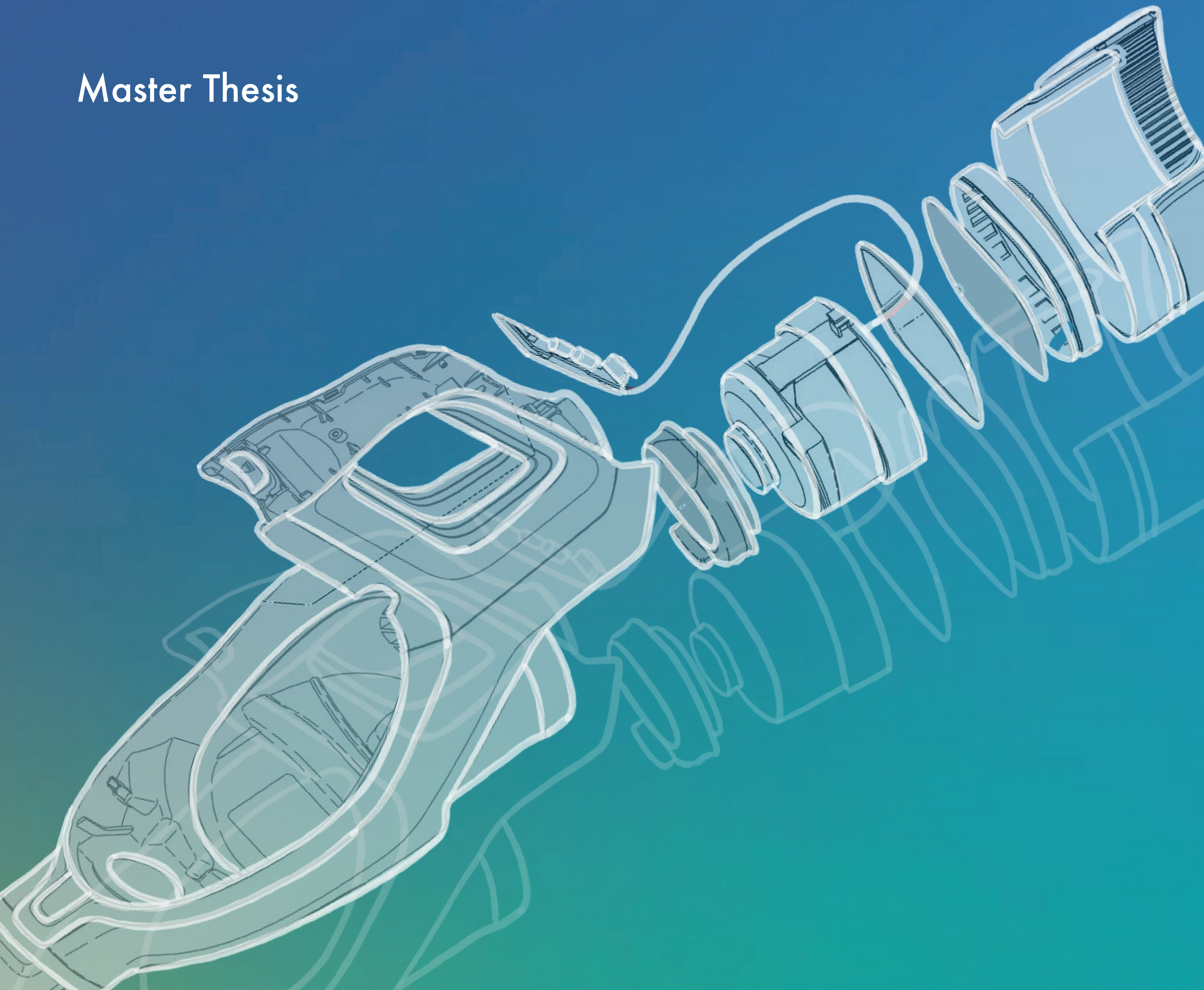
Master Thesis



IMPROVING REPAIRABILITY IN CORDLESS VACUUM CLEANERS

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Executive Summary

The incentive of this graduation project was to determine the repairability of Philips cordless vacuum cleaners and propose strategies to improve their repairability. This was done using two assessment methods; the Disassembly map and the French Repairability Index (FRI). During this project the French Repairability Index became of large importance due to its sudden planned introduction for vacuum cleaners in January 2022 in France. Therefore the focus of this project shifted to repair in the context of the FRI.

The final outcomes of this project are an assessment of two Philips cordless vacuum cleaners, a tool which provides guidance during FRI assessment (The adapted Disassembly Map) and design guidelines on how to design for FRI. Furthermore advice on how Philips can introduce 'Design for FRI' into their design process is shared, to ensure that their products will become more repairable and generate high FRI scores. Lastly insights on the FRI as a repair scoring system are given.

When designing for FRI it is most important to keep the amount of disassembly steps low to obtain priority parts. This can be done by limiting the amount of tool changes during disassembly, placing priority parts close to the surface in a product's architecture and ensuring that priority parts are separable from each other.

In our current day and age the lifetime of many types of electric and electronic consumer goods has been decreasing. (Bakker, C., Wang, F., Huisman, J., & Den Hollander, M. (2014). This leads to more products being discarded and more new products being produced, which are both unsustainable effects. Product lifetime extension strategies, for instance enhancing repairability, are needed to effectively create a circular economy and a sustainable future.

Six cordless vacuum cleaners were assessed on their repairability by creating Disassembly Maps. These maps give an overview of a product's architecture during disassembly for repair. Subsequently the products were scored using the second category of the French Repairability Index. This category looks at the physical qualities of the product in terms of repair. Conducting the FRI assessment showed that a large amount of assumptions were needed to determine the amount of disassembly steps, type of tools needed and type of fasteners in a product. This insight led to the conclusion that a guiding tool would be helpful to assist with generating correct and reproducible FRI scores.

The existing Disassembly map was altered to guide during FRI assessment and help produce reliable FRI scores. This adapted Disassembly map was tested by four design students on an existing cordless vacuum cleaner. The adapted Disassembly map did not ensure correct FRI assessment. Analysis of the test led to the conclusion that the current definitions and instructions of the FRI Category 2 are not specific enough. In Chapter 7 suggestions are described that could improve the current definitions and instructions.

Tests with the adapted Disassembly map showed that the tool was very useful in detecting product design characteristics that would hinder repair. When used in the early stages of a design process these characteristics can still be easily altered and have a large positive impact on the repairability of the final product.

List of Abbreviations

CTN	=	Consumer Type Number
DfR	=	Design for Repair
DfD	=	Design for Disassembly
DM	=	Disassembly Map
FSS	=	Final Score Sheet
aDM	=	Adapted Disassembly Map
ErP	=	Energy related Product
FRI	=	French Repairability Index
PCBA	=	Printed Circuit Board Assembly
RSS	=	Repair Scoring System
VC	=	Vacuum cleaner
WEEE	=	Waste Electrical and Electronic Equipment

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1. Introduction

1.1 Problem scope

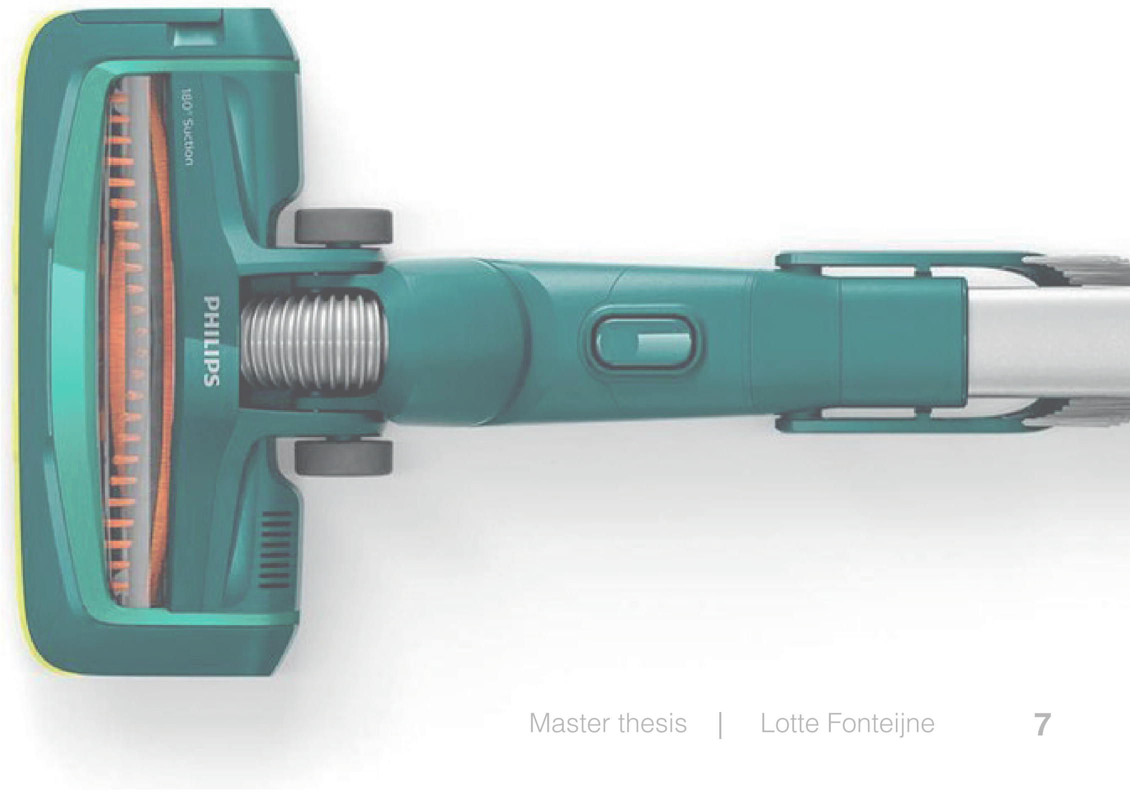
This thesis focuses on the repairability of cordless vacuum cleaners and has been a collaboration between the Faculty of Industrial Design Engineering of the Delft University of Technology and Philips. Philips had the wish to gain insight in the current repairability of their cordless vacuum cleaners and how to improve the repairability of this product group.

So far, Philips has been using different strategies to enhance sustainability in their products and processes. By using recycled plastics, decreasing packaging materials and starting up refurbishment programs. Philips' current design process however does not yet include extensive requirements for design for repair. Increasing repairability has the potential to decrease exchange rates, field call rates in general and increase customer satisfaction by extending product lifetime.

In the last five years, cordless vacuum cleaners have grown to own the largest share in the vacuum cleaner market (Arizton, 2021). Research of consumer organisations however shows that the average lifetime of cordless vacuum cleaners, until a serious fault emerges, is only two and a half years (Consumer.org, 2020). This lifetime is half as long as that of the average of canister vacuum cleaners. Manufacturers, like Philips, often exchange whole assemblies instead of repairing broken components, as exchange is often cheaper than repair (Consumers & Repair of Products, EU briefing, 2019).

These developments lead to the increase of Waste Electrical and Electronic Equipment (WEEE), energy use and use of scarce materials. This emphasizes the necessity of increasing the lifetime of cordless vacuum cleaners and hereby 'Slowing resource loops' (Bocken et. al, 2016). Besides that Design for durability can delay the occuring of serious faults in cordless vacuum cleaners, Design for repair can improve the chances of resolving these faults.

Not only consumers want cordless vacuum cleaners to last longer, The European Union and national governments have been introducing new legislation and policy on increasing repairability of energy related products. In the EcoDesign working plan 2016 - 2019 the introduction of new labelling systems for repair, with the goal of increasing durability, repairability, upgradeability and re-manufacturing, was commissioned by the European Commission (European Commission, 2016). In January 2021 France nationally launched the first mandatory repair label, which will be launched for vacuum cleaners in 2022. These developments show how repair policy and repairability assessment of energy related products is currenty highly relevant.



1.2 Research questions

The main research question (MRQ) of this graduation project is:

MRQ. How repairable are Philips cordless vacuum cleaners and how could this be improved?

Before the assessment of the Philips cordless vacuum cleaners and competitor models could be performed, the exact definitions of repair and disassembly needed to be determined, as design for repair and Design for disassembly are often wrongly used synonymously.

The definition of repair used in this thesis is:
'The process of returning a faulty product to a condition where it can fulfil its intended use.'

The definition of disassembly used in this thesis is:
'A process whereby a product is taken apart in such a way that it could subsequently be reassembled and made operational'

Both definitions are taken from the regulation EN45554 'General methods for the assessment of the ability to repair, reuse and upgrade energy-related products'. Disassembly and repair are not the same, however disassembly is an important strategy for improving repairability. Broken components need to be obtained through disassembly before they can be replaced and a product can be repaired. 'Improved component accessibility facilitates reuse, repair, refurbishment, remanufacturing and recycling' (Vanegas et al., 2017).

Several subquestions have been created to help answer the main research question. As cordless vacuum cleaners are assessed on their repairability using repair scoring frameworks, these frameworks and their corresponding criteria needed to be described and understood. Frameworks use only a selection of assessment criteria and therefore comprehension of the in- and exclusion of criteria in these assessment methods was needed. It was important to understand the current policy landscape on repair. By who and why is new legislation on repairability being developed and in what timeframe will new legislation be implemented. The issues raised above were captured in the following research questions:

Research Question 1 (RQ1)
How is repairability currently assessed in Energy related Products?

Research Question 2 (RQ2)
What are current regulations and policy on repair for cordless vacuum cleaners in the European Union and what is to be expected in the future?

Research Question 3 (RQ3)
How do the current cordless vacuum cleaners of Philips score in terms of the most important repair regulation?

Research Question 4 (RQ4)
How can the French Repairability Index scores of these products be improved?

1.3 Research Approach

To answer the main research question and sub research questions in this research, the Double Diamond design method (See Figure 1.) was used.

In the first stage '**Discover**' literature research and interviews were done to find out how repairability is currently assessed and which repair regulations and policy is currently relevant for cordless vacuum cleaners.

In the second stage '**Define**' the repairability assessment of the selected products was carried out and analysed to find opportunities on how to improve the repairability in these products.

In the third stage '**Develop**', ideas on how to play into the found opportunites were created and further detailed.

In the final stage '**Deliver**' these strategies on improving repairability were tested and evaluated

In a case study six cordless vacuum cleaners were analyzed using the Disassembly Map (DM) and the second category 'Ease of Disassembly' of the French Repairability Index (FRI). This resulted in six disassembly maps which provided insight in the product architecture and obstacles for successful disassembly for repair. The FRI assessment generated quantitative scores that gave insight in repairable the selected products were in terms of the repair criteria chosen by the FRI. Based on the findings of the assessment, oportunities for improvement of repairability were described and Design for FRI Guidelines were created. The disassembly map was altered to match the criteria of the FRI and provide guidance during the complex FRI assessment. Lastly a reflection on the FRI as a repair scoring system and how improving repairability fits in Philips design process is shared.

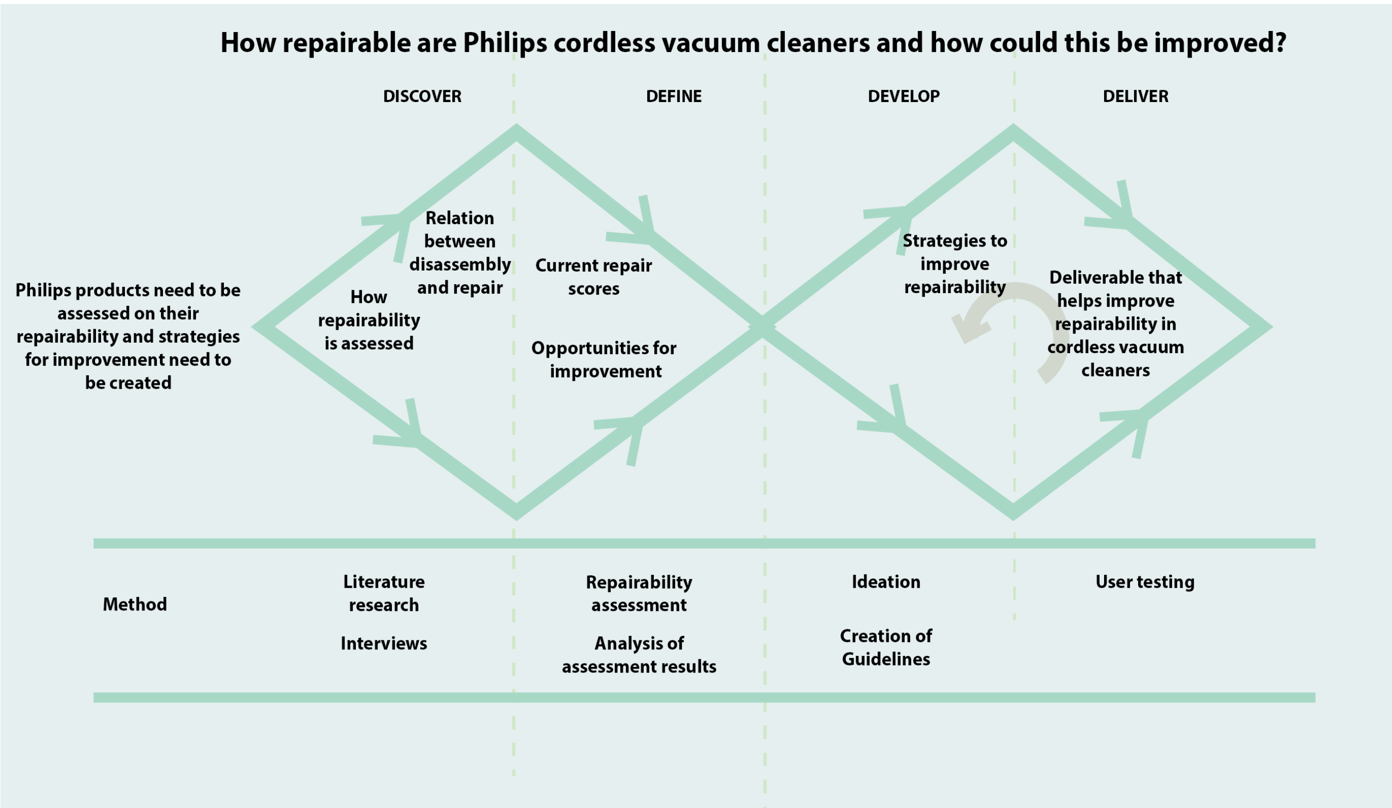


Figure 1: The double diamond design method (British Design Council, 2005)

2. Context & Research

2.1 Introduction

Chapter 2. Context & Research sets out to describe a context in which research questions 1 and 2 can be answered.
RQ1: ‘How is repairability currently assessed in Energy related Products?’ and
RQ2: ‘What are current regulations and policy on repair for cordless vacuum cleaners in the European Union and what is to be expected in the future?’

In Chapter 2.2 current and relevant repair scoring systems are described.

In Chapter 2.3 the most recent and expected changes in regulation and policy on repair for cordless vacuum cleaners are discussed.

Reducing replacement frequency
Before we can start answering research question 1 and 2 we need to understand why increasing repairability is desirable. As explained in Chapter 1.1 the average product lifetime of vacuum cleaners has been decreasing, like many other types of energy related products (Bakker, C., Wang, F., Huisman, J., & Den Hollander, M. (2014). This leads to more products being discarded and more new products being produced, which are both unsustainable effects.

Product lifetime extension strategies, for instance by enhancing repairability through product design, can help effectively create a circular economy and a sustainable future. The strength of the strategy of reducing replacement frequency through product design is that it doesn’t demand people to agree to pro-environmental behavior. They are simply tempted to do so without being aware of the pro-environmental (Van Nes, 2006).

Interplay between sustainable strategies
When solely focussing on the physical characteristics of these products, a multitude of strategies emerge as possible approaches in tackling this problem. Design for reuse, disassembly, repair, service, maintenance, refurbishment, remanufacturing, upgrading and modularity all qualify as strategies with major potential to reduce replacement frequency. Since many of these have strong affinity with each other, it is no surprise that physical materialisation of individual strategies can serve a collection of the above mentioned. However the opposite is also true, where types of fasteners, product architecture or material choices can hinder extending the product lifetime in terms of a different strategy. The same goes for disassembly and repair as Design for disassembly in the context of remanufacturing does not always benefit repairability and can possibly hinder it. This interplay between strategies should always be considered when applying these strategies to physical product design

Which sustainable strategy to use is highly dependent on the product category, the type of user and the expected use time of a product. To develop insight and advance in our application of these strategies it is therefore important to learn through application. By applying strategies to specific product categories we gain knowledge on what physical characteristics enable sustainable strategies and what the interplay between strategies looks like. This research hopes to add to this collection of knowledge, gained through application

2.2 Repair scoring systems

In 2019 the European Union introduced the idea of new labelling systems, to support development of sustainable strategies in product design, in the Ecodesign Working plan supporting these design aspects was introduced and supported further in the Ecodesign Working Plan 2016-2019 (European Commission, 2016).

The goal of repair scoring systems is to assess products on their repairability. The table below (Figure 2.) gives an overview of existing repair rating and scoring systems. As can be seen, many systems also focus on other sustainable strategies besides repairability. The outcomes of these frameworks differ from generating scores to labels and standards.

Criteria of Repair scoring systems
Repair scoring systems (RSS's) need to be transparent, easy to use and comprehendible. A selection of the right criteria for the framework is necessary, balancing completeness and usability. If a RSS is too detailed, it is more likely that errors will be made in assessments and the results are harder to check. At the same time creators want to capture the many facets of repairability in repair scoring systems. Repair criteria can be dependent on the assessed type of product and therefore it is beneficial if RSS's are specified for product groups

The relevant scoring systems can be divided them into three groups based on the types of criteria that they use for input (Bracquené et al., 2018; CEN/CLC TC10 European Standard, 2017):

- Qualitative assessment methods
- Semi-quantitative assessment methods
- Quantitative assessment methods

Most RSS's both take into account qualitative aswell as quantitative criteria and produce a numerical score as a final product. The two systems that only take into account qualitative input generate a standard and a label.

An interesting finding is that many RSS mainly focus on the first part of repair, disassembly and replacement of faulty components. The process of re-assembly, and its enabling or disabling factors, are not always considered.

Existing rating systems	Input type	Type	Scope	Applicable to
JRC Scoring system for repairability	Semi-Quantitative	Scoring system	Repairability, Upgradability	Energy related Products
Austrian standard ONR 1921022014	Qualitative	Standard	Repairability, Durability	White and brown goods
Product 10Y Repairable label	Semi-Quantitative	Label	Repairability	Small household appliances
i-Fixit 1, scoring system for repairability v1 (published)	Semi-Quantitative	Scoring system	Repairability, Upgradability	Portable IT products
i-Fixit 1, scoring system for repairability v2 (beta version to date)	Semi-Quantitative	Scoring system	Repairability	Portable IT products
Labo Fnac's "Indice de réparabilité"	Semi-Quantitative	Scoring system	Repairability	Laptops and smartphones
Benelux study on "Repairability criteria for energy related products"	Semi-Quantitative	Scoring system	Repairability	Energy related Products
prEN 45554: General methods for the assessment of the ability to repair, reuse and upgrade energy related products	Semi-Quantitative	Standard	Repairability, Upgradability, Reusability	Energy related Products
French repairability index (ADEME)	Semi-Quantitative	Scoring system	Repairability	Electrical appliances
Reparability (from a Slovakian NGO)	Quantitative	Label	Repairability	Assembled goods
Ease of Disassembly Metric (eDIM)	Quantitative	Metric	Disassemblability	Electrical appliances
LONGTIME label	Qualitative	Label	Durability, Repairability	Assembled goods

Figure 2: Overview of existing rating systems on repair and disassembly

Analysis of the existing repair measurement tools and scoring frameworks resulted in a non-exhaustive list of criteria concerning repairability grouped by theme (see Figure 2b. As this research uses two repair assessment methods, the Disassembly map and the French Repairability Index, it is shown which criteria are incorporated per method.

It can be seen that the French Repairability Index is a broad scoring system, incorporating criteria from many different themes. This will be further explored in Chapter.

The Disassembly map, in contrast, only scores technical criteria and uses the environmental impact of components to determine which one are the most important in terms of repair. This will be further explored in Chapter 3

		Theme	French Repairability Index	Disassembly Map
1	Disassembly steps	Technical		
2	Re-usability of fasteners	Technical		
3	Disassembly sequence	Technical		
4	Ease and possibility of resetting of software	Technical		
5	Modularity and upgradeability	Technical		
6	Accessibility and level of standard of tools needed	Technical		
7	Exerted force during disassembly	Technical		
8	Failure diagnostics	Information		
9	Available documentation on repair	Information		
10	Diagnosis and support interfaces	Information		
11	Required repair skill level	Information		
12	Disassemby time	Economical		
13	Availability of spare parts (kept in stock)	Economical		
14	Price of replacement components	Economical		
15	Shipping time of spare parts	Economical		
16	Proximity of authorized repair centers	Organisational		
17	Reverse logistic systems and information on the take back process	Organisational		
18	Commercial guarantee	Legal		
19	Environmental impact of individual components	Environmental		

Figure 2b: Non exhaustive list of criteria impacting repair and their inclusion in the DM and FRI

2.3 Repair policy development

Policy and regulation have large influence on how products are designed. The two most important policy changes, at the time of this research, that are relevant for cordless vacuum cleaners, are the expected 2022 update of the EcoDesign Directive and the introduction of the French Repairability Index in 2021.The first is a EU-wide directive which introduced mandatory sustainability requirements for specific product categories. The second is a new repairability index which requires manufacturers, who deliver energy related products to the French market, to rate their products on their ease of repair and feature this score at physical and online retail locations. This legislation will widen its scope to more products in 2022, including cordless vacuum cleaners, and possibly more EU countries in the near future.

Influential legislation on product design
The main focus of sustainble policy for vacuum cleaners has been originally not been repairability, but lowering of energy use during the use phase. The 2013 EcoDesign Directive update for vacuum cleaners is a good example of a influential policy. This Directive was introduced in 2009 for 40 different product groups and induced mandatory regulations, specified per product category. As vacuum cleaners consume a large amount of energy in their use phase (See Figure 3.), compared to the production and end-of-life phase, first addressing this area is to be expected. *In 2010, 0,7% of electrical energy used in all 27 European countries was used by vacuum cleaners which stresses the large energy impact this product group has.* (Impact Assessment VC EcoDesign Directive, 2013).

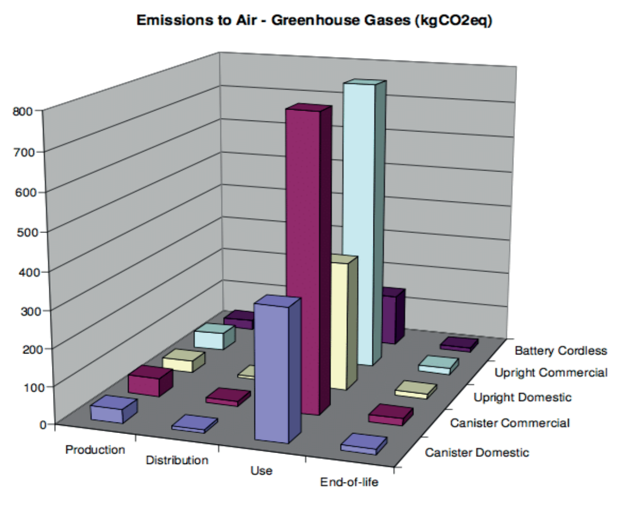


Figure 3: Energy usage per lifecycle stage for different types of vacuum cleaners (AEA, 2009)

One of the most influential policy developments for cordless vacuum cleaners, was the verdict of the European Court of justice in 2017 on the lowering of the maximum capacity of vacuum cleaners from 1600 Watts to 900. This change was estimated to generate a decrease in energy of 20 TWh yearly on a European level. This example illustrates the large impact that policy can have on product design. It also underscores how product lifetime extension is not always the most sustainable option.

The EcoDesign Directive update and the cordless stick vacuum cleaner
The EcoDesign Directive is currently (July 2021) in the process of being revised and is expected to become active in March 2023. The most important expected changes in the directive update for cordless vacuum cleaners will be (Draft EcoDesign Amendments, 2021):

- Extending the time in which spare parts need to be available to professional repairers after placing the unit on the market to six years.
- Requiring that spare parts need to be able to be replaced without permanently damaging the product with the use of commonly available tools.
- Requiring a list of spare parts and the procedure for ordering them to publicly be available on the free access website of the manufacturer, importer or authorised representative, at the latest two years after the placing on the market of the first unit of a model and until the end of the period of availability of these spare parts.

The expected changes in the EcoDesign Directive should be taken into account when developing requirements for future ErP's in the Philips portfolio and in this case especially for cordless stick vacuum cleaners.

The French Repairability Index and the cordless stick vacuum cleaner

The newly introduced French label is the first mandatory repairability assessment in the European Union that is obligatory for manufacturers to perform. The FRI was introduced in the beginning of 2021 and is a scoring system which scores Energy related Products on their ease of repair. The label is being evaluated throughout the year 2021 after becoming mandatory for only five product groups. In 2022 the FRI will become obligatory for more products in France. In that case the studied cordless stick vacuum cleaners will have to be assessed with the FRI. Furthermore although the policy is now only active in France there is a high chance that it will be expanded to the whole European Union or form the basis of a new EU wide assessment system.
The assessment is done by manufacturers themselves by filling in the FRI excel sheet which can be found on the website of the label. Manufacturers are obliged to display the score near to their products in retail environments and providing the Final score sheet (FSS) is obligatory when this is requested.

The FRI is the most important development at the present time for the studied product category. Because of the approaching new legislation Philips wants to assess the current state of their products in terms of repairability. Not only to be able to be compliant with the FRI but also to get the following side effects of increasing repairability namely: decrease exchange rates, the process of products being exchanged instead of repaired when sent back, field call rates in general and increase customer satisfaction by total product lifetime extension.

2.4 Summary

Disassemby plays an important role in repair. Optimising a product for disassembly is however not equal to optimising a product for repair.

Ease of repair and disassembly is measured by looking at how a product scores on selected criteria. Repair scoring systems choose a selection of repair criteria and can differ largely from each other, depending on the criteria that they have chosen to include or exclude. In the case of this study the French Repairability Index (FRI) is used to assess repairability. The FRI model is a semi-quantitative model and therefore uses a combination of qualitative and quantitative criteria.

The EU is trying to increase repairability in energy related products through policy, like the EcoDesign Directive. The new draft for the EcoDesign Directive has been put on hold for a long time. in the meantime European countries are creating national policy on repair. France is launching the FRI, Spain is elongating the minimum time that spare parts need to be kept in stock to 10 years and Sweden has introduced a tax break on repair activities. The update on the EcoDesign Directive for vacuum cleaners will be influential and introduce new required mandatory changes, the exact new requirements are not defined yet. The new draft for Ecodesign for different product groups (dishwasher etc.) includes keeping spare parts in stock for a minimum of 7 years, delivery of spare parts in a maximum of 15 days and acces to repair and maintenance information for professional repairers (including a disassembly map and exploded views).

2.5 Conclusion

Research question 1 'How is repairability currently assessed in Energy related Products?'
can be answered as following:

Repairability can be assessed using many different criteria, ranging from technical to economical. Repair scoring systems use a combination of criteria and produce repair scores or grant approval of a standard or label after succesful assessment.

Research question 2 'What are current regulations and policy on repair for cordless vacuum cleaners in the European Union and what is to be expected in the future?'
can be answered as following:

The new version of the EcoDesign Directive will influence the cordless vacuum cleaner group, as the additions will become mandatory requirements. This directive has been put on hold for the last two years but is expected to become active in the Spring of 2023. In short term the French Repairability Index is most influential for the cordless vacuum cleaners of Philips as it is the first mandatory repair label. The label will become active for this product group in the beginning of 2022 in France.

3. Assessment of cordless vacuum cleaners

3.1 The Disassembly Map

This chapter lays the groundwork for answering Research question 3: How do the current cordless vacuum cleaners of Philips score in terms of the most important repair regulation? In this assessment the Disassembly Map tool was used to analyse the repairability of Philips' cordless vacuum cleaners. The created disassembly maps later formed the basis of the FRI assessment as they helped establish necessary input.

The Disassembly Map was chosen to use as a method in this case study for a number of reasons. Using the tool would generate clear maps of the products which could be easily compared by eye on product architecture depth Most notably Philips had expressed interest in creation of Disassembly Maps for their two cordless vacuum cleaners and competitor models, the tool was previously developed in 2019 by De Fazio in collaboration with Philips and was used to map Philips' canisters and those of competitors. Inclusion of a disassembly map is mentioned in the draft update of the EcoDesign Directive for vacuum cleaners, as part of the repair and maintenace information for professional repairers in the future. If this is adopted in the final version of the directive, disassembly maps will become more widely used.

The goal of the original and second edition of the Disassembly Map is to provide a visual representation of product architecture, display sequence of disassembly and dependency of components during the act of disassembly for repair (De Fazio, 2020).There was no preference for a different rating or scoring framework which would deliver a quantifiable score, as no obligatory policy besides the FRI was active at the time for the product category.

Even though the Disassembly Map is not a traditional repairability scoring framework, it is highly useful to gain visualise the product architecture during disassembly for repair. These results can help highlight obstacles in the context of repair. After mapping the disassembly process the result gives a vertical overview (Figure 4.) of the product architecture, the types of action needed to extract components, additional information on the exerted force during disassembly, obstacles and the types of tools needed.

In the paper 'Further development of the Disassembly map' a more detailed version of the Disassembly map was presented, changes were made to make the tool applicable to different product categories (De Fazio, 2020). This addition however also made the tool more complex to use and the final map harder to read. Since the original tool was created for vacuum cleaners and easier to read, this version was chosen to use in the case study.

Like all repair scoring tools, the Disassembly map has used a selection of criteria that can be used to score repairability. The tool mainly focusses on the process of disconnecting components in context of repair and leaves the re-assembly mostly out of scope. When using the tool to assess repairability this should be taken into consideration.

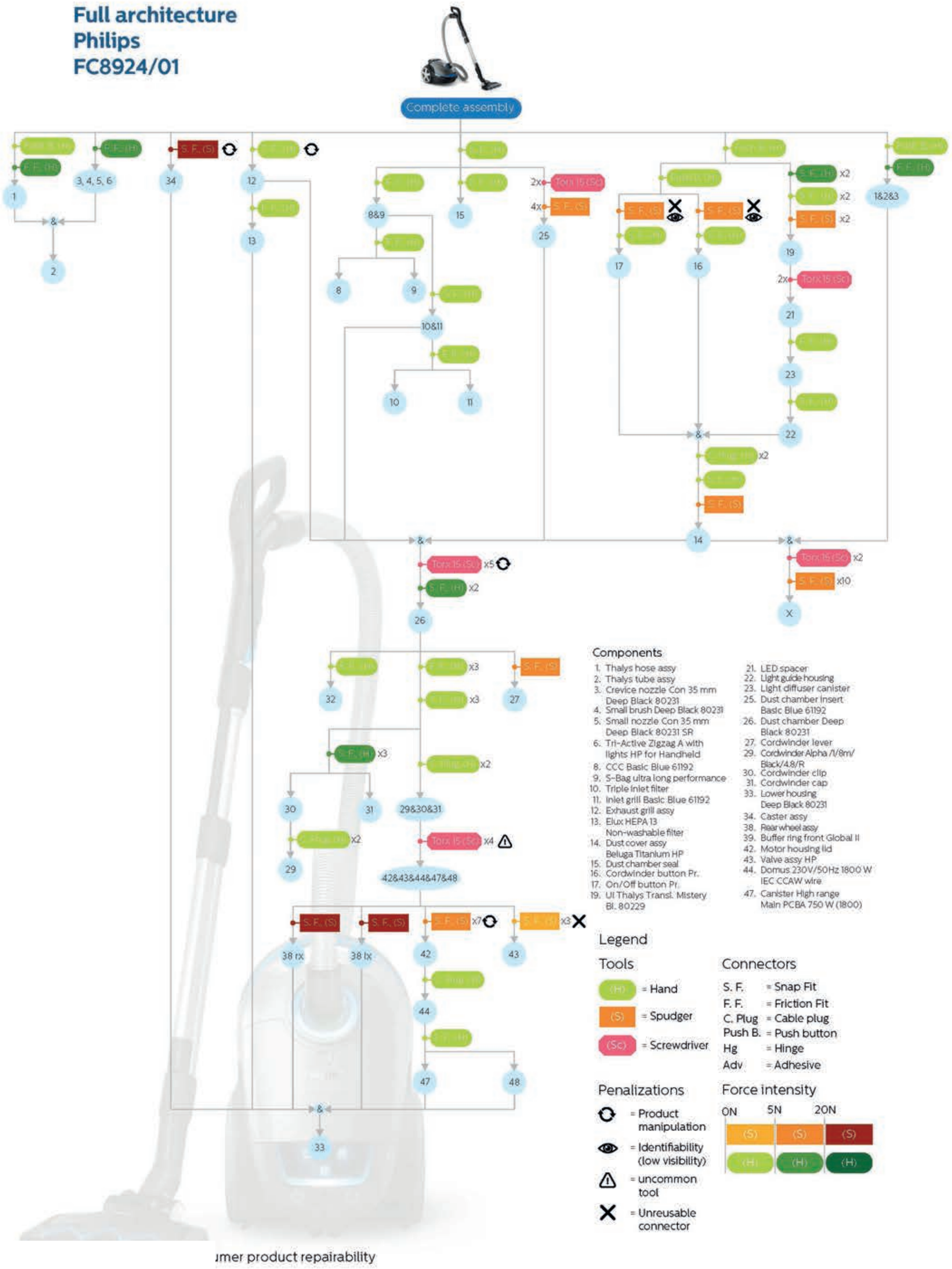


Figure 4: The original Disassembly Map

How to read a disassembly map
The disassembly map showcases a legend with four types of information;

- Tools
- Connectors
- Penalisations
- Force Intensity.

The disassembly is mapped using different visual elements. Undoing of fasteners is represented by three types of boxes (See Figure 5.). a motion involving a screwdriver, a motion involving a spudger and a hand motion. Components are visualised by blue circles, the number in the component bubble corresponds to the complete component list.

The three types of action boxes are:

- A motion involving a screwdriver
- A motion involving a spudger
- Hand motion.

These boxes and bubbles are vertically placed in order of the extraction out of the complete assembly. The type of fastener is described in text in the action boxes while the shape of the box conveys the type of movement needed to loosen the fastener.

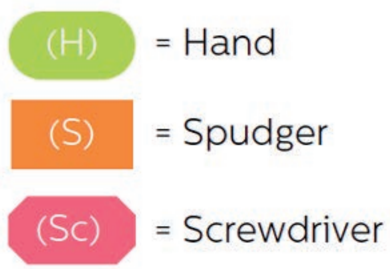


Figure 5: The three types of action boxes in the Disassembly Map (De Fazio, 2019)

Force intensity
The Disassembly Map also takes the amount of force into account that is needed to undo fasteners (See figure 6.). A large amount of force is visualised by a darker colour of an action box. Since force does not play a role in the undoing of screws, this is only applicable for hand and spudger motions.

Penalisations
After mapping the full product architecture, four types of penalisations can be added to the map (See Figure 7.). Having to turn and move the product during disassembly results in a 'product manipulation' penalty. When fasteners are hidden or not easily visible this can be marked with the 'Identifiability' penalty. The third penalty is awarded if an uncommon tool is used and the last penalty is given when connectors or fasteners can not be reused.
There are 4 types of penalties that can be added to the map:

- 'Product manipulation' penalty; this penalty is about having to turn and move the product during disassembly
- 'Identifiability' penalty; fasteners are hidden or not easily visible.
- The third penalty is awarded if an uncommon tool is used.
- The fourth penalty is given when connectors or fasteners cannot be reused.

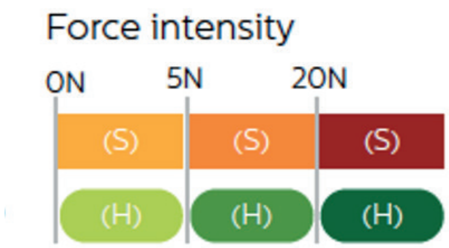


Figure 6: Force intensity range when undoing fasteners (De Fazio, 2019)

Figure 7: Disassembly Map penalties (De Fazio, 2019)

Product selection

Two cordless vacuum cleaners (See Figure 8 and 9.) were selected in collaboration with Philips to be assessed on their repairability:

- The Speed Pro
- The Speed Pro Max

These two products are representable for the main body of the total cordless Philips Floorcare product portfolio. Many versions of the two above-mentioned models exist under different CTN's (Commercial Type Names). The main body of the product is the same while slightly different versions are created through small differeing details, accessories and changes in power supply configurations

Competitor model selection

The four competitor models were selected because of their level of similarity to the two Philips cordless vacuum cleaners. Reason for this was that this would result in the most accurate comparison and therefore assessment of the Philips models.
The following competitor models were selected and can be seen in Figure 10:

- Miele Triflex HX1
- Bosch Unlimited serie 8
- Dyson V11
- Rowenta Air force flex 560

Product details of the Philips cordless vacuum cleaners and the selected competitors can be found in Figure 11.

Figure 8.: The Speed Pro cordless vacuum cleaner

Figure 9.: The Speed Pro Max cordless vacuum cleaner

Figure 10: The selected competitor models

Brand name	Product name	Battery time (minutes)	Sound level (Db)	Volume (L)	Weight (kg)
Philips	Speed Pro	40	80	0,4	3,5
Philips	Speed Pro Max	70	84	0,6	2,7
Miele	Triflex HX1 Pro	60	80	0,5	3,7
Bosch	Unlimited Serie 8	40	76	0,4	2,9
Dyson	V11	60	82	0,8	3
Rowenta	Air Force 560 Flex Aqua	35	82	0,7	3

Figure 11: Comparison of product specifications of the six selected cordless vacuum cleaners

3.2 Priority parts

Before the Disassembly maps could be created, the most important parts of cordless vacuum cleaners, in the context of repair, needed to be defined. The concept of 'Priority parts' was introduced by Braquene in 2014 in the study 'Repairability criteria for energy related products'. These parts are defined as the most important parts of a product to consider when it comes to repair and used in multiple repair scoring systems. The two factors 'Functional importance' and 'Frequency of failure and upgrade' are considered when determining what parts of a product are priority parts (Cordella, 2019). The European Standard EN 45554 determines priority components as: 'Parts which are more prone to be repaired, reused, replaced or upgraded for a determined product group'.

Functional Importance
If a component supports an important function, such as the primary function or basic function, it can be labelled as a priority part. Miles (1972) divided the functions of a product into use functions and aesthetic functions. The use function was further divided into a basic (or primary function) and secondary, tertiary and lower functions. Aurisicchio (2011) describes how functions are subjective and normative, meaning that not all users will agree on why and how a product should or can be used. Designers set-up requirements in their design process to which a product needs to tailor, however these written requirements are not communicated to consumers. In the perspective of products becoming obsolete, the user is the ultimate judge of what the basic functions of a product are. According to the standard EN 45552 a primary function is necessary to fulfil the intended use, whilst a secondary function enables, supplements or enhances the primary function (Cordella, 2019).

Frequency of failure
The second factor in determining priority parts is how often a component breaks or fails, the frequency of failure. Different sources can be used to determine this frequency like Field Call Rates (FCR's). These are paretos statistics drafted by manufacturers from data on their broken products that are sent back and are one of the most reliable sources for tracking the frequency of failure of components in a product.

Due to COVID-19 pandemic the service center of Philips could not be visited and FCR's were used to understand which components have a high failure rate. These rates can not be shared in this research due to confidentiality. Cordella (2019) also mentions many other different types of information which can contribute to the frequency of failure like Failure Mode Effect Analysis, experts' judgement and field experience, repairers, reuse and remanufacturing organisations, consumer testing organisations, insurance companies and researchers and regulators.

The Joint Research Centre (JRC) proposed in 2019 that :
1. Priority parts are functionally relevant parts that are typically associated with at least 3% of the typical failure rates for that product group. A weight equal to 1 could be assigned to such parts.
2. If failure rates are 10% or more, a high priority and a higher weight (=3) could be set for these parts.

Target components
The Disassembly Map has its own version of priority parts, called 'Target components'. These components do not only take into account the functional importance and Frequency of failure, but also the highest mass and/or cost values in the BOM and remaining useful life (for part harvesting), and the highest embedded environmental impact (for recycling). (De Fazio (2020)). Based on research question 3, which asks: 'How do the current cordless vacuum cleaners of Philips score in terms of the most important repair regulation?' it was chosen to use priority parts, which are used in the FRI, for the creation of the Disassembly Maps instead of target components.

Priority components in cordless vacuum cleaners
Multiple sources were used to compile a list of priority components for cordless vacuum cleaners. Field Call Rates of the Speed Pro and the Speed Pro Max, EU commissioned technical reports and review studies and data from consumer organisations. Lists of priority parts for vacuum cleaners with cords have been created often before in technical reports (Cordella, 2019), Review Studies (Rames, 2018 and Bracquené

2018). Cordless vacuum cleaners however are a relatively new product group and differ from canister vacuum cleaners. Not all priority parts that are featured in canister vacuum cleaner could be used for the cordless vacuum cleaners group. As these products for instance use batteries for their energy source and do not have other components like cord winders. Combining the multiple sources of data a final list of priority components for cordless vacuum cleaners was formed. Since the Disassembly Map does not use weightings for priority components this was left out of the selection.

The most important parts in terms of functional importance where found to be:

1. Battery
2. Handheld Motor
3. Handheld PCBA
4. Switches
5. Nozzle
6. Tube
7. Battery charger
8. Bucket
9. Filter

The most important parts in terms of frequency of failure where found to be:
1. Battery
2. Handheld Motor
3. Active Nozzle belt
4. Active Nozzle motor
5. Active Nozzle PCBA
6. Casing
7. Filter

The following page gives an overview of the selected priority parts as can be seen in Figure 12.

Figure 12: Priority parts of the Speed Pro Max used to visualise priority parts in cordless vacuum cleaners

3.3 Disassembly Maps

All six cordless vacuum cleaners were disassembled with the goal of reaching the defined priority parts in the least amount of steps while using non-destructive disassembly.

The disassemblies were done using a set-up in which two cameras recorded from a top angle and a horizontal angle. As disassembly time was not an included assessment criteria, the unfamiliarity with the products did not have to be taken into account by executing the disassembly multiple times. See Appendix I to VI for all disassembled products

It was chosen to do complete disassemblies for the products.The reason for this was that there is no standard accepted exact formula to determine priority parts, which means that this can change per rating system and product category. Complete disassembly maps leave the option for future alteration when needed. New versions of electronic consumer products often become more detailed and extensive over time, which also increases the chance of priority parts being added. An example from the last five years is the recent addition of active brushes in the nozzles of vacuum cleaners

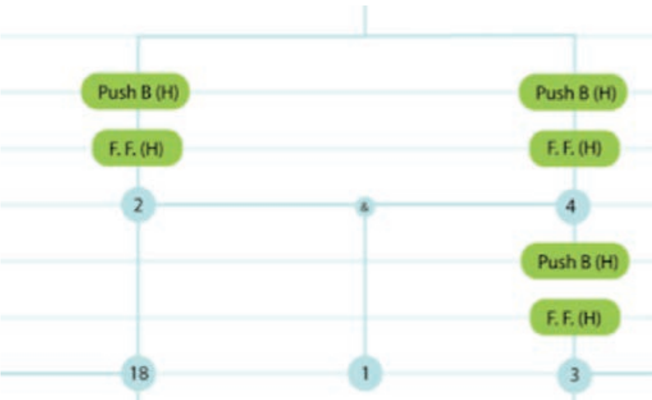


Figure 13: Seperation of the tube and nozzle from the handheld

Comparing of the Disassembly maps

The Disassembly maps are mostly useful for analyzing a single product and less so for comparing multiple products. This is mainly because visual comparison of multiple maps is hard to do due to the level of detail and size of the maps. When the priority parts in the map are known to the reader it is easy to establish if these parts are located 'deep' in the product or are at a shallow level (and therefore easier to acquire).

Based on these observations the reader can get an idea of if the product architecture is suitable for repair or could be improved. Without any explanation the DM's are hard to understand for designers and other Philips employees. Additional text was provided per DM to explain the results. All disassembly maps have the same box shape structure at the basis of the map because this represents the separation of the three main assemblies; the handheld, the tube and the nozzle (See Figure 13).

Bosch

The Bosch DM can be found on page 29 in Figure 14. The small size of the map stands out, together with the small amount of awarded penalties and the low amount of force that was needed to disassemble the product.

Miele

The Miele DM can be found on page 30 in figure 15. Like the Bosch DM the size of the map and low amount of penalties stand out in this map. The one unreusable connector was found near the PCBA, destructive disassembly would be needed to separate the PCBA from the housing. This product required more force to undo snapfits compared to the Bosch product, higher exerted forces increases the risk of components accidentally breaking.

Dyson

The Dyson DM can be found on page 31 in figure 16. Like the Bosch and Miele DM's the size of the map is small, which means that priority parts can be obtained in a low amount of steps. Since glue is applied to the PCBA a penalty for unreusability is awarded. The product does not have a belt in the nozzle motor. The nozzle is still shown in the map as this might be useful for future research.

Rowenta

The Rowenta DM can be found on page 32 in figure 17. This VC has a large DM which means that many steps are needed to obtain the priority parts. A large amount of force is needed to separate one of the top casing parts and destructive disassembly takes place as a result.

Speed Pro Max

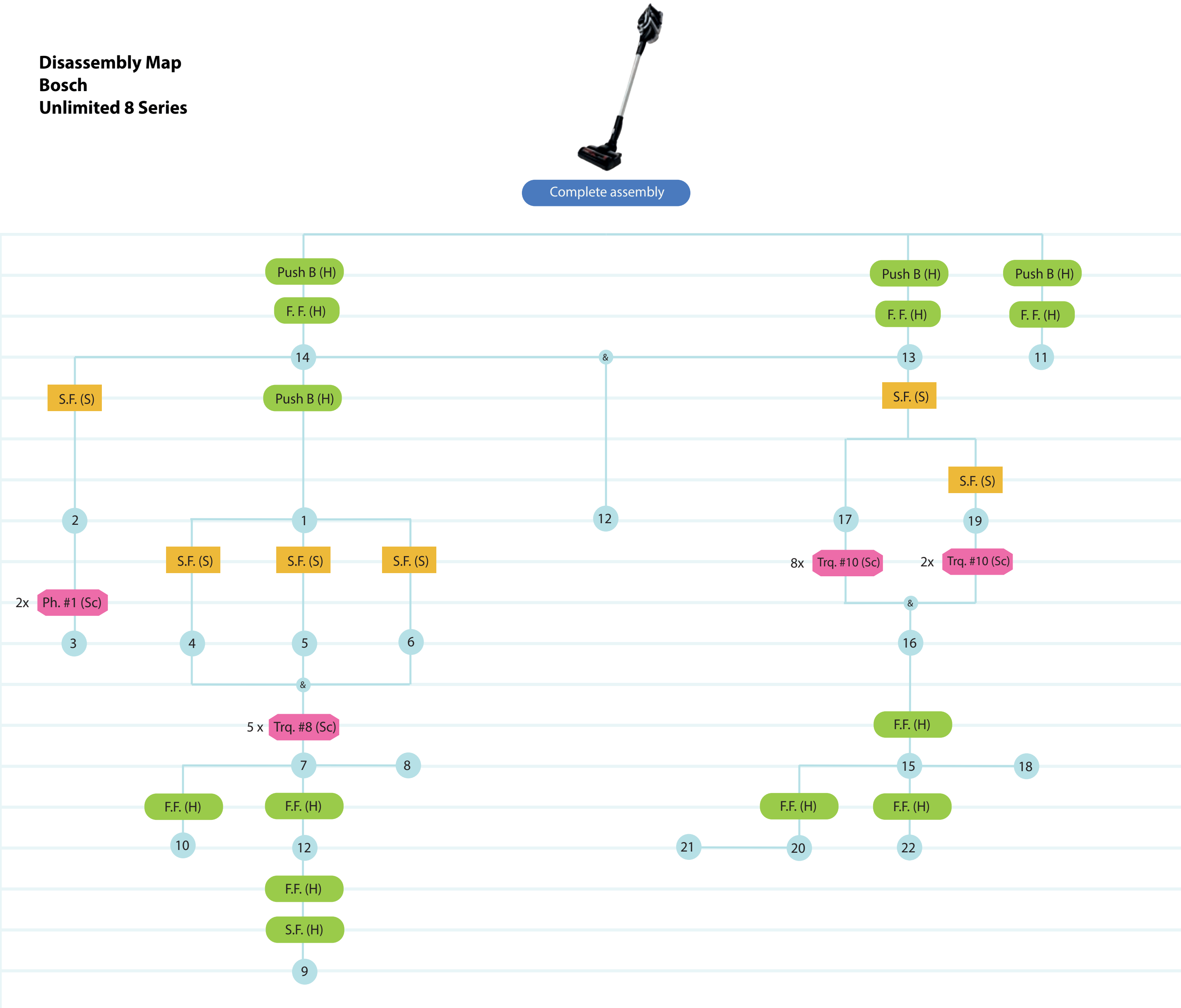
The Speed Pro Max DM can be found on page 33 in figure 18. This product has one of the most extensive DM's and requires a large amount of steps to obtain a priority part. Two penalties for unreusable connectors are awarded for the side panels of which snapfits broke during the disassembly. This part of the disassembly however was not needed to obtain only the priority parts. Since this is a Philips' VC these disassembly steps were also taken into account in the map.

Speed Pro

The Speed Pro DM can be found on page 34 in figure 19. This VC has a DM with an average size, meaning that an average number of disassembly steps is needed to acquire the priority parts. Two penalties are awarded for unreusable connectors. This destructive disassembly takes place when a panel part and the motor need to be separated using a spudger with a high amount of force.

Figure 13b The disassembled Speed Pro Max

Disassembly Map
Bosch
Unlimited 8 Series



Components

1	Dust bucket	15	Nozzle Tube assy
2	Top panel 1	16	Clear top cover
3	Top panel 2	17	Top cover
4	Top ring	18	Brush
5	Side panel 1	19	Small top panel part
6	Side panel 2	20	Active Nozzle belt
7	Mirrored casing parts	21	Active Nozzle axis
8	Switch assembly	22	Nozzle motor
9	Motor assy (+ PCBA)		
10	Filter		
11	Battery		
12	Tube		
13	Nozzle		
14	Active Nozzle belt		

Legend

Tools

(H) = Hand
(S) = Spudger
(Sc) = Screwdriver

Force Intensity

0 N	5 N	10 N
(S)	(S)	(S)
(H)	(H)	(H)

Connectors

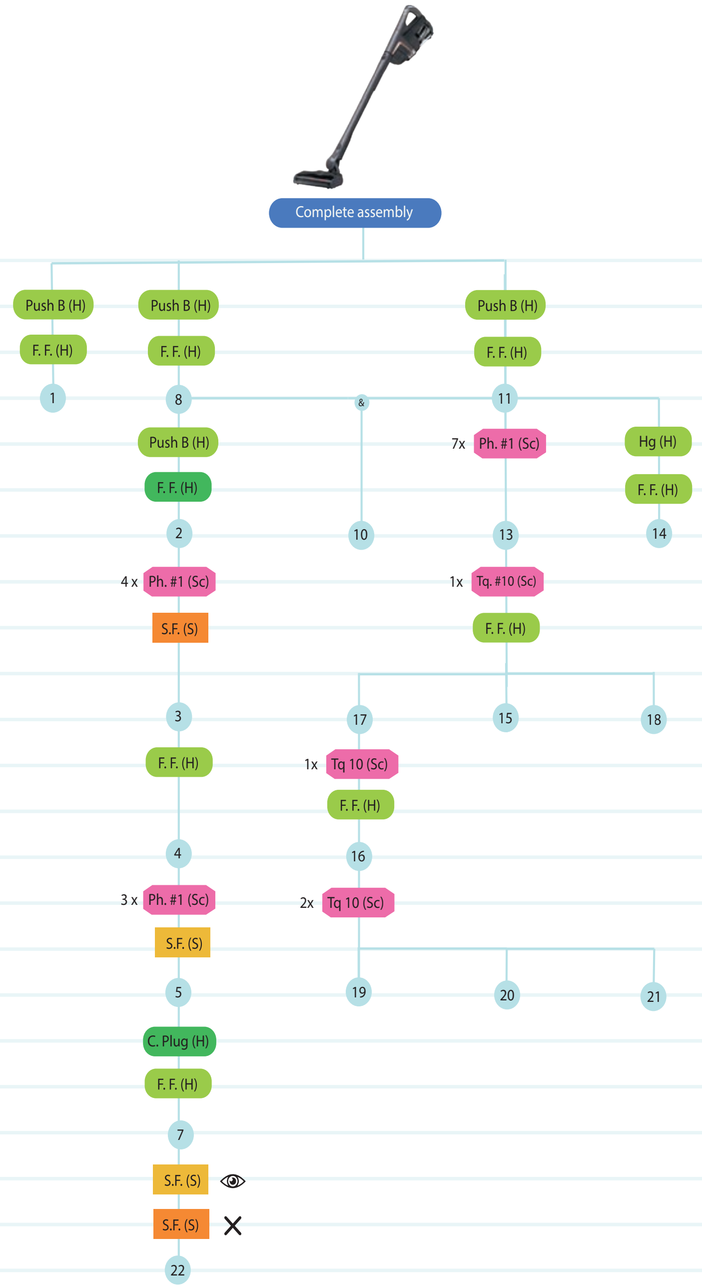
S. F. = Snap Fit
F. F. = Friction Fit
C. Plug = Cable plug
Push. B = Push Button
Hg = Hinge
Adv = Adhesive

Penalizations

= Product manipulation
= Identifiability (low visibility)
= Uncommon tool
= Unreusable connector

Figure 14 The Disassembly map of the Bosch Unlimited 8 Series

Disassembly Map
Miele
Triflex
HX1 Pro



Components

1 Battery
2 Dust Bucket
3 Front panel
4 Ring panel
5 Side panels
7 Motor
8 Handheld
9 Filter
10 Tube
11 Nozzle Assy
12 Nozzle Motor
13 Top cover
14 Brush
15 Active Nozzle assy
16 Active Nozzle background
17 Active Nozzle panel
18 Motor rubber
19 Active Nozzle belt
20 Active Nozzle belt 2
21 Nozzle Motor
22 Handheld PCBA

Legend

Tools

(H) = Hand
(S) = Spudger
(Sc) = Screwdriver

Force Intensity

0 N 5 N 10 N
(S) (S) (S)
(H) (H) (H)

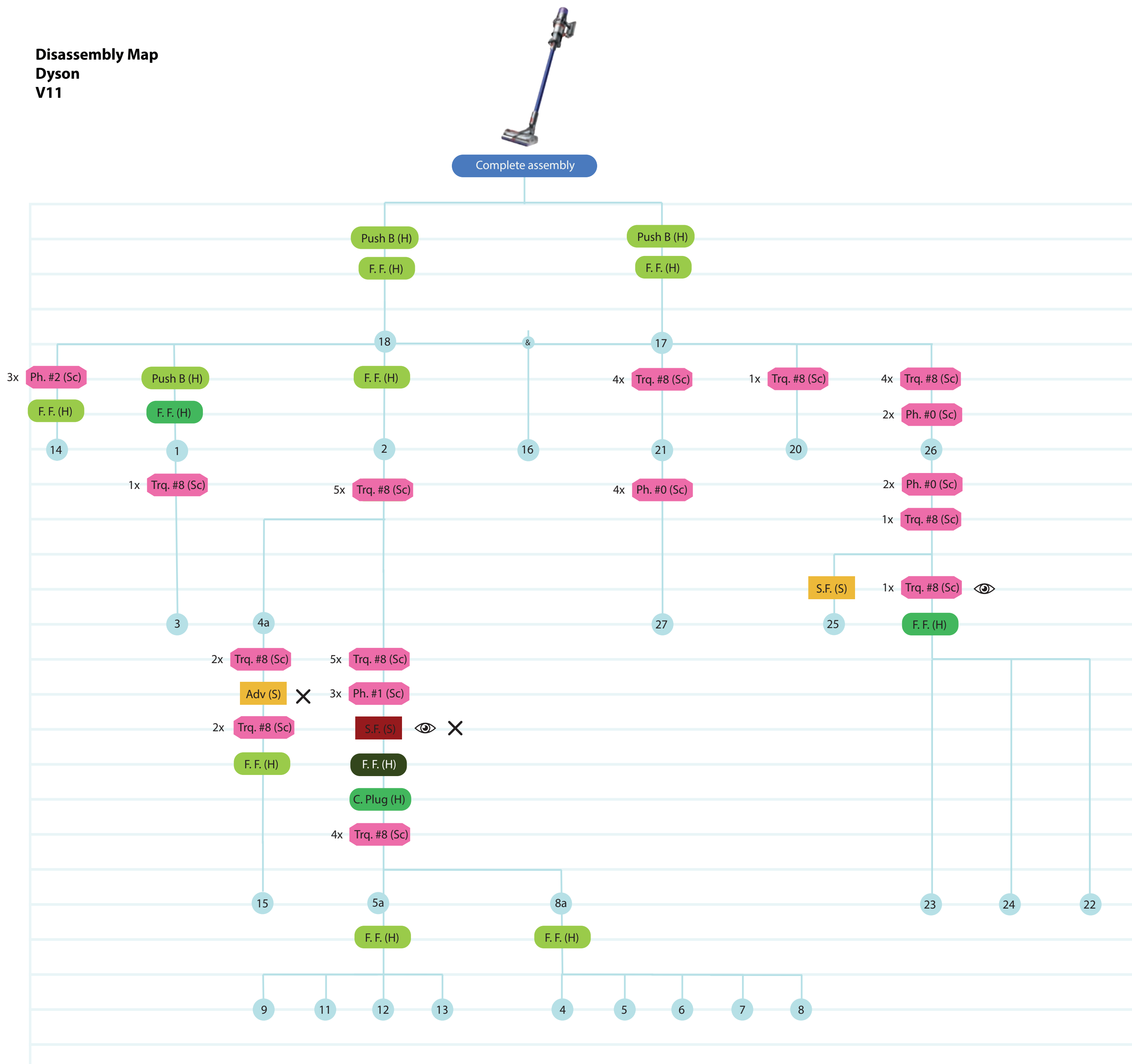
Connectors

S. F. = Snap Fit
F. F. = Friction Fit
C. Plug = Cable plug
Push. B = Push Button
Hg = Hinge
Adv = Adhesive

Penalizations

= Product manipulation
= Identifiability (low visibility)
= Uncommon tool
= Unreusable connector

Figure 15 The Disassembly map of the Miele Triflex HX1 Pro



Components

- 1 Bucket
- 2 Filter
- 3 Bucket shoot
- 4a Handheld subassy
- 4 Inner filter cannister
- 5a Cyclone assy
- 5 Cyclone mesh
- 6 Cyclone bottom
- 7 Ring
- 8a Flower assy
- 8 Flower bottom
- 9 Flower middle
- 10 Flower top
- 11 Flower stem
- 12 Red seal
- 13 Grey seal
- 14 Battery
- 15 Motor
- 16 Tube
- 17 Nozzle
- 18 Handheld
- 19 Nozzle Assy
- 20 Brush
- 21 Bottom part felt
- 22 Active Nozzle assy
- 23 Active Nozzle assy top
- 24 Active Nozzle assy cilinder
- 25 Top panel
- 26 Bottom panel
- 27 Clear cover
- 28 Switch pressure button

Legend

Tools

- (H) = Hand
- (S) = Spudger
- (Sc) = Screwdriver

Force Intensity

0 N	5 N	10 N
(S)	(S)	(S)
(H)	(H)	(H)

Connectors

- S. F. = Snap Fit
- F. F. = Friction Fit
- C. Plug = Cable plug
- Push. B = Push Button
- Hg = Hinge
- Adv = Adhesive

Penalizations

- = Product manipulation
- = Identifiability (low visibility)
- = Uncommon tool
- = Unreusable connector

Figure 16 The Disassembly map of the Dyson V11

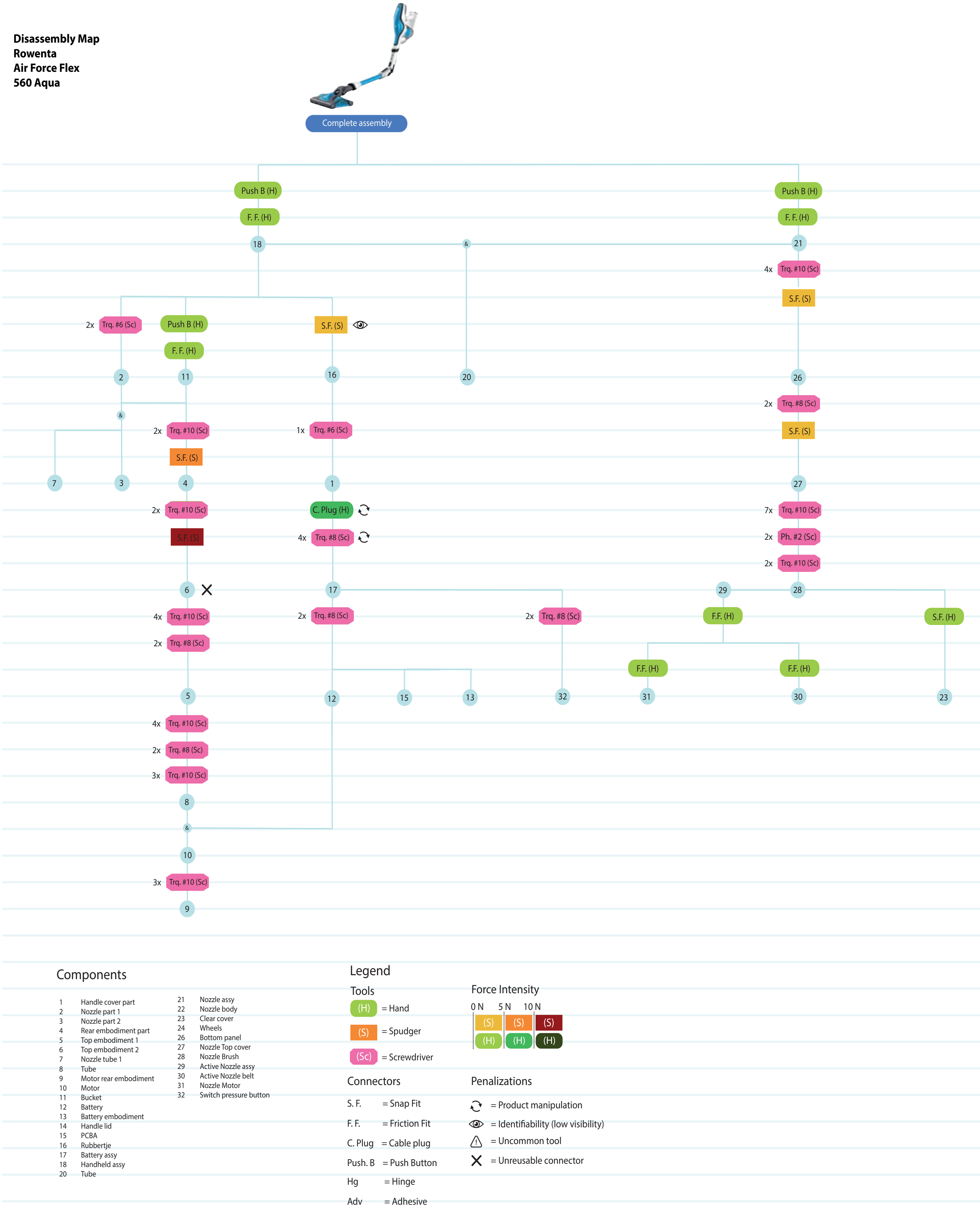
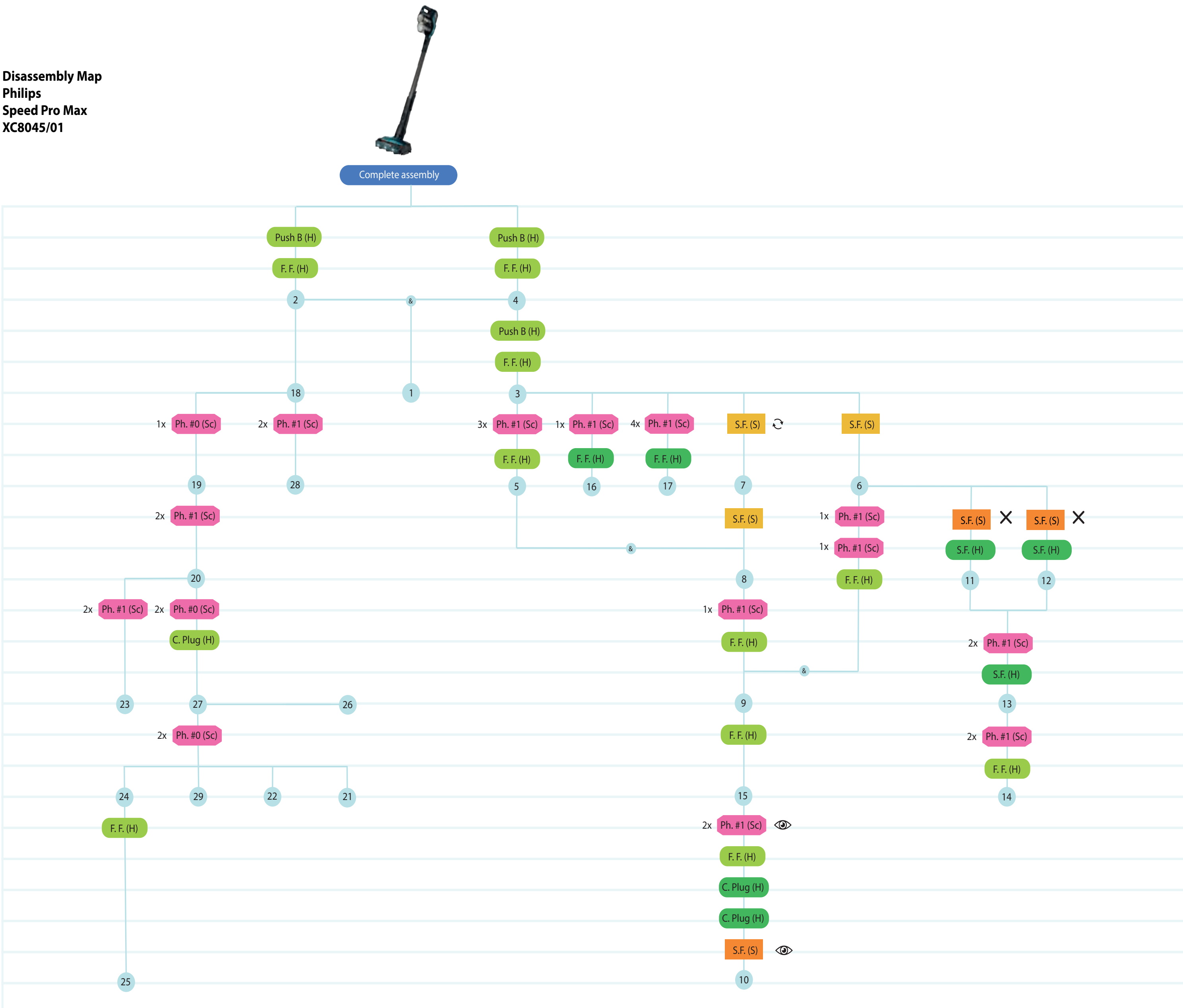


Figure 17 The Disassembly map of the Rowenta Air Force Flex 560 Aqua

Disassembly Map
Philips
Speed Pro Max
XC8045/01



Components

1	Tube	18	Nozzel assy
2	Nozzle	19	Nozzle tube panel
3	Bucket	20	Nozzle top panel
4	Handheld assy	21	Nozzle brush assy
5	Battery	22	Nozzle clear cover
6	Switch handle panel	23	Nozzle tube
7	Rubber button	24	Nozzle active Nozzle assy
8	Button sheet	25	Nozzle active Nozzle belt
9	Exhaust Gril Cap	26	Nozzle corner panel 1
10	Motor & PCBA assy	27	Nozzle corner panel 2
11	Panel Left	28	Nozzle wheels
12	Panel Right	29	Nozzle motor
13	Handle grip	30	Nozzle PCBA
14	Half ring panel		
15	Inner exhaust gril assy		
16	Handheld inlet		
17	Charging disk assy		

Legend

Tools

(H) = Hand
(S) = Spudger
(Sc) = Screwdriver

Force Intensity

0 N 5 N 10 N
(S) (S) (S)
(H) (H) (H)

Connectors

S. F. = Snap Fit
F. F. = Friction Fit
C. Plug = Cable plug
Push. B = Push Button
Hg = Hinge
Adv = Adhesive

Penalizations

= Product manipulation
= Identifiability (low visibility)
= Uncommon tool
= Unreusable connector

Figure 18 The Disassembly map of the Speed Pro Max

Figure 19 The Disassembly map of the Speed Pro

Insights

In Figures 14 to 19 the generated Disassembly maps can be seen, exploded views are added in Appendix 1 to 6. The following insights were gathered from comparing the disassemblies:

- All maps, except the Bosch map, contain the cross penalisation symbol, which means that in five out of six disassemblies, destructive disassembly occured. In all cases, except for the Dyson this was due to snapfits warping or breaking. On the PCBA of the Dyson glue was applied and had to be removed to undo two screws.
- The Bosch, Miele and Dyson had batteries that could be easily separated from the casing by pushing a button by hand. For the Speed Pro Max the battery could be extracted by loosening 3 screws and tilting the handheld. In the case of the Speed Pro and the Rowenta it took a lot of actions to obtain the battery. This made disassembly less safe as the battery could turn on during disassembly if the switch was accidentally touched or moved.
- Something that can not be seen in the DM's, is the way the casing was designed. The Bosch, Miele and Rowenta all have casings made up of two symmetrical mirrored parts. While the Dyson, Speed Pro and Speed Pro Max have casings that have one main body. The simple mirrored casing design of the Miele and Bosch were most easy to take apart and felt robust.
- The side panels on the Speed Pro Max and the Speed Pro both were unusable after disassembly as many snapfits warped or broke. Due to the different directions that these snapfits have, the panels on which the fits are located needs to be moved in a multitude of different directions to be loosened. The result is that many snapfits are forced into directions that they do not have flexibility in, which leads to them breaking.
- On the top part of the Bosch a small panel with snapfits was used to hide screws. These snapfits remained intact after several disassemblies and is an example of effective snapfit use in combination with repairability.
- In many cases the motor was inseparable from the printed circuit board assembly, this was present in the Bosch, Speed Pro Max and Dyson. When unseperable parts are placed in different parts of the product, in all cases it took more steps to completely extract the assembly of priority parts as the product needs to be opened up from different directions.
- During the disassembly process it became apparent how problems can go by undetected that become more clear during re-assembly. Destructive disassembly is especially harmful for effective repair. In the Disassembly map an 'unreusable connector' is placed on the same level of importance as 'low visibility', 'uncommon tool' or 'product manipulation'. While when an additional component breaks, next to the component that is already broken and initiated the repair in the first place, this makes the process of repair more complex. An additional new part needs to be acquired besides the broken part that lead to the repair in the first place.

Summary

The Disassembly map is a tool that helps visualise the product architecture during disassembly for repair. Six cordless vacuum cleaners were assessed on their repairability using the Disassembly map. The creation of Disassembly maps has helped gain insight in how repairable the two Philips cordless vacuum cleaners are, looking at the process of disassembly for repair and not taking into account the replacing of broken components or the following process of re-assembly. The created maps are useful for those familiar with the mapped product and interested in the product architecture in context of repair. They are harder to read by those unfamiliar with the product and should not be seen as complete repair assessments.

The Disassembly maps (DM's) of the Bosch, Miele and Dyson VC stood out as being the most simple maps of the six analysed cordless vacuum cleaners. The disassembly of the Bosch resulted in zero penalties and no high amounts of force are needed during disassembly. This leads to the conclusion that the Bosch cordless vacuum cleaner is the most repairable out of the six. The DM's of the Speed Pro Max and Rowenta are the most extensive maps which indicates that they require a large amount of actions to acquire priority components. These maps also have the largest amount of penalties. This leads to the conclusion that these two cordless vacuum cleaners are the least repairable.

Based on the Disassembly map we can see that most of the priority parts of the Philips cordless vacuum cleaners are located at the largest disassembly depths in the total product architecture. Especially the motor, PCBA and battery in the Speed Pro have potential to be surfaced in the product architecture and thereby increase in repairability. For the battery in the Speed Pro Max the disassembly sequence was already much shorter compared to that of the Speed Pro. The motor and the printed circuit board however require long disassembly sequences as these priority parts could not be seperated.

Conclusion

This chapter aimed to draft initial answers to the main research question:

MRQ. How repairable are Philips cordless vacuum cleaners and how could this be improved?

The first part of the main research question 'How repairable are Philips cordless vacuum cleaners' is answered as following:

The creation and comparison of the Disassembly map of the Speed Pro has shown that this product has an average repairability compared to the selected competitor products. This conclusion was based on the average size of the map, the average amount of penalties and average needing of large forces during disassembly.

The creation and comparison of the Disassembly map of the Speed Pro Max has shown that this product is less repairable compared to the selected competitor products. This conclusion was based on the large size of the map.

The second part of the main research question 'How could the repairability of Philips cordless vacuum be improved' is answered as following:

The Speed Pro could be improved by moving the battery higher in the product architecture, excluding snapfits that break during disassembly and redesigning the motor component so that less force is needed to extract this component.

The Speed Pro Max could be improved by decreasing the amount of components (for example by creating more subassemblies), by excluding snapfits that break during disassembly, increasing the visibility of the screws connecting the motor to the casing and increasing the visibility of the PCBA fastener mechanism.

4. The French Repairability Index

4.1 The FRI scoring method

The second assessment method in this research is the second category of the French Repairability Index. As described before, the FRI will become active in France in 2022 for vacuum cleaners. The assessment is an Excel sheet which needs to be filled in by manufacturers for their own products. The assessment sheets can be found on: www.indicereparabilite.fr.

The FRI uses both quantitative and qualitative criteria. It generates a final score for products between zero to ten (as can be seen in Figure 21) and is created from five scoring subcategories (See Figure 20)
The five subcategories of the FRI are:

- The availability of technical documentation on repair
- The ease of disassembly
- The availability of spare components
- The price of spare components
- The product specific criteria

Contrary to most existing repairability rating mechanisms, the focus of the FRI lies not on technical factor but on economic factors like availability and the price of spare components. Only the second category ‘ Ease of Disassembly’ and the fifth category ‘ Specific Criteria’ score physical design characteristics on repairability. Which has the effect that 20 to 40% of the awarded points in the score are determined by physical characteristics of the product.

The fifth category however only has up to two qualitative questions, which were not yet determined for vacuum cleaners. Therefore it was chosen to only use Category 2 ‘ Ease of Disassembly’ to rate and score the products in this case study. Both categories are explained further below.

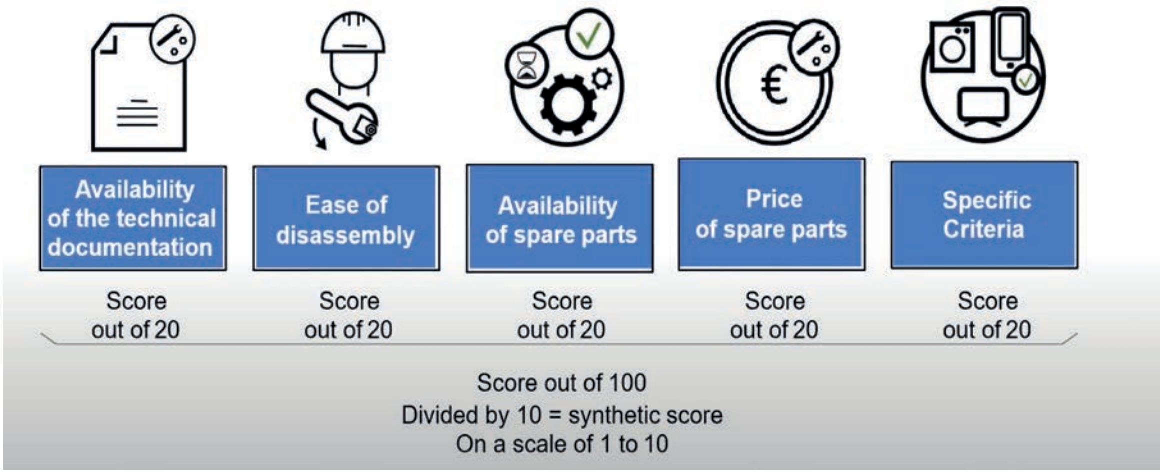


Figure 20 The five subcategories of the French Repairability Index (ADEME 2020)

RI rating	Color	Symbol	Example
0-1.9	Red		
2-3.9	Orange		
4-5.9	Yellow		
6-7.9	Light green		
8-10	Dark green		

Figure 21 The colour ranges of the French repair index labels expained (ADEME, 2020)

Ease of Disassembly
The second category of the FRI uses priority parts as an important factor in assesing repairability. The priority parts are grouped in two lists. List 2 is defined by ranking three to five spare parts which break most often in the product. List 1 is a ranking of up to ten parts which are not featured in List two and that are essential for the product to execute its primary functions. List 2 seems to be the most important list, which is confusing based on its name. This list is used to score all three subcriteria in the second Category, while List 1 is only used to score one criteria.

The second category 'Ease of Disassembly' focuses on physical characteristics of a product (see Figure 22), in which the following three subcriteria are scored:

- The amount of disassembly steps needed to remove the parts of List 2, called 'Ease of Disassembly'
- Types of tools needed to remove the parts of List 2, called 'Necessary tools for disassembly'
- Re-usability of the fasteners needed to remove the parts of List 1 and 2, called 'Fastener characteristics'

Product specific criteria
The rating criteria in category five, the 'Product specific category' differs per product category, as can be seen in Figure 23. For battery powered lawn mowers, one of the five product groups for which the FRI has already been implemented in 2021, the two parameters are: 'Availability of online assistance' and 'The possibility to use a multi-product battery which is exchangeable within a product portfolio'. An example of this is the Bosch Unlimited 8 Serie cordless vacuum cleaner which uses a battery that can be mounted on their cordless vacuum cleaner as well on their power drills and other products. This category will not be used in the assessment but is adressed here as it does focus physical characteristics.

Product specific criteria	Active for product group
Free remote assistance	**All products** Washing machine, Laptop, Lawnmower, Smartphone, TV
Information on updates	Laptop, TV, Smartphone
Software reset	Laptop, TV, Smartphone, Robot lawnmower
Usage counter	Washing machine, TV
Multi-product battery	Robot & Battery powered lawnmower

Figure 23 Criteria per product group in the Product Specific Category

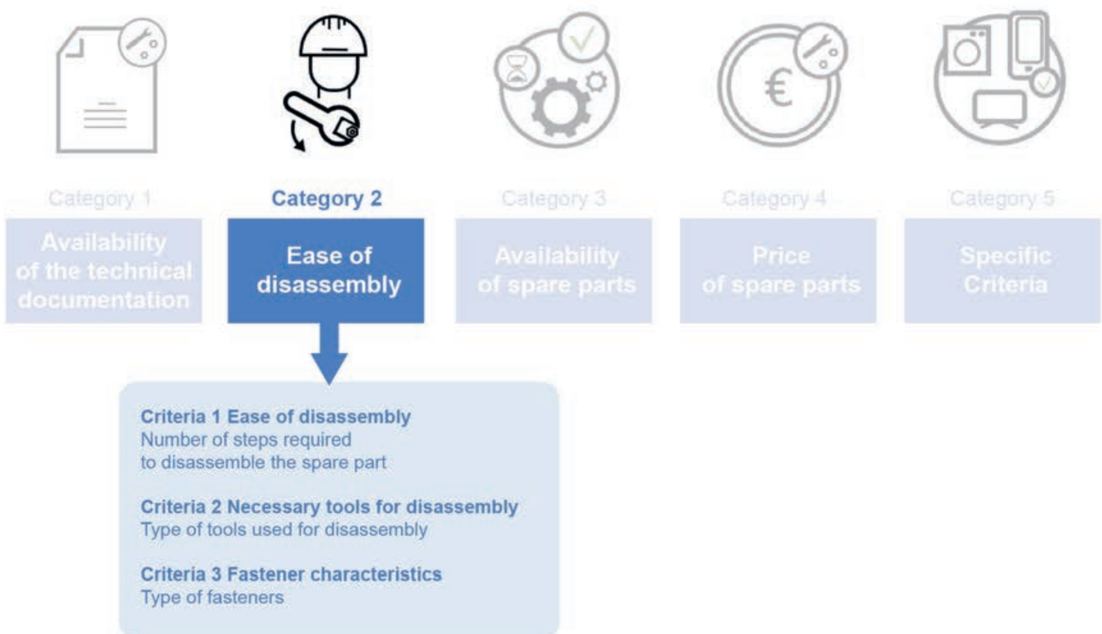


Figure 22 The three criterias of the second FRI category 'Ease of Disassembly'

Criteria 1 Ease of Disassembly
This criteria is worth 50% of the points given in the Category 2 of the FRI and only the priority parts of List 2 are considered. In this criteria the amount of disassemby steps that is needed to extract priority parts of List 2 are counted.

Disassembly steps are defined by the FRI as following: *A disassembly step always ends with the extraction of a component, except when a tool change occurs in between.*

The French Repairability Index does not take disassembly or re-assembly time into account. The French Repairability Index tries to still take into account high disassembly times by incorporating this factor in the definition of disassembly steps. A disassembly step is not simply defined by equating a step to removing a component, changing a tool is also counted as a step. This penalises using multiple fasteners or variants that need to be loosened using different types of tools. Figure 24 shows a visual provided by the FRI on how to count disassembly steps.

For each product category the FRI has determined different ranges of disassembly steps. Washing machines for instance are allowed to have more disassembly steps compared to battery powered lawnmowers. The possible scores that can be received are three, two, one and zero points per priority part. The range of steps can be seen in Figure 25 where the assessment sheet of the FRI is shown.

Criteria 2 Necessary tools for disassembly
This criteria is worth 25% of the points given in the Category 2 of the FRI. The second criteria that is graded are the types of tools used during extraction of priority components and only the priority parts of List 2 are considered. For this criteria the FRI again determined four different ranges that produce four different scores; three, two, one and zero points.
These four ranges are the same for all different product groups in contrast to the ranges in 'Ease of Disassembly'. The ranges of this criteria can be seen in Figure 26.

The best score is awarded to use of basic tools, not needing any tool or use of a tool that is provided with the product. The lowest score is awarded when a component is not removable. Needing specific and proprietary tools result in the awarding of one and two points. A specific tool is defined as: A tool that is commercially available but not included in the tool list of EN45554. A proprietary tool is defined as: A tool that is not

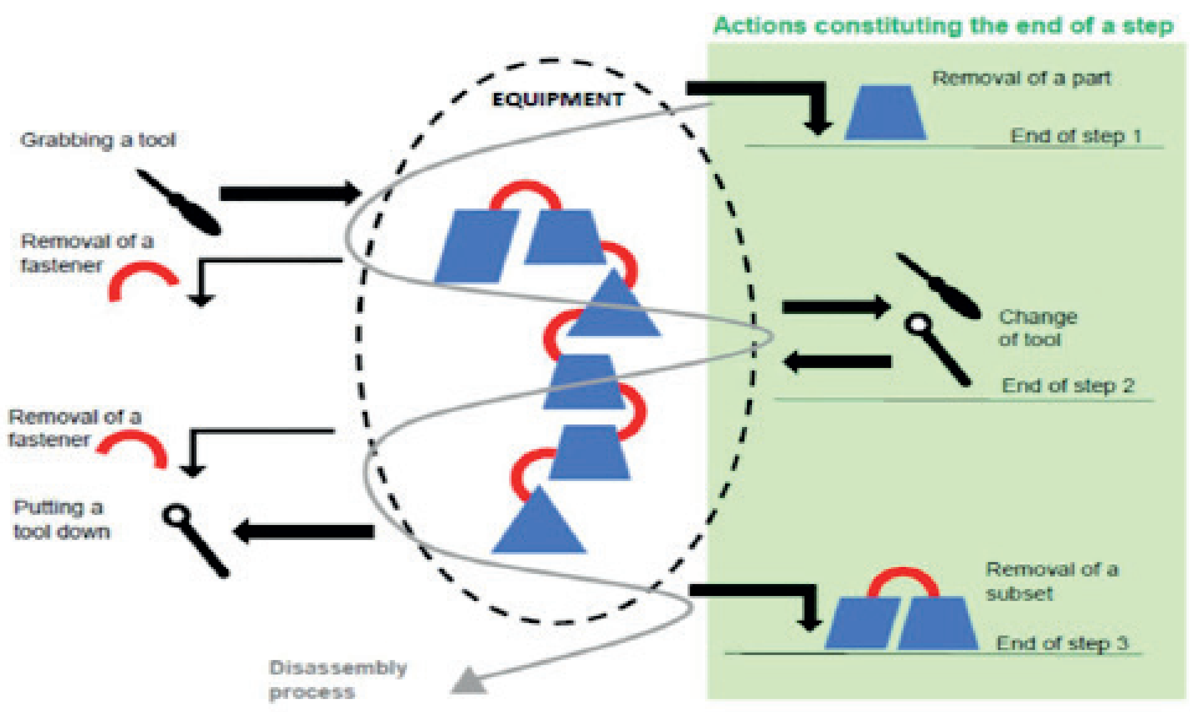


Figure 24 Definition of a Disassembly step (ADEME, 2019)

commercially available and is owned exclusively by one party or company, and under which its use by another party (an end user or customer) involves copyright, license and/or cost. In the case of needing multiple types of tools the lowest scoring tool must always be chosen.

Criteria 3: Reusability of fasteners
This criteria is worth 25% of the points given in the Category 2 of the FRI. The last criteria in the second category of the Disassembly Map is the reusability of fasteners. Next to the priority components of List 2, the parts in List 1 are also considered here. Three ranges are used in this category and can be seen in Figure 27. The worst score is 'non removable' which implies that the product breaks when components are separated. The best score is awarded when fasteners are removable and reusable. One point is awarded when a fastener is removable yet not reusable.

The FRI is a semi-quantitative assessment method using a combination of quantitative and qualitative criteria. It takes into account a wide array of criteria categories, from available information on repair to physical characteristics and economic factors. Use of the FRI in the case study showed that many of the criteria are unambiguous and leave room for interpretation, which creates a risk of subjective assessment. Reusability of fasteners can only truly be assessed when re-assembling a product again. Currently this is not yet described in the FRI.

Ease of disassembly		Rating	
List 2 : Broken / malfunctioning parts		Number of steps required to disassemble the spare part	Subtotal
2.1.A	Battery	if NA or DDi ≥ 9	0
2.1.B	Motor	if NA or DDi ≥ 9	0
2.1.C	PCBA	if NA or DDi ≥ 9	0
2.1.D	Active Nozzle belt	if NA or DDi ≥ 9	0
Total sub-criterion 2.1			*0* /12
			0 /10

Figure 25 Scoring Criteria 1 of Category 2 of the FRI ‘ Disassembly step’

Necessary tools for disassembly		Rating	
List 2 : Broken / malfunctioning parts		Type of tools used for disassembly	Subtotal
2.2.A	Battery	D : Removable with no tool with tools supplied with the product or with basic	4
2.2.B	Motor	D : Removable with no tool with tools supplied with the product or with basic	4
2.2.C	PCBA	D : Removable with no tool with tools supplied with the product or with basic	4
2.2.D	Active Nozzle belt	D : Removable with no tool with tools supplied with the product or with basic	4
Total sub-criterion 2.2			*16* /16
			10,0 /10

Figure 26 Scoring Criteria 2 of Category 2 of the FRI ‘’Type of tools used for disassembly’

Fasteners characteristics		Rating	
List 1 : Functional parts List 2 : Broken / malfunctioning parts		Type of fasteners	Subtotal
2.3.A	Handheld	C : Removable and reusable	2
2.3.B	Tube	C : Removable and reusable	2
2.3.C	Battery charger	C : Removable and reusable	2
2.3.D	Active Nozzle PCBA	C : Removable and reusable	2
2.3.E	Bucket	C : Removable and reusable	2
2.3.F	On/Off switch	C : Removable and reusable	2
2.3.G	Battery	C : Removable and reusable	2
2.3.H	Motor	C : Removable and reusable	2
2.3.I	PCBA	C : Removable and reusable	2
2.3.J	Active Nozzle belt	C : Removable and reusable	2
Total sub-criterion 2.3			*20* /20
			10,0 /10

Figure 27 Scoring Criteria 2 of Category 2 of the FRI ‘Type of fasteners’

4.2 FRI Assumptions

This chapter describes the assumptions that have been made to be able to perfom the French Repairability Index assessment. Some of these assumptions needed to be made because the FRI is not yet active for the studies product group. Other were made during the assessment on how to interpret instructions and definitions.

FRI Priority parts
As described earlier, the French Repairability Index is still in a pilot phase at the time of writing this thesis. The list of priority parts, which is determined by France, has not yet been released for vacuum cleaners. To be able to perform the FRI assessment this list needed to be assumed.

The already active product group 'cordless lawnmower' (See figure 28) was most similar to that of cordless vacuum cleaners and therefore has been used as a starting point for making a cordless vacuum cleaner assessment sheet.

Based on the analysis in Chapter 3.2 the chosen priority parts are:

List 1
- Handheld
- Tube
- Battery charger
- Active nozzle PCBA
- Bucket
- On/Off switch

List 2
- Battery
- (Handheld) Motor
- PCBA
- Active Nozzle belt

The components in List 1 were based on their functional importance. List 1 and 2 for cordless mowers and cordless vacuum cleaners can be seen in figures 29 below.

While creating the scores for the different cordless vacuum cleaners in the second category of the FRI, it became clear how the assessment still grants room for improvement and clarification. A list of assumptions during FRI assessment for cordless vacuum cleaners have been summarised per criteria.

Fasteners characteristics List 1 : Functional parts List 2 : Broken / malfunctioning parts	
.A	Handlebar
.B	Grass collector
.C	Mowing height adjuster
.D	Hood/bonnet
.E	Engine
.F	Cutter blades
.G	Blade holder
.H	On/Off switch
3.I	Wheels

Figure 28 FRI list of priority parts for cordless lawnmowers

Fasteners characteristics List 1 : Functional parts List 2 : Broken / malfunctioning parts	
2.3.A	Handheld
2.3.B	Tube
2.3.C	Battery charger
2.3.D	Active Nozzle PCBA
2.3.E	Bucket
2.3.F	On/Off switch
2.3.G	Battery
2.3.H	Motor
2.3.I	PCBA
2.3.J	Active Nozzle belt

Figure 29 Newly created list of priority parts for cordless vacuum cleaners

Assumptions made during the disassembly of cordless vacuum cleaners in general

Disassembly steps

- It was assumed that the battery of a cordless vacuum cleaner should be removed before removing the motor, for safety reasons. This means that the steps that need to be taken to remove the battery should be added to the disassembly steps of the motor.
- Taking apart the tube and the nozzle from the handheld is considered a step. As the complete vacuum cleaner is assessed and not only the handheld.

Reusability of fasteners

- It was assumed that soldered connections are seen as permanent fixtures that are non removable.
- It was assumed that snapfits that stay intact and do not change shape are reusable
- It was assumed that snapfits that warp or break are removable but unreusable
- It was assumed that non removable fasteners can only be undone by destructive behaviour like; cutting cords, scraping glue away or purposely breaking fasteners.
- It was assumed that unreusable fasteners differ from non removable fasteners as they break during an action that did not have the purpose of destructively undoing fasteners. Examples are: snapfits that accidentally warp when undoing them and fasteners that use an adhesive that is weak enough to undo without breaking parts but not strong enough to be reused.

Assumptions made during the disassembly of the Speed Pro Max

Disassembly steps

- The small UI timer panel is not considered a part because of its small size and insignificance for function and disassembly.
- Multiple components in the exhaust grill are seen as an assembly as they come apart together when loosening the screw under the button sheet.

Reusability of fasteners

- The motor and the PCBA are currently a subassembly and can only be separated when cutting the cord between the components, this is seen as non removable. Since the motor and the PCBA are calibrated together these parts can not be replaced seperately. The parts are only available to buy as an assembly, therefore this separation is not desired. The parts are seen as an assembly and a non removability penalty is not awarded.
- The snapfits of the side panels were seen as unreusable as a large amount of warping took place when disassembling the components. They are unfit for reassembly after the repair.
- The snapfits of the UI panel were seen as reusable as the snapfits did not warp or deform when separating it from the main assembly.
- The adhesive on the rubber button cover was sticky enough to successfully reuse it when assembling and therefore seen as reusable.
- The fasteners of the PCBA were scored as unreusable as they warped during the extracting of the disassembly and posed a problem when replacing the PCBA in the main assembly

4.3 FRI Assessment

To perform the FRI assessment the input of the three criteria needed to be gathered. As Disassembly maps were created in the previous assessment they could be used to generate input for Category 2 ‘Disassembly’. The maps proved to have potential for counting disassembly steps and were also of help for determining the two other criteria.

Counting disassembly steps
The FRI step definition however does not match the build up of the Disassembly map, the FRI step count could not be applied seamlessly to the existing maps. Boxes were placed on the maps to visualise FRI disassembly steps, in this way the amount of steps per component could be counted (See Figure 33). To count the needed disassembly steps of a part one should start on the top with the complete assembly and count down vertically. It can be seen that these boxes differ in size. One reason for this is that the disassembly map takes into account actions carried out by hand which are not recognized in the FRI. Another is that sometimes a step is only the removal of a component, while at other times the step includes use of a tool or (multiple) hand motions. Figure 30 shows the visualisation of the three possible disassembly steps. In Figure 32 it can be seen how these steps differ in size and Figure 33 gives an overview of a complete disassembly map with highlighted FRI steps. Because handmotions are not taken into account in the FRI but are included in the Disassembly map they influence size difference of these drawn blocks (See Figure 31).

Determining type of tools and type of fasteners
To determine the type of tools that were needed for the disassembly, the text in the action boxes, the penalisation of ‘Uncommon tool’ and disassembly notes were used. Lastly the input for the (un)reusability fasteners was determined using the ‘Unreusable connector’ penalties and notes of the disassembly.

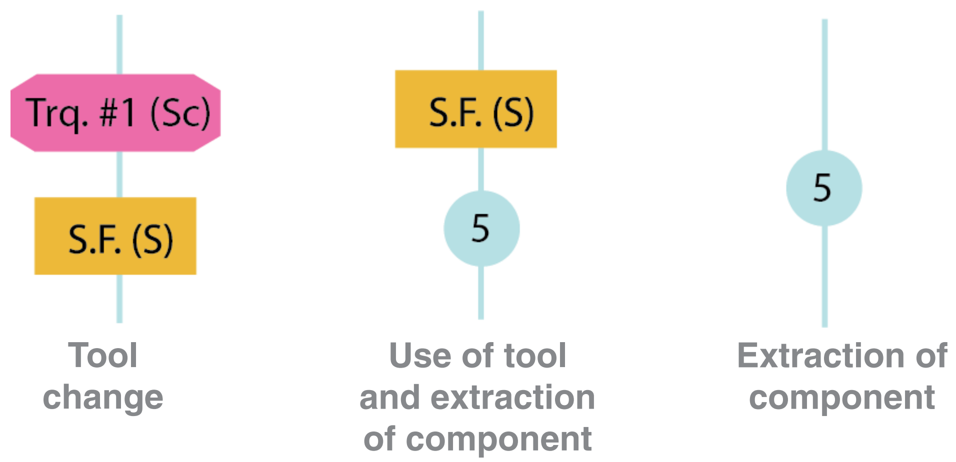


Figure 30: The three possible FRI disassembly steps expressed in Disassembly map components

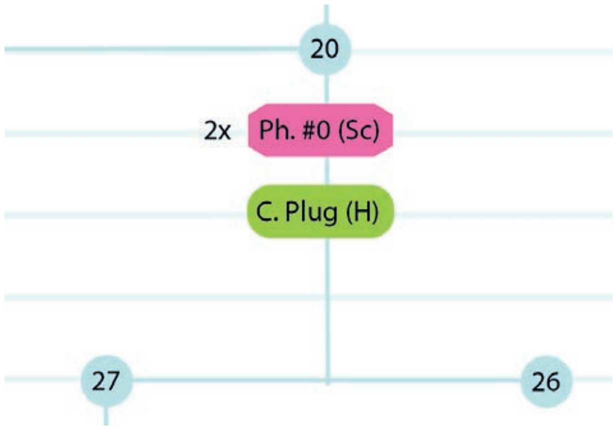


Figure 31 Part of a disassembly map featuring use of a screwdriver and removal of a component

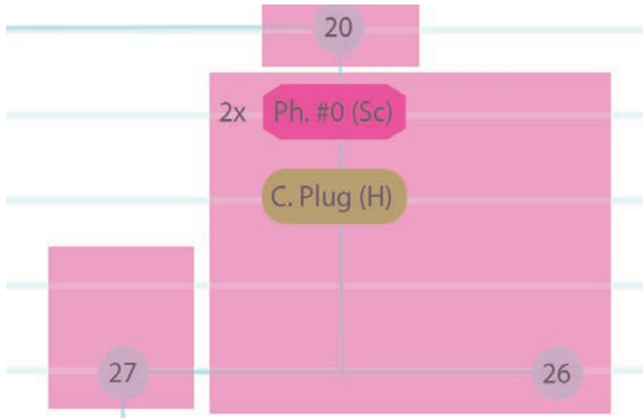


Figure 32 Boxes indicating the FRI disassembly steps in the Disassembly map

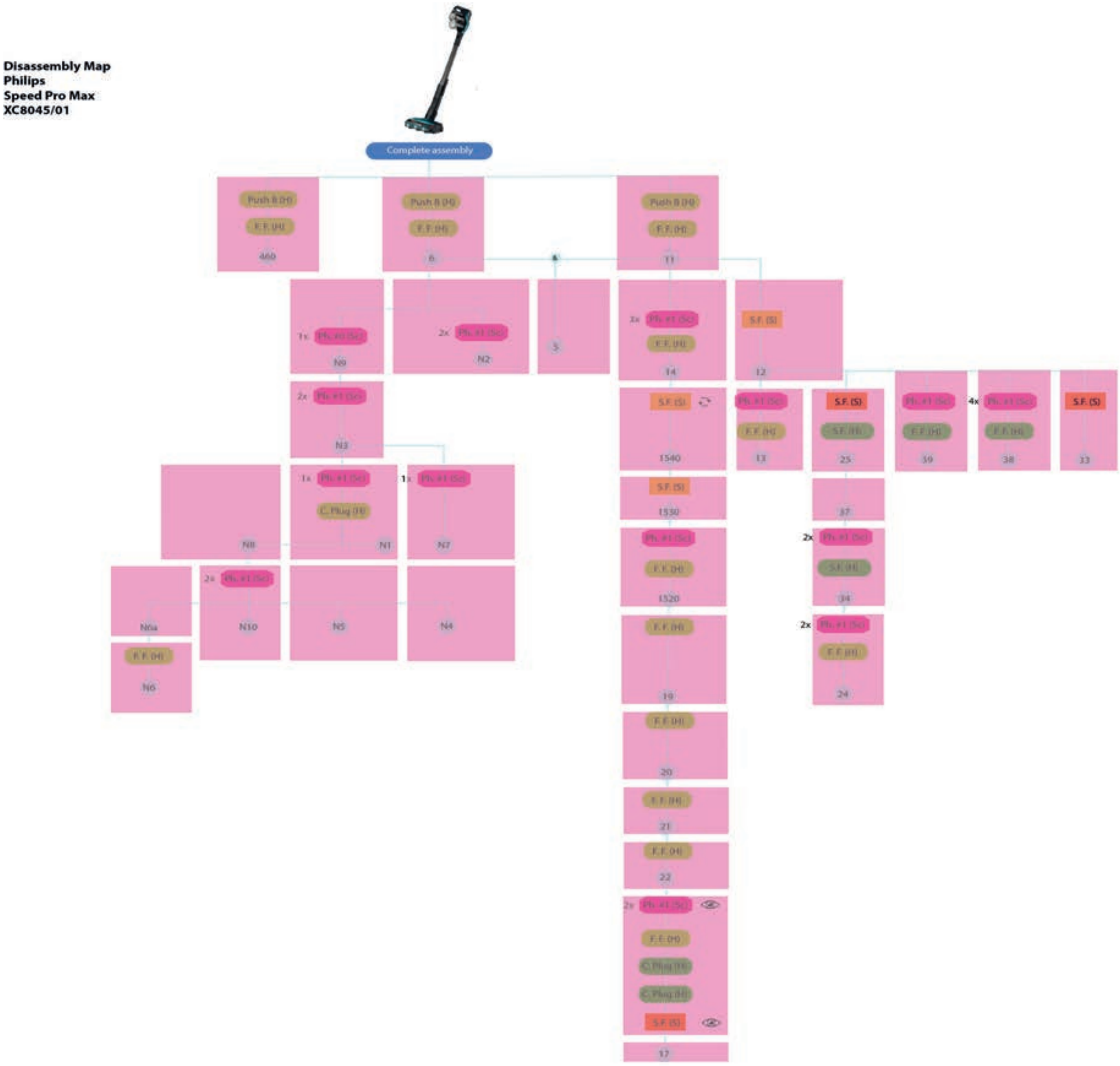


Figure 33 Boxes drawn over the Disassembly map in order to count Disassembly steps

FRI Category 2 assessment results
The Category 2 tab of the FRI assessment sheet was filled in and this resulted in scores for all six cordless vacuum cleaners (See table 34). The FRI Category 2 provides quantified results which are easier to compare with each other in contrast to the Disassembly maps.

The table in figure 35 shows the Category 2 scores for the FRI for the six cordless VC's. The colour grades are taken from the FRI proposed ranges for disassembly steps for battery powered lawnmowers. The total scores in figure 35 show how the Speed Pro received the worst repairability score (for Category 2), while the Dyson VC received the highest score. The other cordless vacuum cleaners all receive a score between 6,5 and 7. The scores on Ease of Disassembly (the amount of disassembly steps) are very low on average, this has a large impact on the final score as this criteria awards half of the points that can be scored in Category 2

All products required use of only basic tools (as defined by EN45554). Interestingly enough the Dyson receives the highest total score but is an outlier in the fastener category. During disassembly multiple fasteners on the handheld and nozzle broke, it has a non reusable adhesive on the printed circuit board and a cable needed to be cut. The higher weighting that is awarded to disassembly steps, compared to tools and fasteners can be seen clearly here. During the full disassembly of the Dyson a sheet of plastic was needed of a specific thickness and shape which classifies as a specific tool. This was only needed to obtain a component in the cyclone assembly, which is not labelled as a priority part. Therefore this penalty is not taken into account in the FRI and the Dyson receives a perfect score on 'Necessary tools for disassembly'. Despite these negative characteristics this cordless vacuum cleaner comes out as the most repairable out of the assessment.

Analysis of the Philips Category 2 FRI scores
The Speed Pro receives the worst FRI Category 2 score of all assessed products. The amount of disassembly steps needed to obtain priority parts is very high and is harshly penalized. One reason for this is that the battery is housed quite deep in the product. Since the battery needs to be removed before other priority parts in the handheld can be removed these steps need to be added to those of other priority parts.
Both Philips products showed problems with reusability of snapfits in the casing parts, which easily deformed. Still both products scored quite high in the category reusability of fasteners.

Priority part	Speed Pro	Speed Pro Max	Miele	Bosch	Dyson	Rowenta	Range
Battery	9	3	1	1	2	5	<5
Motor	11	9	9	9	5	15	X>5
Active nozzle belt	5	8	5	7	X	9	X>7
PCBA	11	9	11	9	5	6	X>9

Figure 34: Disassembly steps to reach the Priority parts of the Speed Pro Max

FRI scores Category 2	Speed Pro	Speed Pro Max	Miele	Bosch	Dyson	Rowenta
Ease of Disassembly	1,7	3,3	4,2	3,3	7,5	3,3
Necessary tools for disassembly	10	10	10	10	10	10
Fastener characteristics	8,5	10	9,5	10	7,5	9,5
Total	5,45	6,65	6,95	6,65	8,15	6,55

Figure 35 Calculation of the Category 2 FRI score for the six cordless vacuum cleaners

FRI scoring interpretations Speed Pro Max

Chapter 4.2 already addressed the assumptions that needed to be made to perform the FRI assessment. To illustrate how the FRI instructions leave room for interpretation, three scenarios for the counting of disassembly steps have been made for reaching the motor in the Speed Pro Max. These scenarios range from the most free interpretation of the FRI instructions and definitions, generating a high repair score, to the most strict interpretation, generating a lower repair score.

In Figure 36 the in- and exclusion of disassembly steps are shown for the different interpretations of the FRI. All actions that are included in the total assembly are listed. Some however are not taken into account in certain scenarios. It can be seen that all actions are included in the most strict scenario. All disassembly steps listed end with a component being extracted, except for step 11, this meant that no shifting of steps could occur if use of a tool was not considered.

The green blocks in the table indicate that a disassembly step is included in the scenario, while a red block indicates that the step is excluded. The figure shows how the total step count in the 'Strict interpretation' scenario (of 12 steps) is more than double of that of the 'Loose interpretation' scenario (6 steps). This large difference has an equally large impact on the score of Category 2 'Ease of Disasssembly', as 50% of the score is determined by the disassembly steps.

On the following pages the different intepretations of counting disassembly steps are visualised and further explained for the three scenario's.

		Free interpretation	Interpretation used in this study	Strict Interpretation
1	Seperating the handheld from the tube and nozzle	Red	Green	Green
2	Taking off the bucket	Green	Green	Green
3	Using a Philips #1 Screwdriver to unscrew three screws that connect the battery with the casing. Taking out the battery	Green	Green	Green
4	Using a spudger and taking off the top handle panel	Green	Green	Green
5	Using a spudger and taking off the rubber button at the bottom	Red	Green	Green
6	Taking away the button sheet	Red	Red	Green
7	Using a Philips #1 Screwdriver to undo two screws holding the exhaust grill cap to the casing and taking off the exhaust grill	Green	Green	Green
8	Taking out the Visual inner cap	Red	Green	Green
9	Taking out the Sound reflector	Red	Red	Green
10	Taking out the Exhaust filter	Red	Red	Green
11	Using a spudger to loosen the PCBA from the casing and undoing two screws that connect the motor to the casing	Green	Green	Green
12	Take out the motor	Green	Green	Green
	Total amount of disassembly steps	6	9	12

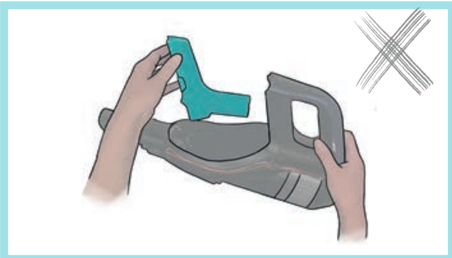
Figure 36: Inclusion and exclusion of disassembly steps in different interpretations of the FRI

Free interpretation
When using this free interpretation of the FRI instructions the total step count to reach the handheld motor is 6. In Figure 37 the assumptions used in this scenario have been visualised

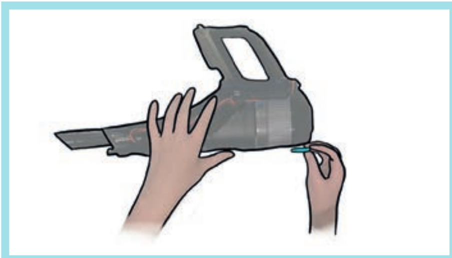
- Figure 37 a. The disassembly is started from the vacuum handheld instead of the complete assembly (with tube and nozzle), this saves one disassembly step. Since the handheld also functions without the nozzle and tube and contains most of the priority parts it is imaginable that manufacturers will make this beneficial assumption
- Figure 37 b. The battery is not removed before starting the disassembly
- Figure 37 c. The rubber button that hides a screw in theory could also be removed using only hands instead of a spudger
- Figure 37 d. The rubber button and button sheet are very small parts of the product and therefore not considered components
- Figure 37 e. The multiple individual parts that come loose after removing the exhaust grill are seen as one assembly

Free interpretation

a. Disassembly started from handheld

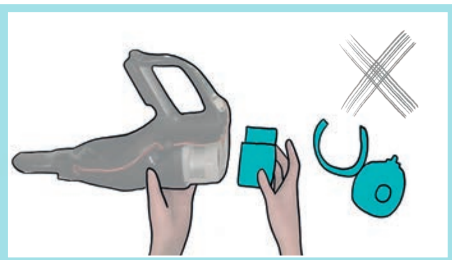


b. Battery **not** removed before further disassemlby



c. Rubber button removed with hands instead of spudger

d. Rubber button and button sheet **not counted** as components



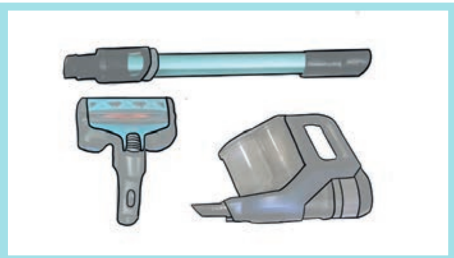
e. Exhaust grill components counted as individual parts

Figure 37 Free interpretation of the FRI Category 2 scoring

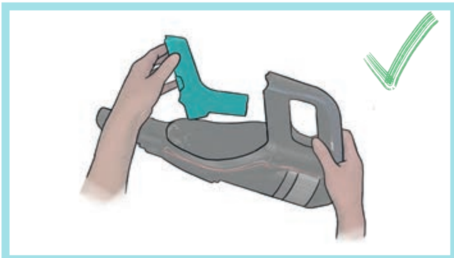
Interpretation used in this study
When using this free interpretation of the FRI instructions the total step count to reach the handeld motor is 9. In Figure 38 the assumptions used in this scenario have been visualised

- Figure 38 a. The disassembly is started from the complete product, with tube and nozzle
- Figure 38 b. The battery is removed first and these disassembly steps are added to those of other priority parts
- Figure 38 c. The button sheet is a very small part of the product and therefore not considered as a component however the rubber button has been considered a part
- Figure 38 d. The multiple parts that come loose after removing the exhaust grill are seen as one assembly

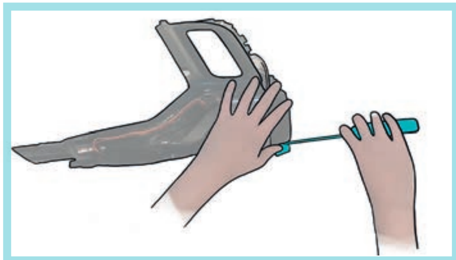
Interpretation used in this study



Disassembly started from complete assembly
+ 1 Disassembly step

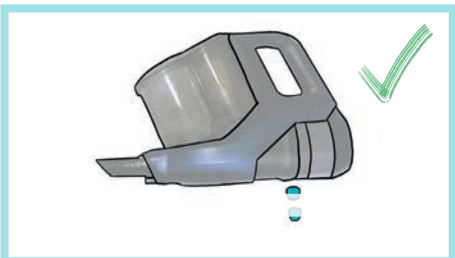


Battery removed before further disassemlby
+ 1 Disassembly step



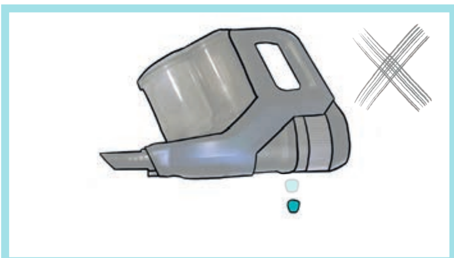
Rubber button removed with spudger

no extra Disassembly step

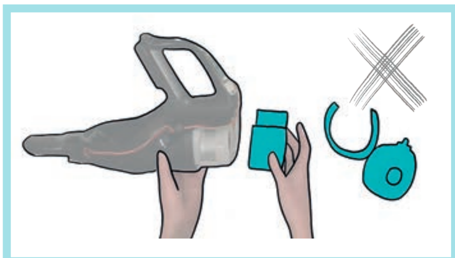


Rubber button counted as component

+ 1 Disassembly step



Button sheet **not** counted as component



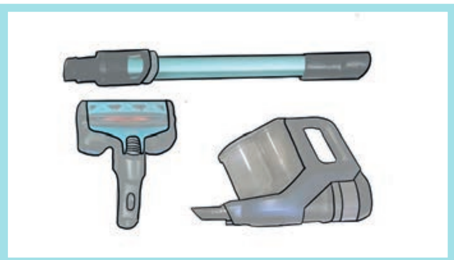
e. Exhaust grill components counted as individual parts
no extra Disassembly step

Figure 38 Interpretation of the FRI Category 2 scoring which was used in this study

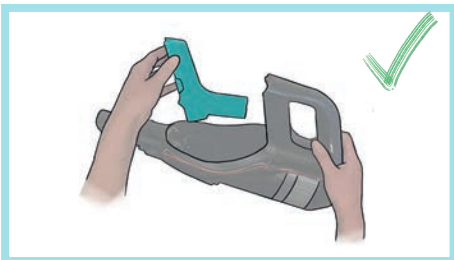
Strict interpretation
When using this free interpretation of the FRI instructions the total step count to reach the handeld motor is 12. In Figure 39 the assumptions used in this scenario have been visualised

- Figure 39 a. The disassembly is started from the complete product, with tube and nozzle
- Figure 39 b. The battery is removed first and these disassembly steps are added to those of other priority parts
- Figure 39 c. The rubber button and button sheet are seen as individual components
- Figure 39 d. The multiple individual parts that come loose after removing the exhaust grill are seen as individual components

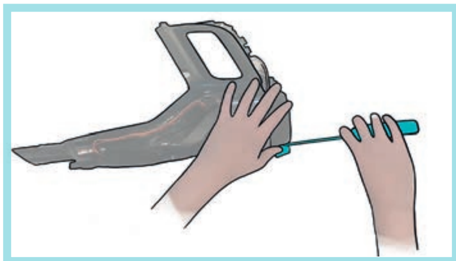
Strict Interpretation



Disassembly started from complete assembly
+ 1 Disassembly step

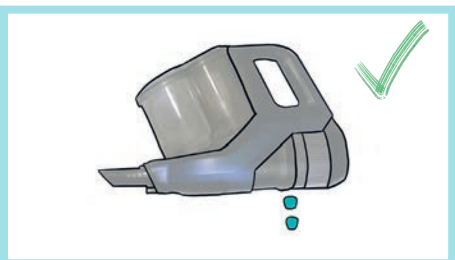


Battery removed before further disassemlby
+ 1 Disassembly step



Rubber button removed with spudger

no extra Disassembly step



Rubber button and button sheet counted as individual comopnents

+ 2 Disassembly steps

e. Exhaust grill components counted as individual parts

+ 2 Disassembly steps

Figure 39 Strict interpretation of the FRI Category 2 scoring

4.4 Reflection on the FRI

As described in Chapter 2.2, repair scoring systems are powerful tools that play an important role in guiding product design in a more sustainable direction. The introduction of the FRI will have impact on manufacturers and their already existing products in the market but even more so on future products that are still in development.Therefore it is important to assess what direction the FRI is steering product design into, especially since the French Repairability Index is currently still being developed and tested, feedback on the assessment is useful.

Since the French Repairability Index is a mandatory label, and the first of its kind, it will have a large influence on how products will be designed in the future. Manufacturers will want to receive high repair scores for their products, since this will influence consumers to choose their product over that of competitors. The definitions and instructions of this policy instrument will therefore be of high influence for the requirements that are set for new products and therefore for the final product that comes out of a design process. These definitions and instructions therefore need to be clear to interpret and leave no room for interpretation.

It has been discussed earlier that repair can be scored in different ways because of the long and diverse list of criteria that affect repairability. Therefore there will be no ultimate repair scoring frameworks as criticism can always be given depending on the lense that it is seen through. The FRI, for instance, awards less than 40% of its score based on physical characteristics of products, which makes it a less technical focused repair scoring system.

Through use of the FRI assessment in this research, certain framework choices stood out.

Weighting ratio between Disassembly steps and reusability of fasteners
The breaking of fasteners and components is barely penalised compared to the amount of disassembly steps. The weight of the score of the disassembly steps is much higher compared to that of the other two criteria. The first reason for this is that half of the points in Category 2 can be scored by the amount of disassembly steps for the four most important priority parts, which makes this characteristic of a product the most influential. Secondly in the third critiria, where reusability of fasteners (and indirectly components) is scored, both lists of priority parts are taken into account. Which decreases the influence on the score of a single fastener or component breaking.

In an extreme example the FRI could influence the design of a product in the following way. For this example two theoretical products, Product A and B, are used and assessed using the FRI.

Product A
All fasteners of the priority parts on List 2 accidentally break, but only needs 5 or less disassembly steps are needed to reach these priority parts

Product B
No fasteners or components break but it takes 9 steps to reach each priority part on List 2.

In this scenario Product A would get a total score of 9,0 for Category 2, while Product B would get a 5,0.

If manufacturers would strictly follow Design for FRI to increase repairability it could have the effect that destructive disassembly during repair would increase in future products. It could lead to products that are designed to break during disassembly as long as the amount of disassemlby steps is kept low. Since destructive disassembly was a relevant problem in five out of six vacuum cleaners assessed in this study, this is seen as a realistic risk.

This emphasis on disassembly steps in the score weighting is especially interesting when looking at the other FRI Categories. The criteria of ‘Delivery time’ in Category 3 is heavily weighted. But if a component breaks during repair, this component would, in most circumstances, need to be ordered before the repair could continue. Especially since destructive disassembly is most often unexpected this would obstruct efficient repair processes. The weighting ratio of difference categories seems out of balance.

Options to resolve this disbalance would be to award more weighting of Category 2 to reusability of fasteners and components. Besides this, the large emphasis on disassembly steps could be decreased. If a high amount of disassembly steps is needed to obtain a priority part, it will most likely take more time (which is especialy valuable in service centers as workers wages are high compared to component and product prices. However if a part unexpectedly breaks and needs to be ordered, or retrieved by a repairer, before the repair can continue this adds an incomparable more amount of time than for instance an extra tool change.

The lack of emphasis on decreasing destructive disassembly could reinforce unneccesary wasting of materials and components. In an extreme example a product could be designed to have a casing which uses snapfits as fasteners that always break during disassembly for repair. This would mean that the whole casing would need to be discarded of. Enforcing the throw-a-way trend and increasing waste during repair.

Evaluation of the FRI shows that the criteria of disassembly steps has been awarded too much weight. The choice to put emphasis on a low amount of disassembly steps is possibly to decrease the disassembly time. However with the total amount of disassembly steps also the risk of components breaking and different types of tools needed decreases.

If decreasing of disassembly time was the reason to put emphasis on criteria 1 this conflicts with the current definition of the disassembly step. The changing of tools without extracting a component in between however is heavily penalised, as this counts as one full disassembly step. However in the current scenario, the amount of fasteners that can be undone with the same tool at the same level of depth in the product architecture, do not increase the score. This means that theoretically an unlimited amount of screws or fasteners, which can be undone with the same tool, can be placed in the product, increasing the disassembly time, and counting only as one disassembly step.

4.5 Design for FRI Guidelines

The insights from the FRI assessment have been gathered in guidelines that can be used during the development of new products, with the goal of creating repairable products, by definition of the FRI. If the FRI will be used as a basis for a mandatory European wide repair label, it will become even more important for manufacturers to receive high repairability scores on their products. Therefore it is useful to summarise the found insights in which product characteristics generate high FRI scores and those that generate low ones.

In the Reference book ‘Design for the French Repairability Index for cordless vacuum cleaners’ guidelines for the design process, product architecture and fasteners has been described. This reference book can be found in Appendix XI. In this chapter only the guidelines physical characteristics will be adressed, which have been created based on the findings of the assessment.

In the previous chapter it has been described how a possible unsustainble consequences of the FRI system could be the increasing of destructive disassembly in products with the goal of decreasing the amount of disassembly steps. This strategy is not incorporated in the collection of guidelines even though it would benefit FRI scores. It is seen as an unsustainable design choice, which actually decreases repairability and therefore is not recommended.

The following three reccomendations are the simplified guidelines for Design for FRI per criteria:

Criteria 1 ‘Ease of Disassembly’
- Minimize the amount of disassembly steps needed to obtain priority parts

Criteria 2 ‘ Types of tools used for disassembly’
- Use fasteners that can be undone with use of no tools, only basic tools (included in the 45554 list) or tools that come with the product

Criteria 3 ‘Type of fasteners’
- Choose fasteners that are removable and reusable

These simplified guidelines are further detailed with visual examples on the following pages.

Guidelines to minimize disassembly steps

- Surface priority parts by bringing them to a more shallow level in the product architecture. By doing so less components need to be extracted before the priority comonent can be removed, this decreases the amount of disassembly steps. Figure 40 shows the motor, which is a priority part, marked with a 'P'. The motor is raised two places in the product architecture and the amount of disassembly steps is decreased by two.

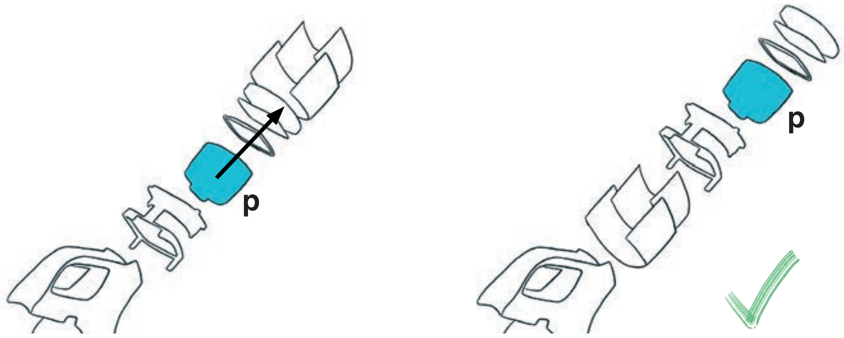


Figure 40 Surfacing of the motor

- Clump components that need to be extracted before priority parts can be removed. By creating subassemblies from individual components, the priority parts also raise in the product architecture and the amount of disassembly steps decreases. The amount of disassembly steps needed to obtain the priority part, the motor marked with a 'P', is decreased by two as three components are clumped together in a subassembly.

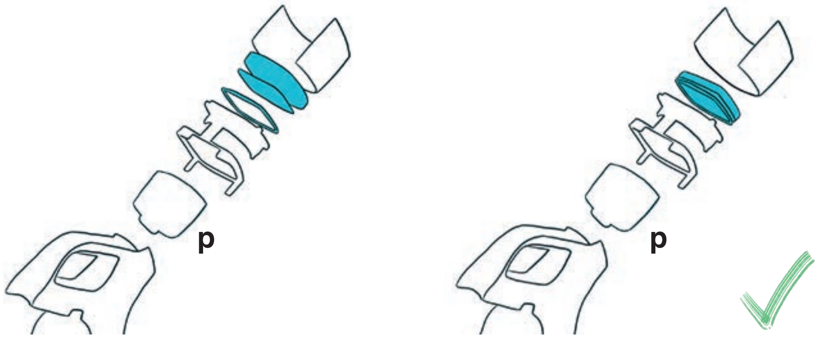


Figure 41 Clumping of three parts into an assembly

- Ensuring that priority parts are seperable can decrease disassembly steps. If two parts are not seperable but located in sides of a product which need to be accessed from different directions this increases the disassembly steps. If the two priority parts can not be separated they should be placed close together so loosening of the fasteners of both priority parts can be done at the same time.

Figure 42 A seperable PCBA and motor

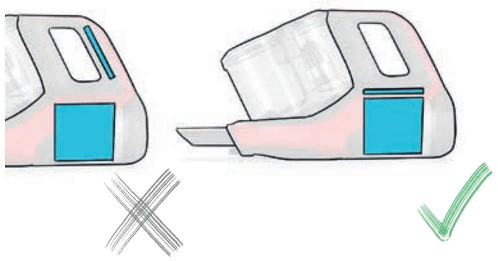


Figure 43 Placement of coneected priority parts

- Using the same type of fasteners can decrease disassembly steps by minimizing tool changes. After the extraction of a component a new tool can be used, however if a tool change occurs before the extraction of a component this counts as a disassembly step. By using the same type of fasteners it is ensured that no penalty disassembly steps, consisting of tool changes, occur.

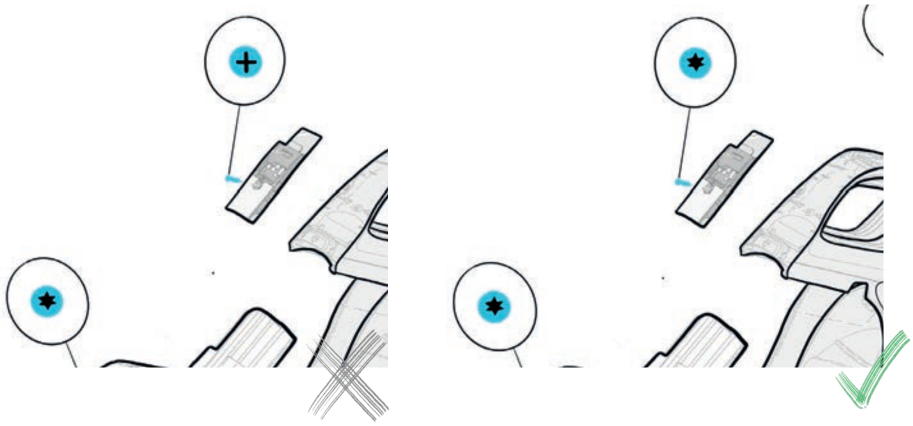


Figure 44 Use of the same type of fasteners

- If the use of different types of fasteners is unavoidable extra disassembly steps can still be avoided. As every disassembly step can have one type of tool use before a component is extracted, it should be made sure that all the same types of fasteners can be removed at the same disassembly step. In Figure 45 this is illustrated. The example below shows how two disassembly steps are decreased to one, by bringing four screws together on the same level in the product architecture. This is only valid when the next action would be use of another tool. In which case it should first be tried to use the same type of fasteners.

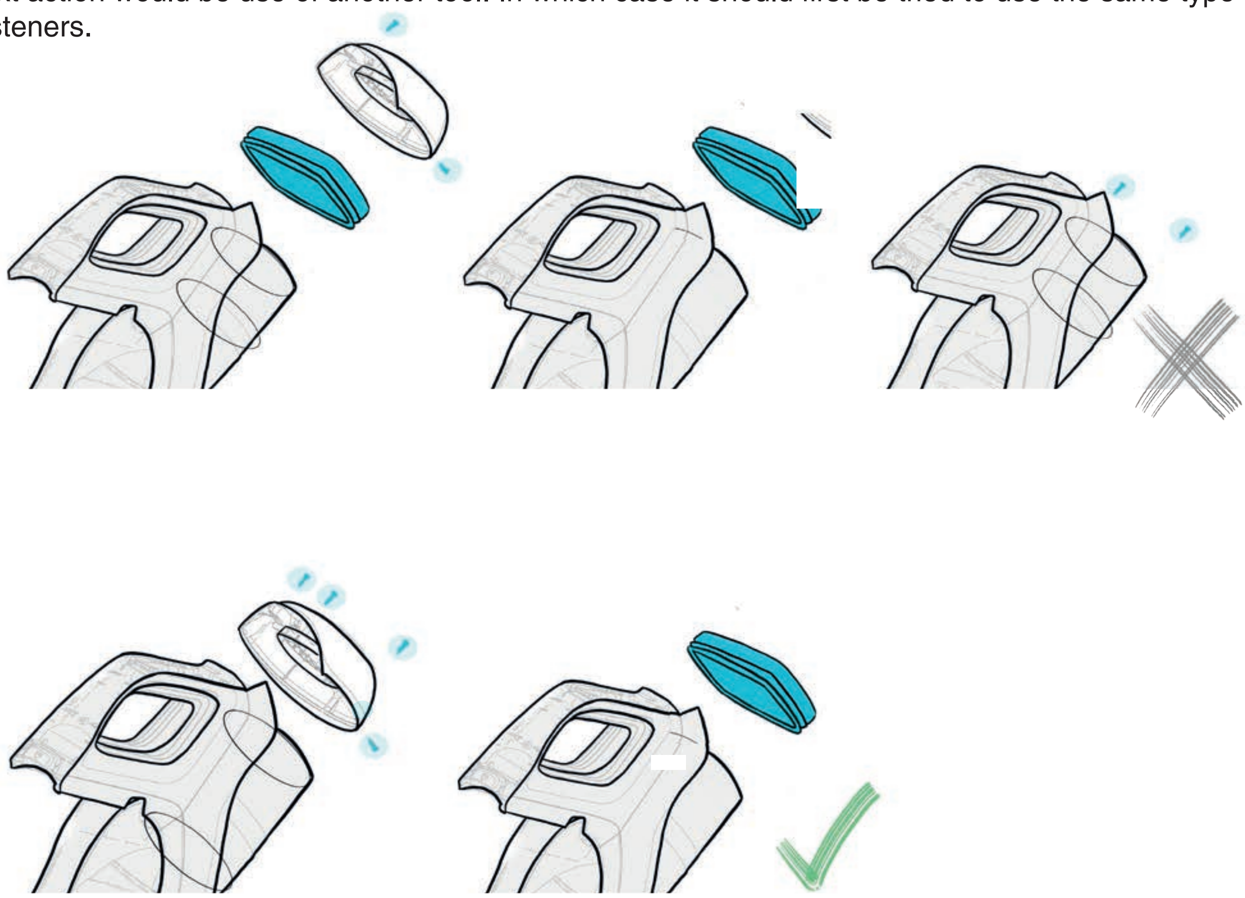


Figure 45 Placement of the same type of fasteners on the same level of depth in the product architecture

- Placement of the battery on the outside of the casing was found to be effective in decreasing the amount of disassembly steps. In the best examples the battery could be disconnected by not needing a tool and pressing a button.

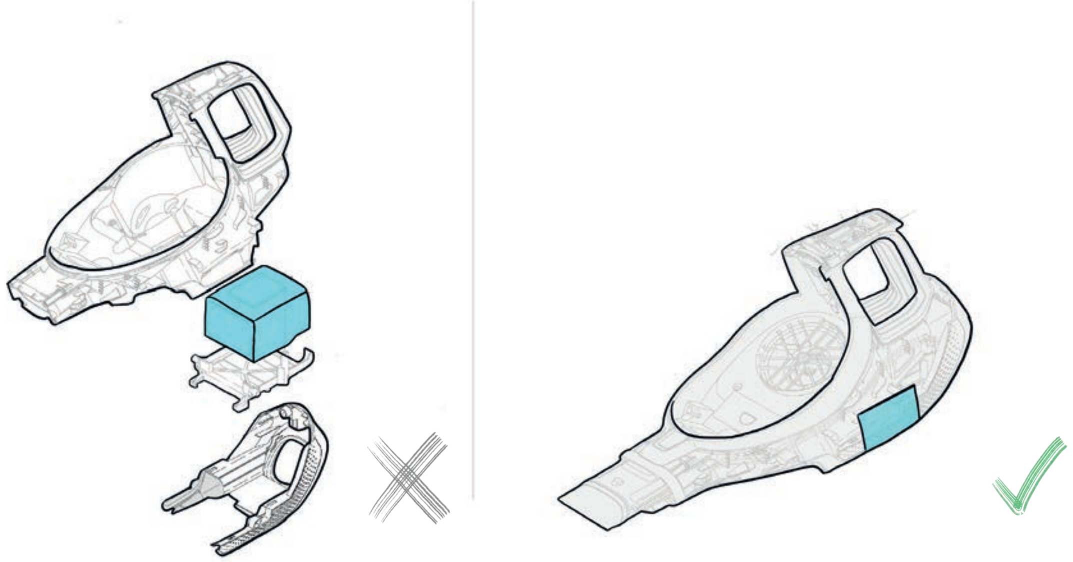


Figure 46 Placement of the battery on the outside of the casing

Guidelines for reusable fasteners

- During the disassemblies, screws were found to be reliable reusable fasteners. Use of snapfits was found to be of higher risk as these would often warp or break. If snapfits are used as fasteners it is advised to choose the same disconnection direction for all snapfits on the component. In this way snapfits unnecessary bending of the sensitive fasteners is avoided. Figure 47 shows two components, one with many snapfits in different disconnection directions, many of which broke during disassembly The other component in Figure 47 shows a component in with snapfits with a the same disconnection direction, the snapfits on this component did not break during disassembly. As described in the paper ‘ Use of snap-fit fasteners in the multi-cycle design of products’ : the design and use of conventional fasteners and every snap-fit used in a product must be designed fiom scratch’ (Sodhi, R. S., Sonnenberg, M., & Das, S., 1999). There is no one type of snapfit that ensures not breaking during disassembly. Avoiding the use of snapfits or early testing is therefore advised to generate high scores for Criteria 3 of FRI Category 2.

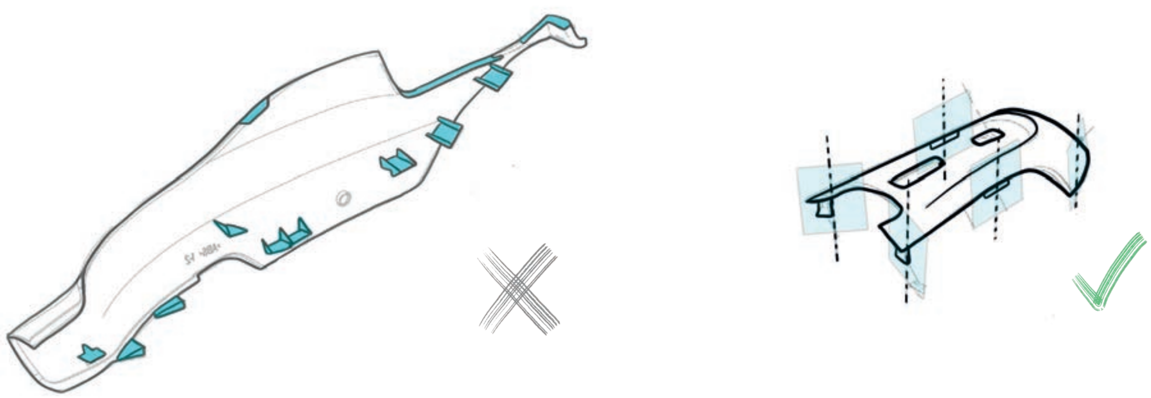


Figure 47 Disconnection directions of snapfits on components

4.6 Summary

The French Repairability Index (FRI) is a new mandatory repair label for energy related products. This label has already been introduced in 2021 for five product categories. In 2022 the label will be introduced for vacuum cleaners, including cordless vacuum cleaners

The FRI has five categories in which points can be scored. Two of them score the physical characteristics of a product. The other three concern available documentation on repair, availability of components and price of replacement components. In this research the focus has been on the second category 'Ease of Disassembly'. This category scores three subcriteria: the amount of disassembly steps needed to reach certain priority parts, the types of tools that are needed to complete the disassembly and the reusability of fasteners that are connected to priority parts.

To be able to perform the assessment of category 2, multiple assumptions needed to be made. Partly because the assessment sheet for (cordless) vacuum cleaners had not been released yet but also partly because some definitions and instructions were not specific enough.

The previously created disassembly maps were used as a guiding tool to generate input for the three scored criteria in the second category. The disassembly map however uses different criteria and the initial view does not provide the user with the necessary input for the FRI category 2 assessment.

The assessment generated quantified repair scores for the cordless vacuum cleaners and gave insight in which criteria's products could improve to raise their score.

Three scenario's illustrate the degrees of interpretation of the FRI definitions and instructions that can be used. Especially in the first criteria of Category 2 it was seen that there was large room for interpretation. A difference of 6 steps was found for an important priority part. Which can lead to a full point of deflection on the final score (of all five Categories together).

A reflection on the FRI and suggestions on how the scoring system could better score destructive disassembly is given. The FRI currently places high importance on the amount of disassembly steps that are needed to reach priority parts. This can lead to unexpected situations, where a product can have multiple components breaking during disassembly yet a low amount of disassembly steps. This can result in a higher repair score compared to a product of which all components can be reused but more disassembly steps are needed.

Finally the insights of the assessment have been gathered into guidelines for FRI that can be used for design of future products.

4.7 Conclusion

This chapter aimed to draft initial answers to research questions 3 and 4.

RQ3 How do the current cordless vacuum cleaners of Philips score in terms of the most important repair regulation?

Currently the French Repairability Index (FRI) is the most important repair regulation for cordless vacuum cleaners, as it is the first mandatory repair label. The Speed Pro received the lowest score, a 5,45, for the second category 'Ease of Disassembly', this was mainly due to the high amount of disassembly steps needed to obtain priority parts. Even though snapfits broke when accessing priority parts, the score for the third criteria 'Reusability of fasteners' was high. All the tools that were used during this disassembly fell into the highest scoring category, meaning that basic tools could be used to obtain all priority parts.

The Speed Pro Max received an average score for the second category, a 6,65, although this product also received a low score for the firs criteria concerning disassembly steps. No unreusable fasteners were encountered when obtaining the priority parts and only basic tools were needed for the disassembly.

RQ4 How can the French Repairability Index scores of these products be improved?

Both the Speed Pro and the Speed Pro Max could raise their FRI scores by surfacing the motor and PCBA. Surfacing of the battery, in the case of the Speed Pro would also have a large positive effect on the final score. The snapfits in the Speed Pro could be excluded or replaced but this would only generate a minimal raise of the score. Since both products already received the highest scores for criteria 2, no changes need to be made for the necessary tools used.

5. Development of a guidance tool for FRI assessment

5.1 Adaption of the Disassembly map

The execution of the FRI assessment, described in Chapter 4, showed how complex gathering correct input for this new repair scoring system is. Based on the importance of the new policy, as the first mandatory repair label, it was found that a tool that helps guide during the assessment would be of great value. This tool could not only help with correct assessment but also provide better insight of where bottlenecks in the physical product design lie that could be improved to generate higher FRI scores. If a tool could offer help during the FRI assesment it could partly answer to the main research question:

How repairable are Philips cordless vacuum cleaners and how could this be improved?

The Disassembly maps, which were created in Chapter 3, formed a good starting point for the FRI assessment in Chapter 4. Therefore it was chosen to adapt the Disassembly Map tool to fit the criteria of the French Repairability Index. In this Chapter it is described how the tool is adapted, how the tool has been tested and what the final results were of these testing sessions.

The new goals of the mapping tool needed to be redefined before the FRI parameters could be implemented into the existing Disassembly Map. Suggested alterations and improvements on the original tool, which were found using the Disassembly map to assess the six cordless vacuum cleaners, were implemented before starting the ideation.

The goal of the original and second edition of the Disassembly Map is to provide a visual representation of product architecture, display sequence of disassembly and dependency of components during the act of disassembly for repair (De Fazio, 2020). The FRI scoring parameters of Category 2 ‘Ease of Disassembly ‘, are to be implemented in the existing tool. The first and second edition of the Disassembly map do have elements that include these parameters, however they can not easily be identified when ‘reading’ the map. The penalty ‘unreusable connector’ for instance gives a hint for the reader of the Disassembly map that this part of the disassembly is important when filling in the third criteria of the Second Category of the FRI. But it does not give information if the fastener is removable but unreausable or not removable at all.

The goals of this new version of the Disassembly map are to:

- Act as an guiding tool for generating correct input for FRI assessment (Criteria 1 to 3 of Category 2 ‘Ease of Disassembly
- Generate a clear overview of the disassembly in context of FRI which can act as a proof of correct assessment
- Improve accessibility compared to the original Disasembly map

The criteria in the FRI concerning physical product characteristics under Category 2 ‘Disassembly’ are:

- The amount of disassembly steps needed to extract priority parts
- The types of tools needed for the disassembly
- The degree of reusability of fasteners that need to be undone to extract priority parts.

As explained in Chapter 4 the amount of disassembly steps has the highest scoring weight of all three criteria in the second Category of the FRI. The previous chapter also showed how there are many ways to interpret the FRI definitions and instructions on disassemblys steps. The FRI assessment could benefit from a tool that helps to clearly visualise and distinguish these steps.

Ideally the information that needs to be filled in for the three criteria in the FRI assessment can be immediatly seen when looking at the adapted Disassembly map. This means that the disassembly steps per priority part can be read, instead of counted. The same goes for the type of tools and reusability of fasteners. The next paragraph explains how the map was adapted so FRI input could be easily found when viewing a map.

Initial alterations of the Disassembly Map
During the creation of Disassembly maps of the six cordless stick vacuum cleaners, a number of initial ideas for alterations were collected before starting the process of adapting the DM to the FRI.

Introduction of components levels in a vertical grid
The first alteration, which was already used in Chapter 3, was to introduce a grid, which would make the map better readible and easier to compare. In 'Further development of the Disassembly Map' (De Fazio, 2020) a grid was introduced which added equal spacing between the components in the map. This version however did not hierarchigally distinguish between action blocks and component bubbles, in contrary to the grid used in Chapter 3. Which placed component bubbles on the same horizontal level. This alteration increased the size of the maps, which could be negative for products with many components but did work for this product category. Being able to identify on which 'component levels' components are located in the product architecture however did not have the effect that disassemly steps could be easily counted for FRI assessment, as we have discussed in Chapter 4.3

Highlighting priority parts
A second alteration was to highlighting the component bubbles of priority parts. Extraction of the most important components is the goal in the disassembly processes for both the Disassembly Map and the French Repairability Index. The location of these components in the total product architecture is one of the most important insights gained from creating a Disassembly map. In the 'Hotspot mapping tool integration version' of the Disassembly map (page 110) in the thesis of De Fazio of 2019, a Hotspot indicator is added to the map to indicate which components are priority parts. However in the version that is presented in the paper 'Further development of the Disassembly Map' priority parts are not highlighted or distinguished from other components. An alteration was done where priority parts where highlighted by using a different infill of the component bubble (See Figure 48)

Adaption of the Disassembly Map for FRI
After the initial changes of adding a grid, with component levels, and highlighting priority parts, the adaption of the DM for FRI could take place.

Removing elements of the Disassembly Map
Since one of the goals of this new tool is to generatea clear overview of disassembly in context of the FRI it is important to protect the visual simplicity of the map. As the three new parameters need to be added to the tool it was chosen to take out some of the existing elements that are not scored in the FRI. The force range in the spudger and hand action boxes, were taken out. All original penalties were removed from the map as they aren't scored in the FRI.

Hand action blocks
Actions completed by hand are not taken into account by the FRI. By completely removing the hand-action boxes from the disassembly map the readability would be impacted. Therefore it was tried to stil have hand actions incorporated in the map, but make change the apppearance from action blocks where tools are involved (See Figure 49). This change however made the overall map harder to read. Since it is not important for FRI assessment and only for the reader to keep track of what happened in the original disassembly, this feature was taken out.

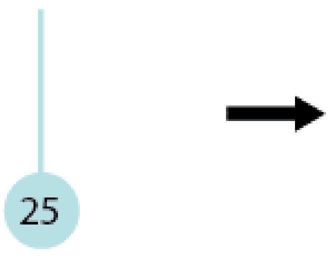


Figure 48: Component bubbles of priority parts are coloured yellow to stand out

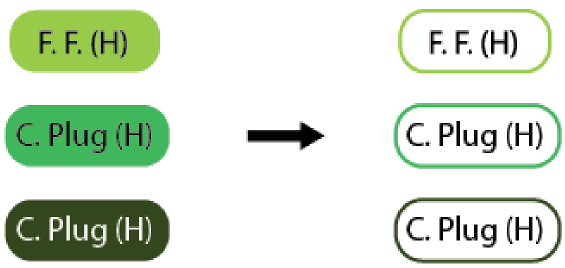


Figure 49: Alteration of hand action blocks which ulimately wasn't included in the adapted Disassembly Map

Counting Disassembly steps
In the original DM it was not easy to count FRI steps and a first move towards being able to count disassembly steps had been made by the implementation of a grid.

To allow disassemby step counting in the map, the disassembly step needed to become the elementary component. Since a hand is not considered a tool, a disassembly step cluster can only consits of (See Figure 50).:

- two tool-action boxes
- a tool-action box combined with a component bubble
- a single component bubble

Action blocks and component bubbles were combined into new elementary disassembly step blocks. These disassembly step blocks allowed easy counting of the disassembly steps. Looking at the map in Figure 51 it can clearly be seen how two priority parts 5 and 6, highlighted in yellow, are located at level three. This means that both components can be obtained by executing three disassembly steps.

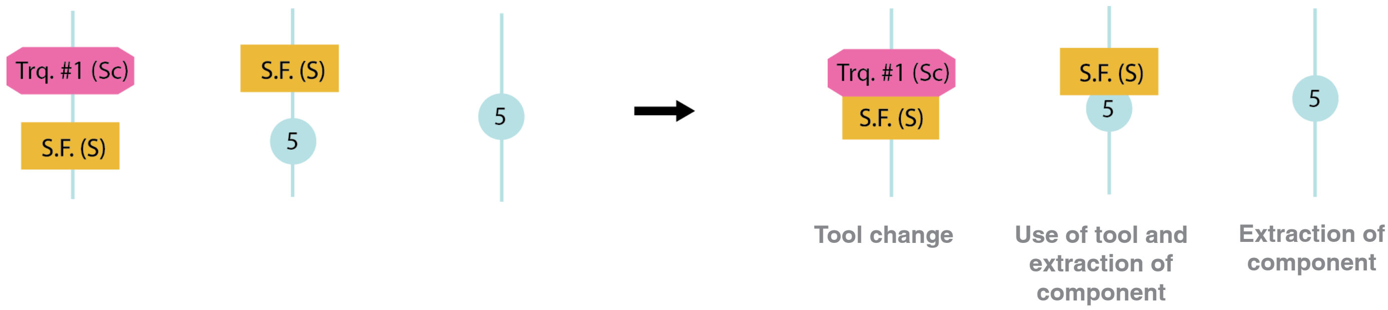


Figure 50: Combining elements of the original Disassembly map into the three possible disassembly step blocks

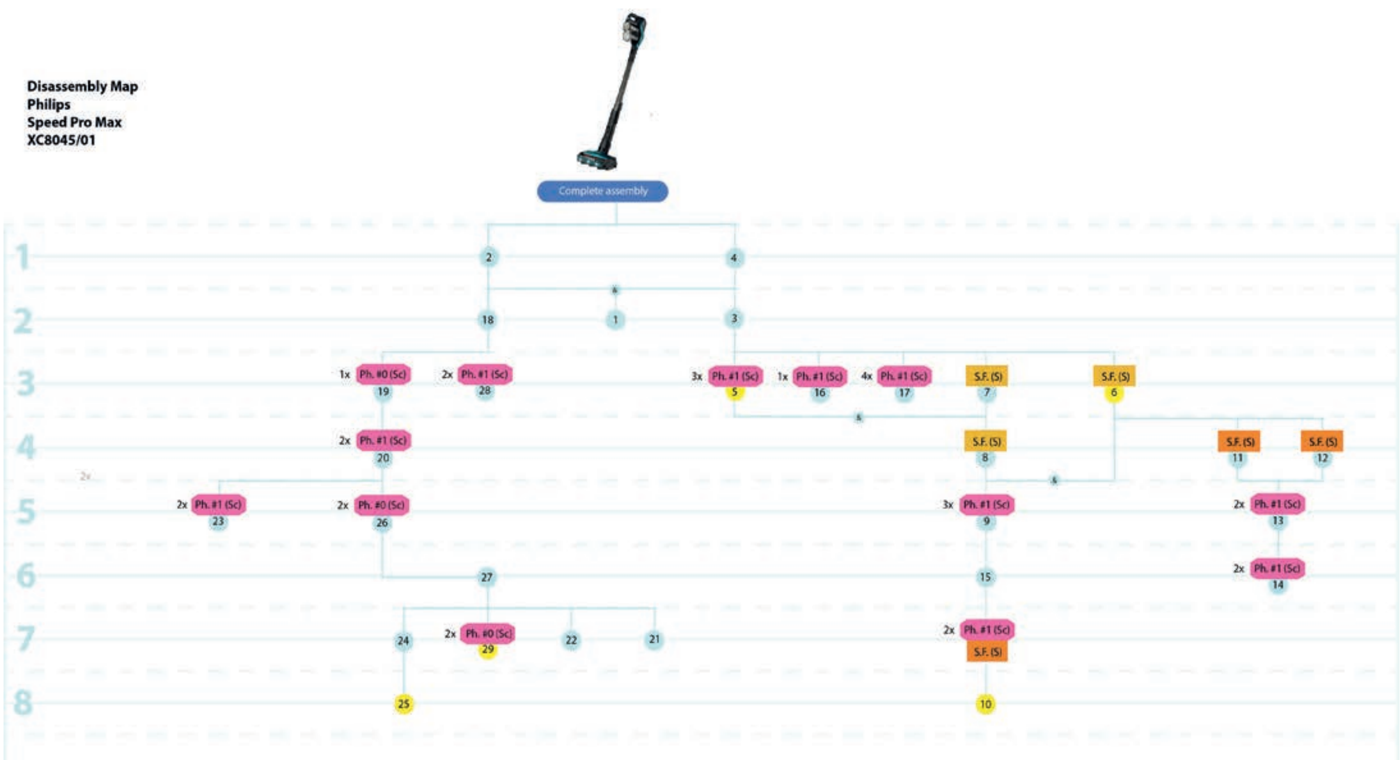


Figure 51: Counting of disassembly steps is possible after introducing disassembly step blocks

Dependency
After use of this adapted version of the disassembly map it was realised how dependency of actions needed to be adressed. When two separate actions need to be performed (signaled by the '&' sign) it does not work with the vertical counting. In Figure 52 this can be seen, components 8 and 6 needs to be extracted before component 9 can be obtained. However since both 8 and 6 are placed on level 3 this would lead to a missing disassembly step in the total count. This was solved in the third iteration, which can be seen in Figure 53, by placing the '&' sign on the level, between the two disassembly step blocks.

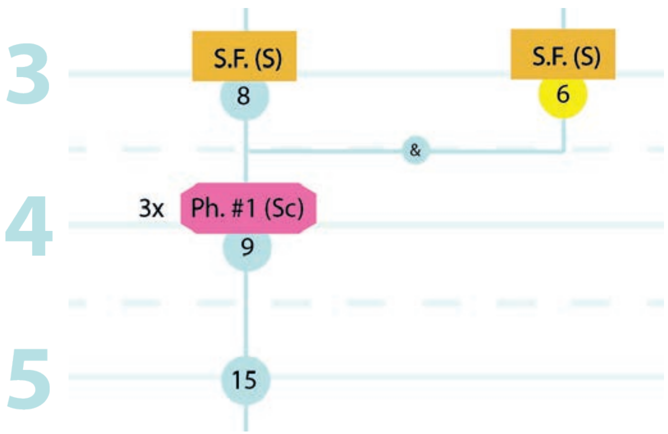


Figure 52: Combining elements of the original Disasembly map into the three possible disassembly step blocks

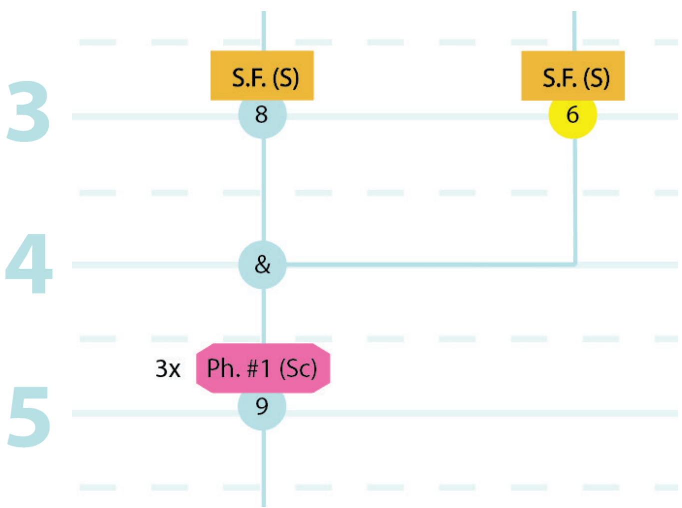


Figure 53: Combining elements of the original Disassembly map into the three possible disassembly step blocks

Including Criteria 2 and 3
In contrast to the criteria of counting steps, which is quantitative, the criterias 'type of tools' and 're-usability of connectors' are qualitative. In chapter 4 it was described how both parameters are scored by letters ranging from the highest scores (C and D) to the lowest score (A). Interestingly the worst score for both parameters overlap; a non removable component is in both scenarios awarded with an 'A' score.
The best scenario's ('D' and 'C') can be used as the default and therefore do not need a notation. Since one of the requirements of the original disassembly map is to only consider non-destructive disassembly processes, this means in the case of a non removable component the component branch would end. For both A scores the 'X' penalty mark could be used and the branch would end. In the case of a removable but not reusable fastener the 'X' symbol with a dotted line is used, representing the branch that can be disassembled further.

Influence of penalties on further disassembly
An iteration that was not adopted was a change to the map which showed the influence of a penalty over the following disassembly.

In Figure 54 it can be seen how branches were coloured to indicate that earlier a penalty had occurred. This change made the map more complex and therefore harder to read. Another reason for not adapting this iteration was that penalties only count for the disassembly step that they occur at. The breaking of a fastener is only penalized once.

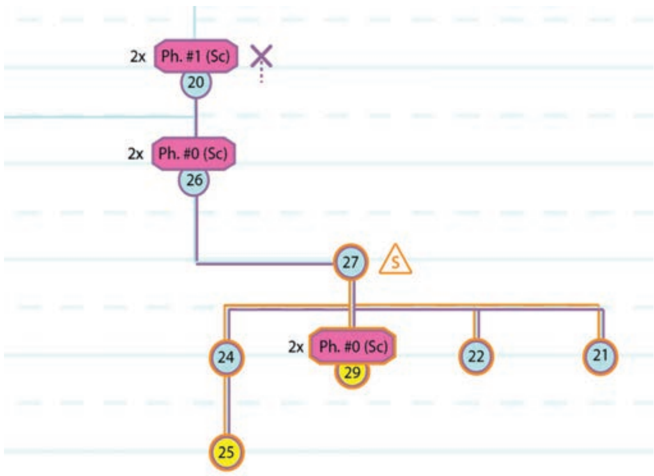


Figure 54: Iteration showing penalties visually influencing following disassembly steps

If a fastener breaks when extracting a handle panel this is penalized in the FRI in Criteria 3 for the handle panel. In the case that the handle panel needs to be extracted before the motor can be obtained this would mean that destructive disassembly occurs when trying to obtain the motor. However in the FRI a penalty is not given to the motor. Therefore trying to show the influence of penalties over the following part of the disassembly is not useful.

Type of tools used for disassembly	Subtotal
A : Not removable	0
B : Removable with proprietary tools	1
C : Removable with specific tools	2
D : Removable with no tool with tools supplied with the product or with basic tools	4

Figure 55: FRI rating of Types of tools used during disassembly

Type of fasteners	Subtotal
A : Neither removable nor reusable	0
B : Removable but not reusable	1
C : Removable and reusable	2

Figure 56: FRI rating of Types of fasteners

Including Tools and Reusability of fasteners
In contrast to the criteria of counting steps, which is quantitative, the criterias 'type of tools' and 're-usability of connectors' are qualitative. In chapter 4 it was described how both parameters are scored by letters ranging from the highest scores (C and D) to the lowest score (A). Interestingly the worst score for both parameters overlap; a non removable component is in both scenarios awarded with an 'A' score.
The best scenario's ('D' for tools and 'C' for fasteners) can be used as the default and therefore do not need a notation. This means that for a disassembly where only basic tools are used and all fasteners are reusable a relatively 'empty' map is created. Which makes filling in the FRI assessment for such a disassembly quick and easy.

In Figure 57 the new penalties can be seen that cover all the input that is needed for Criteria 2 and 3 of Category 2 of the FRI. Since both worst case scenario's for the two criteria are the same (a component or fastener is not removable), these scores share the same penalty symbol.

Use of proprietary tools and specific tools both have their own penalty symbol. Fasteners that are removable but not reusable also receive their own penalty symbol.

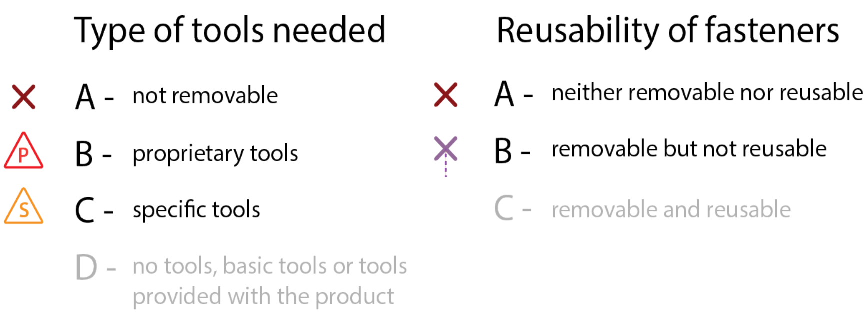


Figure 57: New penalties for the adapted Disassembly Map that represent Criteria 2 and 3

Increasing accessability
To increase accessability of the tool it was chosen to change the digital environment from Adobe Illustrator to Miro. Miro is a digital whiteboard which can be used by multiple users at the same time and can be accessed through a web browser. In the free version of the tool (at the time of mid 2021) a user can store three different boards, which mean that a template could be easily distributed and accessed by users worldwide.

A Miro template was created for the adapted Disassembly Map using the new disassembly step blocks (See Figure 58). The blocks in the legend can be copied and dragged, enabling easy and quick creation of Disassembly Maps.

The Final FRI Disassembly Map template (See Figure 59) can be accessed through the following link
https://miro.com/app/board/o9J_lyEPMrU=/
This will enable free use of the template for all users.

The main elements in this template are:
1. The yellow instruction bar on the left
2. The mapping template background
3. The map legend
4. The box for the component list
5. The box for the exploded view or photo of the product
6. The box for the Category 2 FRI scores
7. The box for a summary of the Category 2 of the FRI assessment

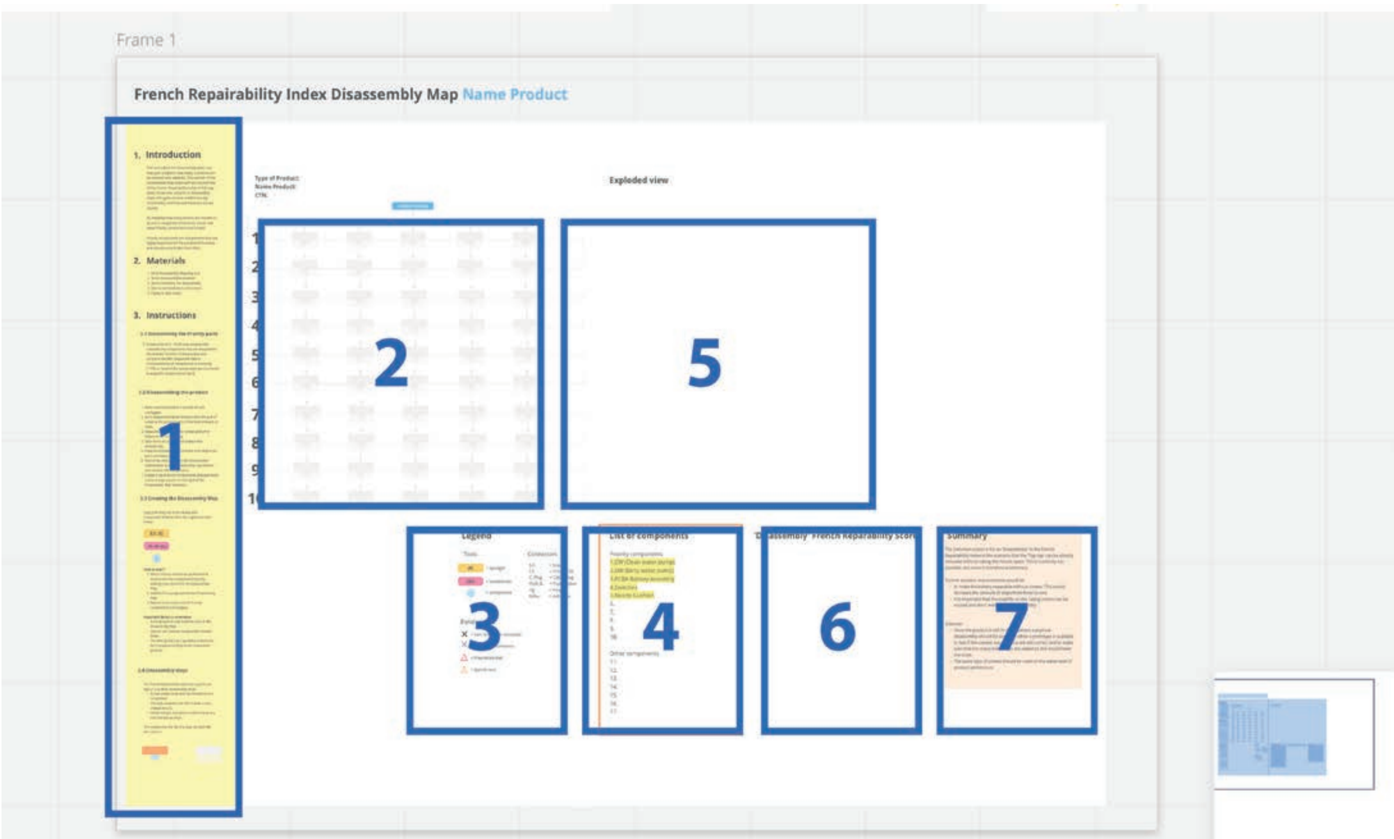


Figure 58: The adapted Disassembly map in Miro with numbers indicating the different components

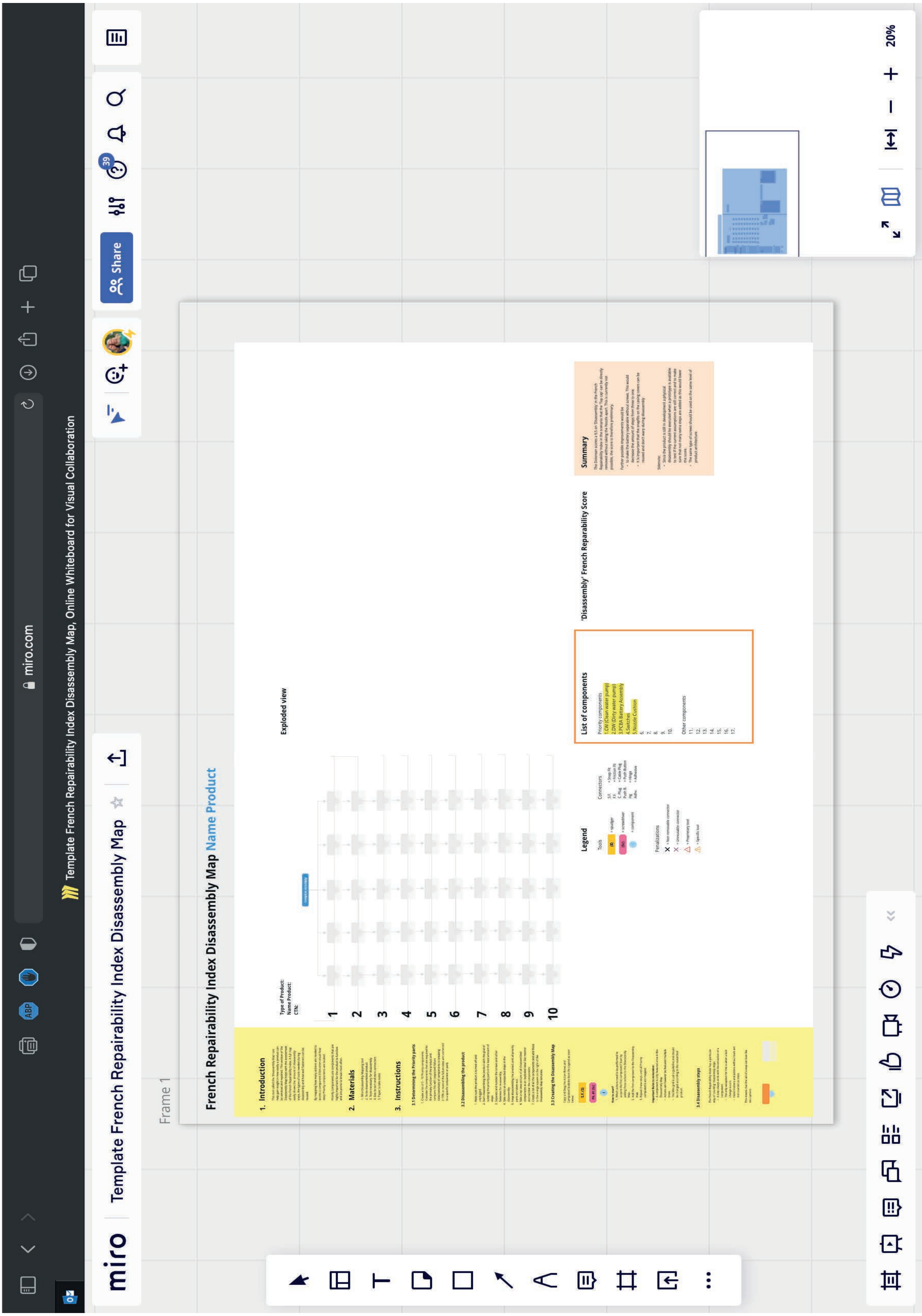


Figure 59: The adapted Disassembly map in Miro

The FRI adapted Disassembly Map

All iterations done to include the FRI criteria in the Disassembly Map can be seen in Figure 60.
All iterations together produced the adapted Disassembly Map for FRI which can be seen in Figure 61

Iteration number	Iteration	Goal	Used	Reason
1	Highlighting priority parts	Emphasizing priority parts	yes	
2	Taking out the forces	Making the map more simple	yes	
3	Taking out original penalties	Making the map more simple	yes	
4	Introducing grid with equal distances between components	Creating a more visually balanced map	yes	
5	Introducing a horizontal component levels	Being able to count disassembly steps	yes	
6	Appearance change of hand actions	Distinguishing hand actions from tool actions	no	Parameter not required in the FRI and makes the final product less clear
7	Introducing disassembly step blocks	Being able to count disassembly steps	yes	
8	Colouring branches when tool penalities occur	Showing the effect of tool penalties on the whole branch	no	Makes the final product less clear
9	Colouring branches when fastener penalities occur	Showing the effect of fastener penalties on the whole branch	no	Makes the final product less clear
10	Change of environment from Miro to Illustrator	Making the tool easier to access and share	yes	

Figure 60: Overview of iterations made to the original Disassembly map to adapt it to the French Repairability Index

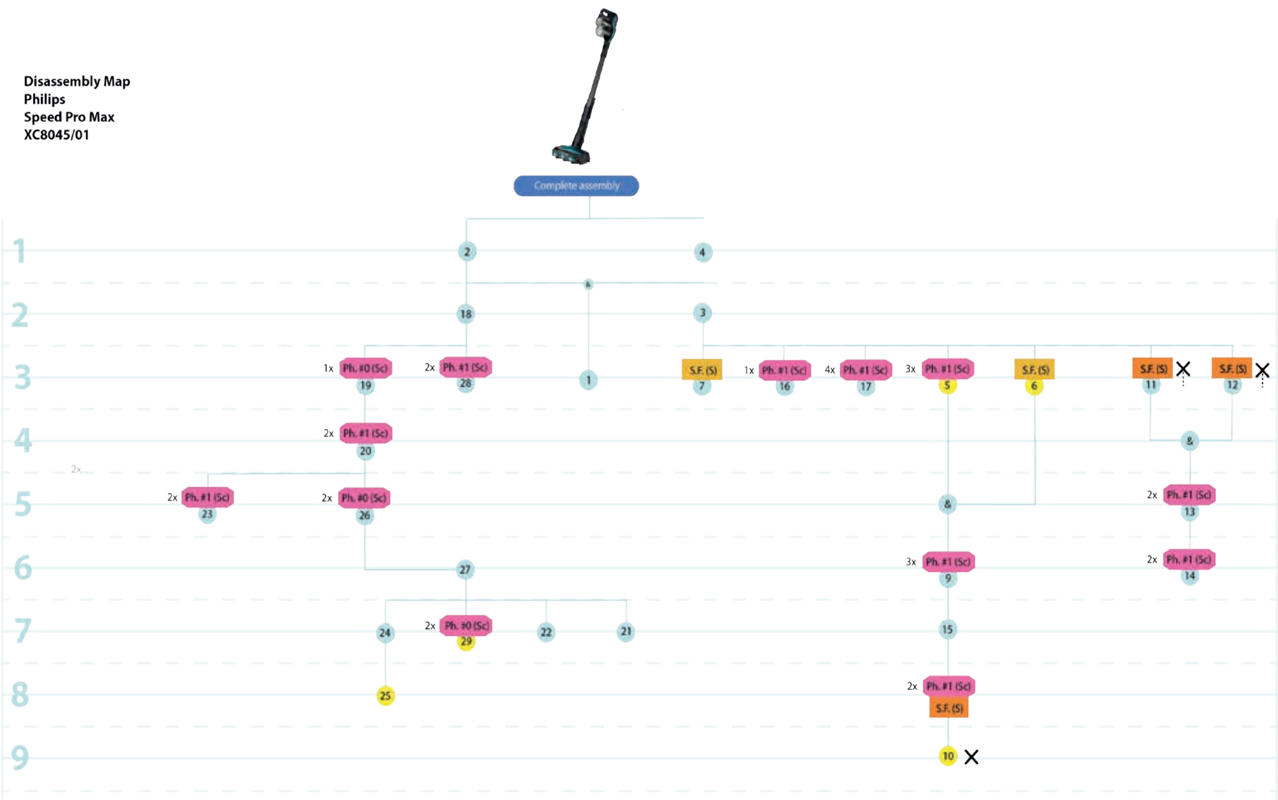


Figure 61: The adapted Disassembly map for FRI showing the disassembly of the Speed Pro Max

5.2 Usability testing

After the original Disassembly map had been adapted it needed to be tested. To validate the usability of the tool four tests were done with Philips designers. Four Disassembly maps for the FRI were created for three products that are still being developed. Due to confidentiality of these projects, the names, type of product and other details could not be shared. The created Disassembly maps however could be shared, without the component lists.

The goal of the first testing sessions were to:

- Gain insight on the level of intuitiveness of the tool for designers
- See how Philips cordless floorcare products could be improved in terms of the FRI (This test goal is connected to the main research question)

The approach used in this tests was the collaborative ceation of the map by the writer and designer and discussion of the results afterwards

During the usability tests it was found that the cooporating designers were very interested in the created Disassembly maps for FRI. It was explained how currently there are no concrete design requirements on repairability. Creation of the maps gave them insight in the repairability of their products, in context of the FRI. During all tests bottlenecks for repair were found in the products that are still being developed. Even though this was not the original goal of the usability tests, these results have been incorporated in this chapter.

The first two tests were done with products in a later development stage. It was clear that the designers in these tests felt less comfortable assessing their products on repairability. In those stages it would be hard and costly to make changes to the product architecture or fasteners. Both designers did acknowledge the relevance of the tool in supporting the FRI assessment.
The third and fourth tests were done with two products in early development phases and a short introduction of the FRI was given. The designers were very open minded about altering the product to improve the repairability score. In both cases they started ideating during and after the creation of the map, on how the most pressing bottlenecks could be solved. In one case this entailed potentially dividing a component into two pieces, so it would grant access to priority components in less disassembly steps. In the second case the place of the connectors from the battery to the PCBA was rethought. The tool needs to be explained before designers could properly use it, however with short clear instructions using the tool could be learned quickly and potentially even become easy to use when used a second time.

Usability test 1
In the first test a nozzle of a developing floorcare product (See Figure 62) was mapped using the adapted Disassembly map. This prototype was at the end of the development stage and a physical prototype was available for disassembly. Due to a lack of time on the designers end, the map was created in Miro by the writer. After creating the map the designer was asked for feedback on the tool and its results.

The designers opinion on the tool
The designer had minimal knowledge on the French Repairability Index before the start of the test. After walking through the map he thought the tool had potential to support during the FRI assessment. The rules and how to use the tool were still quite unclear to him and he would not be able to map a product himself without any additional explanation. This was not unexpected as this designer had not been able to create the map himself. The designer was interested but not glad to see the insights on repairability. Since this product was already in a further stage of development it would not be possible to change the location of fasteners or the product architecture.

Insight on repairability
The final map shows that the first step is skipped, this is because the Nozzle was disassembled, which would first need to be disconnected from the handheld. Three insights were found that could improve the FRI score:

- The disassembly steps needed to obtain priority part 1 could be decreased to five instead of six, this would mean that the part falls in the lowest step range and is awarded more points.
- This decreasing of steps could be done by using the same screwtypes in disassembly step three. Since two different types of screws are used a tool change now occurs.
- The needed use of a proprietary tool, which is uncommon for most Philips Floorcare products, results in penalty.

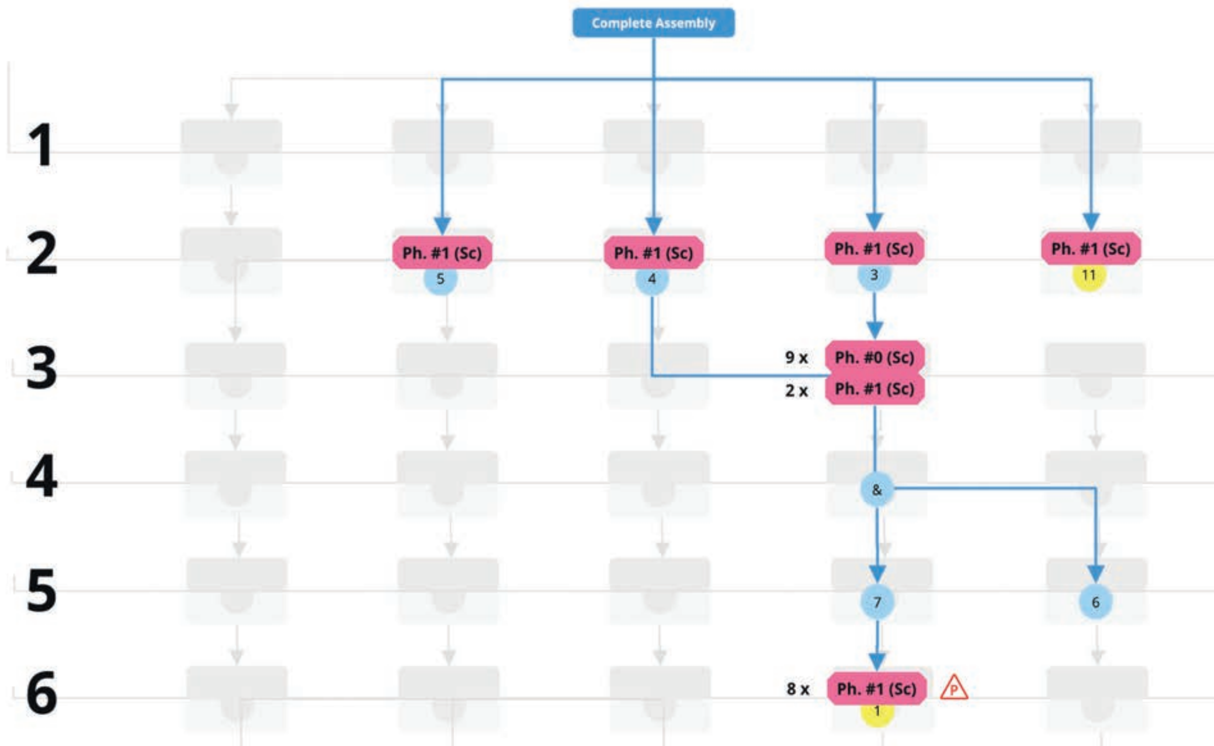


Figure 62: Usability test 1, a nozzle in development mapped with the aDM

Usability test 2
The second test was done on the handheld of the same product as in test 1. This subassembly was in the same development phase as the previously mapped Nozzle and a physical prototype was also available for the mapping process.

The designer disassembled the prototype of the handheld in a digital meeting. At the same time the adapted disassembly map was created by the writer. After creating the map the designer was asked for feedback on the tool and its results.

The designers opinion on the tool
The designer had minimal knowledge on the French Repairability Index before the start of the test. After creation of the map he thought it would be a useful tool to generate input for the FRI assessment. The designer however thought that the map was most useful in detecting repairability weaknesses in the product. The rules and how to use the tool were still quite unclear to him and he would not be able to map a product himself without any additional explanation.

Insight on repairability
The final map (See Figure 63) shows again that the first step is skipped, since the handheld needs to be disconnected from the tube and nozzle.The map shows that the current prototype scores quite well in terms of disassembly steps. All priority parts can be obtained in four steps or less. But reusability of fasteners should be improved if possible. The large amount of snapfits, that are sensitive for warping and deformation, pose a threat for labels of unreusable fasteners.

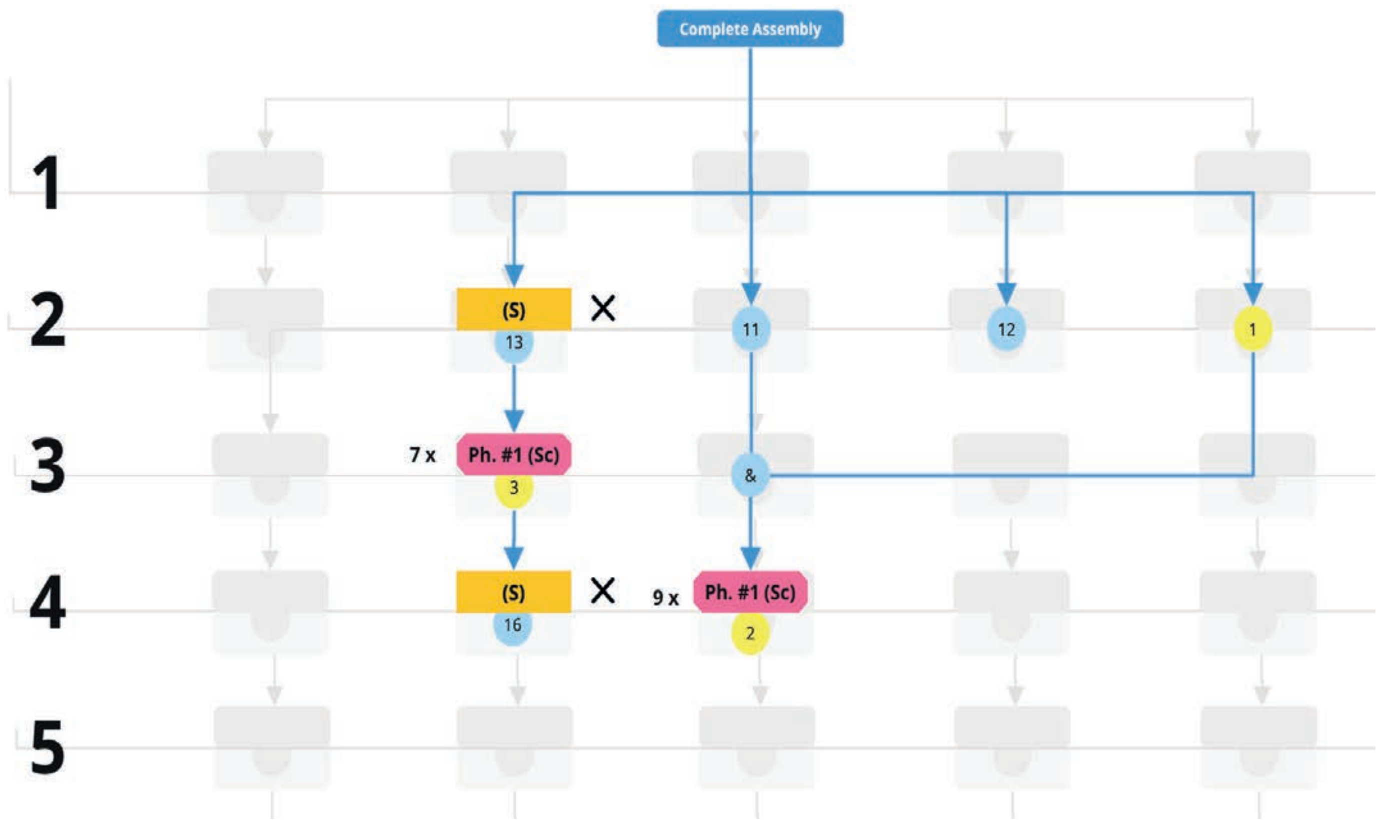


Figure 63: Usability test 2, a handheld in development mapped with the aDM

Usability test 3
In the third test the tool was used to map the handheld of a developing floorcare product. A digital computer model was used to visualise disassembly. The disassemby map was collaboratively created in Miro by the designer and the writer and discussed afterwards.

Designers opinion on the tool
The designer had a basic understanding of the French Repairability Index. After the test the designer had a good understanding of the FRI criteria in Category 2 and how to use the Miro tool. He thought the tool was an excellent support for the FRI assessment and provided important insights in the repairability of the developing product. He anticipated that he could use the tool by himself with help of the instruction bar in the future. The designer needed an explanation on why a step should be skipped after using an '&' sign but did not have problems with that concept later on.

Insight on repairability
The final map (See Figure 64) showed that the current version of the handheld did not receive a great score for disassembly steps. For two priority parts, eight steps are needed. Since the product was still in an early phase of development, the designer started thinking about ways to decrease the amount of steps during the creation of the map. Ideas were for instance to replace the connector point of the wire between the battery and the PCBA. This could have the effect that the product would only need to be opened up from one side instead of loosening the embodiment and casing parts from multiple sides. As a result priority part 1 could be obtained through five steps instead of eight. Since the product was still in a stage of early development these improvements could be applied to the design. The designer stated that was going to try to solve the repairability bottlenecks in the design based on the assessment.

It was expected that applying the tool in early stages of the development process would have high potential of increasing repairability. As product architecture and fasteners are not definitely defined yet in this stage.

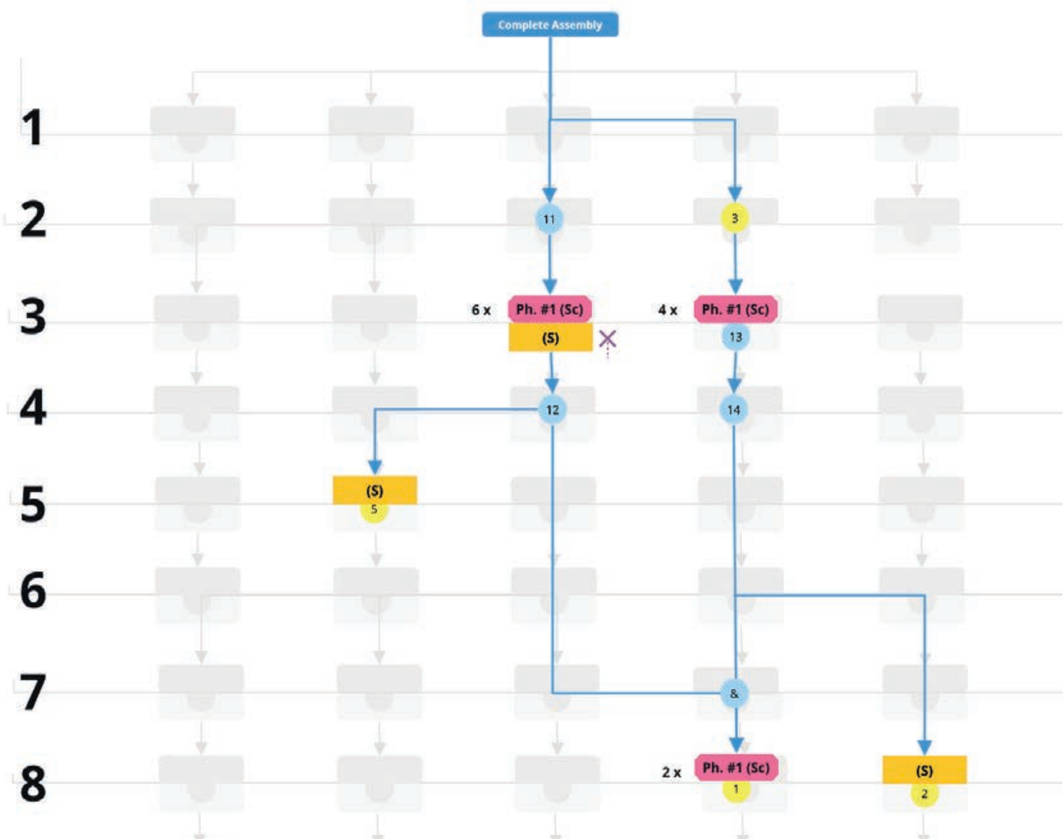


Figure 64: Usability test 3, a handheld in development mapped with the aDM

Usability test 4
In the fourth test the tool was used to map the handheld of a developing floorcare product. A digital computer model was used to visualise disassembly. The disassemby map was collaboratively created in Miro by the designer and the writer and discussed afterwards.

Designers opinion on the tool
The designer had a basic understanding of the French Repairability Index. After the test the designer had a satisfactory understanding of the FRI criteria in Category 2 and how to use the Miro tool. He thought the tool could help guide during the FRI assessment and had provided important insights in the repairability of the developing product. He anticipated that he would have a hard time using the tool by himself with only the help of the instruction bar but expected that he thought that one more session would bring him to a level on which he could individually use the tool.

Insight on repairability
The final map (See Figure 65) showed that the current version of the handheld had a serious problem with one of the components blocking access to priority components.To be able to access these components the complete nozzle of the product would also need to be disassembled. Since the intention of the test was only to map the handheld ,and not the nozzle, a purple box was added as a placeholder for this complete component. The decision was made to finalize the map as if the, now blocking, component could be removed with one action. Just like in the third test the designer immediately started ideating on how this problem could be solved. The designer was happy to have gotten this insight on the bottleneck in the dissasembly and stated that he was going to discuss solutions with his team.

Test evaluation
Based on the four executed usability tests it could be concluded that the aDM tool needed extensive explaining before it could be used by designers. It can therefore be said that the tool is not very intuitive for users that are not familiar with the original Disassembly map or the French Repairability Index.

Use of the tool was however very insightful for the designers in seeing how repairable their products were in terms of the FRI. During the session designers were already aware of bottlenecks in the design and started creating solutions to make their products more repairable and create higher FRI scores.

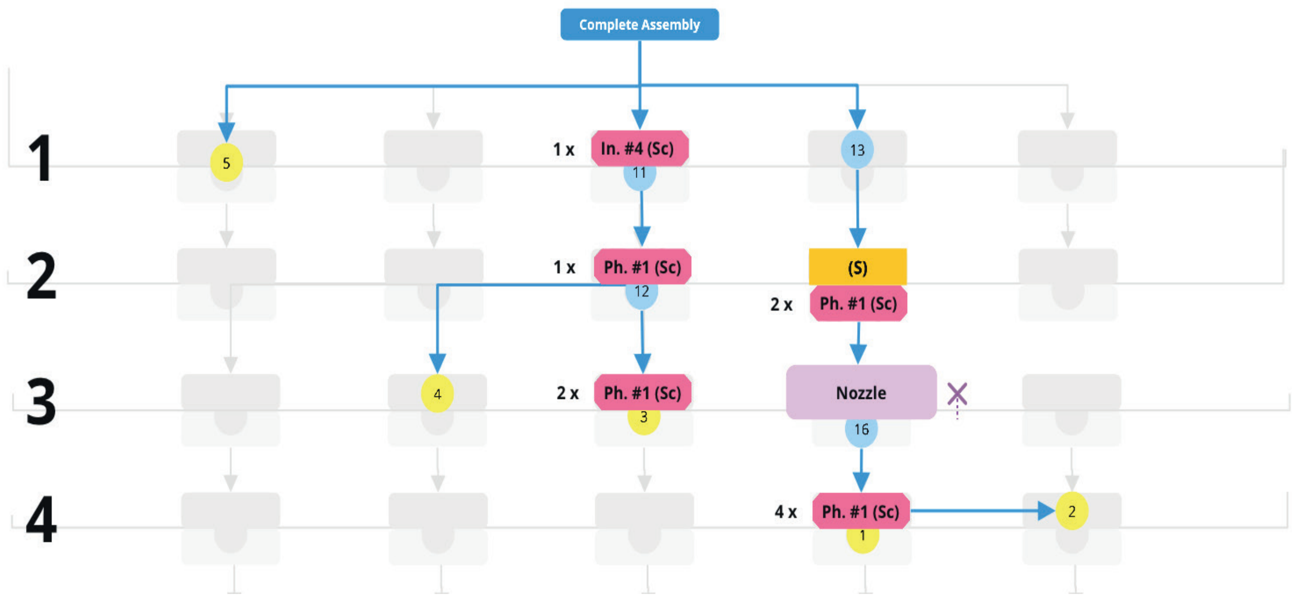


Figure 65: Usability test 4, a handheld in development mapped with the aDM

5.3 Assessment testing

In this chapter four tests were described that had the goal of validating the adapted Disasembly map (aDM) as a tool that helps create correct FRI assessments. The Disassembly map was used by four Industrial Design Engineering students while creating a French Repairability Index score for the Speed Pro Max cordless vacuum cleaner for the second Category 'Disassembly'.

The goals of these second testing sessions were to:

- See if the Disassembly Map helped create a reliable FRI score in the second Category
- See in what ways the DM influences the process of creating a FRI score in the second Category

Approach
Two designers were asked to create a French Repairability Score for Category 2 'Disassembly' of the Speed Pro Max handheld without the use of the Disassembly Map. The other two designers were asked to create the same FRI score but with the help of the DM. After completing the assessment the students were asked (See Appendix VII for the transcribed interviews) if they thought that the assessment was easy, how they approached the assessment and if they thought they had created a reliable assessment result.

To both groups it was explained that the goal of the test was to fill in the second Category of the FRI assessment sheet for three priority components (The battery, motor and PCBA). They received explanations on the definitions of a disassembly step, the ranges of tools and the reusability of fasteners. After this general session the first two designers started on their assessment while the second group was taken into a seperate space and got a short explanation on the Disassembly Map tool in Miro.

Both groups had access to:

- The FRI Excel assessment sheet
- The third Annex in the FRI excel sheet with definition of a disassembly step
- Video of the disassembly of the Speed Pro Max (uploaded on Youtube)
- The disassembly manual of the Speed Pro Max
- Paper, pens and coloured markers

The second group also had access to:

- An empty Miro DM template
- A printed version of the Miro DM template

The Category 2 FRI assessment of the Speed Pro Max, created by the writer, was taken as the correct assessment. However in chapter 4 it was

		Without the aDM	Without the aDM	With aDM	With aDM
Disassembly steps	Writer	Student 1	Student 2	Student 3	Student 4
Battery	<5	<5	<5	<5	<5
Motor	9>x>7	->9	->9	9>x>7	9>x>7
PCBA	9>x>7	<5	->9	9>x>7	9>x>7
Types of tools					
Battery	D	D	D	D	D
Motor	D	D	D	D	D
PCBA	D	D	D	D	D
Reusability of fasteners					
Battery	C	C	B	C	C
Motor	C	C	B	C	C
PCBA	B	C	B	B	C

Figure 66: Results of the testing of the adapted Disassembly map during FRI assessment

described how different interpretations of the FRI definitions and instructions could lead to different assessment results.

Results
The four designers all produced a complete Excel FRI assessment sheet for the second Category ‘Disassembly’. The results of these assessments can be seen in figure 66. The correct assessment, done by the author, can be found in the first row.

Only one asesessment out of four matched the assessment done by the author. This result was not unexpected as Chapter 4 discussed the range of freedom that exists in the current definitions and instructions of the FRI and the assumptions that were made to create an assessment score for the Speed Pro Max.

Disassembly steps
Two out of four students, the two that made use of the aDM in Miro, had the correct amount of disassembly steps for all three priority parts. The results of the Miro tool however showed that these right input numbers were accidentally created. The maps did not match those of the author, even though the outcome of the tool gave the right amount of steps, mistakes had been made in the disassembly map.

The two students who did not use the aDM also made mistakes during the applying of the FRI definitions of disassembly steps to the disassemby process. This however also led to wrong input for the FRI assessment

Types of tools
All students assessed the correct scores for the types of tools. Since all used tools fell into the basic tool category, students did not have to assess the difference between specific or proprietary tools if tools.

Reusability of fasteners
Only one of the four students, student 3 who used the aDM, had the correct assessment results for the reusability of fasteners. When looking at the created aDM it could however be seen that again wrong assumptions were made.

“I found it hard to understand that a tool change also counts as a disassembly step and not just extracting a component” (Test 3)

Self created guiding tools
The testers that did not use the disassembly map created their own method (as can be seen in figures 40 and 41) to count the steps, types of tools and types of fasteners. These methods, mainly listing the actions and types of tools that were used, proved useful for filling in the FRI excel. They however did both make basic errors , for example the counting of removal of fasteners as components, their own created guiding tools did not prevent this from happening. In the last test however can be seen how disassembly steps were also applied incorrectly while using the Disassembly Map.

Test evaluation
About the first test goal the following can be said: Using the Disassembly map tool for the first time when creating an FRI assessment does not guarantee a correct outcome. The only correct assessment score in these tests was made with the help of the Disassembly Map, this score however was accidentally correct as it ontained multiple mistakes.

About the second test goal it can be said that a a method is used first and afterwards the excel is filled in. The criteria in Category can not filled in without a guiding tool. Students 1 and 2 used their own created method instead of the Disassembly map. Students 3 and 4 emphasised that it was easy to fill in the FRI sheet based on their created Disassembly Maps.

The test results emphasise how complex designers find counting disassembly steps and assessing reusability of fasteners when using the definitions of the FRI. All test persons made different assumptions using the information provided with the FRI assessment sheet and this resulted in different assessment scores.

In these tests the creators weren’t asked to compare their assessments with each other. However one of the participants pointed out that under real circumstances design teams will probably do so and that the Disassembly map in that case poses a benefit as a general structure and method is already present. This can save teams time and provide guidance.

*“If the French government would provide a tool like this with the assessment sheet then at least everyone would be using the same method that then could be compared. I think that would lead to a more honest rating” (*student 4)

5.4 Summary

To help guide during the assessment of the second category of the French Repairability Index (FRI), the original Disassembly map (DM) was adapted into the adapted Disassembly Map (aDM) . This was done by integrating the scoring criteria of the FRI into the components of the DM.

Disassembly blocks were made from action blocks and component bubbles. By introducing these new blocks the disassembly steps can be read from the aDM. Criteria 2 ‘ Type of tools used for disassembly’ and 3 ‘Reusability of fasteners’ were incorporated by using penalty symbols. These clear symbols make it possible to also read the input needed for criteria 2 and 3 out of the map without further investigation.

To test the usability of the new tool, four tests were done with Philips’s designers on products that were still being developed. The goal of these tests was to find out if the new tool was easy to use and if they could help improve the repairability of cordless floorcare products (this is connected to the main research question). These tests showed that the tool was complex to use for designers that had never used the Disassembly map before or did not know about the (definitions used in the) FRI. The tool however helped the designers gain insight in the bottlenecks of their products and was a good way to help improve the repairability of the products in development.

The second round of testing was done with four design students to see if the tool could help correct assessment of the second category of the FRI. Two of the students performed the assessment without the use of the aDM, while the other two could use the aDM. This test showed again how multi interpretable the definitions and instructions of the FRI currently are. Only one student, with help of the aDM, generated the same assessment score as the author. However also this student made multiple mistakes and created the right score by accident.

5.5 Conclusion

The results of the usability and assessment tests in this chapter show how the goals of the new adapted Disassembly Map were partially validated.

Goal 1:
Act as a guiding tool for generating correct input for FRI assessment (Criteria 1 to 3 of Category 2 'Ease of Disassembly
This goal was tested in the assessment tests with design students. The test results however showed that none of the performed FRI assessments were correct. After looking into the details of the assessments it became clear that all students had made wrong interpretations of the instructions and definitions of the FRI. Therefore the advice is given to the FRI to further detail these definitions, especially for criteria 1 and 3 of the second category.

It was however seen that in all tests a helping system was used or developed, a method of creating overview is needed in order to be able to count steps, assess the types of tools needed and reusability of fasteners. Providing an existing tool, like the Disassembly Map, gives the tester a framework that is ready to use. This saves time and makes it easier to compare results. Therefore the aDM does succeed in reaching its main goal; providing support during the FRI.

Goal 2:
Generate a clear overview of the disassembly in context of FRI which can act as a proof of correct assessment
In the assessment tests two adapted Disassembly maps were generated which helped the author understand what choices the students had made during the assessment. This leads to the conclusion that the created maps can act as a form of proof and overview of what interpretatios have been made during the assessment.

Goal 3:
Improve accessibility compared to the original Disasembly map
The adapted Disasembly map is used in Miro, a digital web based environment. The template of the adapted Disasembly map has been uploaded here and can be freely accessed. The accessability has therefore been improved.

The main research question and research question four have also been partially answered in this chapter.

MRQ. How repairable are Philips cordless vacuum cleaners and how could this be improved?
RQ4 How can the French Repairability Index scores of these products be improved?

During the usability tests with the Philips designers it was shown how the tool helps gain insight in where products can be improved on their repairability and FRI scores.

The tool has definitely shown a huge potential in highlighting repairability bottlenecks in the early phase development process of products. Two important obstacles became apparent after mapping the products. The designers agreed that the map gave insight into obstacles in the product architecture in the context of repair and how this could be solved and that it could give guidance and be a form of proof of correct assessment for the FRI.

The outcomes of the four tests in the previous chapter show how much potential use of repair scoring tools, early in the design process, can have on the physical product characteristics which enable repair. As the bottlenecks of two products that were assessed while still being in the early phases of product development will be resolved. This means that two new products in the Philips portfolio will become much easier to repair, in terms of the FRI.

6. Conclusion

This thesis set out to answer the Main research question
'How repairable are Philips cordless vacuum cleaners and how could this be improved?'

The answer to this question was found by answering four sub research questions

RQ1 How is repairability currently assessed in Energy related Products?
RQ2 What are current regulations and policy on repair for cordless vacuum cleaners in the European Union and what is to be expected in the future?
RQ3 How do the current cordless vacuum cleaners of Philips score in terms of the most important repair regulation?
RQ4 How can the French Repairability Index scores of these products be improved?

In two different repairability assessments, one using the Disassembly Map and the other the second Category of the French Repairability Index, Philips cordless vacuum cleaners were scored on their repairability and both assessments gave different results.

Using the Disassembly map the Speed Pro was perceived to have an average repairability while the Speed Pro Max was perceived not easy to repair. While using the FRI assessment method the Speed Pro Max scored a 6,65 and the Speed Pro a 5,45.

Both asessments however showed that the cordless vacuum cleaners of Philips were not the most repairable compared to their competitors. This was mainly due to the high amount of disassembly steps needed to obtain priority parts. Or in terms of the Disassembly map, their maps were large and vertical disassembly sequences were long. Both products use snapfits as fasteners for their side panels, these fasteners break often and decrease overal repairability.

The Speed Pro can be improved in terms of repairability by surfacing the motor, battery and PCBA and excluding or replacing snapfits with reusable fasteners.

The Speed Pro Max can be improved in terms of repairability by surfacing the motor and PCBA and excluding or replacing snapfits with reusable fasteners.

7. Reccommendations

Based on the findings in this thesis, the following reccommendations are given:

To Philips and other manufacturers of cordless vacuum cleaners
Based on the rapid introduction of the French Repairability Index it is reccommended to include requirements on repair and disassembly in the development process of future products. Interviews with designers showed that requirements are very powerful when it comes to implementing strategies in the design of products. These requirements would need to be short, clear and based on the most influential future repair regulations. Introducing a requirement like: 'Priority parts must be obtainable in five disassembly steps or less' will lead to revolutional repairable new designs and ensure high FRI scores.

It is also advised to use sustainability, and in this case repairability, assessment methods as early as possible in the design process. In these stages changes can still be made to the design without bringing hours of work and large costs with it.

To ADEME, the creators of the French Repairability Index
Using the French Repairability Assessment it was found that the definitions and instructions in Category 2 are quite unclear. Currently too many assumptions need to be made, which are not clearly enough described in the FRI manual, which leads to a high deviation among assessment results. The definitions and instructions of the FRI need to be detailed per product category in order to make the French Repairability Index reliable on national and European scale. In Chapter 4 this has been addressed and suggstions for improvement have been given.

The most important reccomendations have been summarised here:

- Provide more information on the details for criteria 1 of category 2 'Ease of disassembly'. What are exceptions for this criteria per product category?
- Provide more information on the definiton of a component. Do very small components also count as full disassembly steps or can these be neglected?
- Shift part of the scoring weight from criteria 1 to criteria 3 as the current situation encourages destructive disassembly.
- Offer a supporting system that helps with generating the input for category 2 which at the same time can work as proof of correct assessment.
- Introduce criteria that assess the ease of re-assembly
- Use logical ranking systems. Use 'A' for the best case scenario and 'D' for the worst case scenario

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Appendix

I

Philips Speed Pro Max Disassembled

Component List

1. Tube
2. Nozzle
3. Bucket
4. Handheld assembly
5. Battery
6. Switch handle panel
7. Rubber button
8. Button sheet
9. Exhaust Grill Cap
10. Motor & PCBA assembly
11. Side panel left
12. Side panel right
13. Handle grip
14. UI Panel
15. Inner exhaust gril assembly
    15 a. Visual
    15 b. Inner visual cap
    15 c. Inner sound reflector
16. Handhelt inlet
17. Nozzle base
18. Nozzle assembly
19. Nozzle tube panel
20. Nozzle top panel
21. Nozzle brush assembly
22. Nozzle clear cover
23. Nozzle tube
24. Active Nozzle assembly
25. Active Nozzle belt
26. Nozzle corner panel 1
27. Nozzle corner panel 2
28. Nozzle wheels
29. Nozzle motor
30. Nozzle PCBA
31. Filter
32. Nozzle corners small 1
33. Nozzle corners small 2
34. Nozzle front ridge

II Philips Speed Pro Disassembled

Component List

1. Handheld assembly
2. Bucket
3. Handle slider panel
4. Handle panel
5. Panel left
6. Panel right
7. Frame
8. Motor assembly
9. Battery
10. PCBA
11. Nozzle subassembly
12. Tube
13. Clear front ridge
14. Top cover
15. Brush
16. Active Nozzle motor belt
17. Motor Axis 1 + 2
18. Active Nozzle PCBA
19. Nozzle Motor
20. Nozzle Motor assembly
21. Nozzle Clear top panel
22. Rear cover
23. Nozzle tube

Dyson V11 Disassembled

Component List

1. Bucket
2. Filter
3. Bucket shoot
   4a. Handhed subassembly
4. Inner filter cannister
   5a. Cyclone assembly
5. Cyclone mesh
6. Cyclone bottom
7. Ring
8. Flower assembly
   8a.Flower bottom
9. Flower middle
10. Flower top
11. Flower stem
12. Red seal
13. Grey seal
14. Battery
15. Motor
16. Tube
17. Nozzle
18. Handheld
19. Nozzle assembly
20. Brush
21. Bottom part felt
22. Active Nozzle assembly
23. Active Nozzle assembly top
24. Active Nozze assembly cilinder
25. Top panel
26. Bottom panel
27. Clear cover
28. Switch pressure button
29. Nozzle Front ridge
30. Motor cover

VI Miele Triflex HX1 Pro Disassembled

Component List

1. Battery
2. Dust bucket
3. Front panel
4. Ring panel
5. Side panels
6. Brush cover
7. Motor
8. Handheld
9. Filter
10. Tube
11. Nozzle assembly
12. Nozzle motor
13. Top cover
14. Brush
15. Active Nozzle assembly
16. Active Nozzle background
17. Active Nozzle panel
18. Motor rubber
19. Active Nozzle belt
20. Active Nozzle belt 2
21. Nozzle motor
22. Handheld PCBA

IV

Rowenta Air Force 560 Aqua Flex Disassembled

Component List

1. Handle cover part
2. Nozzle part 1
3. Nozzle part 2
4. Rear embodiment part
5. Top embodiment 1
6. Top embodiment 2
7. Nozzle tube 1
8. Tube
9. Motor rear embodiment
10. Motor
11. Bucket
12. Battery
13. Battery embodiment
14. Handle lid
15. PCBA
16. Rubber component
17. Battery assembly
18. Handheld assembly
19. Brush cover
20. Tube
21. Nozzle assembly
22. Nozzle body
23. Clear cover
24. Wheels
25. Brush cover 2
26. Bottom panel
27. Nozzle top cover
28. Nozzle brush
29. Active Nozzle assembly
30. Active Nozzle belt
31. Nozzle motor
32. Switch pressure button

V

Bosch Unlimited Serie 8 Disassembled

Component List

1. Dust bucket
2. Top panel 1
3. Top panel 2
4. Top ring
5. Side panel 1
6. Side panel 2
7. Mirrored casing parts
8. Switch assembly
9. Motor assembly + PCBA
10. Filter
11. Battery
12. Tube
13. Nozzle
14. Active Nozzle belt
15. Nozzle tube assembly
16. Clear top cover
17. Top cover
18. Brush
19. Small top panel part
20. Active Nozzle belt
21. Active Nozzle axis
22. Nozzle motor

VII

Transcribed interviews

Assessment test 1
Question: Did you find it easy to make an assessment?

What I had to fill in was clear. But especially to find out how many disassembly steps were needed was difficult in my opinion.

Question: What did you use or do to find these Disassembly steps?

Watch the Disassembly video a lot of times. And take notes where the steps ended. I found out later that in the Annex there was a better explanation of the definition of the disassembly steps. First I did not understand this well. It was good to read up on this halfway during the test. I wrote down all the steps in short words, like 'Philips screwdriver' or ' a component is going away', ' screws are extracted'. I had a feeling about what a disassembly step was, I thought that putting away a tool and using your hands would be a step but that wasn't the case. So later I took those steps out.

Question: Do you think you generated a reliable score?

I think I did! I could always make more steps of it. In the video a pincer was used, but this was not necessary so I did not count it as a step. If I would have to give proof I would make a manual with pictures that are more clear and put emphasis on the end of a step, something like that.

Assessment test 2

Question: Did you find it easy to make an assessment?

I thought it was doable. It is easy but you need to understand everything very well and you need to research it very well. I first looked at all the information and then went into the details. There are a lot of rules on what a disassembly step is and what is not. The combination of the video and the manual, which is not super clear, I used to form these steps. There are a lot of exceptions and things that are not intuitive.

Question: What did you use or do to find these Disassembly steps?

I made notes. And I first read the whole manual because I find this important. Like when setting up a tent, I want to know what is coming. After this I watched the disassembly video. After that I read the definition of a disassembly step and I did not really understand it. After that I thought I understood the definitions and I watched the video again. I wrote down what I saw in the video and at the same time tried to number the steps. I would pause the video in between.

Question: Do you think you generated a reliable score?

I now see that I forgot to add a step.. I think I could defend my assessment with my notes and I think that all the information is in my notes. I am definitely sure about the tool rating that I did. I am also pretty sure about my assessment of the reusability of fasteners because I watched the video closely.

Assessment test 3

Question: Did you find it easy to make an assessment?

You really have to understand well how the Disassembly Map works and how it is put together. But also how the product works and how it is taken apart. If you are the designer of the product you probably have a much better knowledge about the build-up. I could fill in the excel very quickly after I made the Disassembly Map. Since I could easily read all the information that I needed from the Miro map. You can count steps very quickly. Without the Miro I would have tallied them? But you need extensive knowledge on how the product is built up to do so.. Calculating disassembly steps without a visual overview is very complex.

Question: What did you use or do to find these Disassembly steps?

I first made a Disassembly Map and after that I filled in the Excel. I found it hard to understand that a tool change is also a disassembly step and not just extracting a component. I added descriptions of the component in the map because I did not like looking at the component list and number each time. I don't know how I would have found the disassembly steps if I did not have the Miro tool, then I would have needed to make my own method and first think about how I would have done that. The boxes in the Miro made it clear for me what a disassembly step was.

Question: Do you think you generated a reliable score?

I think I did but I don't know how they would check it. Who is going to check my assessment and understand the product on the same level that the designer does? It will be easy to cheat with in my opinion. I think that if my score would be checked the government would also need instructions on how to read the Disassembly Map.

Assessment test 4

Question: Did you find it easy to make an assessment?

Looking back on it now it is easy. But you first had to understand how the framework of the Disassembly Map was set up. The excel sheet was very limiting, you could not detail your answers, it is very straight forward. In the fasteners I thought you have to look at component level. But the problem lies in the parts in between the components. But you can't say that in the sheet. If you have a visual overview, like the Miro map, you can easily fill in the excel.

Question: What did you use or do to find these Disassembly steps?

First I needed to understand what the product build up was like to make the Disassembly Map in Miro. After that I quickly filled in the FRI excel. Without the map I would have needed to make my own method before I could fill in the excel, I don't know how I would have approached that.

Question: Do you think you generated a reliable score?

I think that each assessment will be different based on the person that is making it. I can imagine that someone else has made a very different map. I know how to defend my assessment because I have the Miro map, I can explain my choices with it. It gives me support. There are so many personal interpretations and assumptions that I have made in my assessment. If the French government would provide a tool like this with the assessment sheet then at least everyone would be using the same method that then could be compared. I think that would lead to more honest ratings. I would use my Miro as proof and also provide a disassembly video to check for the authorities. If I could use this together with other colleagues we could better discuss because we are using the same tool. And if we use it together the results would probably become more reliable.

VIII Notes usability test 1

DEFINITIONS

FRENCH REPAIRABILITY ASSESSMENT PHILIPS SPEEDPRO MAX

① disassembly sequence:
order of steps needed to remove part from product

② STEP:
operation that finishes with the removal of a part or a component, and/or with a change of tool.

③ component (Part):
may include one or several parts

! STEP COUNTING

✓
removal of part
removal of subset
change of tool
unplug equipment of mains
↳ assume this is the case

✗
grab tool
put tool down (hand & fastener are not tools)
remove fastener

Steps required to disassemble parts | TOOLS | FASTENERS

BATTERY: 3 STEPS

1. Disconnect from mains
2. Removal of bucket part
   - Grab tool Philips #1 Screwdriver
   - remove 3 screws P
~~3. change tool to flat screwdriver~~
~~4. remove U2 panel by lifting it up w/ flat screwdriver~~
~~3. remove battery by moving it backwards~~
~~3. change tool to small flat screwdriver~~
3. remove battery ~~by using small flat screwdriver to unclick battle panel,~~ ~~lift up battery~~ by moving it backwards.

IX Notes usability test 1

MOTOR : ~~8~~ 12 STEPS

- grab flat screwdriver

1. remove handle panel by lifting it up with small flat screwdriver
2. change tool to Philips screwdriver
   - remove screw E
3. remove UI panel by lifting it up from PCB
   - grab tool philips screwdriver
   - remove screw F on top of exhaust grill
4. change tool to flat screwdriver
5. remove rubber part (friction interface) with flat screwdriver
   - ~~remove sc~~
6. change tool to philips screwdriver
   - remove screw G under rubber part (and screw cone)
7. remove exhaust grill with hands
8. remove visual cap ~~cover with hands~~ with hands
9. remove ~~sound reflector~~ visual cap inner with hands
10. remove sound reflector with hands
11. remove exhaust filter with hands
    - grab tool philips screwdriver
    - remove 2 screws H
    - remove 2 fasteners: disconnect 2 small connectors from PCB
    - grab tool flat screwdriver
    - ~~detach~~ unstuck PCB by lifting it if contact with flat screwdriver
    - remove fastener: disconnect battery connector by pushing with thumb on backside of PCB and...
    - grab tool: flat screwdriver
    - lift with flat screwdriver
12. remove motor away

PCBA: 4 STEPS

step 1-3 from MOTOR removal < philips screwdriver: 2 screws with philips screwdriver / flat screwdriver

- remove 2 fasteners: disconnect 2 small connectors from PCB.
- grab tool flat screwdriver
- unstuck PCB by lifting it if contact with flat screwdriver
- remove fastener: disconnect battery connector by pushing with thumb on backside of PCB and...
- grab tool: flat screwdriver

X Notes usability test 2

~~battery~~ PCBA & motor

1. bucket
2. schroevendraaier (philips → special)
   → schroeven eruit → batterij met 1 stap eruit
   ↳ extra
3. platte schroevendraaier
   → panel eraf
4. schroevendraaier (ph)
   → plaatje los (maar niet verwijderd) → later wel
5. zelfde schroevendraaier (ph)
   → schroefje los
6. platte schroevendraaier
   → rubber los (met ligm?)
7. ph schroevendraaier
   → schroefje los
   ↳ onderdeel eraf (achterkant)

(8.) ↳ onderdeel los (2x subret?)

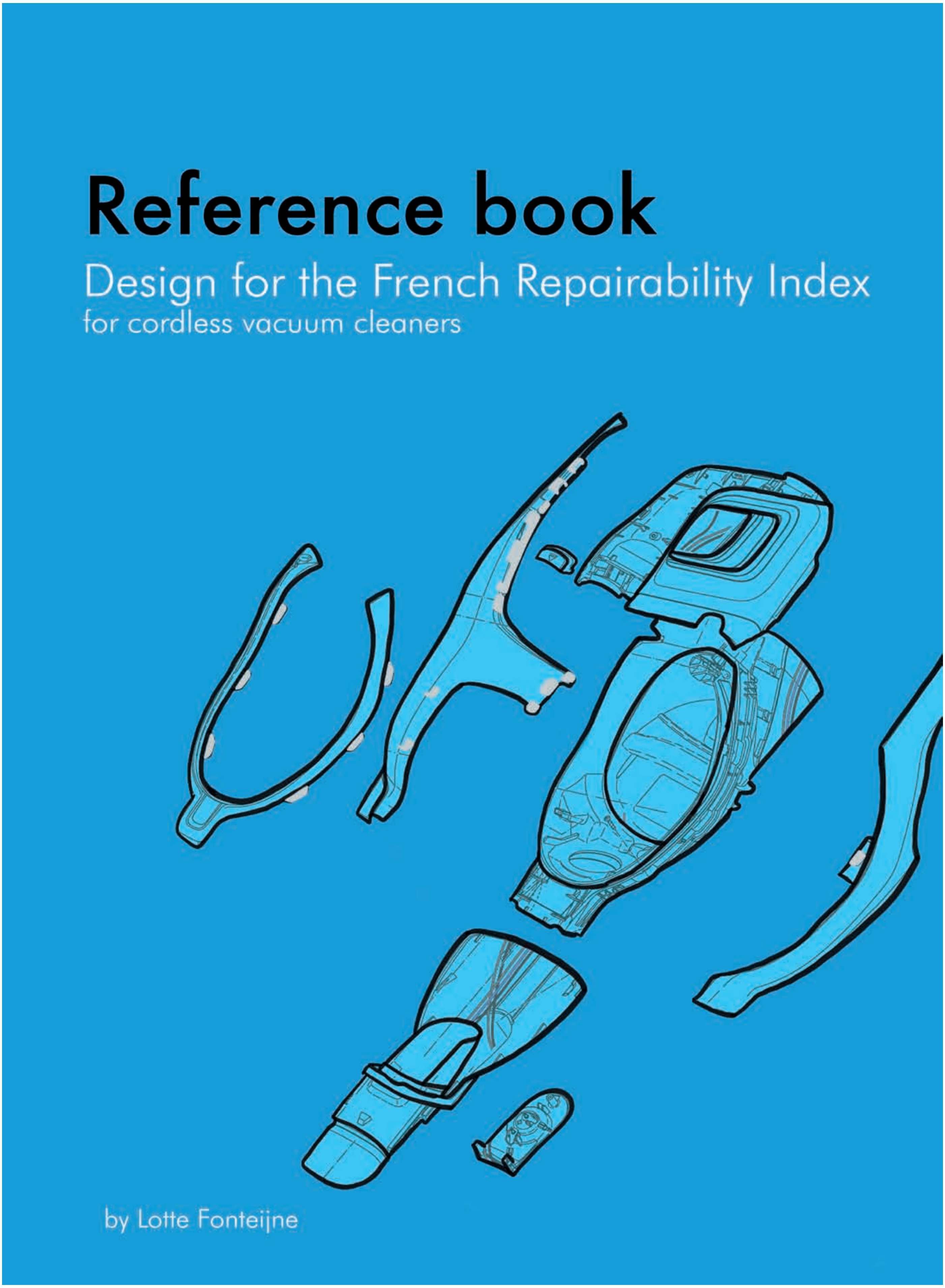
8. schroevendraaier (ph)
   ↳ 2 schroefjes los

(9) wissel gereedschap → stekkers los

10 platte schr. dr.
   → PCB eruit
   + motor

~~knoppen?~~

XI Reference book



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2. Priority parts 4
3.1 FRI guidelines for design processes 5
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Introduction

This booklet was created with the goal of providing guidelines to achieve a high French Repairability Index score for cordless vacuum cleaners. These guidelines only consider the physical characteristics, in terms of the FRI, of a product. It's contents were summarized from the findings of a case-study on the repairability of six cordless vacuum cleaners. The guidelines are best used by designers of (cordless) vacuum cleaners in the early stages of the development processes, when fasteners and product architecture are not definitely defined yet.

- **The first part gives insight on what approaches can be taken to design for repairability**
- **The second part explains what priority components are and how they can be defined.**
- **The third part describes design guidelines for FRI in four categories:**
  - Design process
  - Product architecture
  - Fasteners
  - Product specific criteria

1. How the FRI measures repair

Since the Industrial Revolution, Western societies have been adopting a single use, throw-a-away culture. Research has even shown that the lifetime of electric and electronic consumer goods has been decreasing in the last decade (Bakker, C., Wang, F., Huisman, J., & Den Hollander, M. (2014). As a reaction designers, users and repairers of consumer goods have been trying to battle this development. Design for repair is a promising strategy for this problem and is an example of how product lifetime can be extended.

In 2021 the French government adopted the French Repairability Index (FRI), a repair scoring framework which generates a score for five groups of Energy related Products (ErP's). In 2022 the legislation will become active for (cordless) vacuum cleaners and there is a chance of the FRI being extended to a European level. Understanding how to design repairable products, which grant high FRI scores is therefore of high importance. More information on FRI, the assessment sheet and instructions for assessment can be found on their website: www.indicereparabilite.fr

Before products can be improved and become more repairable, we need to define how repairability is measured in the FRI. The French scoring framework uses five categories in which many different criteria are considered. The guidelines described in this booklet only touch on four criteria that affect the physical characteristics of cordless vacuum cleaners.

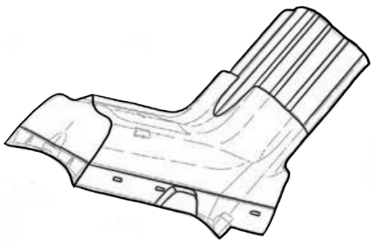
FRI criteria that score physical product characteristics:

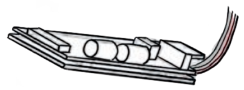
- Amount of disassembly steps to obtain priority parts
- Types of tools needed to obtain priority parts
- Re-usability of fasteners
- Product category specific criteria, determined by the FRI

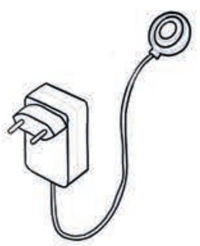
Priority parts

At the moment of writing this booklet (August 2021), the priority parts for cordless vacuum cleaners are not yet defined for the FRI. This list will be made public before the start of 2022. Priority parts or priority components are the most important parts of a product to consider when it comes to service, repair and upgrade. The most important components for repair need to be easy to extract and replace. The EN 45554 states that : "It is necessary to prioritize parts because not all will be equally relevant to repair, reuse, or upgrade. The parts that have been prioritized are considered priority parts".


Motor


Battery


Printed Circuit Board


Battery charger


Active Nozzle motor


Active Nozzle motor belt


Switches


Nozzle


Tube

FRI guidelines
for the design process

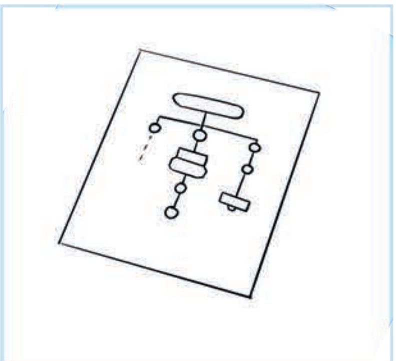
The priority parts of a cordless vacuum cleaner should be easy to reach and replace. This can be achieved through the product's architecture and smart use of fasteners. But first the following three steps need to be implemented in the design process.

1. Determine the priority parts

If the list of priority parts is not already provided by the FRI a preliminary list needs to be made. This can be done by looking at a similar product group that is already active in the FRI and looking at literature on the topic. For cordless vacuum cleaners the list on the previous page can be used.

2. Define requirements for Disassembly steps and fasteners

A maximum amount of disassembly steps should be set for each priority part. By doing this boundaries are set and can be evaluated at the end of the design process. The same should be done with the degree of reusability of fasteners and the types of tools needed for the disassembly. It should be opted to only use fasteners that are reusable and removable and basic tools (see EN 45554 for the list of tools that are defined as basic).



3. Choose a validation system

User tests in the master thesis 'Improving repairability in cordless vacuum cleaners' have shown that a system is needed to correctly assess disassembly steps, types of fasteners and tools. The Adapted Disassembly map in Miro can be used for this (found here: FIXME) or a different system can be created.

FRI guidelines

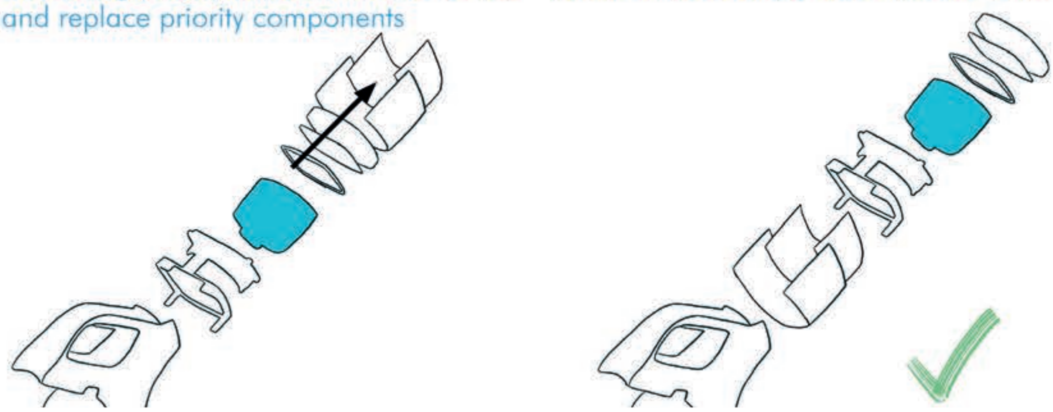
for product architecture

The goal is to create a product architecture that requires the least amount of disassembly steps (or the number previously defined in the requirements) to obtain the priority parts. The least amount of disassembly steps results in the highest FRI score for this criteria. A disassembly step is defined by the FRI as "an operation that finishes with the removal of a part, and/or with a change of tool". Fasteners and connectors are not seen as parts and hand aren't considered to be tools.

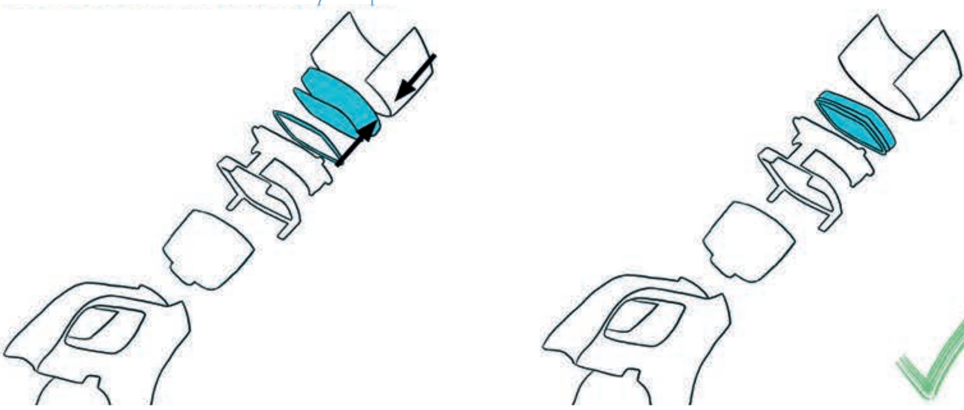
When a priority component is located deep in the product it means that many actions need to be carried out to reach the product. Not only does this increase the amount of disassembly steps but also the risk of fasteners and components breaking during the repair.

The following product architecture strategies improve repairability and FRI scores:

- **Surfacing** priority parts can decrease the amount of disassembly steps needed to reach and replace priority components



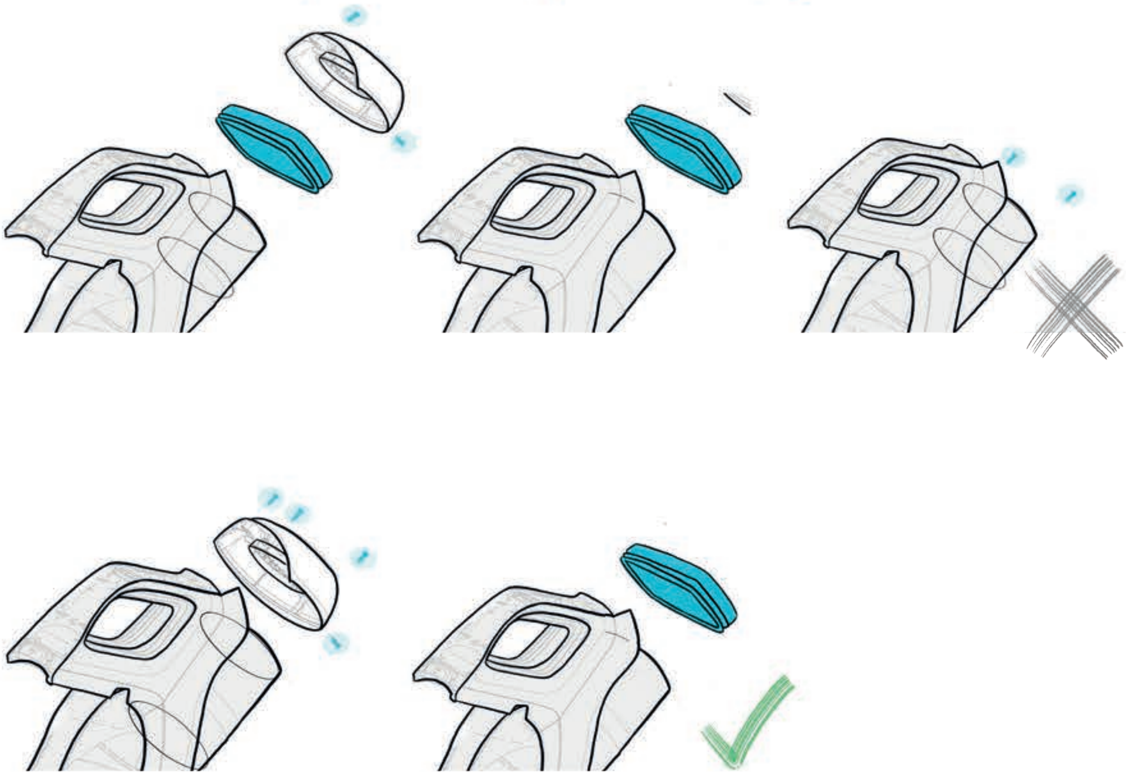
- **Clumping** parts together and creating subassemblies can help surface priority parts and decrease disassembly steps



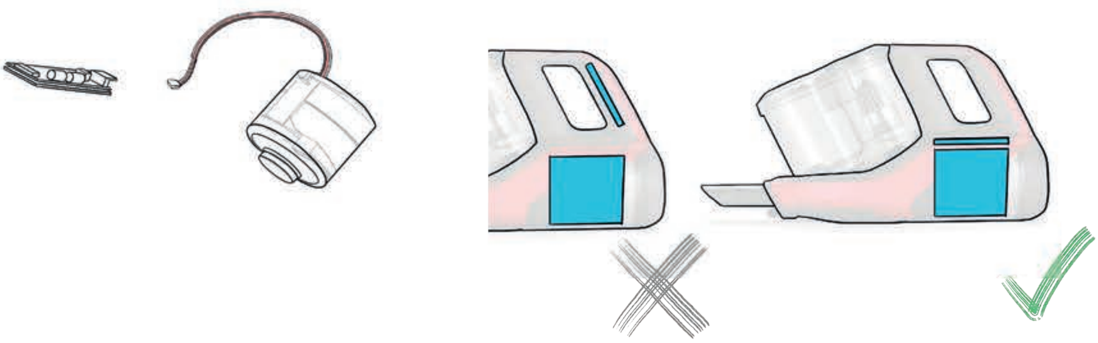
6

FRI guidelines
for product architectur

- **Levelling** of the same type of fasteners, like the same type of screw, can decrease the amount of disassembly steps needed to obtain a priority part. The example below shows how two disassembly steps being decreased to one by bringing four screws together on the same level in the product architecture. This is only valid when the next action would be use of another tool. In which case it should first be tried to use the same type of fasteners. See the example for standardizing of fasteners on page 8.



- Making priority parts **seperable** from each other improves non destructive disassembly. Or place priority components close to each other to decrease disassembly steps.

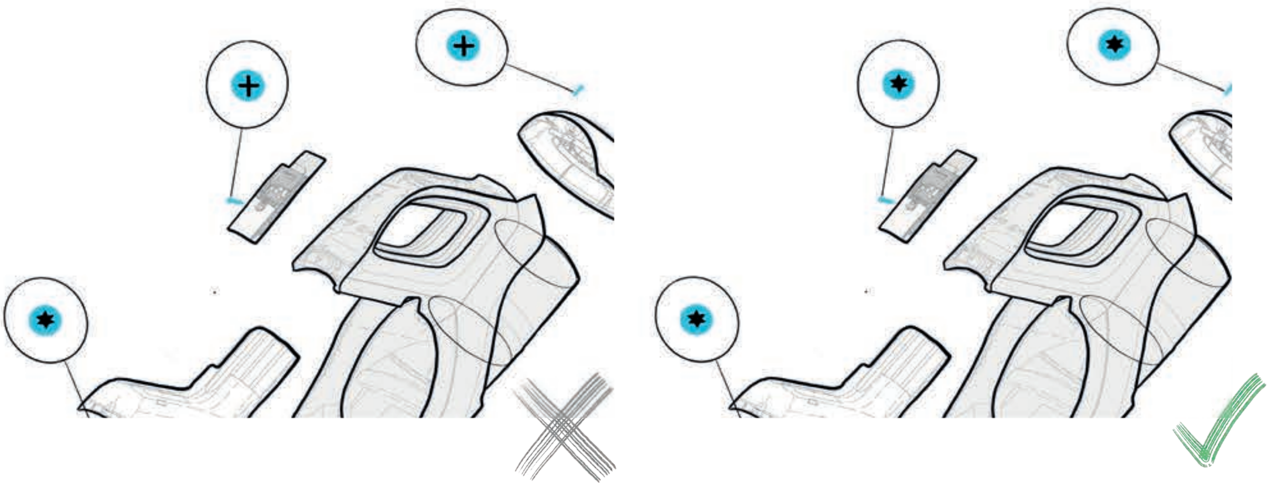


FRI guidelines
for fasteners

Fasteners have a large influence over the repairability of a product. They influence the time that it takes to reach and replace priority components but they also influence (non-) destructive disassembly and reassembly. To test if fasteners are suitable for repair they should be tested during disassembly and reassembly. By limiting the different types of fasteners in a product, repair time decreases. It is advised to only use fasteners that can be undone by using 'basic tools' which are defined in EN45554. The types of fasteners that are used most often in cordless vacuum cleaners are: screws, adhesives, snap fits and friction fits

Screws are highly effective for non-destructive and successful repair. They have a high reusability. Trade offs are higher cost compared to snap or friction fits and more notable in the design compared to snap or friction fits. Different types of screws should be limited in design for FRI as a different screwhead would need a change of tools, which adds to the amount of disassembly steps.

- Standardizing fastener types so no tool change needs to occur, decreasing the amount of disassembly steps



Use of adhesives in cordless vacuum cleaners is discouraged when designing for repair and FRI. They tailor seamless design but have many trade offs. Most adhesives are non removable or reusable is and when adhesives can be softened this time process is intensive.

8

FRI guidelines
for fasteners

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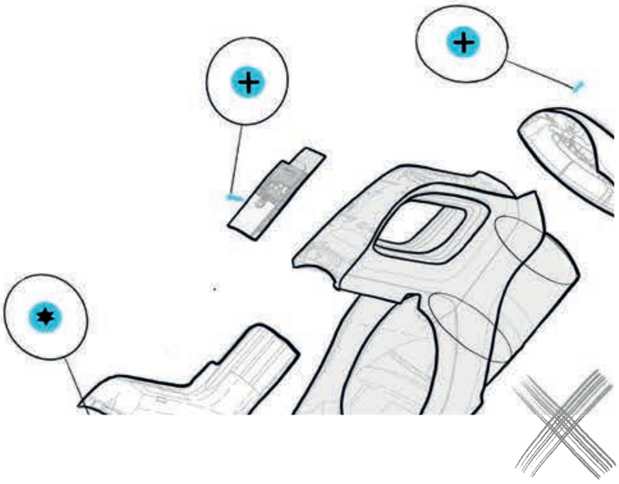

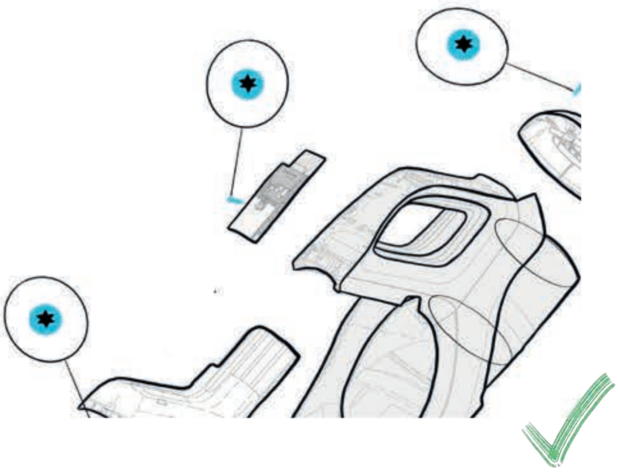

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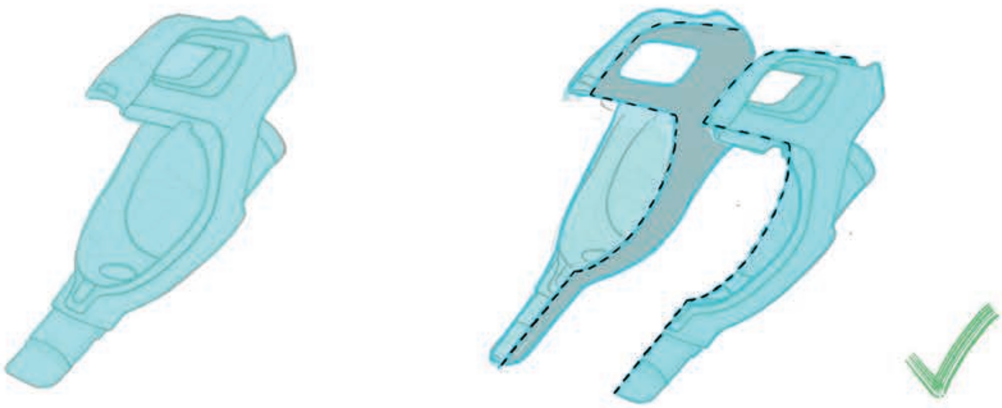
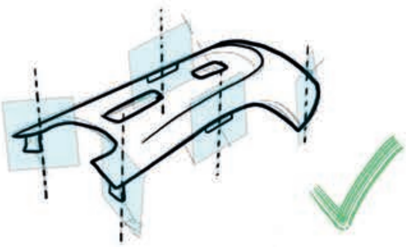
FRI guidelines
for fasteners

Snap fits and friction fits can be successful fasteners in disassembly and reassembly processes. But when these fasteners are not designed for non-destructive disassembly they can warp, bend and break. This often has the result that a new component is needed for the repair. The success of these fits depends on their shape, the type of material they are made of, what kind of motion is needed to undo them and how easily they can be used in reassembly. Since new snapfits always need to be designed 'from scratch' (Sodhi, R.S., 1999) it is crucial to test these fasteners for successful dis- and reassembly.

- Use mirrored outer casing parts with screws instead of one piece casings to avoid snapfits



In the case study it was found that the use of snapfits with different directions of extraction on a component increase the risk of them breaking or warping during disassembly. It is therefore recommended to place snapfits in such a way that they share a plane in which they need to be moved for disassembly.

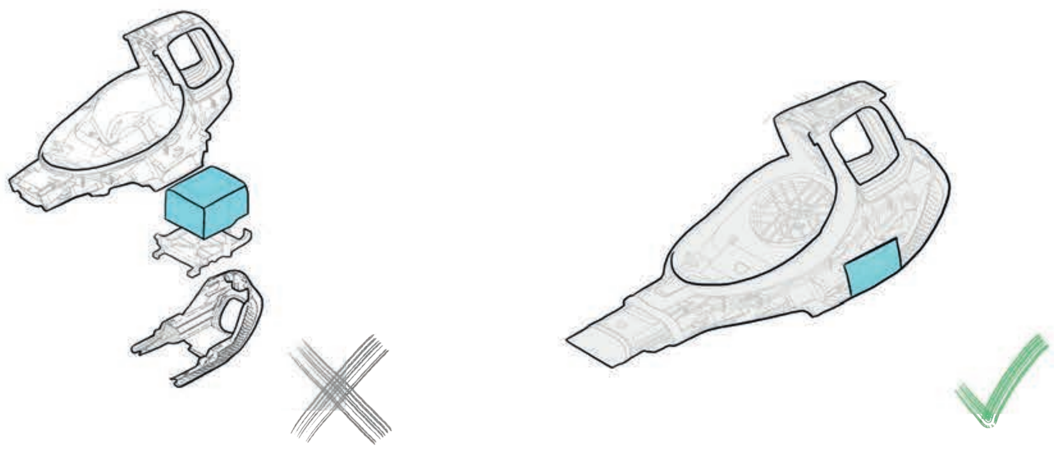


9

FRI guidelines
for product specific category

The fifth FRI category scores criteria that are product group specific. At the time of writing this manual these criteria are still unknown. The product category that is already active and most similar to that of cordless vacuum cleaners is the product category of battery powered lawnmowers. For this group the criteria in the fifth category that is scored on, is use of a multi-product battery. The Bosch Unlimited Serie 8 cordless vacuum cleaner has such a battery, which can be also used on power drills and other appliances. A first step towards multi product batteries being possible is to:

- Place the battery outside the casing makes it easier to extract and replace and gives opportunity for multi-product batteries.



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