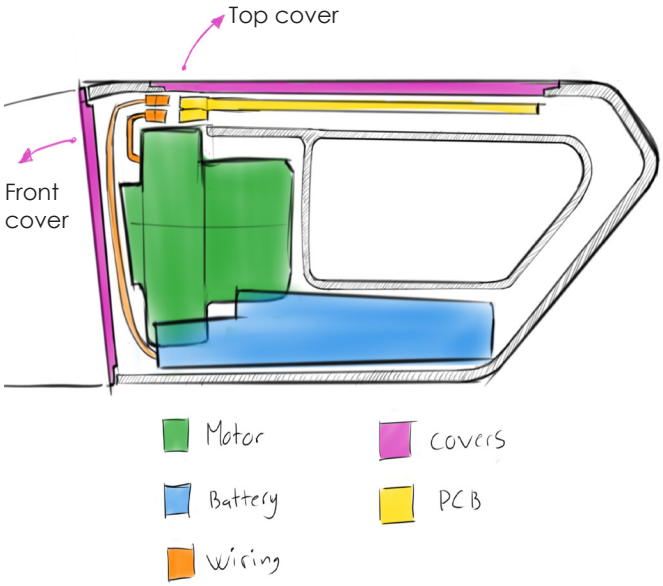
The priority parts of the handheld unit can be made accessible in two main ways; by having external modules like the battery on a power tool (ill. 79), or by creating easy access to the internal priority parts through a lid or cover of sort (ill. 80).

The concept of internal priority parts allows access to all internal parts and wiring through the front and top covers. Thereby it is possible to use the principle of multi-stepped snap-fits because the two outer shells making up the main body never have to be separated again. In the modular concept, this will not be possible as internal wiring in the main body will have to connect the modules to the PCB, and thereby the outer shells must be able the separate in case the wiring needs to be replaced. The internal priority parts concept is deemed to be the best option.

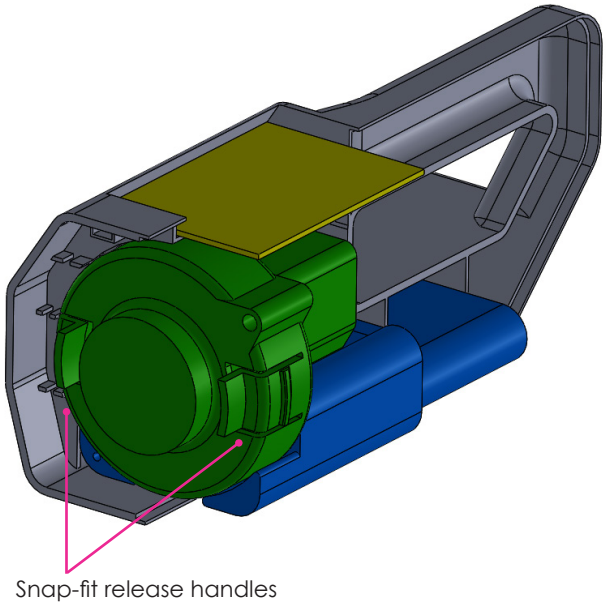
A Solidworks mock-up was modelled to visualize the concept. When the motor and battery unit is inserted through the front it will be possible to fasten the parts by adding a snap-fit to the plastic housing of the motor unit ill. 81. This snap-fit will snap in position behind internal ribs. The snap-fits features two handles which are easily pushed to release the snap-fit. The battery module is inserted before the motor and is thereby secured in position by the motor and internal ribs. The 3D printed prototype confirmed that snap-fits on the motor unit housing works well to hold the internal component, and makes it very easy to remove the priority parts (ill. 82).



ill. 79 External modules



ill. 80 Internal priority parts



ill. 81 Solidworks mock-up

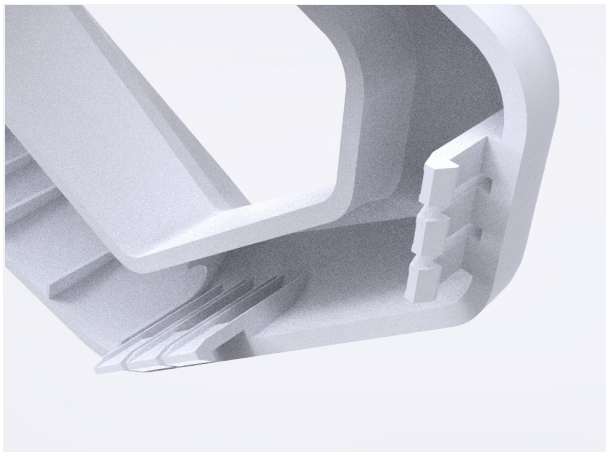
ill. 82 3D printed protorype

Handheld unit concept

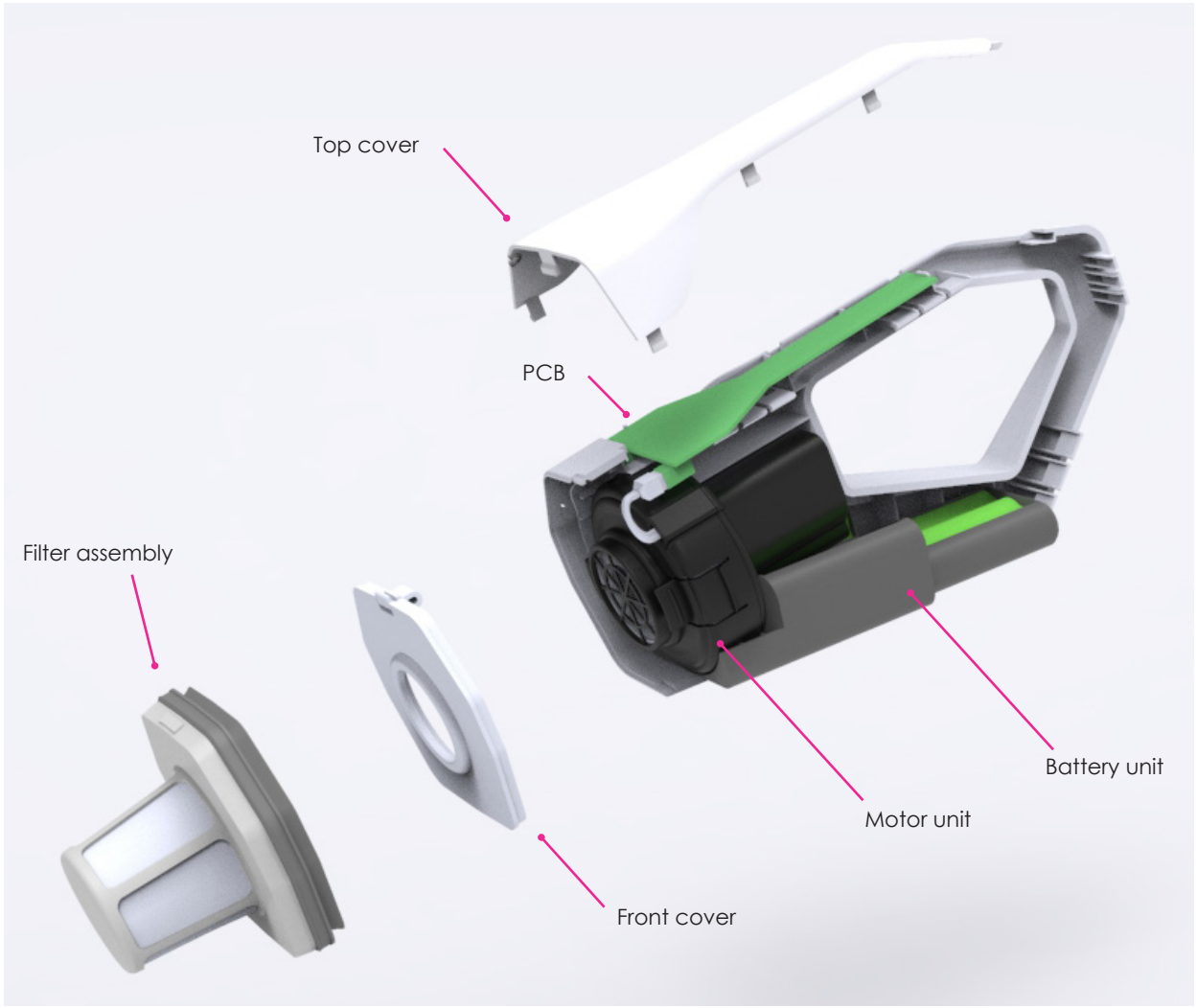
The final product concept for the handheld unit, named Nilfisk Infinity, is seen in ill. 83. The concept builds on the concept of easily accessible internal priority parts rather than external modules.

The construction is assembled entirely with snap-fits of different types. The two outer shells which form the main body is assembled using the principle of multi-stepped snap-fits (ill. 84). The snap-fits are positioned at five places along the edges corresponding to the position of screws in the Nilfsik Easy.

ill. 83 Nilfisk Infinity



ill. 84 Multi-stepped snap-fits detail



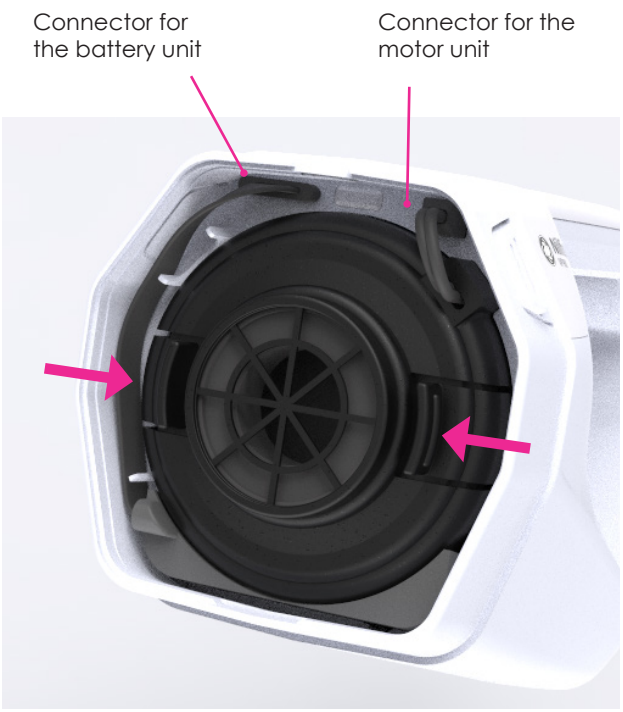
ill. 85 Exploded view

Repair of motor and battery

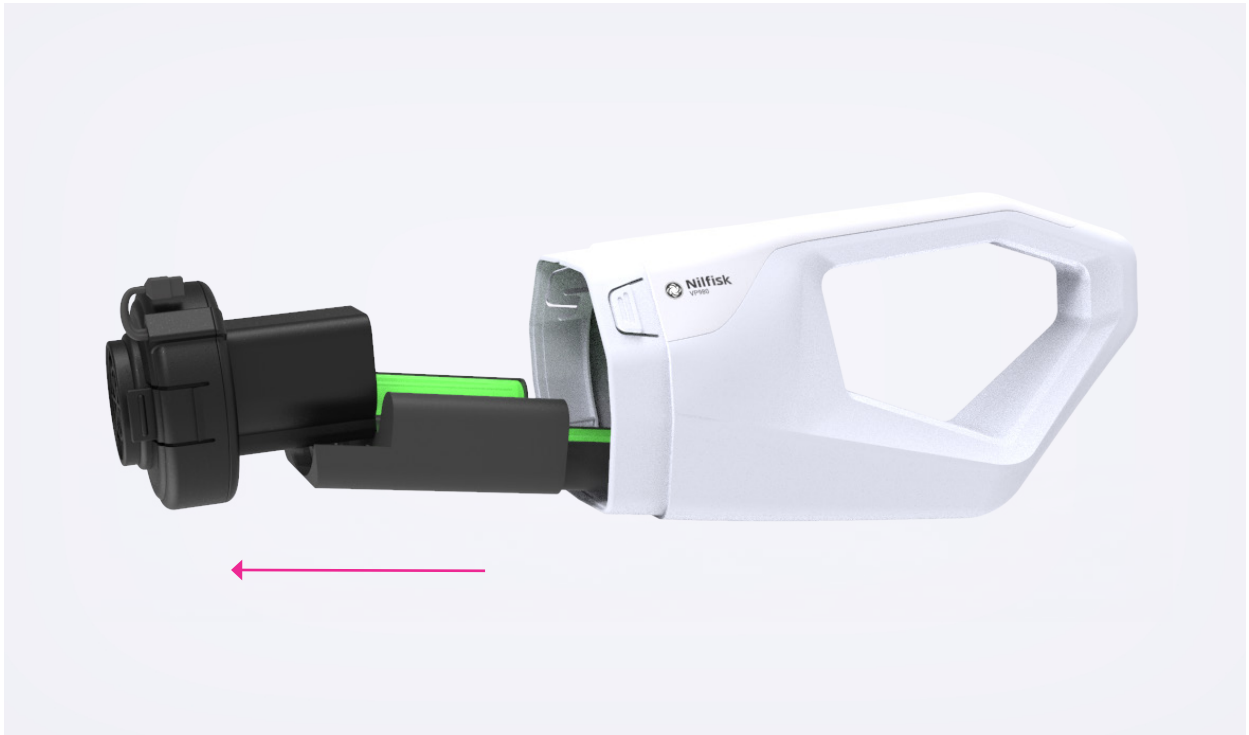
When the front cover is removed the consumer will have easy access to replace the motor and battery priority parts. Firstly the consumer must disconnect the connectors running from each priority part to the PCB. Next, the motor unit can be removed by push the release handles on the motor unit housing (ill. 86), and finally, the battery unit can be slid out (ill. 87).
The internal priority parts must be designed to avoid any safety hazards by covering mechanically moving parts and live electronics. This means the hole in the front of the motor unit must have a grid covering it. The two connectors are differently shaped, which will prevent any wrong assembly making the repair operation intuitive and safe for the consumer.

Durability of interfaces.

The interfaces must be durable to ensure that consumers who are inexperienced in performing repairs don't risk breaking the parts. The connectors resemble a regular USB cable which is designed to be handle by consumers regularly. The connectors should be designed to the same quality as a common USB cable.
There is a concern about the durability of the current design of the motor unit release handles. The component has long slots in the side which is necessary to allow the release handles to flex. However, there might be a risk of breaking off the handles, if they are bent in the wrong direction. If the handles break off, the consumer has access to a moving mechanical part which would impose a safety risk.



ill. 86 Interface details



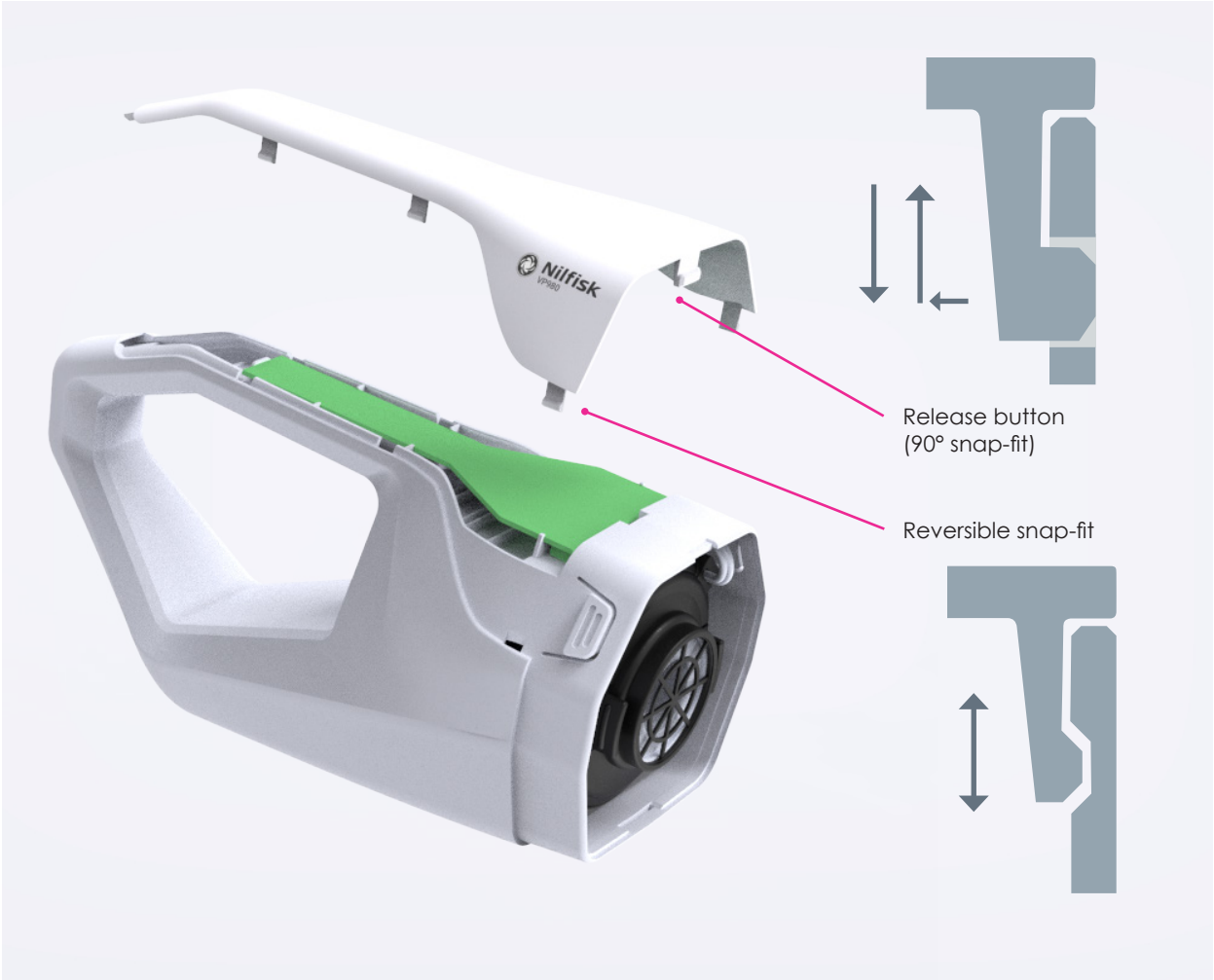
ill. 87 Removing motor and battery unit

Replacement of the PCB

To live up to the future repairability label it must be possible to access and replace the PCB. Replacement of the PCB board is possible when the top cover is removed. The top cover extends a long way back to make space for the charging port which is not included in this CAD model.

The top cover can be removed by pressing the button marked in ill. 88 and ill. 89. The button is actually a snap-fit with a 90° angle which acts a the main fastener of the top cover. The 90° angle ensures it can only be released if the button is pressed. Reversible snap-fits are positioned along the edges as secondary fasteners to prevent any gaps between components.

ill. 88 Release button detail



ill. 89 Top cover detail

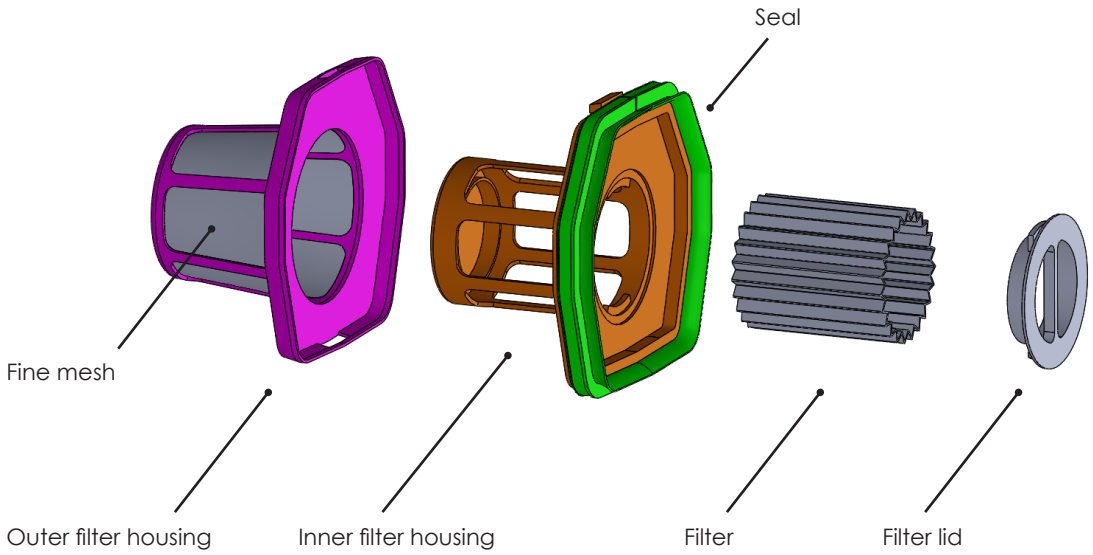
Filter assembly

The filter assembly is accessible when the dust canister is removed from the vacuum cleaner. The dust canister is removed by pressing the two release buttons on each side of the handheld unit (ill. 92). The dust canister release buttons are integrated into the plastic shells and its the material that flexes to releases the dust canister. This solution means there is no need to add a metal spring to the construction. Furthermore, it removes a step from the assembly process as the part will leave the mould with full functionality.

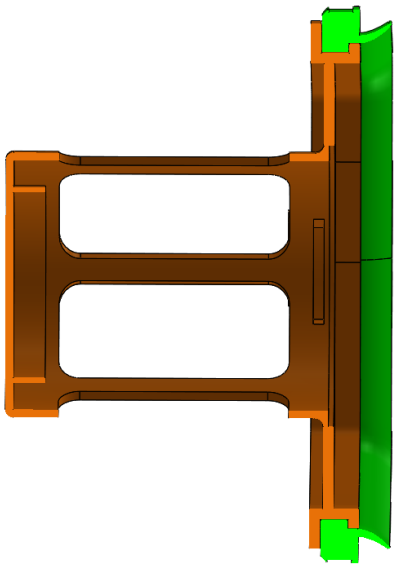
An exploded view of the filter assembly can be seen in ill. 90. The outer filter housing which will filter out larger debris through a fine mesh. Next is the inner filter housing which houses the actual filter. The filter should be replaceable as blocked filters, leading to suction deterioration, is one of the most common faults in vacuum cleaners according to the EU Commissions research [Cordella et al. 2019]. The filter can easily be replaced by removing the filter lid.

Material liberation

The seal will ensure that only air which has passed through the filters can be sucked into the engine. The seal is fastened to the inner filter housing, but it must be able to separate during the recycling process. As the seal is made of a stretchable material (rubber/ silicone), it will be possible to push the seal into position behind an edge on the inner filter housing (ill. 91). During the shredding process, the inner filter housing will be crushed and the seal is no longer fastened to the housing.



ill. 90 Filter assembly exploded view



ill. 91 Inner filter housing section view

ill. 92 Release button detail

Material and production

ABS is the most obvious material choice as the Nilfisk Easy is made from ABS and Stena Recycling are also recommending ABS. ABS is a low cost, versatile material with good impact resistance, toughness, dimensional stability and surface quality [Lefteri 2014]. The design relies heavily on flexible parts, such as the snap-fits, the dust canister release buttons and motor unit handles. Therefore it is important that the material can withstand repeated bending. The butadiene rubber content in ABS provides the elasticity to spring back from minor deformations [Thomson 2017], and the ABS seems to be a suitable material. However, it is worth considering the use of PP, as PP is widely considered the best plastic material for repeated bending [Lefteri 2014]. Like ABS, PP is tough and has good impact resistance [Thomson 2017]. Nilfisk already has experience with using PP in their products as the Nilfisk VP600 is made from PP. If necessary it is possible to use a combination of the two materials and still maintain good recyclability as discussed with Stena recycling.

Use of Re-ABS from Stena Recycling

The future environmental regulations are pushing for higher use of recycled materials in new products. Therefore the use of recycled materials must be considered in the product concept. Stena Recycling is already producing a recycled ABS material which is sold to other producers of consumer electronics. When presenting the opportunity of using Stena Recyclings Re-ABS plastic to Nilfisk, several important parameters was pointed out.

1. Cost and material properties compared to the existing material,
2. Delivery circumstances to the production facility in China,
3. Security of supply.
4. Look and feel compared to existing material.

Stena Recycling was not able to provide a datasheet in time for the project hand-in. Therefore a comparison between the Re-ABS and the currently used ABS will be made in between hand-in and the exam.

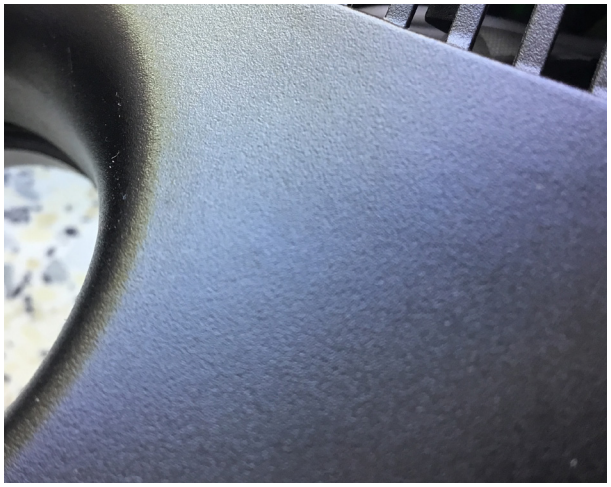
Injection moulding consideration.

The two main shells are designed to be injection moulded. The parts feature a similar level of complexity as the corresponding Nilfisk Easy parts and could be produced in the same manner. The parts have has several small undercuts to mould the internal snap-fits properly (ill. 95).

Injection moulded parts require a draft angle to be ejected from the mould. The draft angle is typically 1° [BASF 2007]. It is important to avoid small visible surface scratches from use, which potentially could prompt a consumer to dispose of the product on aesthetic grounds. A slightly textured surface finish will hide scratches better than the shiny surfaces. Textures surfaces require an increased draft angle of 1° for every 0,025mm depth of texture [Ticona 2009]. For comparison, a textured and a shiny surface from Nilfisk Easy is seen in ill. 93 and ill. 94.

The part wall thickness for ABS is typically between 1,14 - 3,55 mm depending on the part requirements [Ticona 2009]. Considering the similarities between the outer shells of the Nilfisk Infinity and the Nilfisk Easy, the same wall thickness of 3,50mm is used.

Ribs are added to increase part stiffness and strength and used to keep internal components in place. To avoid sink marks on the outside surface the rib thickness must be between 30-50 % of the outer wall thickness, depending on the surface texture [BASF 2007]. Ribs should have a minimum draft angle of 1/2° and feature a 0,12mm radius at the base.



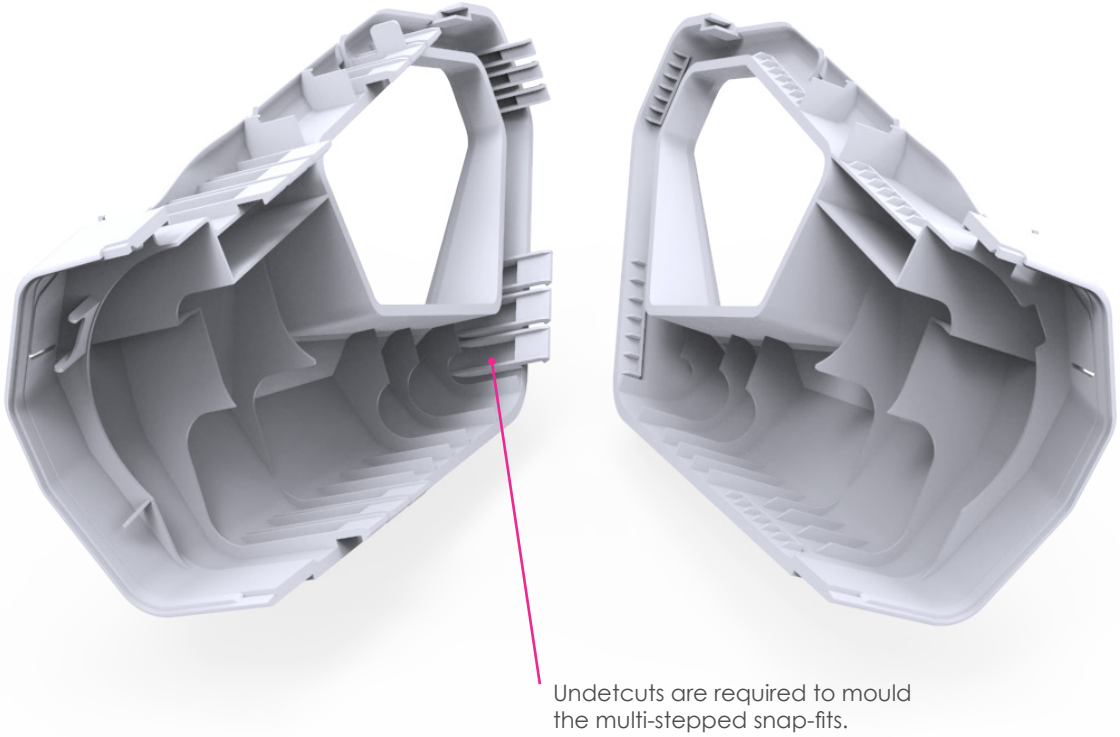
ill. 93 Textured surface detail

ill. 94 Gloss surface detail

Design review by Stena recycling

The product concept was presented to Stena Recycling review get their feedback on the recyclability of the product. Stena Recycling reviews the product as being very well suited for recycling as the absence of screws and extensive use of snap-fits ensures proper material liberation. The only point of improvement is the fine-meshed filter in the outer filter housing. The fine mesh is intended to be glued in place, similarly to the Nilfisk Easy, because the fine mesh is difficult to join otherwise. It would be beneficial if another joining method could be used but, as Rikke Helstrup points out, it is a very small detail which will not have a noticeable impact on the overall recyclability.

The design is confirmed to be well suited for recycling ✓



ill. 95 Plastic shells detail

4

Epilog

Closing thoughts about the project are elaborated in this chapter, along with a description of different ways to handle material efficiency at Nilfisk.

Material efficiency options

The new addition to the ecodesign directive will come into effect 1st March 2023. From this date, Nilfisk will no longer be able to sell the Nilfisk Easy on the European market, as it does not comply with the future regulations in regards to accessibility to priority parts. To prepare Nilfisk for the new regulations, three different options of action have been identified.

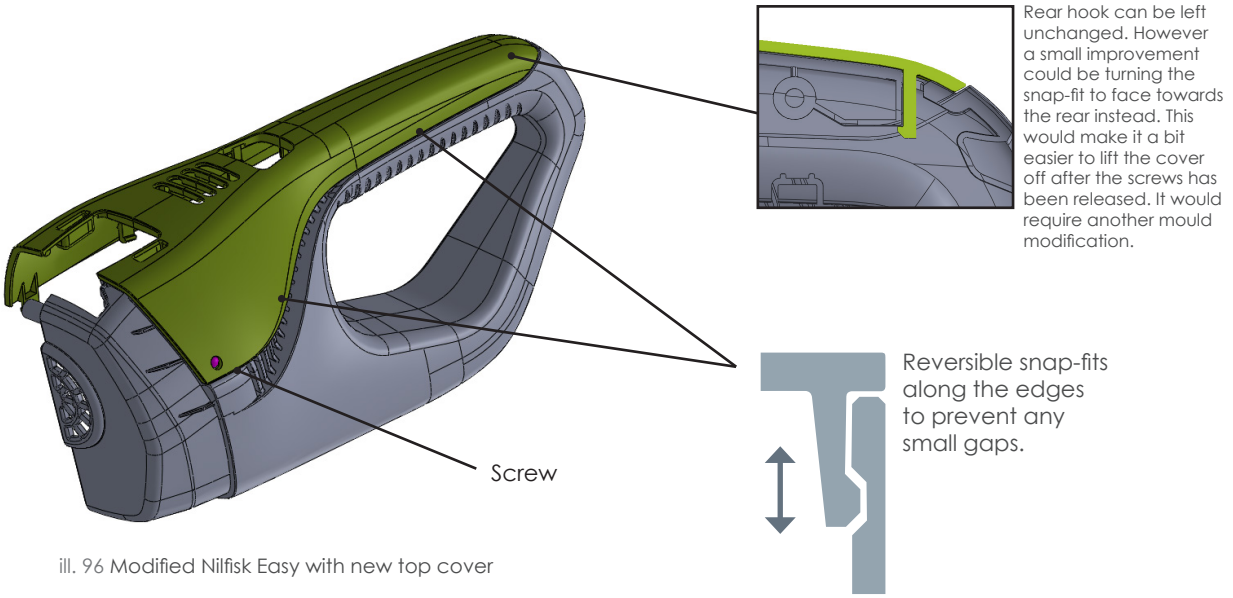
1) Modified Nilfisk Easy

The main problem with the Nilfisk Easy is that priority parts (motor, battery and PCB) inside of the handheld unit are not accessible with the use of common tools without causing damage to the product. This is a result of using irreversible snap-fits to fasten the top cover as described in the disassembly study p. 24. Two ways to solve the problem with removing the top cover has been identified.

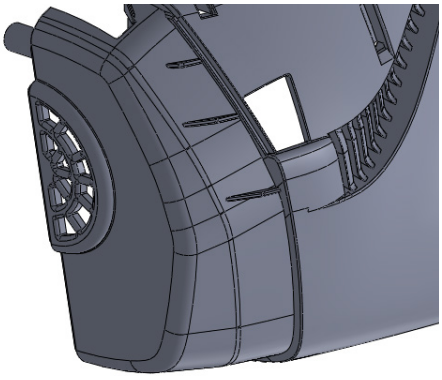
Option 1, screws.

The first option is to design a new top cover which is fastened with screws at the front end, replacing the irreversible snap-fits in the original design (ill. 96). A boss acting as a receptacle for the screw needs to be added to the outer plastic shells of the Nilfisk Easy. This addition will require a small modification to the mould design. When modifying moulds it is possible to remove metal from the mould, enlarging the cavity, but it is usually not possible to add material to the mould. Therefore the basic rule of modifying moulds is that plastic can be added to the part but not taken away [Protolabs n.d.]. The boss can be added at the existing void in the outer shells (ill. 97, ill. 98, ill. 99).
By CNC milling material away as explained in ill. 100, it is possible to mould the boss.

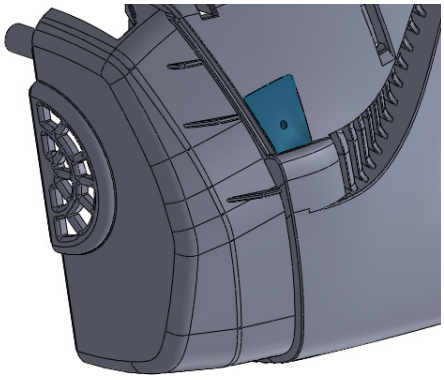
The snap-fits along the side of the top cover should be changed to reversible snap-fits. The rear hook can be left unchanged. These changes will make it possible to remove the top cover without causing any damage. To improve the finish, visible screws could be hidden with small covers.



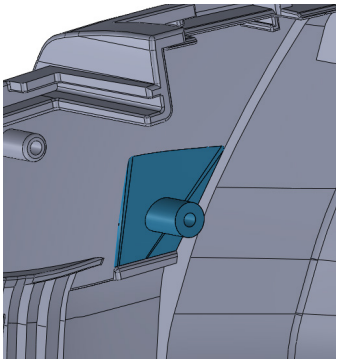
ill. 96 Modified Nilfisk Easy with new top cover



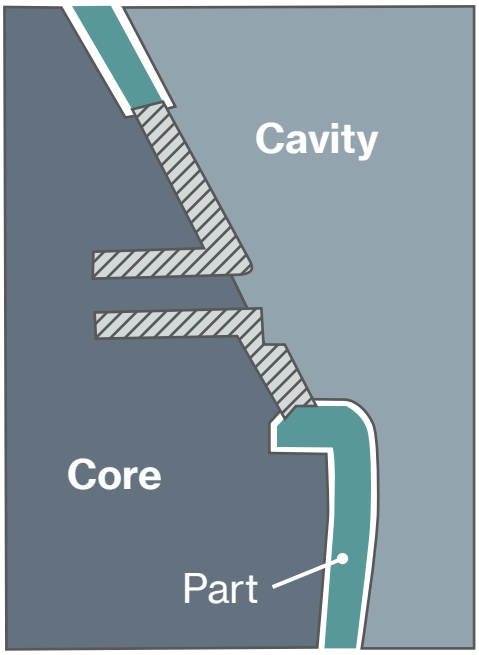
ill. 97 Existing void in the outer shells



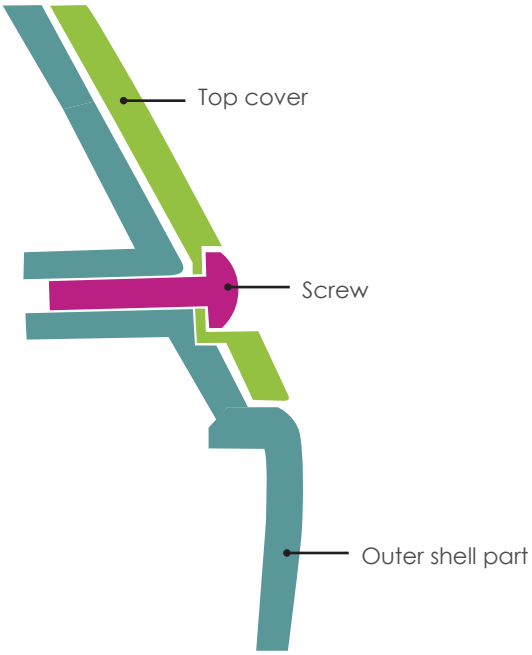
ill. 98 Modified part front view



ill. 99 Modified part rear view. The Boss for the screw.



ill. 100 By CNC-milling the hatched area away from the core and cavity, the boss can be added to the mould.a

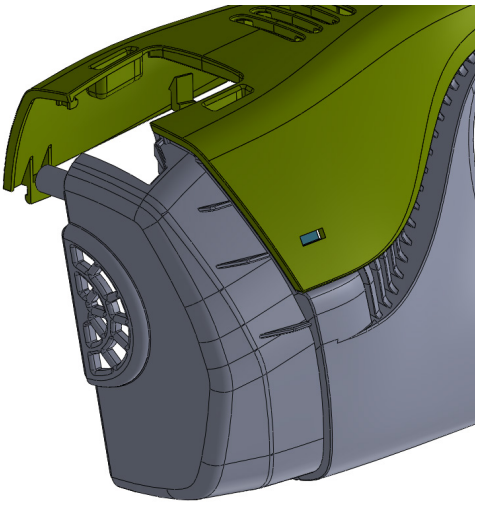


ill. 101 Screw assembly

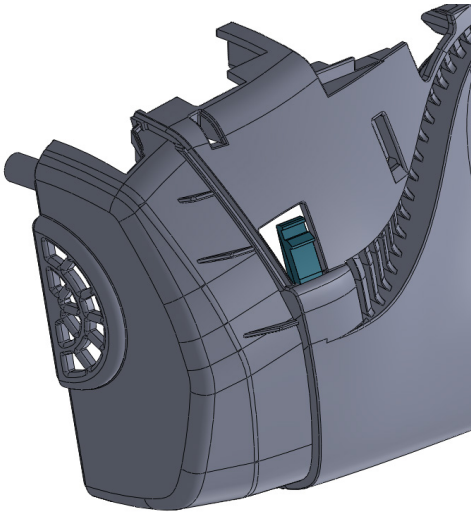
Option 2, snap-fit

The second option is to design a new top cover with a snap-fit solution as seen in ill. 102. The snap-fit will be added at the previously mention void in the outer plastic shells (ill. 103) by modifying the mould through CNC-milling (ill. 104). This snap-fit is reversible by releasing it with a screwdriver through a hole in the newly designed top cover (ill. 105). As the first option, the snap-fits along the side of the top cover should be changed to reversible snap-fits and the rear hook can remain unchanged.

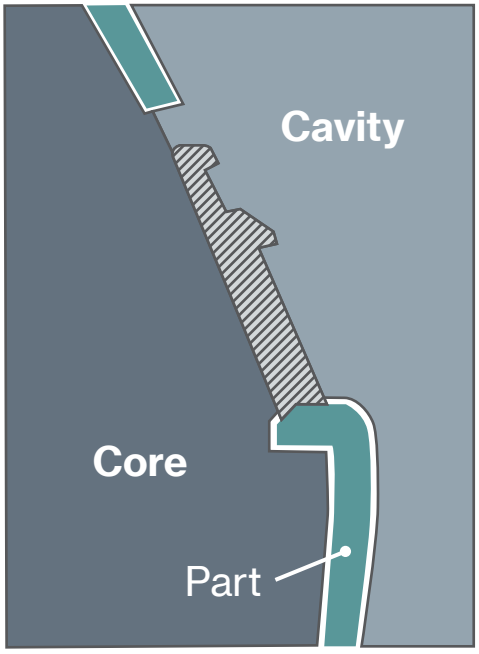
Option 1 or 2 would enable Nilfisk to sell the Nilfisk Easy beyond 1st March 2023. The changes will not lead to an actual improvement in material efficiency as self-repair is still not possible, and the product cannot be repaired at an acceptable cost at a professional repair shop. Furthermore, even with the changes, the Nilfisk Easy is not expected to achieve a particularly good score in the repairability label as the disassembly time and depth are still quite high. Modifying the Nilfisk Easy is more likely to be used as a temporary solution until a new product with a proper focus on material efficiency is developed.



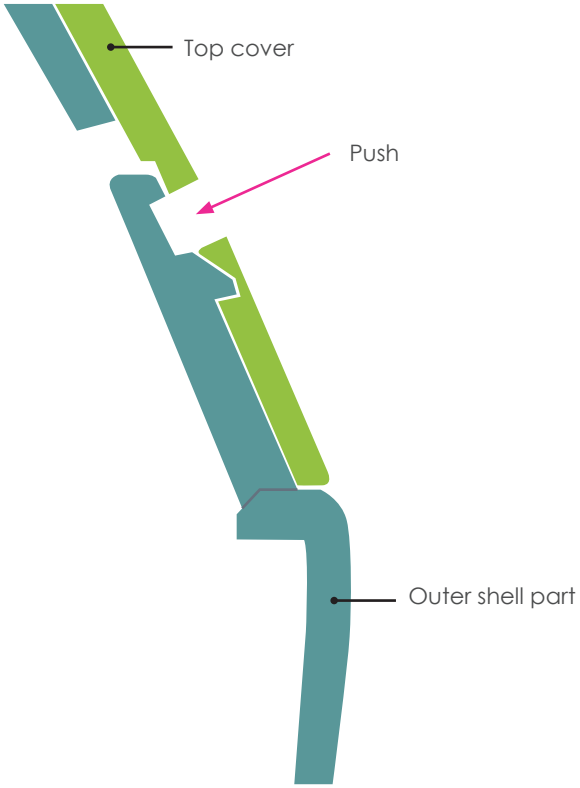
ill. 102 Modified top cover



ill. 103 Snap-fit (blue) positioned at existing void



ill. 104 By CNC-milling the hatched area away from the core and cavity, the snap-fit can be added to the mould.



ill. 105 The snap-fit can be released by pushing the tip of a screwdriver through the hole in the top cover.

2) Nilfisk Infinity compartible with Nilfisk Easy stick unit

The current Nilfsik Easy mouthpiece and stick unit allows access to the priority part (Motor brush PCB) with common tools, but it is a very comprehensive procedure which includes soldering of electrical components. However, there is an opportunity to design the Nilfisk iĺnfinity to be compatible with the current mouthpiece and stick unit, and thereby form a new 2-1 stick vacuum cleaner that complies with the future regulations. The repairability label score would be medium as only the Nilfisk Infinity handheld unit is optimized for repair.

3) Nilfisk Infinity concept

The final option is the Nilfisk Infinity concept combined with an associated stick unit and mouthpiece, which follows the principles for repairability and material recovery explored in this project. This option would mean the development of a completely new product to be introduced ahead of the planned changes 1st March 2023.

To secure the future of the company it will be important for Nilfisk to be at the forefront of regulations and follow the development of the regulations closely. The Nilfisk Infinity could provide the opportunity to be on the forefront of regulations, as it exceeds the planned regulations by allowing consumers access to all priority without any tools and considers the recyclability in the design as well.

Construction principles of the Nilfisk Infinity could eaily be translated to other products in the Nilfisk product portfolio as the products are quite similar in terms of materials and manufacturing methods.

Conclusion

The focus of this thesis project has been to explore how a future Nilfisk consumer vacuum cleaner could be designed to increase material efficiency in order to meet future regulatory measures and appeal to increasingly environmentally conscious consumers.

Findings in the project establish that the design of existing Nilfisk consumer vacuum cleaners must change significantly to comply with the future material efficiency requirement set out by the Eco-design directive. The main focus area is considered to be the prolonging of product lifetime through repair actions. Research in this project shows that an acceptable repair cost of consumer vacuum cleaners can only be meet by allowing consumers to perform repairs themselves, which will have a substantial impact on the product design of future products.

The result of the project is the Nilfisk Infinity product concept; A handheld consumer vacuum cleaner that is easily repairable by the consumer at a reasonable cost while being optimized for high-quality recycling at its End-of-Life. Multiple construction principles have been explored throughout the project and applied to the Nilfisk Infinity. The explored principles could be applied to the majority of the next generation of Nilfisk products and thereby preparing Nilfisk for the nearby future of increased, and continuously increasing, focus on material efficiency.

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