PHILIPS

TU Delft

Enhancing consumer product repairability

a case study on vacuum cleaners

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Master Thesis
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Executive Summary

The European Commission pointed out in 2015, with "An EU action plan for the Circular Economy", the importance of energy and resource preservation, by respecting Earth's resilience and renewability (European Commission, 2015). A transition towards Circular Economy is necessary in this sense to create new sustainable advantages, protecting businesses from future potential resource scarcity and boosting the economy. In order to enable this transition, the way products are designed must change by taking into account product life-extension, reuse, refurbishing and recycling.

In recent years, Philips has expressed a growing interest in circular economy, becoming global partner of the Ellen MacArthur foundation (Ellen MacArthur Foundation, 2017), and setting the target "Healthy people, sustainable planet", committing itself to reach 15% of turnover coming from solution respecting circular principles by 2020 (Philips.com, 2016). This pushed the company to investigate the current state of their product portfolio and new ways of designing consumer goods. In this sense, product repairability and disassembly represent some of the most important design requirements in order to enable circular business models.

Carried out in collaboration with the company, this research project practically investigates design features which influence positively and negatively product repairability, eventually proposing new design guidelines and methodologies for design for repairability and product retirement.

The European Commission Joint Research Centre released in 2019 a Scoring Assessment System for Repair and Upgrade of Products (Cordella et al., 2019). This system has been applied on seven consumer products, part of the vacuum cleaners product group, assessing more than 260 disassembly operations.

Firstly, insights gathered during this analysis have resulted in a list of practical design recommendation for the manufacturer and remarks on the assessment system itself.

Additionally, a new design tool for product architecture mapping, called Disassembly Map, was created. This is an effective method to represent the architecture of a product, showing disassembly depth of all the product components and the intricate logic connections which link them to each other. The most important components for product repairability and retirement are spotted using special indicators, guiding the attention of designers towards these products' "hot-spot".

This design tool, together with the insights collected from the repairability assessment, were tested by redesigning a representative consumer product, together with the Philips I&D department. During this process, the following design methodologies have been explored:

- Redesign for disassembly time optimization through clumping methodology
- Redesign for hotspot components accessibility through bottom-up assembly
- Redesign for legislation compliance and use of common tools
- Redesign for sequential independent disassembly and safer self-repairs

The results achieved convinced the manufacturer to define together new serviceability design requirements, which will be implemented in the development of future Philips canister vacuum cleaners.

This research concludes suggesting new assessment values for a discrete rating system of canister vacuum cleaners, which could be used by the European Commission Joint Research Centre for possible future iterations of the Scoring System for Repair and Upgrade of Products.

List of Abbreviations

CE	Circular Economy
CRP	Consumer Repair Part
CTN	Commercial Type Name
DfD	Design for Disassembly
DfPR	Design for Product Retirement
eDIM	ease of Disassembly Metric
EoL	End of Life
ErP	Energy related Products
ERC	European Repair Center (Trier)
FC	Floor Care
JRC	Joint Research Centre
LCA	Life Cycle Assessment
MOST	Maynard Operation Sequence Technique
OEMs	Original Equipment Manufacturers
PH	Personal Health
PCBA	Printed Circuit Board Assembly
RRU	Repair Reuse Upgrade
Vc’s	Vacuum Cleaners

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1. Introduction

Objectives, definitions and process

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1.1 Problem statement and research objectives

Problem statement and parts involved

The European Commission pointed out in 2015, with "An EU action plan for the Circular Economy", the importance of energy and resource preservation, by respecting Earth's resilience and renewability (European Commission, 2015). A transition towards Circular Economy is necessary in this sense to create new sustainable advantages, protecting businesses from future potential resource scarcity and boosting the economy. The intention to define new guidelines and legislations to facilitate CE initiatives throughout the Union was presented, and specific attention was dedicated to product design, as an important tool to increase product durability, enhancing repairability, upgradability and re-manufacturing. The idea of new labelling systems supporting these design aspects was introduced and supported further in the Ecodesign Working Plan 2016-2019 (European Commission, 2016). Since then, different studies have been carried out concerning the assessment of product repairability, meant to define standards, protocols and scoring systems that can both help to create a new labelling system and to guide the redesign of more durable consumer products.

The following report describes an extensive research carried out by TU Delft in collaboration with Royal Philips.

Philips

In recent years, Philips has expressed a growing interest in circular economy, becoming global partner of the Ellen MacArthur foundation (Ellen MacArthur Foundation, 2017), and setting the target "Healthy people, sustainable planet", committing itself to reach 15% of turnover coming from solution respecting circular principles by 2020 (Philips.com, 2016). This guided initiatives such as refurbishing solutions for MRI systems (Philips Healthcare, 2014) and use of recycled material for the production of some consumer products (Philips.com, 2017). Moreover, the Philips Consumer Care department started in January 2018 a big refurbishing program, called "5R program", which aims to refurbish 4000 consumer product units a month (Eric Marco, Head of Network Global, Consumer Care).

TU Delft

Circular Product Design (CPD) is a research area of the Design Engineering department of the TU Delft Industrial Design Engineering faculty. The research team strives to explore new design strategies for circular economy, investigating business models related to product life extension, reuse, refurbishing and recycling (Bakker, 2019). The ultimate goal is to create new tools and design methodologies to guide the design of products beyond the traditional single life-cycle.

Research objectives

Philips project objectives were:

- Assessing product repairability and upgradability of a representative selection of products from the Philips Personal Health product portfolio
- Defining design guidelines to enhance their current state
- Determining the possible economic impact of enhanced product repairability on the company business.

TU Delft project objectives were:

- Investigating design features which can enhance product repairability
- Defining new guidelines or methodologies to enhance product repairability

Based on the mutual interests expressed by the university and the company, the following six research objectives have been defined:

- **RO.1 Identifying design aspects which most influence product repairability**
- **RO.2 Determining how much repairable Philips consumer products currently are**
- **RO.3 Comparing different product architectures, identifying the most optimised structures for product repairability and upgradability**
- **RO.4 Identifying design aspects which might obstruct product repairability**
- **RO.5 Defining and testing new guidelines or methodologies that can guide designers in the design for product repairability**
- **RO.6 Investigating the economic impact that enhanced repairability might determine for the manufacturer.**

Disclaimer

This project was co-financed by Royal Philips.

1.2 Definitions

Repairability

Multiple definitions of repairability can be found in literature. The CEN-CENELEC defines repairability as "the characteristic of a product that allows all or some of its parts to be separately repaired or replaced without having to replace the entire product" (CEN/CLC TC10 European Standard, 2017). The European Commission Joint Research Centre defines repairability and upgradability as "the ability to restore functionality of a product after the occurrence of a fault, and the ability to enhance the functionality of a product, meant to prolonging the lifetime of products" (Cordella, Alfieri, & Sanfelix, 2019). Repairability and upgradability can refer to one or more parts composing a product, which can be either hardware or software (Cordella, Sanfelix, & Alfieri, 2018). To this definition time and economic factors can be added with the definition proposed by Flipsen et al. (2016): "repairability is the ability to bring a product back to working condition after failure in a reasonable amount of time and for a reasonable price".

Disassembly

Disassembly is defined by the prEN 45554 (definition 3.8), as "process whereby an item is taken apart in such a way that it could subsequently be reassembled and made operational" (CEN/CLC TC10 European Standard, 2017). Bracquené et al. (2018) further specify this definition describing disassembly as a "reversible process", where single components are divided from each other in a "non-destructive" or "semi-destructive" operation. In fact, according to Bracquené et al. (2018) and Cordella et al. (2019), partial breakage of fasteners and connectors is acceptable only if their damaging does not obstruct product reassembly and functionalities restoration.

RRU (Re-usability, repairability and Upgradability)

Most of the scoring systems and standard analysed do not consider only repairability, but re-usability and upgradability as well. This is because re-usability and upgradability are strictly related to product repairability, representing two additional factors necessary to repristinate the serviceability of an item, extending product life. Moreover, the conditions which determine higher repairability often influence positively also re-usability and upgradability.

Priority parts

Modern products, in particular Energy-related products (ErP), are usually composed by many different parts. However, just some of them are the most likely to fail or to be damaged during usage, consequently compromising product serviceability. The prEN 45554 defines priority parts those components more prone to be repaired, reused, replaced or upgraded for a determined product group. Bracquené et al. (2018) added to this definition the concept of "product service life" and "desired function", specifying that: "priority parts are components most likely to be repaired or replaced during normal service life of the product and/or parts that are characterized by a high assumed failure rate and/or are critical for the product to deliver the main desired function". Priority parts identified for repairability might be different from those to be considered by analysing refurbishing or recycling processes (CEN/CLC TC10 European Standard, 2017). Priority components are usually defined by functional importance, failure and replacement frequency (Bracquené et al., 2018; Cordella et al., 2019).

Other definitions related to repairability

Other definitions, specified by the prEN 45554 (CEN/CLC TC10 European Standard, 2017), that are used in this research are:

- Disassemblibility (definition 3.7), as "characteristic of a product which can be disassembled in several parts, and subsequently be reassembled (with the same or equivalent parts) and made operational"
- Reusability (definition 3.12), as "characteristic of a product that allows all or some of its parts or the product as a whole to be used again for the same purpose".
- Refurbishing (definition 3.14, in accordance with IEC 62542 definition 6.11), as "functional or aesthetical maintenance or repair of an item to restore to original, upgraded, or other predetermined form and functionality".
- Remanufacture (definition 3.15, in accordance with IEC 62542 definition 6.12), as "production process that creates products using parts from previously used products".
- Serviceability (definition 3.19, in accordance with ISO 4306-1:1990, definition 1.2), as "ability of a product to perform the specified functions".
- Spare parts (definition 3.20), as "part which can replace a faulty, failed or worn-out replaceable part".
- Upgradability (definition 3.21, modified from ISO 14021:1999, definition 3.1.4), as "characteristic of a product that allows all or some of its parts to be separately upgraded or replaced without having to replace the entire product".

1.3 Research approach and design process

Current methodologies concerning design for product repairability

Design for repairability and disassembly is often mentioned in literature related to Product Service System Design, with in-depth analysis of Tukker (Tukker, 2004, 2015; Tukker & Tischner, 2017), Vezzoli (Vezzoli, Ceschin, Diehl, & Kohtala, 2015; Vezzoli et al., 2017) and Bakker (Bakker, den Hollander, Van Hinte, & Zljlstra, 2014; Bakker, Wang, Huisman, & Den Hollander, 2014; Bocken, de Pauw, Bakker, & van der Grinten, 2016). In fact, product repairability and upgradability usually require to set up product service system business models to become more desirable for manufacturers. This has directed the interest of literature, related to circular economy and DFPR, towards a more strategic business-oriented approach and less towards practical product design. For this reason, few concrete design approaches and tools concerning product redesign for repairability and upgradability have been found.

Design guidelines for product repairability and upgradability have been investigated and presented in Chiu and Kremer (2011), who propose an extensive review of methodologies related to Design for Efficiency and Green Design (DfX). Flipsen, Bakker, and van Bohemen (2016) investigated parameters for the assessment of product repairability; their study has been used for the development of some of the assessment systems analysed in the next chapters. However, most of the recent literature presents just general design guidelines and suggestions, usually concerning modular design, parts accessibility and disassembly.

Ishii Kosuke (1957-2009) is one of the few who really developed design tools related to product architecture optimization for product disassembly (Bryan, Eubanks, & Ishii, 1992; Ishii, Eubanks, & Marks, 1993; Ishii, Eubanks, & Di Marco, 1994; Ishii & Kmenta, 1995; Ishii & Lee, 1996; Marks, Eubanks, & Ishii, 1993). In 1992, he developed the graphic method called "Linker", which can be used to represent the architecture of a product, by considering assemblies and sub-assemblies, component relations (also called liaison, Bourjault (1984)), and the product retirement scenarios of different parts. In 1993, he introduced the concept of "clumping", which means grouping the product components based on their EoL scenarios and priority importance. Eventually, in 1996, he developed the "Reverse fish-bone diagram" a graphic tool in aid of design for product retirement (Ishii & Lee, 1996). To this day, this is one of the few graphic tools which designers use in order to map product architecture to improve its disassembly. This method has never been updated since the 90's and it can be quite limited, without fully complying with the latest regulations and researches concerning RRU (Reusability, repairability and upgradability).

Design process

This study was structured upon the following steps (Fig. 1):

1. **Investigation of the most important parameters and design features which influence product repairability and upgradability** (Chapter 2). 11 assessment systems, which partially or fully involve product repairability, have been analysed, following previous researches of Bracquené et al. (2018) and Cordella et al.(2019).

2. **Repairability assessment of seven consumer products, part of the same product group** (Chapter 3 and 4). Four Philips and three competitors' vacuum cleaners (bag canisters, bagless canisters and stick) have been assessed using the JRC scoring system (Cordella et al., 2019).

3. **Assessment results analysis and comparison of different product architectures, identifying the best product design strategies for product repairability** (Chapter 5). Product architectures and design features of different models have been compared to each other, identifying the best configurations to enhance repairability.

4. **Definition of a list of recommendations for the manufacturer based on the products assessment** (Chapter 5). Insights gathered from the product assessment have been combined in a list of design recommendations for the improvement of consumer product repairability.

5. **Creation of a new design tool for architecture mapping and DFPR** (Chapter 6). A new design tool called "Disassembly Map" was developed based on insights gathered from the literature review and the products assessment. This map is a valuable aid to guide designers in the design of repairable and disassemblable products.

6. **Application and testing of the new methodology by redesigning a representative consumer product** (Chapter 7). The Disassembly map tool and the insight gathered from the products assessment have been used for the redesign of a representative Philips consumer product, testing their effectiveness.

7. **Assessment of the redesign proposals in order to objectively quantify the repairability improvement** (Chapter 7). Product repairability of all the redesigns proposed was assessed as well, objectively quantifying the design improvements.

8. **Calculation of the economic impact of the different redesign proposal** (Chapter 7). The economic impact of each redesign has been calculated, considering savings in repair service due to faster disassembly and possible additional production costs determined by the enhanced design.

9. **Definition of new design requirements for the Philips I&D department** (Chapter 8). Eventually, Philips proposed to define new serviceability design requirements for the I&D department. These will have to be respected in the development of future canister vacuum cleaners.

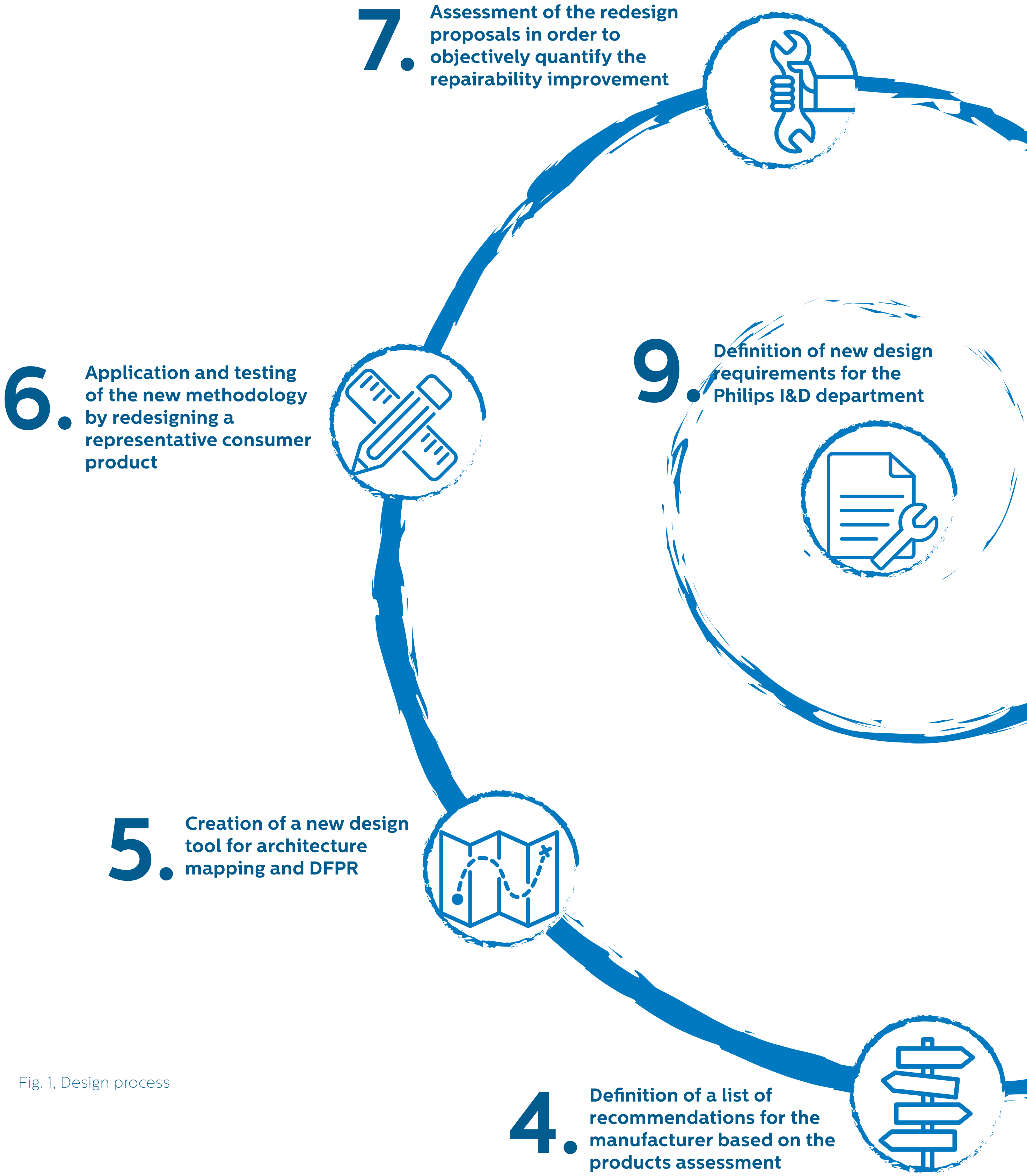
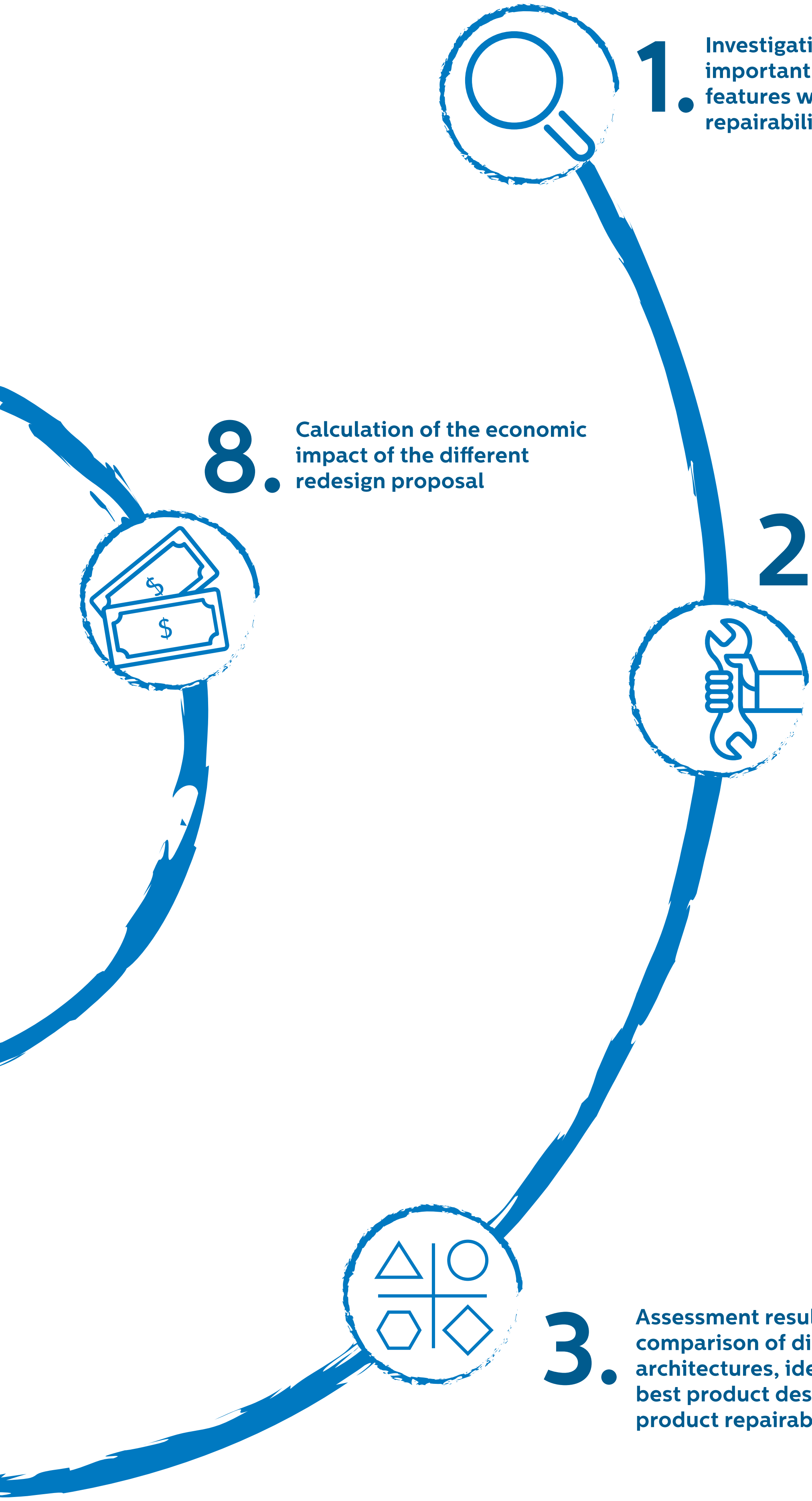


Fig. 1, Design process



1. Investigation of the most important parameters and design features which influence product repairability and upgradability

2. Repairability assessment of seven consumer products, part of the same product group

3. Assessment results analysis and comparison of different product architectures, identifying the best product design strategies for product repairability

8. Calculation of the economic impact of the different redesign proposal

2. Literature review:

Repairability assessment systems

2.1 Introduction

As previously analysed by a recent Benelux study on repairability (Bracquené et al., 2018), there are different existing initiatives related to the environmental performance assessment of energy related products (ErP). Most of them also consider and value the transition towards circular economy, hence repairability is often considered as one of the assessment parameters. These assessment methods can be clustered in three main categories (Bracquené et al., 2018; CEN/CLC TC10 European Standard, 2017; Cordella et al., 2019):

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

This chapter presents the main differences and commonalities among assessment methods already in place for the assessment of product repairability. The scope is to select the most suitable assessment methodology for this research, while still considering insights gathered from this initial wider overview of different methodologies.
This literature research allows to explore the first research objective:
RO.1 Identifying the design aspects which most influence product repairability

2.2 Qualitative assessment systems

Qualitative methods are usually related to a quality labelling system; they consist of a set of criterions, product specific check lists of positive attributes, that has to be satisfied in order to receive a quality label. (CEN/CLC TC10 European Standard, 2017). Bracquené et al. (2018) identified three main labelling schemes that include repairability as one of the criteria assessed and that can be applied to ErP's.

Blue Angel Label

This is a German labelling system, managed by the company RAL GmbH. The set of environmental related criteria has been defined by the Federal Environmental Agency and Independent Environmental label Jury (Bracquené et al., 2018). The assessment system defines specific requirements for different product groups, but repairability is not always included. In particular for vacuum cleaners the criteria considered are performance/durability tests, ease of disassembly, spare parts supply, while Instruction on maintenance/repair, upgradability, priority parts and warranty/guarantee are excluded. The Blue Angel Label takes in consideration spare parts availability and introduce the term "universal tools" (recently further specified by the prEN 45554). It requires quick and easy disassembly, determined by fasteners easily accessible and public availability of disassembly instructions.

Nordic Swan Label

It is an assessment system developed by the Nordic Council of Ministers (Bracquené et al., 2018) with the scope of guiding a more sustainable consumption of products. In this case the eco-impact of the whole product life-cycle is taken in account. The label requirements are reviewed by the Norwegian government every 3-5 years. Currently Vacuum cleaners are not included in the product groups assessed by the label (Nordic Swan Ecolabel, 2019), but it covers other ErP products like White goods, Computers, TV and projectors. Even in this case, different requirements are applied to different product groups. Repair instructions are not required, but ease of disassembly results to be a criterion asked for the ErP's listed before. Contrary to the Blue Angel label, warranty information is asked for some product groups.

Groupe SEB's "Product 10Y Repairable" label

This quality label, also analysed by Cordella et al. (2019), is meant to promote repairability of small household appliances of the brands part of the group itself (Krumps, Tefal, Rowenta, Mulinex). Even if this label does not represent any official or governmental institution, it is a good example of how a brand can communicate effectively to consumer their efforts in investing product repairability. As analysed by Cordella et al. (2019), the label wants to communicate to consumers:

- Proximity of authorized repair centres
- Non-destructive product disassembly and re-assembly
- Affordable cost of spare parts (maximum cost of 50% of the product price)
- Fast availability of spare parts (24-48h shipment time)
- Long spare parts availability period (at least 10 years of spare parts stock)

European Eco-Label

The eco-label is a voluntary labelling system, which manufacturers can apply for in order to obtain an official recognition about the eco-impact of their product. It is provided by the European Commission and set through Regulation of the European Parliament and Council. The criterions that compose this qualitative assessment can be updated and modified, but only through a process which can requires significant resources and time (at least 2 years), because of the many stakeholder and government bodies involved (Bracquené et al., 2018). The label can be obtain only respecting a list of criterions, presenting official declarations and test reports (Bracquené et al., 2018). This assessment still involves few ErP's, and repairability is often excluded. However, this recently changed with a new requirements list developed for computers (Bracquené et al., 2018).

2.3 Semi-quantitative assessment systems

Semi-quantitative systems involve both qualitative and quantitative assessment methods according to the specific criterion analysed. A quantitative methodology is based on objective measurements, determined by the use of specific and standardized assessment values and rating systems.

Austrian standard ONR 192102:2014

This standard is published by the Austrian Standard Organization. It is a normative composed by semi-quantitative criterions to assess product durability and repairability (Bracquené et al., 2018; Cordella et al., 2019). There are 40 criterions for white goods (17 of which are mandatory requirements) and 57 for brown goods (21 of which are mandatory criterions). The requirements are divided in "general requirements", related to the product design, and "Service delivery", related to provision of information and services. A product is scored from 1 to 10, and there is a minimum score that has to be reached in order to obtain the certification (5/10). A certain amount of points has to be obtained for "general requirements" (30) and for "service delivery" (15), requiring both these two different repairability aspects.

ADEME French Life Cycle labelling

The ADEME, the French Agence De l'Environnement et de la Maîtrise de l'Energie, has paid particular attention to product repairability in the recent years. In 2018, they released a report called "benchmark international du secteur de la réparation" (Hervier, Logle, & Descos, 2018), which describes the current state of the repair sector not only in France, but also in other courtiers of the world. As synthesized by Cordella et al. (2019), this document provides an overview on "actors, circuits, access to information, the state of the sector and its evolution, the actions to support the sector (taxation, guarantee, labels, support) and the potential replicability of certain actions in France".

The French agency announced in 2018 the intention of creating a new labelling system for all consumer products related to the product life-cycle. The initiative will be on voluntary bases until 2021, for then becoming mandatory (Marco, Philips Director Global Repair Management). Initially, just some product categories will be included (such as laptops, TV, smartphones, mower, washing machines and other B2C product that have still to be defined), while in the long run more and more ErP categories will be added to the system.

In February 2019, the ADEME sent to Philips a draft of the repairability index (Appendix B) which might be implemented soon for this new labelling system. The method, the criteria, the sub-criteria, their weighting and their gradation, had still to be validated at that moment by the Ministry and the ADEME. Therefore, changes and improvements could be still applied.

Compared to the scoring system created by the JRC (Cordella et al., 2019) or the one developed by KU Leuven (Bracquené et al., 2018), the ADEME framework is more limited, but share many similar criterions. In particular, the repair indexes make a clear distinction between authorized repairer, professional repairer and the general public. Each repairability criterion can receive three different scores based on these different target groups. Moreover, there are no pass/fail criteria: a grade of zero (or several zero marks on related subjects) is considered sufficiently penalizing. Weighting and gradation can help highlighting strong product differentiations. The repairability index consists of a set of criteria subdivided into sub-criteria.

Four generic criteria are evaluated:

1. Documentation; the criterions concerning documentation are very similar to those proposed by the JRC and the KU Leuven. They include repair safety information, complete BOM of all the components, exploded views, electronic schematics, disassembly/reassembly procedures, list of tools required, list of error codes or repair guide for faults diagnosis and product maintenance information.
2. Accessibility, disassembly and reassembly; the ADEME index assesses the number of disassembly steps and type of tools required. Disassembly time is not included as criterion, and no specific definition of "single step" is provided, except for general examples. However, the ADEME clearly indicates the standard prEN 45554 (CEN/CLC TC10 European Standard, 2017) as a reference for the complete list of common tools. It is not clear if the assessment has to be carried out for each priority component (as required by the JRC (Cordella et al., 2019)), or if the assessment has to be done once at the product level.
3. Availability and price of spare parts; in this case, the criterions fully reflect the requirements defined by the JRC. They involve: clear communication of the spare parts availability period, prices, use of general and standard components. Moreover, also the price of spare parts is assessed, even if no specific scoring framework in this direction has been suggested yet.
4. Product specific evaluation criterion. As presented also by the JRC and the KU Leuven, assessment criterions have to be adapted

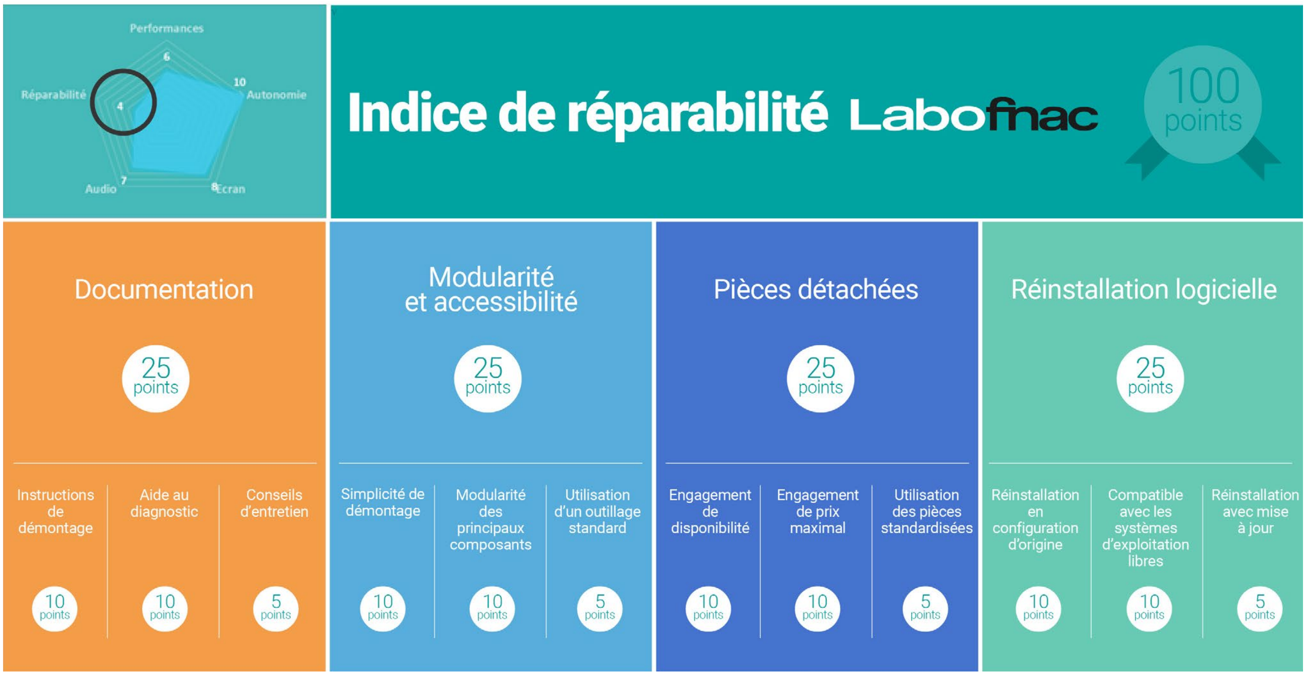


Fig. 2, Indice de réparabilité (labo.fnac.com, 2018)

to the specific product group assessed (Bracquené et al., 2018; Cordella et al., 2019). In this case, the ADEME leave the 4th criterion for possible product specific requirements. An example proposed is software updates.

Labo Fnac's "indice de réparabilité"

As analysed by Cordella et al. (2019) as well, Labo Fnac created a relatively new repairability index for the assessment of laptops (labo.fnac.com, 2018). This index is composed by 12 different criterions, grouped in 4 different categories (Fig. 2):

- Documentation, which includes disassembly instruction, diagnosis support, maintenance guidelines
- Modularity and accessibility, where not only disassembly, but also modularity is assessed, followed by type of tools required
- Spare parts, assessing parts availability period, price and component standardization
- Software and firmware, considering reset to original condition, updates, compatibility with open-source software's.

The maximum score reachable is 100 (normalized to 10), and all the four different categories have the same weight (25%).

iFixit

iFixit is an online platform, where repairability of many consumer products (mainly laptops, smartphones and tablets) is assessed. Products are scored on a scale that goes from 1 to 10, with 10 as easiest to repair. Repairability criterions are ease of disassembly, availability of service manuals, type of fasteners used, number of tools required, modular design and upgradability (Cordella et al., 2019). TU Delft is currently collaborating with iFixit in order to define a new and optimised scoring framework. In particular further research has been carried out on repairability indicators for electronic products (Flipsen et al., 2016), and a new online portal "design for repairability" is in development (ifixit.com, 2019). This new tool is meant to assess consumer products (in particular brown goods) by using 20 different criterions. In this case, the scoring system assesses products based on private consumers self-repairs, without defining any clear distinction with professional repairs. Moreover, a new scoring framework which combines disassembly depth and disassembly time is under development, and it might become an alternative solution to the eDIM method, used in both JRC and KU Leuven scoring systems (Bracquené et al., 2018; Cordella et al., 2019). Compared to all the previous assessment systems analysed, iFixit makes publicly available all the product assessment results, provides public repair guidelines for private consumers, and sell professional tools for the disassembly of different product categories.

Benelux study on "Repairability criteria for energy related products"

This study represents one of the most comprehensive academic researches concerning assessment of product repairability. It provides a complete overview on existing initiatives, a new methodology to assess repairability, case studies of the assessment of different product groups and a study about product lifecycle costing. Many of the criterions investigated and proposed by KU Leuven in this document (Bracquené et al., 2018) have been later adopted by the JRC scoring system (Cordella et al., 2019). The assessment framework proposed is based on five main repair steps (product identification, failure diagnostic, disassembly and reassembly, spare parts replacement, restoring to work condition) and three different repairability criterion (information provision, product design, service)(Fig. 3, Fig. 4). This framework defines 24 different criterions, each of them assessed using different scoring rules (some criteria can receive a score equal to 0-2-5-10, others 0-2, 0-5-10, etc., Fig. 4) and a maximum score of 164. This structure determines a very comprehensive methodology, but it also risks to make the assessment procedure relatively complex and counter-intuitive. However, the study reflects fully the latest dispositions presented by the European standard prEN45554 (CEN/CLC TC10 European Standard, 2017) concerning “General methods for the assessment of the ability to repair, reuse and upgrade energy related products”. It introduces the definition of priority parts, it distinguishes the assessment target groups in private consumers and professional repairer, and implements a quantitative method for the assessment of disassembly time (eDIM). Eventually, the framework proposed has been tested in three case studies.

2.4 Quantitative assessment methods

Ease of Disassembly Metric (eDiM)

The eDiM is a quantitative method developed to assess the time required to disassemble a complete product (complete disassembly) or specific components (partial disassembly) (Peeters et al., 2018; Vanegas et al., 2016). The eDiM is a register of disassembly actions, quantified in time, which can be added to each-other based on the nature of the disassembly sequence.

The Maynard Operation Sequence Technique (MOST) (Zandin, 2002) has been used in order to define standard amount of times required to carry out each disassembly actions. This measuring technique is often used and applied on a wide range of products by industrial engineers to calculate assembly time (Vanegas et al., 2016). It is based on fundamental basic motions, expressed using alphabetic letters, and which represent the

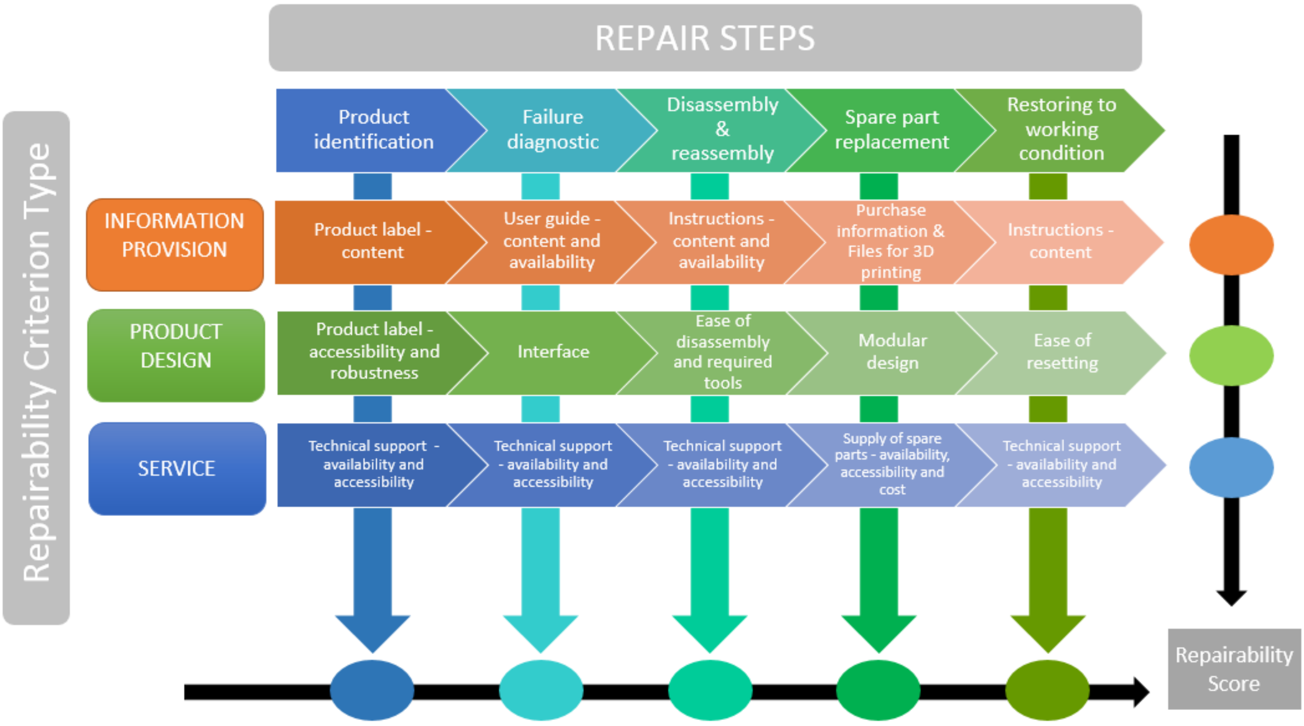
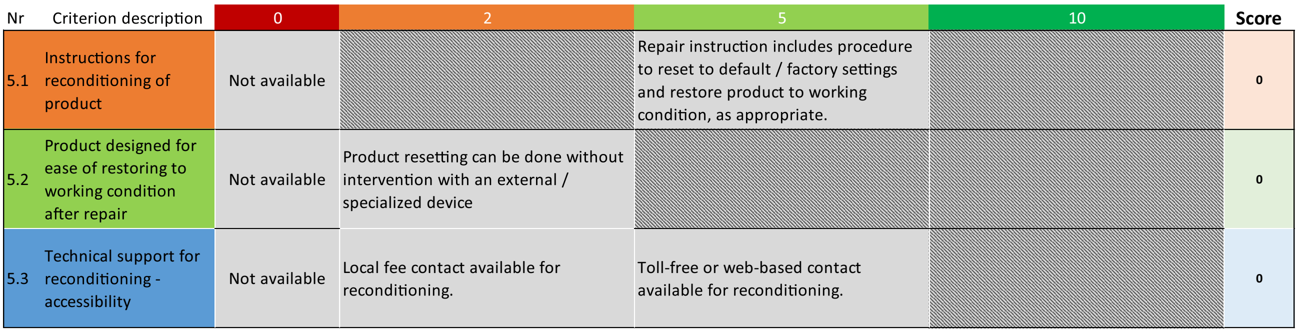
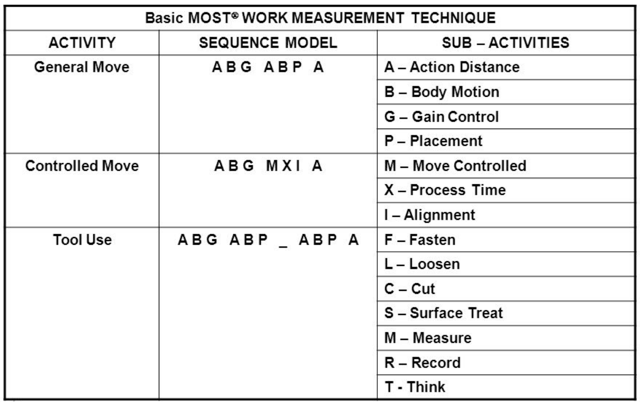


Fig. 3, Overview of the assessment methodology followed by KU Leuven (Bracquené et al., 2018)



Nr	Criterion description	0	2	5	10	Score
5.1	Instructions for reconditioning of product	Not available	▨	Repair instruction includes procedure to reset to default / factory settings and restore product to working condition, as appropriate.	▨	0
5.2	Product designed for ease of restoring to working condition after repair	Not available	Product resetting can be done without intervention with an external / specialized device	▨	▨	0
5.3	Technical support for reconditioning - accessibility	Not available	Local fee contact available for reconditioning.	Toll-free or web-based contact available for reconditioning.	▨	0

Fig. 4, Example of criterions assessment used by the KU Leuven (Bracquené et al., 2018) performance of an average skilled worker, at normal pace and supervised working conditions (Vanegas et al., 2016). Each basic motion corresponds to a specific quantity of time. By combining together different basic motions it is possible to obtain standard sequences, for instance: get a tool, put the tool in place, tool action, put tool aside, return to position. Sequence models are long sequences of basic motions; examples of sequence models could be “General move, controlled move, tool use” (Vanegas et al., 2016) (Table 1).



Basic MOST® WORK MEASUREMENT TECHNIQUE		
ACTIVITY	**SEQUENCE MODEL**	**SUB – ACTIVITIES**
General Move	A B G A B P A	A – Action Distance
		B – Body Motion
		G – Gain Control
		P – Placement
Controlled Move	A B G M X I A	M – Move Controlled
		X – Process Time
		I – Alignment
Tool Use	A B G A B P _ A B P A	F – Fasten
		L – Loosen
		C – Cut
		S – Surface Treat
		M – Measure
		R – Record
		T - Think

Table 1, Examples of MOST basic sequences (Zandin, 2002)

Disassembly task	**Description**	**Sequence**	**TMU**	**Time (s/task)**
Tool Change	Fetch and Put back	|A1B0G1|+|A1B0P1|	40	1.4
Identifying	Localising connectors			
	Visible are > 0.05 mm^2			0
	Hidden: visible are < 0.05 mm^2	|T10|	100	3.6
Manipulation	Product handling to access fasteners	|A1B0G1|+|L3 |	50	1.8
Positioning	Positioning tool onto fastener	|A1B0P3A0|	40	1.4
Removing	Removing separated components	|A1B0G1| + |A1B0P1|	40	1.4

Table 2, eDiM Disassembly tasks (Vanegas et al., 2016)

1	2	3	4	5	6	7	8	9	10	11	12	13
Disassembly sequence of components	Disassembly sequence of connectors of components	Number of connectors	Number of product Manipulations	Identifiability (0,1)	Tool Type	Tool Change (s)	Identifying (s)	Manipulation (s)	Positioning (s)	Disconnection (s)	Removing (s)	eDiM (s)
1...												
2...												
...												
...												
...												
N												

|---------------------**Provided** ---------------------------||-----------**Calculated** -----------|

Table 3, eDiM calculation sheet (Vanegas et al., 2016)

Vanegas et al. (2016) identifies six different disassembly tasks which usually compose disassembly processes:

- Tool change
- Identifying connectors
- Manipulation of the product
- Tool positioning on the connector to be disassembled
- Disconnection of the connector
- Removing of disassembled components

Pre and post disassembly actions, such as product delivery, un-boxing/boxing, positioning and removal of the product from the working surface, are not considered in the eDiM. Disassembly "inefficiencies", like time spent on unsuccessful disconnection attempts or unnecessary actions, are not considered as well (Vanegas et al., 2016). Standard sequences are proposed for five out of six disassembly tasks (Table 2), while the sequence for "fastener disconnection" changes in accordance with the specific type of fastening system involved in each different disassembly sequence. While tool positioning, fastener disconnection and part removal tasks are considered in almost all the disassembly procedures tool change, identifying and manipulation time are considered just if those specific tasks have to be carried out.

Disassembly sequences, defined by using the disassembly task previously described, can be added to each-other using a calculation sheet. The spreadsheet structure, proposed by Vanegas et al. (2016) and shown in Table 3, has been used in this study as well.

The eDiM method has been further developed in 2018 (Peeters et al., 2018), by focusing on disassembly of laptops. Based on that specific product group, some changes have been applied to the original eDiM calculation sheet (Vanegas et al., 2016):

- New standard sequences for new type of connectors have been created (i.g. Cable connectors, cable plugs, glue)
- Reassembly operations have been included in the time assessment
- Correction factors have been applied to the previous sequences
- Influence of connector labelling on the final disassembly time has been included as well
- Manipulation of small-medium size products have been taken in account

Currently, the main limitation of the eDiM is the limited library of fastener disconnection sequences. In fact, most of them have been optimized for laptops and, apart for basic sequences developed to describe snap fit connectors in the first version on the eDiM (Vanegas et al., 2016), a more extensive research has to be done in this direction.

During this study, new standard sequences have been developed in Chapter 3.

2.5 European Commission Joint Research Centre scoring system for repair and upgrade of products

The European Commission Joint Research Centre developed in 2019 a scoring system to assess product repairability and upgradability (Cordella et al., 2019). This is a study that has a preparatory purpose; therefore, it is not meant to have any effect on product regulations currently under discussion (Cordella et al., 2019). Despite this, because of its completeness and effectiveness, it is likely to be considered as starting point for a future product labelling system. For these reasons, it has been analysed more in depth and later used for the product assessment carried out during this research.

Standard prEN45554

The JRC scoring system has been developed following the preliminary draft of the standard EN45554 concerning general methods for the assessment of the ability to repair, reuse and upgrade energy related products (CEN/CLC TC10 European Standard, 2017), which is very likely to become the official guidance for the creation of future European repairability scoring systems. The standard provides:

- Clear definition of terminology related to RRU (some of which have been already introduced in Chapter 1)
- Guidance to define priority parts that has to be assessed
- Parameters which can directly influence product repairability and upgradability
- Definition of parameters related to manufactures consumer support which can facilitate RRU
- Clear list of "common tools", indicating related ISO norms.
- Proposal of different rating criterions and grading frameworks for different assessment parameters

This document is currently a draft (in August 2019), its final version should be published by the end of the coming year.

Approach for the creation of the scoring system

The process followed by the JRC to develop this scoring system involved (Fig. 5):

- Analysis of different methodologies for the assessment of product repairability and upgradability already in place
- Extensive workshops and interviews with stakeholders coming from the academic and

professional environment;
- Definition of priority parts, key parameters, rating and aggregation frameworks
- Analysis of different product specific cases, testing the assessment framework on three different product groups (laptops, washing machines, vacuum cleaners)

Priority parts

As introduced by Bracquené et al. (2018), not all the product components have to be assessed. On the contrary, only the most important parts, which influence product repairability and upgradability the most have to be considered. In fact, consumer products, in particular ErP, can be composed by a high number of parts and sub-components. However, it does not make sense to assess all of them in the same way, since some could have a very long life-span or never break, while others could be more fragile or subjected to particular wear.

Considering and prioritizing disassembly of priority parts is very relevant for design for repairability as well. Product repairability is not about making every component disassemblable; on the contrary, enhancing product repairability means simplify priority part accessibility, making this component easy and fast to disassemble and reassemble.

The JRC proposes to consider two main features while defining a list of priority parts: functional importance and frequencies of failure and upgrade. These have to be identified at the product group level.

Functional importance

Any part which provides primary or secondary functions should be considered as a priority part (Cordella et al., 2019), and they should have high priority during the assessment (CEN/CLC TC10 European Standard, 2017). Parts delivering third functions can be left out from the product assessment. However, functional importance has always to be considered together with the likelihood of component failure (Cordella et al., 2019).

Frequency of failure

Components likelihood of failure is one of the most important information to be considered while assessing product repairability (Cordella et al., 2019). Reliable data related to frequencies of failure can be retrieved only after years that an item has been widely commercialized and used by consumers. Therefore, it is not always possible to retrieve data about each specific product assessed. On the contrary, the faults registered for the entire product group (e.g. laptops, washing machines, vacuum cleaners) should be considered. This allows to define a parts list shared by most product part of the same group, which assessment can be then comparable. Data concerning frequency of failure can be found in technical-scientific documents concerning product design analysis, durability/reliability testing results, consumer surveys and manufacturers statistics (Cordella et al., 2019).

Software upgradability is an important aspect to take in account for all those products provided of a user interface, or which functionalities are based on the use of a software.

Most of the manufacturers aims to contain the number of products returned during the warranty period (around 3%) (Cordella et al., 2019). Moreover, if the main business of a manufacturer is based on the sale of low-mid price range products, it becomes way less likely that consumers are willing to pay for an out of warranty repair. These two aspects are very important to be considered while analysing official manufacturer call rates; they usually provide a reliable and precise overview of faults which, on the other hand, are registered mainly just in the first 2 years of product life and for a limited number of products compared to the total selling volume (usually 30 times bigger).

Economic and environmental aspects

Cordella et al. (2019) did not consider economic aspects for the definition of priority parts. It was argued that the wiliness of consumers and manufacturers to carry out a repair is highly influenced by the cost of spare parts, and this would lead to prioritize cheaper components over more expensive ones. However, the price of

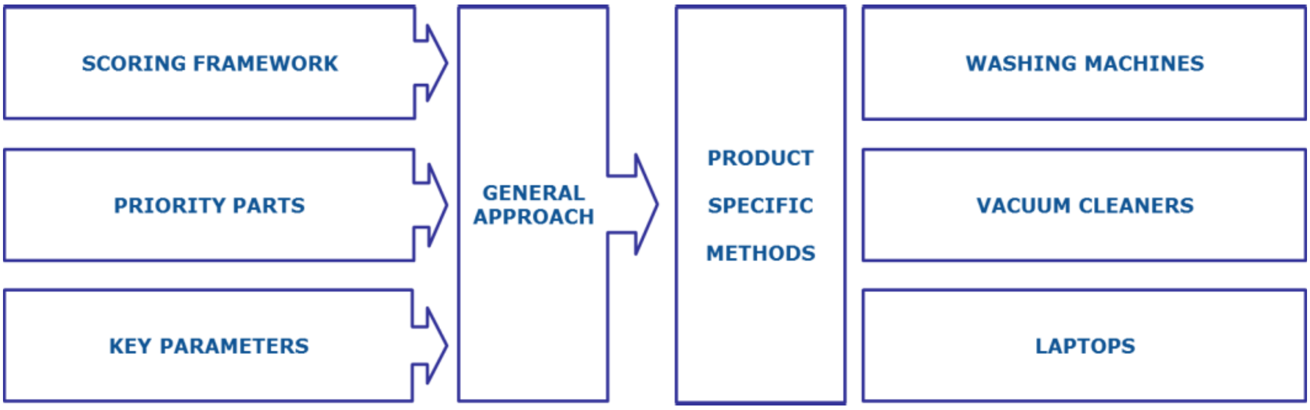


Fig. 5, JRC approach for the development of the scoring system (Cordella et al., 2019) a part does not actually influence its importance for product repairability; therefore, price has not been considered for the identification of priority components. Despite this, the economic values of components becomes very important for refurbishing and harvesting processes, since this could be a valuable reason for a manufacturer to make a part easier to harvest and reuse.

Environmental aspects are not considered as well for the identification of priority components, since they are very important for the assessment of the environmental impact of the product, but not for the assessment of its repairability. However, it is very important to consider environmental impact of single components while designing the disassembly of an item for product retirement (Ishii & Lee, 1996).

Selection and weighting

Priority parts have to be defined at the product group level: laptops priority parts are of course different from those of a vacuum cleaner. At the same time, even products which part of the same group might present very different designs (upright, canister, robot vacuum cleaners). Not all the priority parts identified for the entire group can be found in all the product sub-families (e.g. battery, hose, motor brushes); in this case the JRC proposed to just exclude them from the specific product assessment.
Threshold values are proposed by Cordella et al. (2019) for the priority part assessment weighting: if a part is associated with at least 3% of the failure rates registered at the product group level, the part weight could be 1; whereas, if a part is associated with more than 10%, the weight can be raised to 3. Ultimately, the scoring system proposes already priority parts and related weighting for three product groups: laptops, washing machines and vacuum cleaners.

Key parameters

The JRC identified 12 different parameters for the assessment of product RRU. They have been defined by considering three main requirements:

- They had to be relevant for repair/upgrade
- They had to stimulate an active market for repair/upgrade, without undermining product safety
- They had to be objectively measurable and verifiable, independently from the territory and year of assessment (Cordella et al., 2019)

These parameters are:

1. **Disassembly depth/sequence**; this is the number of steps required to reach a priority part. It expresses the depth of a component in the disassembly sequence of a product. It assesses the effort required to reach a component and replace it. The Commission Decision (EU) 2016/1371 defines a step as: "A step consists of an operation that finishes with the removal of a part, and/or with the exchange of a tool". Product disassembly depth can be enhanced by reducing the number of steps required to reach a priority component and by providing clear instructions about how to correctly disassemble each part. Disassemblability has always to be reversible and not destructive (CEN/CLC TC10 European Standard, 2017). This is valid also for all the following parameters.
2. **Fasteners**; the JRC assesses fasteners by considering their reversibility and reusability. The un-reusability of a fastener is accepted only if it replacement is provided together with the spare part of the component disassembled (Bracquené et al., 2018; Cordella et al., 2019). Fasteners are very important for product repairability, since their nature and visibility can influence disassembly time, skills and tools required for the disassembly. However, the JRC chose to cover all these other aspects in order parameters assessment.
3. **Tools**; this parameter is assessed by considering if the tools required for the disassembly of a product are common tools (as specified by the prEN45554), uncommon tools, or proprietary tools.
4. **Disassembly time**; this parameter assesses the time required to disassemble and reassemble a priority component. Moreover, time can be important to calculate costs related to repair activities (Cordella et al., 2019). Despite this, according to the JRC this parameter is already described by the assessment of the previous 3 parameters, therefore it can be excluded in many cases (for instance, assessing vacuum cleaners). This interpretation is not shared by this research, and this aspect will be further exploded in next chapters.
5. **Diagnosis and support interfaces**; this parameter concerns the availability of information which facilitate the identification of product faults. In can also concerns availability of interfaces for RRU processes which can also include the resetting or recalibration of certain parameters and settings. These interfaces could be incorporated in the product or provided separately by the manufacturer.
6. **Type and availability of information**; this parameter assesses availability of repair information. The JRC adopted a similar approach to the one introduced by Bracquené et al. (2018), by differentiating the assessment of this parameter based on the target group of professional repairer and private consumers. The type of information that has to be provided to these two different target groups has to be specified at the product-group level.
7. **Spare parts**; this criterion evaluates the availability of spare parts over time and for

different target groups, component prices and delivery time.

8. **Software and firmware**; this parameter concerns the availability period of software and firmware updates. It is usually applicable to ICT products (e.g. laptops, smartphones, tablets).
9. **Safety, skills, and working environment**. This criterion assesses the type of skills required to carry out repair procedures on the product analysed. Overall, a product should be designed to allow to as many target groups as possible to carry out safely repairs. However, there are some exceptions, where specific product groups cannot be safely repaired by normal private consumers without any technical knowledge. In this case, safety is considered the most important factor.
10. **Data transfer and deletion**; this parameter has to be considered for all those products which can store personal user data. These items should be provided with a pre-installed software which can allow repairers to delete all the stored data before carrying out any repair activity which could compromise consumer privacy.
11. **Password reset and restoration of factory settings**; even in this case, items should be provided with a pre-installed software which can allow repairers to delete sensitive information stored on the device. This is important for those repair operations which involve continued use or reuse of products (Cordella et al., 2019).
12. **Commercial guarantee**. According to the JRC, commercial guarantee can be a useful tool for influencing products failure rates and promoting repair operations when needed (Cordella et al., 2019). Moreover, the commercial guarantee period should be adapted to the life-span of the product group analysed.

Not all the 12 parameters have to be always considered. Based on the product group analysed, some parameters can be excluded. For instance, in this specific study concerning vacuum cleaners, parameters 5, 8,9,10 and 11 have not been taken in account. This will be better explained in the next chapter.

Scoring framework

Assessment of single parameters

Cordella et al., 2019 propose a hybrid scoring system, composed by:

- Pass/fail criterions which have to be fulfilled in order obtain an RRU rating;
- Rating/classification criterions, which express to what extent a product is repairable and upgradable;

Each parameter is assessed differently, with a score that goes from 0 to 1 pt. In some cases, different scores are assigned based on different target groups (professional repairer and private consumers). The scoring framework has been developed considering previous assessment systems already in place, feedback from stakeholders and the standard prEN 45554.

The 12 criterions previously presented are composed by quantitative and qualitative parameters. In most cases, parameters are assessed using a discrete rating system, which means that a specific amount of point is assigned if specific requirements are fulfilled. Instead, other parameters, for instance disassembly time and sequence, can be assessed using a continuous rating system. This can be done only with quantitative assessments, where

Table 4, Single criterion rating (Cordella et al., 2019)

Parameter	Pass/fail criteria	Rating classes	Support to assessment (A) and verification (V)
1)Disassembly depth/sequence	For each priority part, information about the disassembly sequence has to be available to the target group of repairers (see #6) Note(s): 1) target group of repairers to be defined for each priority part at product specific level 2) The disassembly sequence is defined as the order of steps needed to remove a part from a product (which might include getting access to fasteners). A step consists of an operation that finishes with the removal of a part, and/or with a change of tool[35]. 3) In general, it is considered that the removal of one or additional fasteners in a consecutive way and with the same tool has similar impact on the ease of disassembly. Therefore, the consequent removal of a group of fasteners with the same tool is considered a step.	A score is assigned for each priority part based on their disassembly depths (DD_i). A continuous rating can be calculated as: $S_{1,i} = 1 - (DD_i - 1) / (DD_{ref} - 1)$ where: DD_i is the depth for the priority part i; DD_{ref} is the reference depth for the priority part i. The score is set to 0 if $(DD_i - 1)$ is greater than $(DD_{ref} - 1)$. Alternatively, a discrete rating could be considered: I) $DD_i < X$ steps = 1 pt. II) $X < DD_i < Y$ steps = 0.75 pt. III) $Y < DD_i < Z$ steps = 0.5 pt. IV) $DD1 > Z$ steps = 0.25 pt. Where: X, Y and Z have to be defined for each priority part of the product group under assessment. Note(s): 1) The disassembly depth is the number of steps required to remove a part from a product. 2) Threshold values to be defined based on the analysis of representative products on the market.	A: A description supported by illustrations of the steps needed to disassemble priority parts is needed. The description has to show that the disassembly is reversible by including the steps needed for the reassembly of priority parts. V: physical disassembly and recording of the operation are needed. Note(s): This is considered sufficient to address the reversible disassembly of priority parts, as also done in the prEN 45554 (November 2018). The inclusion of the reassembly of parts in the rating could be considered as well in future applications.

reference values are used to proportionally calculate the scores. A clear example is discussed in chapter 3, for the assessment of disassembly time and sequence of the vacuum cleaners analysed. Table 4 shows an example of criterion rating.

The list of parameters and their ratings proposed by the JRC for the assessment of vacuum cleaners can be seen in Appendix C, while the general rating criterions product group independent can be found in Cordella et al. (2019) (page 37 to 50).

Aggregation of individual parameters

Half of the parameters (1,2,3,4,7,9) have to be assessed for each priority part, while the other half (5,8,10,11,12) are assessed once for the hole product. In order to be considered repairable/upgradable, a product has to fulfil all the pass/fail criterions. The maximum number of points assigned depends from the number of priority parts and parameter considered.

Each priority part can be differently weighted, based on the failure rates analysis. Rating parameters can be weighted differently as well.

The different scores can be aggregated in different ways:

- At the product level, also defined as final overall RRU score (by aggregating parameters from 1 to 11, excluding commercial guarantee)
- At the priority part level, by calculating a specific repairability score for single component
- As parameter score, which indicates the final rating of each specific criterion for all the priority parts analysed (by considering parameters from 1 to 11, excluding commercial guarantee)
- In a score for design for disassembly, which aggregates parameters related to product design (parameters from 1 to 4)
- In a score for repair and upgrade process (parameters from 5 to 11)
- In a score for commercial guarantee (parameter12)

This framework defines different indices, which can facilitate the communication of the results. Table 5 shows the score aggregation system proposed by the JRC.

2.6 Conclusions

Based on previous research (Bracquené et al., 2018; CEN/CLC TC10 European Standard, 2017; Cordella et al., 2019), eleven different methods and labelling systems related to the assessment of product repairability have been analysed. These can be clustered in three main categories (Bracquené et al., 2018; CEN/CLC TC10 European Standard, 2017):

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

The scope of this analysis was to investigate the main parameters and design features which influence design for product repairability. This information has been used

- In Chapter 3 to define a suitable research methodology
- In Chapter 6 to create a new design tool called "Disassembly Map"
- In Chapter 7 to redesign a representative model of vacuum cleaners to enhance its repairability

Among the literature analysed, the most relevant is:

- **Standard prEN45554.** This is a standard preliminary draft, concerning "General methods for the assessment of the ability to repair, reuse and upgrade energy related products (CEN/CLC TC10 European Standard, 2017). This is very likely to guide the creation of

Table 5, Aggregation of scores (Cordella et al., 2019)

Parameter	**Score [0 -1] for priority part 1 (and weight)**	**…**	**Score [0 -1] for priority part N (and weight)**	**Parameter Score [0 -1]**	**Parameter Weight**	**RRU indices for product** [0 -1]
#1 Disassembly depth / sequence	$S_{1,1}$ (ω_1)		$S_{1,N}$ (ω_N)	$S_1 = \sum_1^N \frac{S_{1,i} \cdot \omega_i}{\omega_i}$	W_1	Disassemblability Index (I_D) = $\frac{\sum_1^4 S_j \cdot W_j}{\sum_1^4 W_j}$
#2 Fasteners	$S_{2,1}$ (ω_1)	…	$S_{2,N}$ (ω_N)	$S_2 = \sum_1^N \frac{S_{2,i} \cdot \omega_i}{\omega_i}$	W_2	
#3 Tools	$S_{3,1}$ (ω_1)	…	$S_{3,N}$ (ω_N)	$S_3 = \sum_1^N \frac{S_{3,i} \cdot \omega_i}{\omega_i}$	W_3	
#4 Disassembly time	$S_{4,1}$ (ω_1)	…	$S_{4,N}$ (ω_N)	$S_4 = \sum_1^N \frac{S_{4,i} \cdot \omega_i}{\omega_i}$	W_4	
#5 Diagnosis support and interfaces	S_5	…	S_5	S_5	W_5	RRU Process Index (I_P) = $\frac{\sum_5^{11} S_j \cdot W_j}{\sum_5^{11} W_j}$
#6 Type and availability of information	S_6	…	S_6	S_6	W_6	
#7 Spare parts	$S_{7,1}$ (ω_1)	…	$S_{7,N}$ (ω_N)	$S_7 = \sum_1^N \frac{S_{7,i} \cdot \omega_i}{\omega_i}$	W_7	
#8 Software and firmware	S_8	…	S_8	S_8	W_8	
#9 Safety, skills and working environment	$S_{9,1}$ (ω_1)	…	$S_{9,N}$ (ω_N)	$S_9 = \sum_1^N \frac{S_{9,i} \cdot \omega_i}{\omega_i}$	W_9	
#10 Data transfer and deletion	S_{10}	…	S_{10}	S_{10}	W_{10}	Overall RRU Index (I_{RRU}) = $\frac{\sum_1^{11} S_j \cdot W_j}{\sum_1^{11} W_j}$
#11 Password reset and restoration of factory settings	S_{11}	…	S_{11}	S_{11}	W_{11}	
#12 Commercial guarantee	S_{12}	…	S_{12}	S_{12}	Not applied	Commercial guarantee Index (I_{CG}) = S_{12}
RRU indices for parts	$I_{RRU,1} = \sum_1^{12} \frac{S_{j,1} \cdot W_j}{W_j}$		$I_{RRU,N} = \sum_1^{12} \frac{S_{j,N} \cdot W_j}{W_j}$			

possible future European repairability scoring and labelling system. It provides clear definition of terminology related to RRU, guidance to define priority parts that have to be assessed, parameters which can directly influence product repairability and upgradability, clear list of "common tools" (indicating related ISO norms) and different rating criterions and grading frameworks for different assessment parameters.

- **Benelux study on "Repairability criteria for energy related products".** This is one of the most recent and extensive researches about product repairability, which has investigated 24 different criterions clustered in information provision, product design and service. It also provides a clear overview on different terminology related to product repairability and it takes into account the preliminary standard prEN45554, proposing a scoring system based on its guidelines. Eventually, this study applies the eDiM methodology in two different case studies, assessing disassembly time required for a vacuum cleaner and a washing machine.
- **European Commission Joint Research Centre scoring system for repair and upgrade of products.** This is a preparatory study carried out by the JRC in 2019 (Cordella et al., 2019). It shows how a possible future repairability assessment system for a new European labelling system could look like. The scoring framework is composed by 12 different criterions, assessed using quantitative and qualitative methodologies. It proposes lists of priority components for laptops, washing machines and vacuum cleaners and specific criterions selections for their assessment. Additionally, a comprehensive scoring framework is suggested, which includes a system of different weights for priority components and parameters and the possibility of calculating specific indices for different assessment aspects (e.g. Disassembly index, RRU process index, Parameters index and priority part index).

Methology used in this study

The JRC scoring system, presented in Cordella et al. (2019), has been used in this research for the product assessment phase. The reasons why this methodology was selected are:

- Clear and effective methodology, which manages to take into account different aspects of product repairability (disassembly index and RRU process index) using a relatively limited number of criterions (12).
- Clear and objective assessment framework, which integrates a weighting system for different priority parts and criterions and which allows to calculate partial indices related to different repairability aspects. This was considered an important feature in order to communicate the results of the score in a clear way to different types of stakeholders.
- It is based on a solid literature research of previous assessment methodologies, including the Benelux study (Bracquené et al., 2018).
- Stakeholders have been involved and inputs from manufacturers, repairers, retailers and NGO's have been taken into account while defining the different criterions and rating
- It is aligned with the latest regulations (preliminary standard prEN45554)
- The European Commission was directly involved in this study, making this scoring system likely to become a first guideline for a new labelling system.
- The French organization for the environment ADEME is also using this system to define a new products label for the French market (Appendix B).

Aspects which influence product repairability

Based on this methodology, 12 aspects which influence product repairability are:

- Disassembly depth/sequence
- Fasteners re-usability
- Disassembly tools required
- Disassembly time
- Diagnosis and support interfaces
- Type and availability of information
- Spare parts availability
- Software and firmware updates
- Safety, skills and working environment
- Data transfer and deletion
- Password reset and restoration of factory settings
- Commercial guarantee

According to most of the literature analysed, economic and environmental impacts should not be considered to define priority components, since they do not influence directly product repairability and upgradability. However, they are important attributes to be considered for DFPR (Ishii & Lee, 1996) and to calculate the economic impact that enhanced product repairability can have on a business (Cordella et al., 2019).

3. Research Method:

Vacuum cleaners repairability assessment

3.1 Introduction

In this chapter the methodology used in this research is presented. This research has been narrowed down to a specific product group: vacuum cleaners. This allowed to develop a more in-depth study, assessing different products of the same category and studying differences and commonalities in product architectures. A specific research protocol has been defined beforehand, ensuring results comparability. A list of priority components to be assessed has been investigated considering:

- Primary product functions delivery
- Philips confidential call rates
- Statistics found in literature
- Consumer association surveys
- Unofficial repairer statistics provided by Repair Café (Natuur&Milieu, 2018)

Assessment parameters, rating system and reference values have been selected, following the guidelines provided by Cordella et al. (2019).

Eventually, eDiM values have been developed for the assessment of disassembly time. These enriched the current metric library of connectors, adding those specific fastening systems often found in this specific product group as in many other white goods (e.g. snap fits and force fits).

3.2 Selection of the case products

This project focuses on the vacuum cleaner's product portfolio of the company, part of the Floor Care business group. This has been agreed during the first research stage with Philips Group Sustainability and Philips Consume Care department base on the following reasons:

- In the recent years, European Commission policies concerning implementation of new labelling systems are firstly applied to this product group (e.g. energy efficiency label), by releasing different studies about vacuum cleaners, and by using them as a product-specific case study in the final version of the JRC scoring system for repairability and upgrade of products (Cordella et al., 2019).
- Vacuum cleaners present a medium complexity product architecture, insights gathered from the product group could be more or less adapted to other product families.

The company portfolio is very wide: only on the Dutch website, the most extensive one in terms of product offer, there are 87 different models of vacuum cleaners (Philips.nl, 2019a), while more than 200 models can be counted on the worldwide total portfolio. Many models are actually very similar to each other's: a different CTN (Commercial Type Name) has to be applied if different accessories are included in the product box, or if the plug and the supply voltage is different. This means that a large part of the total portfolio is just composed by different combinations of accessories and power supply configurations, while the design of the main product body is repetitive.

The Philips Floor Care portfolio is divided in five different categories (Fig. 6):

- Vacuum cleaners without dust bag (Bagless), Cylinder vacuum cleaners (EN 60312-1:2017)
- Vacuum cleaners with dust bag (Bag), Cylinder vacuum cleaners (EN 60312-1:2017)
- Stick vacuum cleaners, Upright vacuum cleaners (EN 60312-1:2017)
- Robot vacuum cleaners (Rames et al., 2018)
- Crumb pistons, Handheld vacuum cleaners (Rames et al., 2018)

Research boundaries and specific products selected for assessment

Within the time limits of this research, it was impossible to analyse all the Philips Floor Care product portfolio. For this reason, some boundaries have been defined, and a selection of products was carried out before starting any assessment. The two main criteria applied for this selection are:

1. Selection of the most representative products to describe repairability of the different product categories under Vacuum cleaners.
2. Selection of a sufficient number of products to determine reliable reference values for the assessment parameters 1, Disassembly depth/sequence, and parameter 4, Disassembly time.

Family groups with similar internal design

The financial results of Floor Care products for 2018 have been analysed in order to determine which product categories represent the most the products that Philips actually place on the market every year. However, this information is confidential and specific insights or data cannot be shared.

In general, bagless products, followed by bag and stick vacuum cleaners, are the best-selling categories, representing together almost a big slice of the revenues and number of products sold. For this reason, the assessment has been narrowed down to these three product categories.

In February 2019, 66 products belonging to these three categories were included in the online portfolio (Philips.nl, 2019a): 29 bagless, 22 bag, 15 stick. The service manuals of all 66 products were analysed and the exploded views and BOM have been compared to each other in order to find similarities (See Confidential Appendix A). It was found that:

- Some service manuals (25 models) officially indicate the same design of other models. They

Fig. 6, Categories of vacuum cleaners sold by Philips (Philips.com). From left to write, bag, bagless, stick, upright, robot

have been catalogued in 5 different groups of products showing the same internal design (FC82XX, FC85XX, FC89XX, FC93XX, FC97XX).

- 36 service manuals were officially not related with any other model but, except for additional accessories provided with the specific model (e.g. additional nozzles), they were describing the same internal product design of other models. They have been catalogued in 8 different groups with the same design (FC83XX, FC87XX, FC95XX, FC99XX, FC64XX, FC68XX).
- Five Stick vacuum cleaners had different, but very similar internal design. Hence, they have been grouped in one single family of models (FC61XX).

In total the 66 models analysed can be grouped in 12 main product families based on identical or very similar internal design. It is assumable that the repairability score is the same for all the vacuum cleaners within these groups.

Representative models selected

The bagless family represents alone around half of the total sales for Floor Care in 2018. Moreover, the internal design of the products part of this category is very similar through out the low, mid and high price range. For these reasons, bagless vacuum cleaners can be considered as the most representative models of the Philips Floor Care portfolio. Two different bagless were selected for the repairability assessment:

- FC9569/01 (low-end); this is the latest model released in the low-end price range for bagless. Its internal design is shared by most of the low-end category (FC93XX, Hulk), but it presents some new additions.
- FC9934/07 (high-end); this model shares the exact same internal design of all the high-end bagless Philips vacuum cleaners.

Selecting these low and high price range products will allow to compare the different scores of cheap and more expensive products, part of the same product group.

The bag family is the second best-selling. The assessment of this category is also relevant in order to have a good overview of the general product-group. One vacuum cleaner was selected from this family: FC8924/01. It is a high-end model, that has been selected for the following reasons:

- The internal design of the series FC89XX is very similar to the one of series FC83XX (low-end) and FC85XX (mid-end), covering 15 products out of 29 of the bag vacuum cleaners part of the online Dutch portfolio in February 2019. Therefore, assessing this model gives a good overview of the repairability of 52% of the bag portfolio.
- This model contains a higher quantity of internal electronic components compared to all the other bag products; these components are likely to increase product complexity (Bracquené et al., 2018). This might make the FC89XX series one of the less repairable among all bag models.

The category defined by Philips as “Stick” is actually composed by two different product categories:

- Upright vacuum cleaners, where the cleaning head is part of the product housing and the cleaner is moved by the means of a handle integrated in the main body (Bracquené et al., 2018)
- Stick vacuum cleaners, similar to the upright models, but with an improved design, usually compact and lightweight, meant for higher manoeuvrability (Bracquené et al., 2018). The handle is integrated in the product body.

In this case the stick model FC6812/01, has been selected for the following reasons:

- A previous study, “Repairability criteria for energy related products” (Bracquené et al.,

2018), already assessed an upright vacuum cleaner, and its complete eDIM (disassembly time assessment) has been provided by the KU Leuven research group.

- This model represents the newest Philips Stick family, SpeedPro Max. It is likely that this product will conquer more and more success, hence sale volumes, seen the latest trends towards uprights light vacuum cleaners guided by Dyson. Moreover, its design is relatively recent and it is very likely that the company will focus on this model for the coming years.

These four products, FC9934/07, FC9569/01, FC8924/01 and FC6812/01, are representative of the 44% of the online product portfolio analysed (29 out of 66).

Eventually, the bagless canister FC9569/01, also called “Zephyr” has been selected for the redesign phase. The main reasons for its selection are:

- This model is widely commercialised, and its production and selling volume is way bigger compared to the high-end models assessed;
- This model belongs to a medium price range (140-170€), which makes it eligible for the Philips refurbishing program;
- This bagless shares the same internal design of the low-end series “Hulk” (FC93XX), which has even higher production and sale volumes. These are the two most common models received by the Philips European Repair Centre (Official Philips Repairer, European Repair Center). Arguably, by improving the design of the Zephyr also the Hulk architecture could be optimized for repairability.

Competitor’s models selected

In order to define a reliable reference value for Parameter 1, Disassembly depth/sequence, and Parameter 4, Disassembly time (Cordella et al., 2019), competitors’ products had to be analysed as well.
The three competitors’ products analysed are:

- Rowenta X-Trem Power Cyclonic, RO6963EA. This model has been suggested by Philips Floor Care since it was analysed during the design of the FC95XX series. Moreover, the architecture of this product is very similar to the one of the high-end bagless FC9934/07.
- Samsung SC8835. This model was also analysed as direct competitor of the Philips Zephyr by Floor Care. It presents an elaborate external design, maintaining a simple internal architecture, integrating interesting design solutions that enhance disassembly.
- Siemens SyncroPower, VS06A111/12. Although this is a low-end bag canister (80-100€) and not a direct competitor of any of the Philips vacuum cleaners analysed, the Floor Care department strongly suggested to include its assessment in this research. In fact, this model is known to be assembled using only 3 screws, presenting an extremely simple internal architecture. Interesting insights have been gathered from this model concerning ease of disassembly. Moreover, including a bag competitor has been useful to determine reference values for the Philips bag model FC8924/01.

3.3 Establishment of priority parts

As previously introduced (Chapter 2), according to the JRC scoring system (Cordella et al., 2019), priority parts can be defined based on:

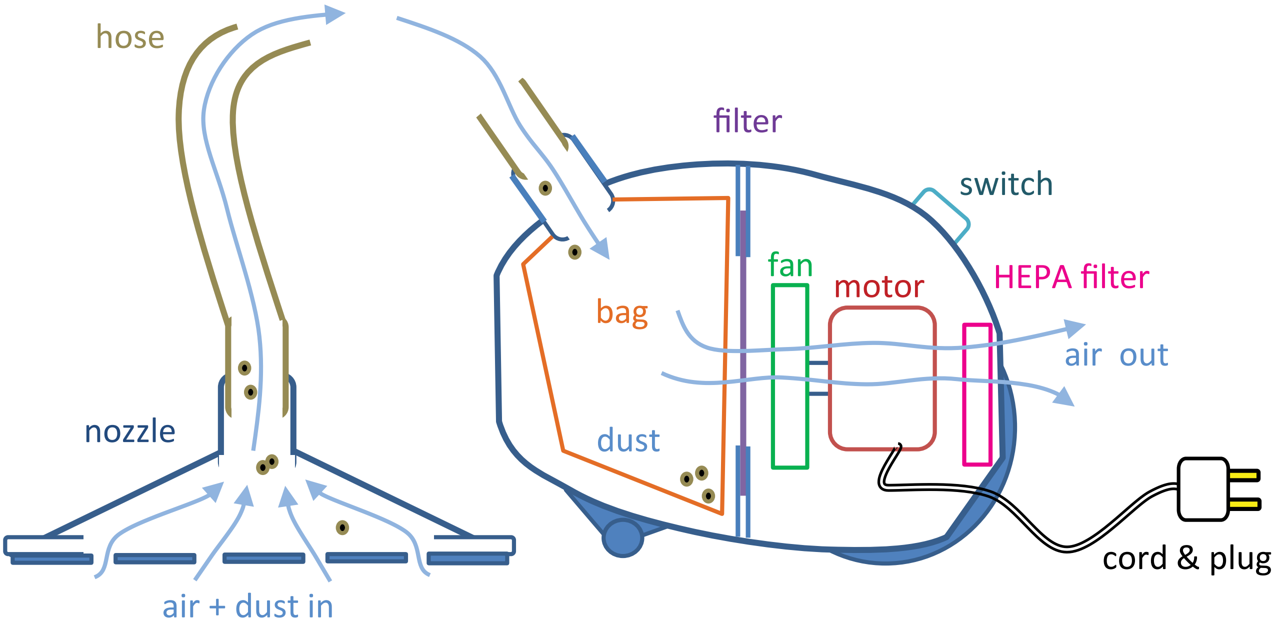


Fig. 7, Key components of a canister vacuum cleaner (Rames et al., 2018)

- Functional importance
- Frequencies of failures and upgrade

Functionally important components

The working principle of a vacuum cleaner is relatively simple. It is based on the creation of an area of low-pressure (vacuum area) inside the product, by means of a fan driven by an electric motor. Suction power is obtained when the pressure of the air inside the vacuum cleaner is lower compared to the one outside the product (Rames et al., 2018).

As it can be seen in Fig. 7, the main components of a vacuum cleaner are:

- Nozzle, the component which allows to have good adherence and suction effect on the surface to be cleaned. Nozzles can be categorized in passive and active. Active nozzles integrate an additional motor, meant to move the brushes touching the surface to be cleaned. According to tests carried out by consumer associations, the motor power can be reduced if active nozzles are used, since they clean more effectively, rebalancing the energetic consumption of the extra motor implemented in the nozzle (Rames et al., 2018). However, it has also been reported that the use of active nozzles increases the likelihood of breakage of vacuum cleaners, due to the additional motor unit implemented (Rames et al., 2018).
- Hose, a flexible corrugated plastic tube that connect the nozzle to the product body, where the suction system is located. Usually it has an inner diameter of 30-35 mm and it represents the main cause of pressure loss, estimated to be around 2-3% (Rames et al., 2018)
- Dust bag (for bag vacuum cleaner), usually made of synthetic fibres, which filter the dust from the air sucked by the motor. Compared to the bucket used in the bagless configuration, the suction power can be affected by the quantity of dust captured in the bag(Rames et al., 2018).
- Dust bucket (for bagless vacuum cleaners), where the filtering of the dust from the airflow is due to centrifugal forces (“cyclone effect”) (Rames et al., 2018).
- Inlet filter, which filters all the residual dust coming from the dust bag or bucket and avoids it to end up in the motor. Usually the centrifugal filtering system of bagless vacuum cleaners is less effective compared to the one determined by a dust bag. For this reason, the inlet filter requires more user maintenance in bagless, where periodically it has to be cleaned (Rames et al., 2018). Lack of maintenance of this filter is one of the main causes of malfunction according to many different stakeholders interviewed in Philips (Jungbluth, Philips Consumer Care; Baaiman-Telkamp, Philips Q&R)
- Motor unit, which is actually composed by a motor driver and an integrated fan. This component determines the difference of pressure inside the vacuum cleaner. The design of the motor unit has drastically changed after the introduction of the Ecodesign and Energy Labelling Regulations. The efficiency of the motors currently implemented for top-model vacuum cleaner in Europe has improved from 30% to 80%. Brush-less motors have started to be implemented (as found also in the Stick analysed in this research, FC6812), and 2000 W motor units have been replaced by 600-800 W ones (Rames et al., 2018). The fan is the component that turning creates suction power.

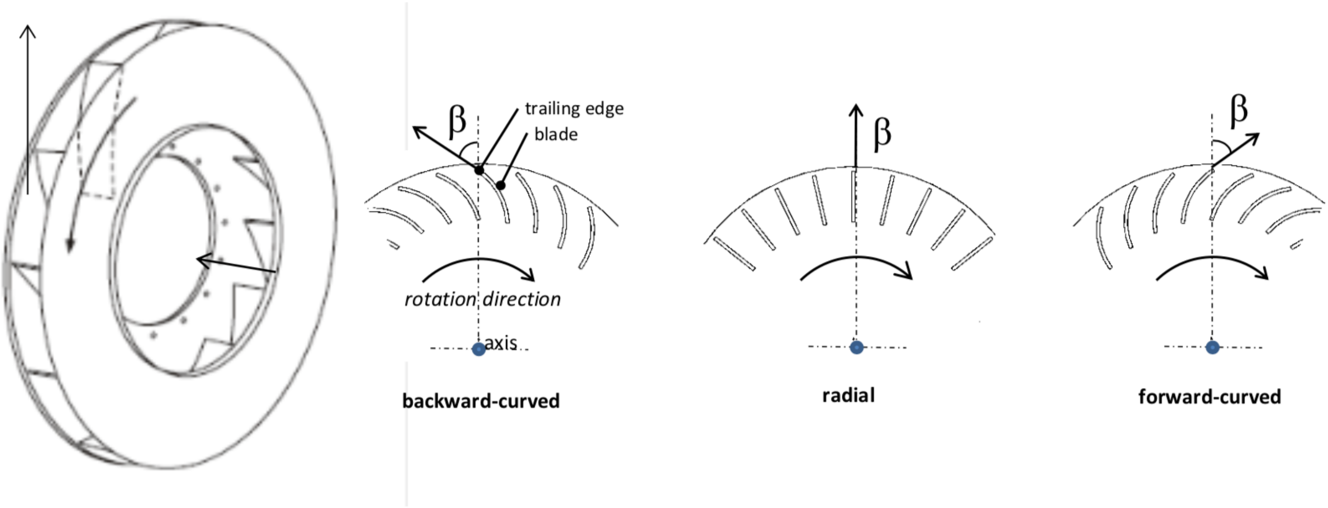


Fig. 8, Different motor blades orientations (Rames et al., 2018)

Household vacuum cleaners usually integrate a centrifugal fan. According to the orientation of the blades (Fig. 8), a fan can be forward-curved, radial or backward-curved. The last one is the most efficient and common one, where the air enters from the front at the centre of the fan, to be then expelled sideways by means of centrifugal force (Rames et al., 2018).

- Outlet filter, which filter the last 0,1% of dust in the airflow and prevent it to be re-emitted in the surrounding (Rames et al., 2018). Usually this filter is an HEPA filter and, contrary to the inlet filter, cannot be cleaned.
- Batteries, which implementation in vacuum cleaners has significantly increased with the introduction of the relatively new wireless generation of handheld and stick vacuum cleaners. This component has functional importance, since it represents the power source for this growing product family. Vc's batteries are usually composed by Ni-MH (Nickel Metal Hydride) or Li-ion (Lithium-ion) (Rames et al., 2018).
- Cord-winder, which provide current to the motor unit through a power cord on average 10-11 meters long (Rames et al., 2018). It is usually composed by a retraction system, composed by a spring mechanism which allows to rewind automatically the cable. This is one of the components which fails more often during the average life-span of a vacuum cleaner (Rames et al., 2018).

Products/components life-time

The JRC scoring system underlines how product group life-time is an important data to take in account before defining priority parts. In fact, if the average life-span of a component is longer than the life-span of the product itself, the part might not be considered as a priority component (Cordella et al., 2019). For instance, the dust bucket of a bagless vacuum cleaner is very important to deliver primary functionalities. However, this component is usually produced in Polycarbonate or ABS, and it is designed in such a way that it is very robust and unlikely to break during the product life-time. Moreover, consumers' wiliness to repair their product is also influenced by the life expectancy of a product. In fact, users are less willing to pay for a repair if the product is close to its life-time limit (Cordella et al., 2019). Vacuum cleaners life-time can range between 5 and 9 years according to many different sources consulted (Bobba, Ardente, & Mathieux, 2015; Cordella et al., 2019; Rames et al., 2018; Reisch, Graulich, Degallaix, Maurer, & Bernefeld, 2010). The Benelux Study defined 8 years as a reference value (Bracquené et al., 2018). Rames et al. (2018) presented the following table (Table 6) with the average life-span of different type of vacuum cleaners.

Through Bracquené et al. (2018) it was possible to retrieve interesting literature about estimated failure rates of the product group. According to Wang, Huisman, Stevels, and Baldé (2013) a failure

Vacuum cleaner type	Average life span (years)	Standard variation (years)
Cylinder domestic	8	2
Upright domestic		
Cylinder commercial	5	2
Upright commercial		
Cordless	6	3
Robot		

Table 6, Average life-span of different types of vacuum cleaners (Rames et al., 2018) rate of 9,7% for the entire product group can be deduced in 2005. Surveys quoted by Bracquené et al. (2018) show how the failure percentage in canister vacuum cleaners was estimated to be 16% in 2016. According to consumer association surveys analysed by Rames et al. (2018) 1 in 5 uprights and 1 out of 10 canister vacuum cleaners fails during the first 6 years of product life.

Generally, the motor is the main cause of final disposal of a vacuum cleaner (Rames et al., 2018). For this reason, the European Commission imposed a minimum life-span of this part of 500 hours, with the Commission Regulation (EU) No 666/2013 of 8 July 2013 (Directive 2009/125/EC of the European Parliament and of the Council with Regard to Ecodesign Requirements for Vacuum Cleaners) (Bracquené et al., 2018). Kemna and Boorn (2016) tested 51 vacuum cleaners from 10 different brands, and identified brushes motor wear as the main cause of motor breakage. Eventually, the German consumer association Stiftung Warentest tested 190 vacuum cleaners in the period 2003-2015. What they found was that 89% of them reached a limit of 600h, independently from the price range (Bracquené et al., 2018; Kemna & Boorn, 2016)

Frequencies of failure

In order to obtain the most objective and reliable overview over frequencies of failure related to the specific product group, four different sources have been analysed:

- Confidential call rates
- Literature statistics
- Consumer association surveys
- Unofficial repair statistics, Repair Café monitor

Confidential call rates

Neither the data set, nor insights obtained from source can be publicly shared. However, a copy of the material consulted can be found in Confidential Appendix B. The call rates retrieved from Philips Q&R (Baaiman-Telkamp, Philips Q&R), describe a clear overview of the parts that fail more often in the general vacuum cleaner portfolio, but also specifically for bagless canister, bag canister and stick. They are a very reliable source, created by analysing data coming mainly from repair centres located in Europe. However, since most of the repairs carried out by Philips happen during the warranty period (first 2 years of life of the products), they describe just partially the failures that can happen during the total life span of the product (around 5-7 years) (Bobba et al., 2015; Bracquené et al., 2018; Cordella et al., 2019; Rames et al., 2018). Apart from the general call rates, confidential failure rates of specific models have been analysed using specific CTN numbers (Commercial Type Name). This analysis has been extremely important for this research but, unfortunately, no insights or observations can be shared in this report. The only interesting insight which can be publicly shared is that a correct user maintenance would avoid many faults registered by Philips. In fact, the repair centres often receive products with clogged filters and hoses. This usually determines motor malfunction, caused by dust deposition or insufficient airflow for the cooling of the motor engine. Moreover, the number of “no failure found” products (officially indicated as NFF), is very high. In this case products sent for repair are actually perfectly working, and do not present any fault. They are cleaned and shipped back to the consumer after being carefully checked.

Literature statistics

Literature statistics are less precise and reliable compared to official call rates provided by the manufacturer, but they give a broader overview. They consider the entire life-span of the product group and different manufacturing brands. Moreover, the following data set have been also used to create different scoring assessment systems for repairability, like one presented in Cordella et al. (2019), but also the one defined by Bracquené et al. (2018). Typical frequencies of failure on upright and cylinder vacuum cleaners has been retrieved by the “Review study on Vacuum cleaners for the European Commission” (Rames et al., 2018) (Table 7). The origin of this information is a previous European Commission study on “Durability assessment of vacuum cleaners” (Bobba et al., 2015). This data set has been analysed also by the JRC repairability scoring system (Cordella et al., 2019). The most common faults seem to be related to suction deterioration, which can be related to internal component malfunctions and blocked filters, likely related to lack of user maintenance (Bobba et al., 2015; Cordella et al., 2019; Rames et al., 2018). Broken belt is a common fault in vacuum cleaners provided with active nozzles; however, Philips implements this type of nozzles just in upright and stick vacuum cleaners.

Consumer associations surveys

Consumer associations surveys results have been collected by the Benelux study on product repairability (Bracquené et al., 2018) and they have been compared In Table 8. Three different consumer associations surveys have been considered:

- Test Aankoop, Belgian consumer association, which carried out a survey among 19000 consumers, and listed the 5 main failures found.
- Consumentenbond, Dutch consumer association, which provided a list of failures, but with no statistics
- Which?, UK consumer association, which conducted a survey among 350 consumers for uprights vacuum cleaners, and 287 for canister models in 2015.

Unofficial repair statistics, Repair Café monitor 2017

Most of the repairs managed by Philips concern products that are still in their first 2 years of life (guarantee period). This is because the best-selling Philips vacuum cleaners are positioned in a medium-low price range; therefore, the cost of a repair on these products is usually higher than 30% of the cost of a new model. In fact, a raft repair cost estimation, carried out with the help of a Service Product Engineer (Consumer Care), shows how the price of a repair can easily go over 100€, considering:

- 15€ of shipping costs
- 60/70€ of labour cost and service
- At least 10€ of spare part
- VAT depending on the nation (between 19 and 23% of the total cost)

This estimation was confirmed by information retrieved on the Philips website, where a standard shipping cost of 15€, research cost of 27,23€ and a quotation limit of 60,50€ are indicated (Philips.nl, 2019b).

Consumer surveys and statistics found in literature show how consumers are not willing to pay for a repair when its cost is higher than 30% of the price of a new product (Bracquené et al., 2018; Cordella et al., 2019; Rames et al., 2018). This is the reason why very few consumers use the official Philips repair channels after the warranty period, and this is also the reason why the information analysed from the confidential call rates provided by Philips probably represent just the faults that happen during the first two year of life of a vacuum cleaner. On the other hand, Repair café's represent the cheapest solution for consumers interested in repairing their products after the warranty period. These are free meeting places where, usually once a month, expert volunteers (e.g. ex professional repairers), offer their expertise for free, helping visitors to repair their broken items (Repair Café, 2019). The Repair Café was initiated in 2009 in Amsterdam, by Martine Postma. The association has rapidly grown, and today many Repair Café's are spread all around the Netherlands (Repair Café, 2019). All these unofficial repair centres kept track of all the repair procedures carried out during the year 2017 in a general "Repair Monitor", which has been

Table 7, Most common faults of upright and cylinder vacuum cleaners (Rames et al., 2018)

Upright vacuum cleaners, Faults experienced	%
Suction deteriorated	24.3%
Blocked filters	21.7%
Belt broken (drive-belt rotating brush)	16.9%
Split hose	13.7%
Motor broken	13.4%
Brush not working properly	12.0%
No suction	10.0%
Brush not working at all	9.4%
Casing cracked/chipped/broken	8.9%
Other	8.6%
Broken accessories	8.3%
Overheating	6.3%
Power cable faulty	5.1%
Wheels/castors broken	4.9%
Handle broken	4.6%
Power not working at all	3.7%
Power cutting out	3.1%
Handle loose	2.3%
Controls broken	0.60%

Cylinder vacuum cleaners, Faults experienced	%
Suction deteriorated	19.5%
Blocked filters	17.8%
Other	15.7%
Broken accessories	12.2%
Brush not working properly	10.8%
Casing cracked/chipped/broken	10.1%
Overheating	8.7%
Split hose	7.7%
Motor broken	6.6%
Power cutting out	5.2%
Power cable faulty	5.2%
No suction	5.2%
Brush not working at all	4.9%
Handle broken	3.8%
Power not working at all	3.8%
Controls broken	2.4%
Wheels/castors broken	2.4%
Belt broken (drive-belt rotating brush)	2.1%
Handle loose	1.7%

	Consumentenbond (2017)	Test aankoop (2015)	Which? (2015) - Canister	Which? (2015) - Upright
Split/broken hose	X	15%	5,27%	7,71%
Power cable	X	11%	9,73%	4,95%
Brushes/Nozzel	X	5%	12,19%	21,55%
Switches/Electronic board	X	5%	1,64%	
Wheels	X	4%	1,64%	2,76%
Motor (carbon brushes)	X		4,52%	7,54%
Broken casing			6,92%	5,01%
Filters	X		12,19%	12,21%
Foreign obstruction	X			
Handle			3,77%	3,88%
Suction deteriorated			16,92%	19,30%
Broken accessories			8,36%	4,67%
Overheating			5,96%	3,55%
Other			10,75%	4,84%

Table 8, Comparison of different consumer associations surveys concerning faults of vacuum clears (Bracquené et al., 2018)

used by the Repair Café International Foundation and the Dutch environmental organization Natuur & Milieu for a research about products faults and life-span (Natuur&Milieu, 2018). The repair monitor database in original language (Dutch), limited Philips products can be seen in Appendix D. This data set is not as reliable as the manufacturer call rates, neither as the consumer associations surveys and statistics; however, it offers a good overview and interesting insights concerning repairs carried out on low price range products after their warranty period, hypothetically from the end of the second till the seventh year of product life. The database covers a total of 2347 repairs, 139 vacuum cleaners, 33 of which Philips branded (Appendix D). Most of the products brought from consumers to the café's in 2017 were Philips branded, with vacuum cleaners as the third most presented product (Natuur&Milieu, 2018). In general, electrical appliances have been successfully repaired 55% of the time (against 90% of repairability rate scored by not electronic products), reaching 60% for Philips products and receiving a repairability score from the Natuur&Milieu study of 6,9 out of 10. Vacuum cleaners have been successfully repaired more than 70% of the time, and the average product life for this specific product group was almost 10 years (Natuur&Milieu, 2018). The main barriers to repair were:

- 30% of the time spare parts were not available, components were not repairable or too expensive to repair
- Another 30% of the time the repair procedure was too complicate or specific non-common tools were required
- 20% of the time it was not possible to disassemble the product without causing part breakage
- 10% of the time the cause of malfunctioning was unknown
- 10% of the time parts were broken and unrepairable

Repair information was rarely found, with service manuals or general information retrieved just 16% of the time(Natuur&Milieu, 2018). The main faults identified for vacuum cleaners are:

- Low suction power, probably related to motor or hose malfunction
- Filter clogging, mainly due to incorrect or missing user maintenance
- Wire connection breakage
- Electric board and switches

Often, the cause of malfunction was unknown. Specifically, for Philips vacuum cleaners (see Appendix D), the faults reported are:

1. Broken wire, 39,4%
2. Electric boards and switches, 33,3%
3. Dirtiness, 15,16%
4. Motor, 12,12%
5. Broken casing, 3%

Priority part list defined by the JRC

Based on the "Review study on Vacuum cleaners" (Rames et al., 2018), on the consumer associations' statistics analysed by the Benelux study (Bracquené et al., 2018), and on interviews to stakeholder involved in the creation of the scoring system, the JRC defined the following priority part list:

- Motor, weight 3
- Motor brushes (for brushed motors), weight 3
- Hose, weight 3
- Power cable, weight 3
- Brushes and nozzles, weight 3

- Filter, weight 3
- Electronic boards and switches, weight 1
- Wheels, weight 1
- Batteries (for wireless vc's), weight 3
- Battery charger (for wireless vc's), weight 3
- Belt (for models with active nozzles), weight 1
- Software and firmware (for robot vc's), weight 1

The complete JRC's priority parts table with the related weights can be seen in Appendix C.

Priority parts analysed in this study

The sources analysed in this study confirm most of the priority parts and weighting proposed by the JRC scoring system and that list has been used in this study as well since Philips was interested in testing the official JRC dispositions. However, further discussion and recommendations about the priority parts list is presented in Chapter 5 and 7. In particular, motor brushes are a component which should not be considered as priority part according to this study.

3.4 Research boundary: definition of single component

Consumer product can be composed by many different internal components, and the total product architecture can be rather complex. In order to carry out the repairability assessment of the seven products selected for this study in a reasonable amount of time and resources, it was essential to constrain the number parts considered as single components. A component can be defined as "a design element that cannot be disassembled without permanent damage to the resulting pieces, or loss of intended function with the resulting pieces" (Bryan et al., 1992). In this research, the analysis depth, hence the definition of a list of single parts, has been determined based on the information contained in the official Service Manuals provided by the manufacturer. In this documentation it is possible to find an exploded view of the product, and a list of components with a related service code (SC). Parts with a SC can also be assembly, therefore composed by sub-components. The reasons why these sub-components are not considered in the assessment are:

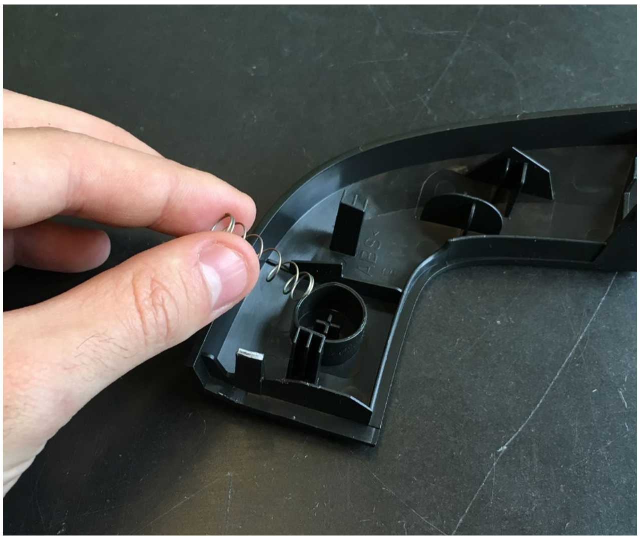
- Sub-components without a SC are never singularly replaceable by the company or authorized professional repairer.
- Spare parts are always organized and managed based on the SC: for instance, if the internal electronic remote control contained in the product handle has to be replace, the spare part provided by the OEM will always be the entire handle.
- There are no disassembly instructions in order to get to sub-component that are lacking SC, and their detachment is often hampered by glue or not reusable fasteners.

Philips Consumer Care (Jungbluth, Philips Service Product Engineer) explained that sub-component are not provided with a SC when:

- The cost of the sub-component is almost the same or even higher (based on commercial agreements with partners) of the cost of the total assembly
- The disassembly of the sub-component would require high disassembly time, determining a repair cost that exceed the cost of the "assembled part" itself, which is then preferable. Disassembly time has been found also in literature as an important aspect that can define the inconvenience of a repair procedure. For instance, (Peeters et al., 2018) observed how extensive repair time can cause high labour costs, which lead to avoiding the repair.
- Sub-components without SC part of the same assembly, tend to deteriorate simultaneously, and the failure of one can be related or followed in a short time frame by the failure of the others.
- Soldered sub-components are also not provided with Service code, since the official Philips repair centres (e.g. Trier) are not provided of soldering equipment, for economic and safety reasons.

Depending on the call rates and pareto analysis carried out during the development of a new model, different spare parts can be provided for different models. This can lead to different service component lists for each model: for instance, for the bag canister FC8924/01, the iron springs located beneath the on/off and cord-wider buttons (Fig. 9) are considered as service components, while they are not indicated as service components

Fig. 9, Button spring: example of less meaningful component provided of SC which was left out from the analysis



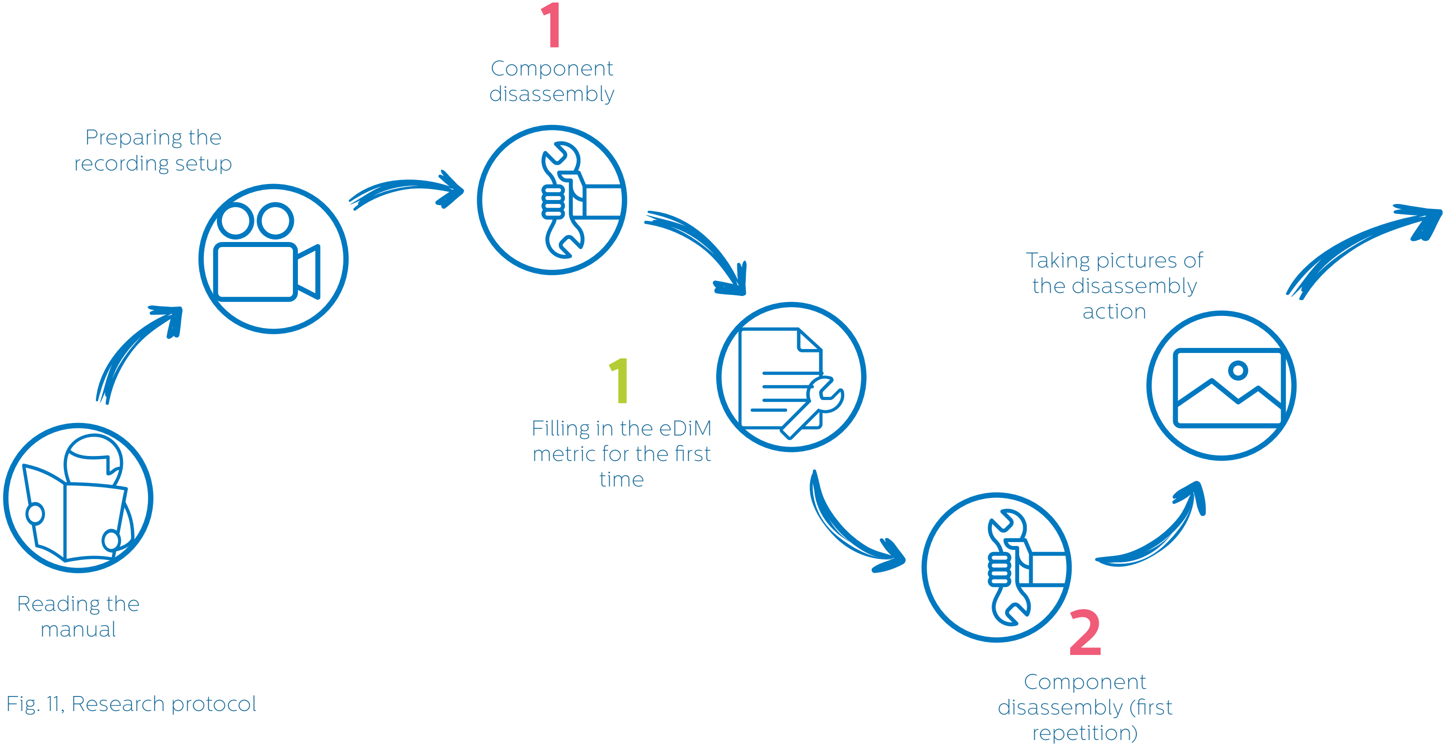


Fig. 11, Research protocol

in the service manual of the bagless canister FC9934/07. Usually these inconsistencies in single component lists are rare and they concern small components, which are not priority parts. In order to ensure comparability of the analysis carried out on different model, only the service components shared by all the models have been taken in account. This led, in some cases, to excluding from the analysis small components provided with SC (such as small iron springs, seals and small plastic components) which, on the other hand, are not significant for the general repairability assessment of the product. At the same time, parts not provided with SC, but considered important for the repairability assessment and future redesign of the product, have been considered in the assessment, even if no spare parts are actually available. For instance, this happened with the bag canister FC8924/01, where the outer aesthetics casing is not a service part, but its assessment is important to be considered in order to redesign a product easier to be refurbished.

3.5 Assessment setup

Research setup

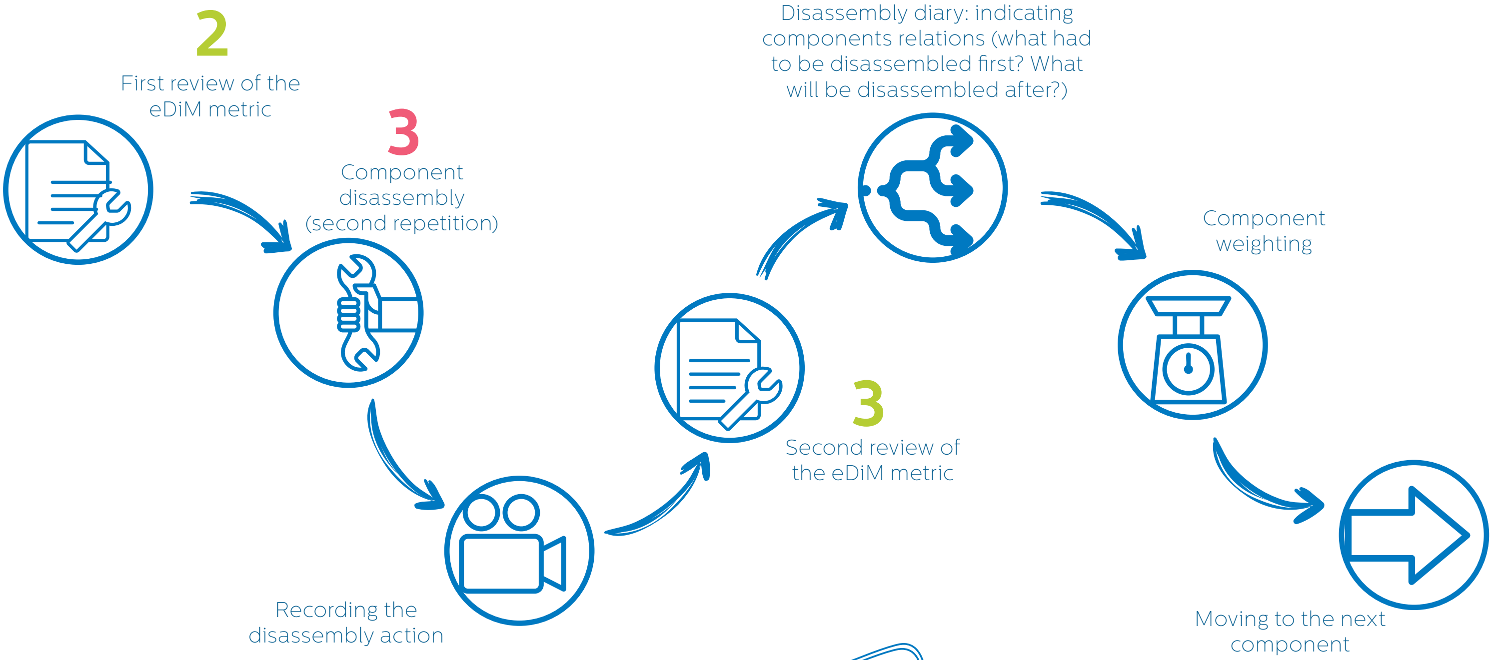
All the vacuum cleaners have been disassembled and assessed using the same assessment setup. This was composed by a big working surface and two cameras, pointing in different directions: a frontal camera and a top-view one (Fig. 10). The cameras recorded all the disassembly procedures at the same time, providing continuous and alternative views on the procedures.

The camera footage was recorded using a computer, where a software automatically joined the two different camera recordings in one single video. For some models analysed, the entire disassembly footage has been post-edited, showing single step procedures and the names of the single components disassembled (Fig. 12).

Research protocol

In order to ensure testing repeatability and comparability of the assessments, a research protocol was created beforehand. This protocol was very redundant, being composed by repetitive disassembly and reassembly of each component for 3 times (Fig. 11). The eDiM metric has been reviewed for three time as well, ensuring a precise and reliable choice of motion sequences. This protocol was mainly composed by 8 phases:

1. **Reading of the service manual and safety recommendations.** In order to have a clear overview of the architecture of the product, the first step of the assessment always concerned reading the service manual. This assessment wanted to simulate the official disassembly procedures suggested by the manufacturer, as an official repairer would do. Official repairers are always provided with service manuals, and they carry out the disassembly procedures following the official guidelines; following the official disassembly steps was important in order to obtain a truthful assessment. This step has not been followed for the analysis of competitors, for which was not possible to retrieve the official service manuals. However, their architecture has been investigated beforehand using different sources (Online disassembly tutorials or exploded view uploaded on the internet by unofficial sources). Safety recommendations are also important to



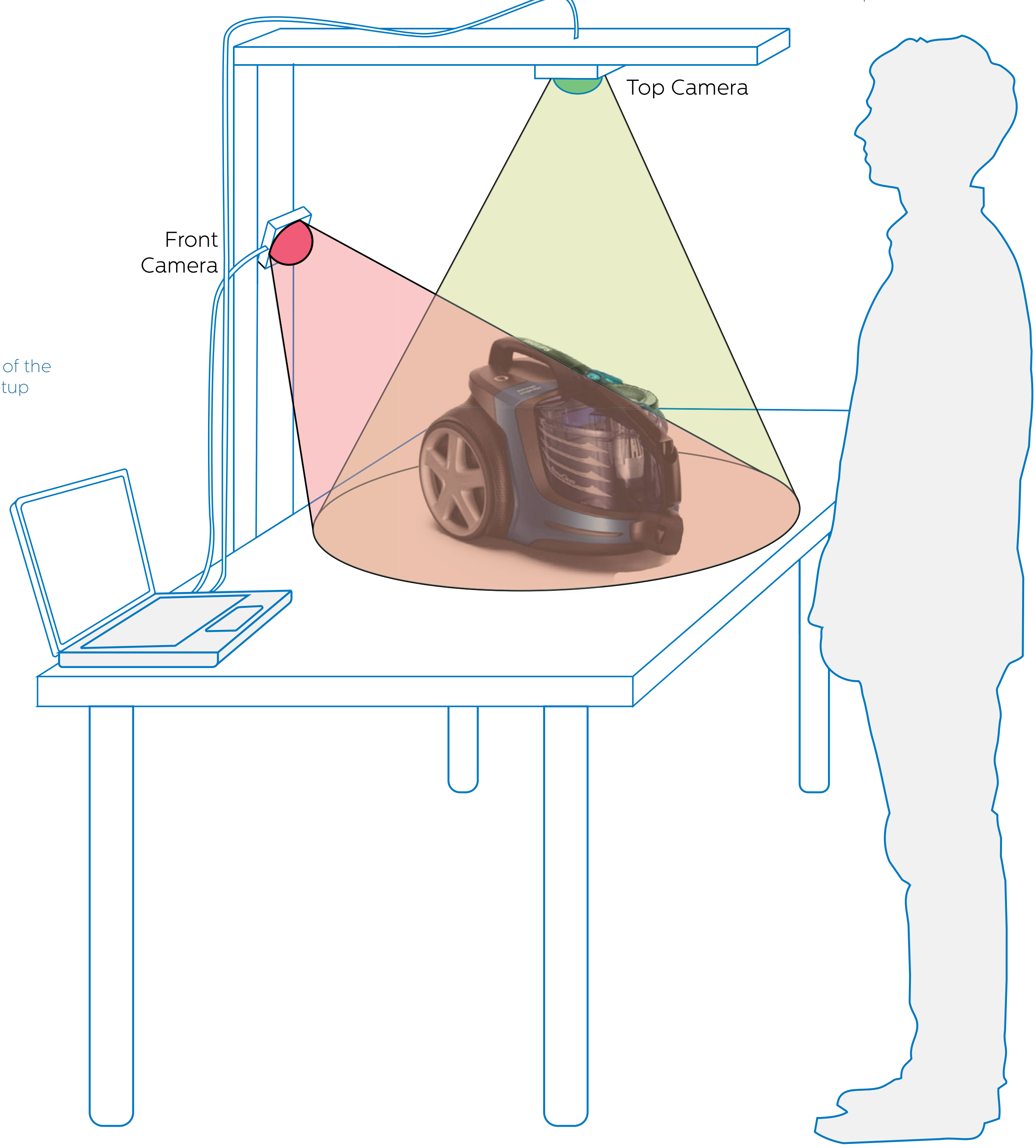


Fig. 10, Picture of the assessment setup be read, in order to be prepared and correctly equipped in case of dangerous procedures.

2. **Recording setup**. Before starting any disassembly, it was very important to setup correctly the recording equipment. Cameras had to be positioned in the right direction and height, based on the dimensions of the different models. For instance, the stick model FC6812/01 is a smaller product compared to a canister, hence the top camera had to be lowered down, obtaining a closer shot of the product. On the contrary, the canister model FC9934/07 is very big, therefore the top camera has been set to a higher point, allowing to have a complete view of the item analysed. The cameras have been connected to a pc, where the image acquisition software was set-up, ready to record.
3. **Disassembly of a part.** From this phase on, every step has been repeated for each single component. Firstly, a part has to be disassembled, following the service manual procedure. Particular attention is dedicated to the type of connectors to be opened, the type of tool required and the intensity of force to be applied. This information was then filled in the eDIM excel sheet, for the calculation of disassembly time.
4. **Taking pictures of single actions**. The part disassembled in the previous step was reassembled, and disassembled again. This time pictures have been taken while carrying out the procedure, for documenting reasons. Modifications to the eDIM could be made after repeating the disassembly for the second time. This step has not been carried out for the FC9934/07, since this protocol step was developed afterwards, analysing the first disassembly experience on that specific model.
5. **Recording of the disassembly.** Only at this point, the disassembly of the part was actually recorded. In order to do this the part was reassembled for the second time, and disassembled for the third time. During the first model assessment, the cameras were left recording during the entire assessment. This led to a four hours video footage, difficult to edit and to analyse afterwards: a lot of mistaken procedures where captured, followed by the correct one. For this reason, from the second assessment on, it has been decided to just record single disassembly step, just after being sure about the correct disassembly procedure. This gave also the possibility to go over the disassembly again, for a third and final time, making the final modifications to the eDIM.
6. **Disassembly "diary"**. After disassembling for the third time single components, an assessment diary has been filled in. All the single parts disassembly procedures have been described precisely and clearly, indicating the actions required, type of tools, connectors, and force intensity. Comments were added, in order to highlight difficulties or important insights which could be forgotten afterwards. It was very important to conclude the description of the disassembly of each component describing the interconnections with other product parts, which means what components had to be disassembled first to

Fig. 12, Edited footage showing single step procedures be able to disassemble the part analysed. This was extremely useful for the creation of the new design tool “Disassembly map” (Chapter 6) and the assessment of disassembly depth. Examples of disassembly diaries can be found in Appendix E. This step has not been carried out for the FC9934/07, since this protocol step was developed afterwards, analysing the first disassembly experience on that specific model.

7. **Weighting of the different components.** In order to create an LCA of the products and to use the HotSpot Mapping tool (Chapter 6) for the redesign of the product, it was very important to weight each part, noting also the material composition. This data has been added to the eDIM table as well.
8. **Picture of the complete disassembly.** At the end of the assessment, when the product was completely disassembled, a complete picture of all the single components has been taken. This was useful afterwards to locate and identify specific parts. The picture of the complete disassembly of a Philips FC8924 can be seen in the next page (Fig. 13), while the pictures of the other models assessed can be seen in Appendix F.

3.6 Key parameters for the RRU assessment of Vacuum cleaners

Parameters excluded

As introduced in the previous chapters, the JRC (Cordella et al., 2019) defined a list of 12 parameters for the assessment of product repairability and upgradability. However, this list has to be adapted to the specific product group analysed. This is because certain parameter might not be relevant for certain products. For instance, the parameters excluded by the JRC for the assessment of vacuum cleaners are:

- **Disassembly time, parameter 4**. The JRC argues that this parameter is already covered by other three parameters: disassembly depth/sequence, fasteners, tools and availability of repair information. Moreover, it is pointed out how more methodological development is still required in order to create an objective and standardized process to assess disassembly time. The eDIM methodology, one of the latest documented methodology to assess disassembly time, includes a relatively limited list of connectors, and it should be further adapted and applied on different product groups. Moreover, reference values, for a representative sample of vacuum cleaners, should be analysed in order to correctly assess this parameter. This has not been done yet, and it would require a significant amount of resources (Cordella et al., 2019). For these reasons the JRC scoring system proposes to avoid the use of this parameter till when more reliable data will be provided. Despite this, disassembly time has been considered in this research, defining new eDiM standard time parameters and assessing 7 different products. The calculation of disassembly time proved to be an excellent tool to compare different product architectures (Chapter 5 and 7) and fundamental to calculate the actual economic impact of enhanced repairability on repair services (Chapter 7). Moreover, by calculating standard deviation and variation of the average time per step of all the disassembly procedures carried out in this research, it was found that, even if correlated, disassembly time was not always truly described by disassembly depth, as argued instead by the JRC.
- **Diagnostic support and interfaces, parameter 5**. This parameter has been excluded for the assessment of vacuum cleaners, since failures and faults have been described by the stakeholders involved in the creation of the scoring system, as rather easy to identify (Cordella et al., 2019). It is argued that a troubleshooting guide should be included in the user manual, and that this one should be sufficient to determine the faults origin.
- **Safety, skills and working environment, parameter 9.** This parameter has been left out by the JRC, since it is argued that no significant differentiation between different models on the market is expected in term of safety, skills and environment for the repair of this product group (Cordella et al., 2019). If differences existed, they would be covered by other parameters, like disassembly depth, fasteners, tools and information provision. No critical procedure has been spotted by the Benelux study while assessing a vacuum cleaner as case study; all the priority parts were reachable without carrying out unsafe actions (Bracquené et al., 2018).
- **Data transfer and deletion, parameter 10.** This parameter is becoming more and more relevant with the evolution of Internet of Things. However, it is not considered relevant for this specific product group, where no private information is usually stored in the product (Cordella et al., 2019).
- **Password reset and restoration of factory settings, parameter 11.** This parameter is also considered not relevant for the specific product group analysed.
- **Software and firmware, parameter 8.** This parameter was not considered in this research, since no robot vacuum cleaner has been analysed. All the product assessed did not include any upgradable software.

Fig. 13. Complete disassembly picture of a Philips FC8924

Parameters included

The parameters presented by the JRC as relevant for the assessment of vacuum cleaners are:
Design for disassembly (DFD):

- **Disassembly depth/sequence, parameter 1**, weight 2
- **Fasteners, parameter 2**, weight 2
- **Tools, parameter 3**, weight 2

Repair and upgrade process (RRU):

- **Type and availability of information**, parameter 6, weight 2
- **Spare parts, parameter 7**, weight 2
- **Commercial guarantee, parameter 12,** weight not applied

This study applied the same assessment parameters officially suggested by the Joint Research Centre in (Cordella et al., 2019). However, disassembly time has been included since it proved to be an excellent tool to compare different product architectures (Chapter 5 and 7) and fundamental to calculate the actual economic impact of enhanced repairability on repair services (Chapter 7)

3.7 Creation of new eDiM disassembly motion sequences

As previously introduced, the JRC scoring system does not include parameter 4, disassembly time, for the assessment of vacuum cleaners (Cordella et al., 2019). The main reasons concern unavailability of information, not standardized ways to access this parameter, and missing of reference values, which should be defined assessing a large number of products parts of the same product group. Moreover, according to the JRC, Disassembly time is also described indirectly by the assessment of disassembly depth, tools, fasteners and availability of repair information (Cordella et al., 2019). However, disassembly time can represent a very important information to compare different product architectures and fundamental to calculate the actual economic impact of enhanced repairability on repair services. In addition, the same attributes used in the eDiM to define different type of connectors have been applied in the creation of a new design tool called “Disassembly Map” (Chapter 6). For this reasons, disassembly time has been considered in this research. Products have been assessed using the eDiM metric, analysing the entire product disassembly of all the Philips vacuum cleanser and partial disassembly of the three competitors. In fact, for time limits, it was not possible to assess completely the competitors’ products as well. The final calculation tables can be found in Appendix H.

New type of connectors

The set of connectors listed in the latest version of the eDIM database at the date of this research (Peeters et al., 2018) has been created analysing laptops. Therefore, although a very wide choice of different electric cable connectors and hinge connectors is presented, any snap fit connections are included. Snap fits are intensively used in the assembly of vacuum cleaners and many other white goods; hence, it is very important to consider them in this research. Based on the first paper released about the eDIM analysis (Vanegas et al., 2016) and on the Benelux study about product repairability (Bracquené et al., 2018), it has been possible to define a list of new connectors specific for the product group analysed. They are all based on two main families, Snap Fit and Friction Fit, but diversified according to the tool and the force intensity required for their disassembly.

Fiction fits

Friction Fit defines a fastening between two part achieved by the friction created pushing one component into the other (Lebeck, 1991). This fastening system is also known as press fit or interference fit. The tightness of the fastening is determined by the amount of interference of the two surfaces, quantifiable with the mechanical allowance, hence the planned difference from nominal size (see Fig. 14). Based on the tolerance between hole and shaft, the fastener can be defined as clearance fit, interference fit or tolerance fit. For this type of connector, the force intensity required for disconnection is the main parameter that influence the total disassembly time.

Snap fits

Snap fit connectors are usually implemented to assemble flexible parts, mainly plastic components, by pushing against each other two interlocking parts (Schlick, 2009). They are an inexpensive option to screws, and their main

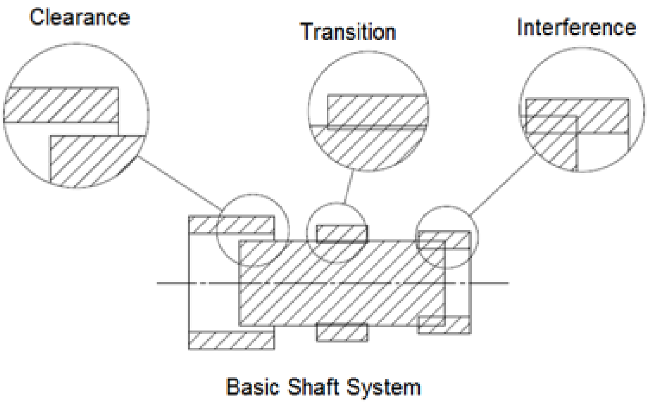


Fig. 14, Different types of friction fits (smlease.com, 2019) advantages are disassembly speed and no loose parts. At the same time, snap fits are usually more fragile compared to screws connectors, breaking more often during disassembly (Tres, 2017). They can be classified in:

- Annular (Fig. 15), where the fastening happens through hoop-strain, as the circumference expansion of the more elastic component when pushed in the more rigid one. This type of fastener can be reused but, after a certain number of disassembly, the more elastic component might acquire permanent strength.
- Cantilever (Fig. 16), characterized by the presence of a lever or pin, which can be pushed to open the fastening. This is the most common type of snap-fit. It can be reusable, if a lever or pin for disassembly is present, or permanent, which breaks if opened (Messler, 2004).
- Torsional (Fig. 17), composed by a large deflection area which, if pressed, releases the second component. These snap fits may present a spring in place to facilitate the opening and automatically fastening if released (Tres, 2017).

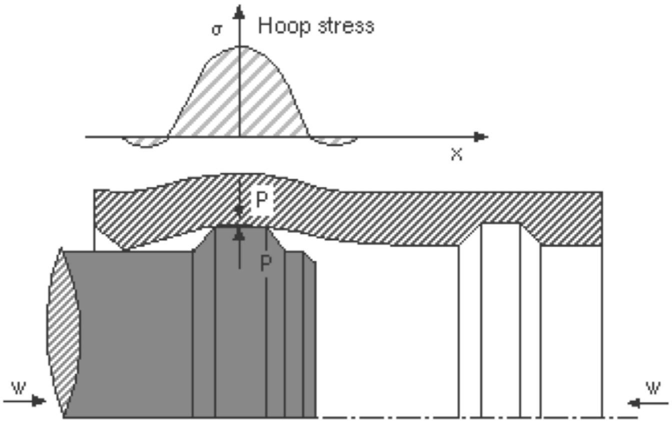


Fig. 15, Annular snap fit (Santa Clara University, 2006).

New eDIM sequences

As introduced in Chapter 2, the author of the eDIM method (Vanegas et al., 2016) defined six main disassembly tasks which, combined, describe a disassembly process. These six tasks are:

- Tool change, MOST sequence |A1B0G1|+|A1B0P1|
- Identifying connectors, MOST sequence |T10|
- Manipulation of the product, MOST sequence |A1B0G1|+|L3 |
- Positioning, MOST sequence |A1B0P3A0|
- Disconnection, MOST sequence based on the type of connector
- Removing, MOST sequence |A1B0G1| + |A1B0P1|

Additional time required for connectors identification, and product manipulation can be described as penalties: they are not essential actions in a disassembly procedure, but they are sometimes required by unoptimized design features for disassembly. These could be hidden connectors, which require time to be located, or fasteners placed in an unconventional position on the product, requiring to manipulate the item in order to be reached.

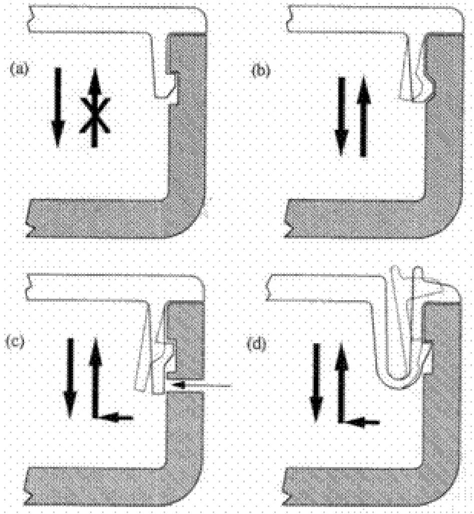


Fig. 16, Cantilever snap fit (Way, 2016)

The new eDIM sequences proposed for snap fits and friction fits have been differentiated based on two different type of tools required for the connector disassembly:

- Hand, where the Tool Change Time is equal to 0 s (Fig. 18; Fig. 20)
- Flat Screw driver, also defined as Spudger (Peeters et al., 2018), where tool change time is 1,44 s (Fig. 19; Fig. 21).

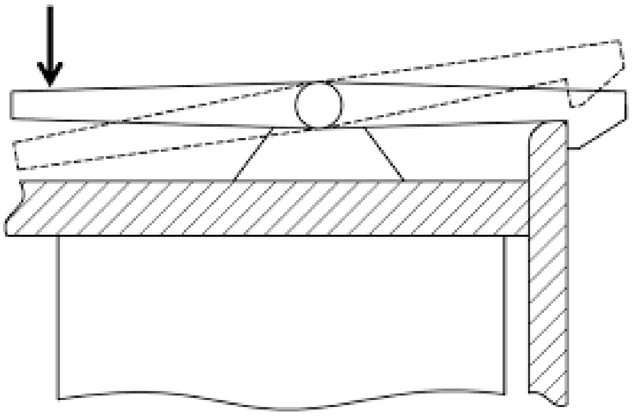


Fig. 17, Torsional snap fit (Way, 2016)

Fig. 18, Examples of Friction fits by hand (force type 1, 2 and 3)

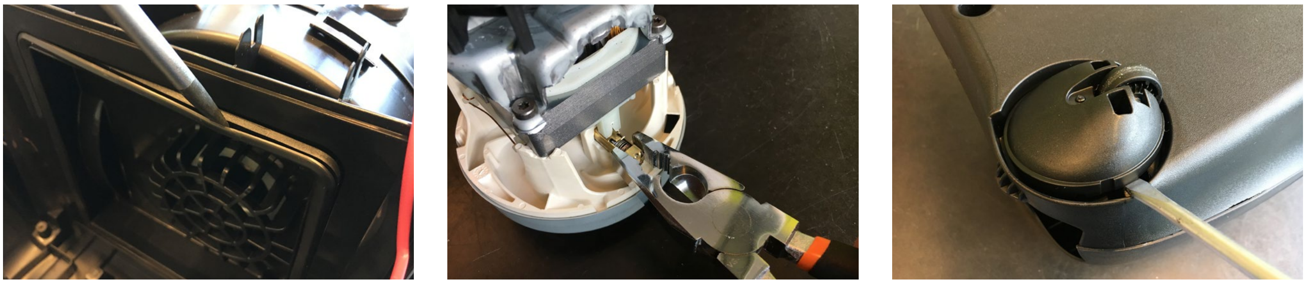


Fig. 19, Examples of Friction fits using a spudger (force type 1, 2 and 3)

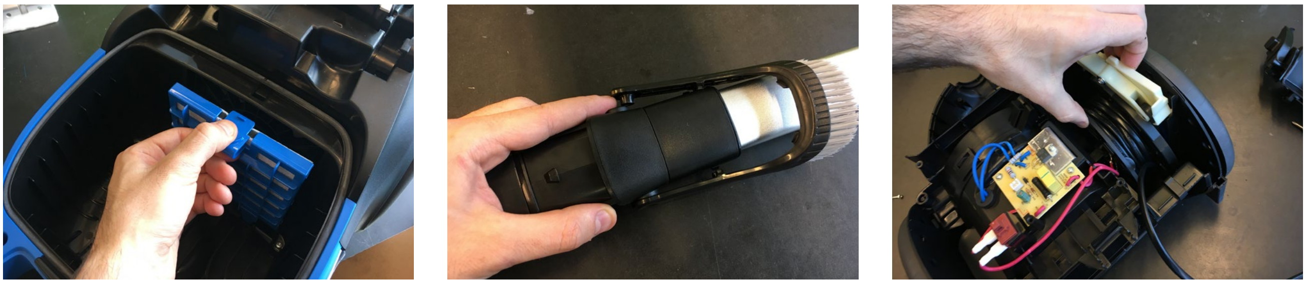


Fig. 20, Examples of Snap fits by hand (force type 1, 2 and 3)

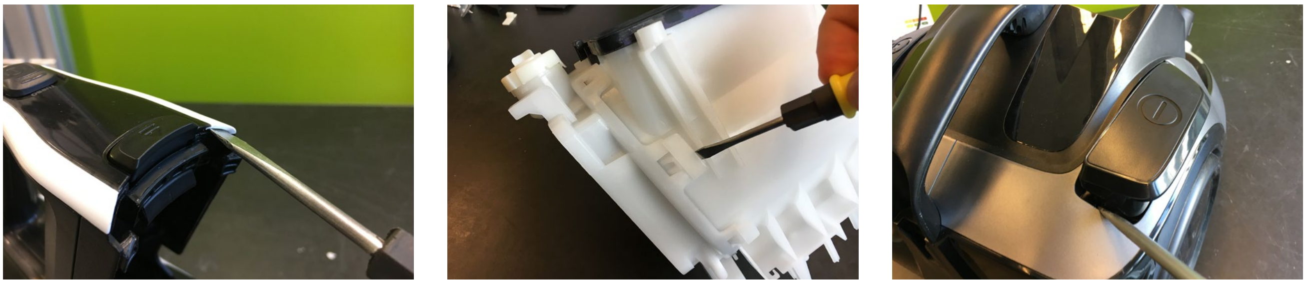


Fig. 21, Examples of Snap fits using a spudger (force type 1, 2 and 3)

Three main force intensity ranges have been defined based on the MOST, Maynard Operation Sequence Technique, and already presented in (Vanegas et al., 2016):

- Type 1: Force < 5N, MOST sequence |L1|, Finger manipulation with force < 5N. Connectors belonging to this force range usually require low intensity disassembly force, mainly carried out just using fingers or partial parts of the hand. This action can be completed with confidence, with a low risk of fasteners and part breakage.
- Type 2: 5N<Force<20N, MOST sequence |L3|, Hand manipulation with 5 N < force < 20N. Connectors belonging to this force range usually require medium intensity disassembly force, which can be applied using the entire hand. This action can be completed with confidence, with a low risk of fastener and part breakage.
- Type 3: 20N<Force, MOST sequence |L6|, Two hands or arm manipulation with force > 20N. Connectors belonging to this force range usually require high intensity disassembly force and the use of both hands. This action is often not completed with confidence, involving a high risk of fastener and part breakage.

Since the disconnection sequences (L1, L3 and L6) are defined based on force intensity and anatomic body part used (fingers, hand, two hands), and not on a specific type of tool, the sequences calculated for “Spudger” disassembly can be extended to any possible artificial tool different from human hands, which can be used to disconnect a snap fit or a friction fit. This means that also the use of pliers can be described as “Spudger”, indicating a force range type 2 or 3: application of force using the entire hand. The definition of spudger has been used to differentiate the disassembly carried out with hands, where tool change is equal to 0 s, and artificial tool, where tool change is equal to 1,44 s. In fact, it is assumable that a disassembly procedure which can be carried out using just hands is preferable compared to a procedure that requires the use of artificial tools, since the retrieval of any tool would not be necessary.

Tool positioning time has been defined as 1,44 s for the lower force ranges 1 and 2, and 2,52 s for the higher force range 3, since during the disassembly procedures carried out for this study it has been observed how more time is required to position the tool when high forces are required for fasteners removal. This variation of time positioning, from 1,44s to 2,52s is presented in the second version of the eDIM, based on physical observations of product disassembly (Peeters et al., 2018).

The MOST sequences related to Friction fits do not require to consider the removal of the disassembled component (1,4 s), since the component is already removed during the action expressed by |L1|, |L3|, |L6|.

Because of the fastener nature, in both cases it has been considered that just hands are needed for the reassembly, since the parts are generally simply pushed back by hand. Therefore, no tool change time has been considered in reassembly phase. The MOST sequences developed during this study can be seen in Table 9.

				DisassemblyA						ssembly				
			Tool Name	Tool Change Time (s)	Tool Positioning Time (s)	Disassembly MOST sequence	Disassembly Time (s)	Part removal Time (s)	Disassembly Total Time (s)	Tool Change Time (s)	Tool Positioning Time (s)	Assembly MOST sequence	Assembly Time (s)	Assembly Total Time (s)	Total assembly and dissassembly Time (s)
Force < 5 N	Snap Fit	Hand	Snap Fit Type 1 Hand	0,0 s	1,4 s	|L1|	0,4 s	1,4 s	3,2 s	0,0 s	1,4 s	|F1|	0,4 s	1,8s	5 s
		Spudger	Snap Fit Type 1 Spudger	1,4 s	1,4 s	|L1|	0,4 s	1,4 s	4,6 s	0,0 s	1,4 s	|F1|	0,4 s	1,8 s	6,4 s
	Friction Fit	Hand	Friction Fit Type 1 Hand	0,0 s	1,4 s	|L1|	0,4 s	0 s	1,8 s	0,0 s	1,4 s	|F1|	0,4 s	1,8 s	3,6 s
		Spudger	Friction Fit Type 1 Spudger	1,4 s	1,4 s	|L1|	0,4 s	0 s	3,2 s	0,0 s	1,4 s	|F1|	0,4 s	1,8 s	5 s
5N < Force < 20 N	Snap Fit	Hand	Snap Fit Type 2 Hand	0,0 s	1,4 s	|L3|	1,1 s	1,4 s	3,9 s	0,0 s	1,4 s	|F3|	1,1 s	2,5 s	6,4 s
		Spudger	Snap Fit Type 2 Spudger	1,4 s	1,4 s	|L3|	1,1 s	1,4 s	5,3 s	0,0 s	1,4 s	|F3|	1,1 s	2,5 s	7,8 s
	Friction Fit	Hand	Friction Fit Type 2 Hand	0,0 s	1,4 s	|L3|	1,1 s	0 s	2,5 s	0,0 s	1,4 s	|F3|	1,1 s	2,5 s	5 s
		Spudger	Friction Fit Type 2 Spudger	1,4 s	1,4 s	|L3|	1,1 s	0 s	3,9 s	0,0 s	1,4 s	|F3|	1,1 s	2,5 s	6,4 s
20 N < Force	Snap Fit	Hand	Snap Fit Type 3 Hand	0,0 s	2,5 s	|L6|	2,2 s	1,4 s	6,1 s	0,0 s	2,5 s	|F6|	2,2 s	4,7 s	10,8 s
		Spudger	Snap Fit Type 3 Spudger	1,4 s	2,5 s	|L6|	2,2 s	1,4 s	7,5 s	0,0 s	2,5 s	|F6|	2,2 s	4,7 s	12,2 s
	Friction Fit	Hand	Friction Fit Type 3 Hand	0,0 s	2,5 s	|L6|	2,2 s	0 s	4,7 s	0,0 s	2,5 s	|F6|	2,2 s	4,7 s	9,4 s
		Spudger	Friction Fit Type 3 Spudger	1,4 s	2,5 s	|L6|	2,2 s	0 s	6,1 s	0,0 s	2,5 s	|F6|	2,2 s	4,7 s	10,8 s

Table 9, MOST sequences created for Snap fits and Friction fits

3.8 Reference values for the assessment of disassembly time and sequence

In order to calculate a score for parameter 1, Disassembly depth/sequence, and for parameter 4, Disassembly time, Cordella et al. (2019) propose a rating system based on the use of reference values. The score can be defined following two different calculations:

- Using a **continuous rating calculation**, suggested by the standard prEN 45554 as well (CEN/CLC TC10 European Standard, 2017), applying the formulas:
    - For disassembly time $S_{1,i} = 1 - DT_i / DT_{ref}$, where DT_i is the disassembly time for the priority part I, DT_{ref} is the reference disassembly time for the priority part I (Cordella et al., 2019).
    - For disassembly sequence/depth $S_{1,i} = 1 - (DD_i - 1)/(DD_{ref} - 1)$, where DD_i is the depth for the priority part i; DD_{ref} is the reference depth for the priority part I (Cordella et al., 2019).

  The reference value for this calculation has been defined by the prEN 45554:
    - For disassembly sequence/depth as “the longest sequence depth for the product group” (CEN/CLC TC10 European Standard, 2017);
    - For disassembly time as “the maximum value of the parameter used to assess the disassembly of the product group” (CEN/CLC TC10 European Standard, 2017)

- Alternatively, a **discrete rating calculation** can be applied (Cordella et al., 2019). This calculation implies the definition of 3 threshold values (X, Y and Z), which determine the final score for each priority part, using the formulas:
    I. DT_i (or DD_i) $< X = 1$ pt.
    II. $X < DT_i$ (or DD_i) $< Y = 0.75$ pt
    III. $Y < DT_i$ (or DD_i) $< Z = 0.5$ pt
    IV. DT_i (or DD_i) $> Z = 0.25$ pt

In this research, the continuous rating calculation has been applied. The main reasons for this choice are:

- The continuous rating is proposed also by the standard prEN 45554;
- In order to define the threshold values required by a discrete rating calculation, a big number of representative products should be analysed.

Despite this, possible new threshold values of a discrete rating assessment of canister vacuum cleaners have been calculated based on all the insights gathered during this research and they are proposed in Chapter 8. These are indicative values, and they have been proposed assessing only seven products, one of which was a Stick vacuum cleaner and four of which were produced by the same brand.

Besides, the formula proposed for a continuous rating has been modified by considering as reference the best vacuum cleaner assessed instead of the worst one. This is because it was found easier to identify the best vacuum cleaners on the market according to repairability. Moreover, it was important to analyse and discuss with the Philips I&D department some of the best competitors on the market, identifying possible design improvements to be applied to the Philips products architecture as well in the redesign phase. At the end of the assessment of all the seven vacuum cleaners, it has been possible to identify very well designed and optimised architectures for repairability, for all the priority parts to be assessed. The priority parts identified as reference are so well designed and optimized for repairability that further optimization would be hardly achievable, deserving without doubt a score of 1/1 pt. On the contrary, it was impossible to define with certainty the worst disassembly sequence or time for the entire product group just analysing seven products .
Eventually, the best disassembly sequences and time for each priority part have been selected from the assessment of the 7 products, and they have been used as reference values in the modified continuous rating formulas:

- $S1,i = DTref/ DTi$ and
- $S1,i = DDref/ DDi$

The disassembly sequences considered as reference are now presented, making the assessment rating used in this research completely transparent.

Nozzle

Model: Siemens VS06A111/12 (Fig. 22)
Number of steps required: 1 step
Disassembly time: 4 seconds (one friction fit force intensity 1, by hand).

Hose

Model: Siemens VS06A111/12 (Fig. 23)
Number of steps required: 1 step
Disassembly time: 5 seconds (two push buttons).

Filter

This priority part required in most cases only 2 steps. The shortest disassembly time registered is 13 seconds, for the models Philips FC9934/07, Philips FC9569/01 and Rowenta RO6963EA (Fig. 24). The filter is immediately reachable just opening the dust bucket lid and extracting it (friction fit, low-intensity force by hand). No previous disassembly is required.

Cord-winder

Model: Samsung SC8835 (Fig. 25)
Number of steps required: 5 steps
Disassembly time: 109 seconds
The cord winder is immediately reachable after removing the clump "rear housing-motor housing". It is easy to disconnect from the PCBA thanks to cable plugs located on the electric board itself.

Wheels

Model: Siemens VS06A111/12 (Fig. 26)
Number of steps required: 1 step
Disassembly time: 10 seconds
In this model, the wheels are all caster wheels. They can be easily disassembled using a spudger, without any previous disassembly.

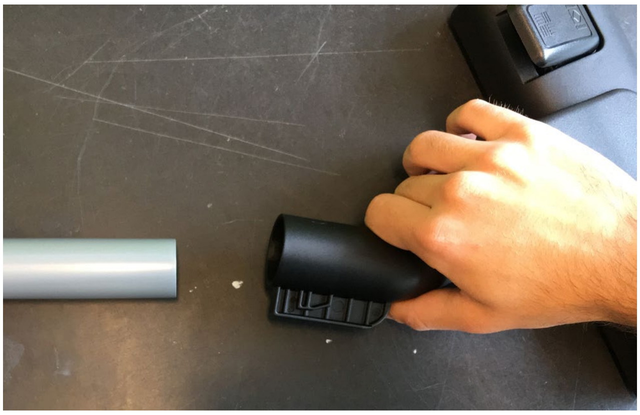


Fig. 23, Hose assessment reference

Fig. 24, Filter assessment reference

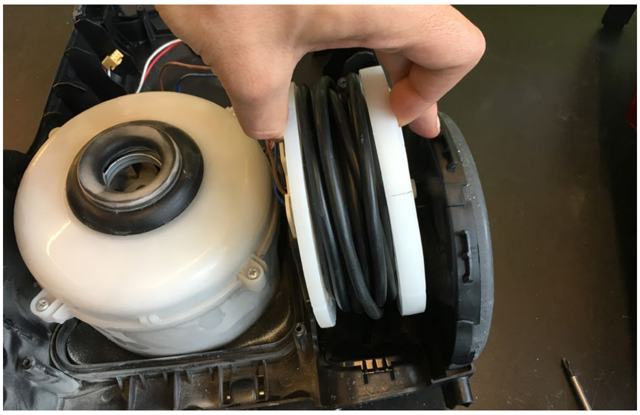


Fig. 25, Cord-winder assessment reference

Fig. 22, Nozzle assessment reference

Fig. 26, Wheels assessment reference

Motor

Model: Siemens VS06A111/12 (Fig. 27)
Number of steps required: 5 steps
Disassembly time: 174 seconds
In this model the motor is immediately reachable just after disassembling the rear housing clump (which incorporates also the motor housing). All these components were assembled using just 3 screws. Moreover, the electric connectors to the PCBA were positioned in such a way to be easily visible and reachable without moving or disassembling any other component.

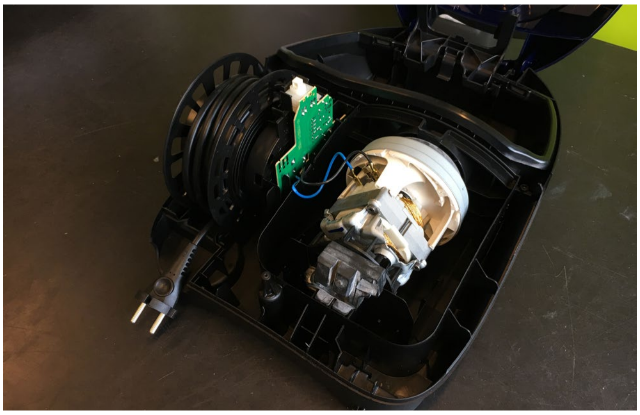


Fig. 27, Motor assessment reference

PCBA and switches

Model: Samsung SC8835 (Fig. 28)
Number of steps required: 3 steps
Disassembly time: 109 seconds
In this model the PCBA is positioned immediately beneath the upper housing. Because of the cable connectors located on the electric board itself, it was possible to disassemble the PCBA independently by the motor or the cord winder.

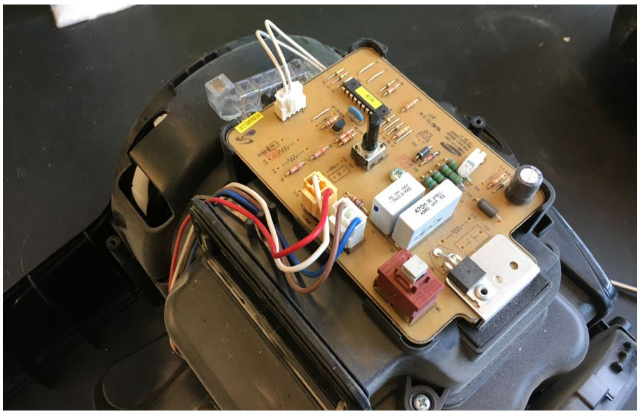


Fig. 28, PCBA assessment reference

Motor brushes

Model: Siemens VS06A111/12 (Fig. 29)
Number of steps required: 7 steps
Disassembly time: 193 seconds
In this model the motor brushes can be easily extracted using pliers.

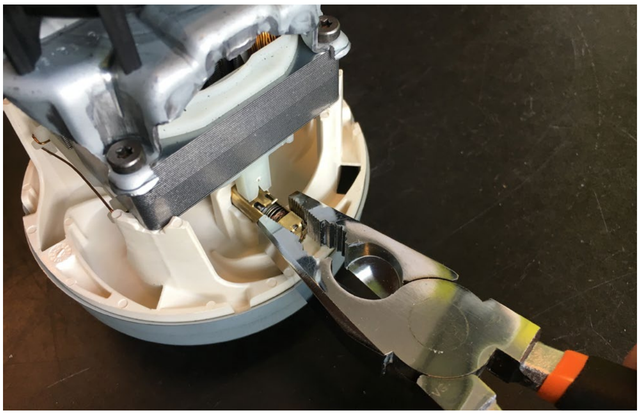


Fig. 29, Motor brushes assessment reference

Battery

Model: Philips FC6812/01 (Fig. 30)
Number of steps required: 2 steps
Disassembly time: 60 seconds
The disassembly of batteries has been observed just for one stick vacuum cleaner. Although more representative products should be analysed in order to define a reliable reference value for this priority part, it is arguable that the only 2 disassembly steps observed in this model, carried out in just 60 seconds, represent an easy and fast operation. Therefore 1 point has been given to this model.


Fig. 30, Battery assessment reference

Battery charger (Fig. 31)
Model: Philips FC6812/01
Number of steps required: 0 steps
Disassembly time: 0 seconds
Even in this case, only one product included a battery charger. However, the charger was composed just by a cable plug, which did not require any disassembly procedure.

Active nozzle motor belt (Fig. 32)
The motor belt has been found only in the stick vacuum cleaner. A reference cannot be defined assessing just one product. However, the disassembly of the belt for the stick FC6812 has been scored with a 0,5 pt. This is because the procedure was time consuming, not intuitive and it required many disassembly steps.

3.9 Fasteners reusability assessment methodology

Fasteners are assessed based on their reversibility and re-usability. This is strictly related to the definition of disassemblability already introduced at the beginning of this report. Disassembly is defined by the prEN 45554 (definition 3.8), as "process whereby an item is taken apart in such a way that it could subsequently be reassembled and made operational" (CEN/CLC TC10 European Standard, 2017). Bracquené et al. (2018) further specify the definition of disassembly as a "reversible process", where single components are divided from each other in a "non-destructive" or "semi-destructive" operation.
Both Bracquené et al. (2018) and the JRC scoring system (Cordella et al., 2019) accept partial breakage of fasteners and connectors only if this does not obstruct reassembly (perhaps replacing specific fasteners or using a spare part composed by a new set of working connectors).
Fasteners are assessed for each priority part. Cordella et al. (2019) defined in the JRC scoring system the following rules for the grading of fasteners:

- Reusable (1 pt): the fastening system can be completely reused; breakage is accepted if a fastener replacement is supplied with the spare parts used for the repair operation.
- Removable (0,5 pt): the fastening system that is not reusable, but this can be removed without causing breakage of other components and without leaving residues which can obstruct the reassembly of components
- Non-removable (0pt): fastening systems are not removable or reusable.

In case different types of fasteners are used in the assembly of a priority part, the worst score should be considered.

Fig. 31, Battery charger assessment reference

Fig. 32, Active nozzle motor belt assessment reference

3.10 Disassembly tools assessment methodology

The type of tools required to disassemble an item has a strong impact on product repairability. Manufacturers play and important role in this case, since the type of fasteners they choose to implement in the design of the products automatically determines the type of tools required to disassemble them. The JRC defines three different type of tools (Cordella et al., 2019):

- Basic tools (1 pt): repair and upgrade operations can be carried out without using any tool, using tools provided with the product itself or with tools included in the common tool list defined by the prEN45554.
- Other commercially available tools (0,66 pt): repair and upgrade operations cannot be carried out using common tools; however the tools required are commercially available. Cordella et al. (2019) include in this list Torx screw driver, even if the prEN45554 explicitly considers them as common tools. Torx screws will be scored with 0,66 pt in this study as well,

since Philips is interested in testing the JRC scoring system as it is. However, this choice is not shared by this study, as explained more in details in Chapter 5.
- Proprietary tools: repair and upgrade operations can be carried out only with one or multiple proprietary tools, not available on the public market = 0.33 pt.

Common tools

According to the professional repairer interviewed at the Delft Repair Café (Appendix I), the use of not common or proprietary tools can make repair procedures very difficult and time consuming. Since many products brought to the repair centres from consumers presented proprietary fastening systems, he had to buy a special kit composed by uncommon and proprietary tools (Fig. 33). The official repairers interviewed at the European Repair Center (Appendix J) uses uncommon tools as well, such as very long screw drivers in order to reach too deep screws (Fig. 34).

The standard prEN 45554 (CEN/CLC TC10 European Standard, 2017) proposes a list of common tools, which has been used also in the Benelux study about product repairability as well (Bracquené et al., 2018). However, some additions have been introduced in the final version of the JRC scoring system (Cordella et al., 2019):

- Screwdriver for slotted heads, cross recess or for hexalobular recess heads (ISO2380, ISO8764, ISO10664);
- Hexagon socket key (ISO2936);
- Combination wrench (ISO7738);
- Combination pliers (ISO5746);
- Half round nose pliers (ISO5745);
- Diagonal cutters (ISO5749);
- Multigrip pliers (multiple slip joint pliers) (ISO8976);
- Locking pliers; Combination pliers for wire stripping & terminal crimping;
- Prying lever;
- Tweezers;
- Hammer, steel head (ISO15601);
- Utility knife (cutter) with snap-off blades;
- Multimeter;
- Voltage tester;
- Soldering iron;
- Hot glue gun;
- Magnifying glass;
- Clean, soft, lint-free cloth;
- Magnifying glass;
- Quick grip clamps;
- Nonslip gloves;
- Painters tape;
- Isopropyl alcohol (IPA) wipe.

Even in this case, a score is assigned for each priority part.

Fig. 33, Kit of “un-common tools” of the repairer interviewed at the Repair Café

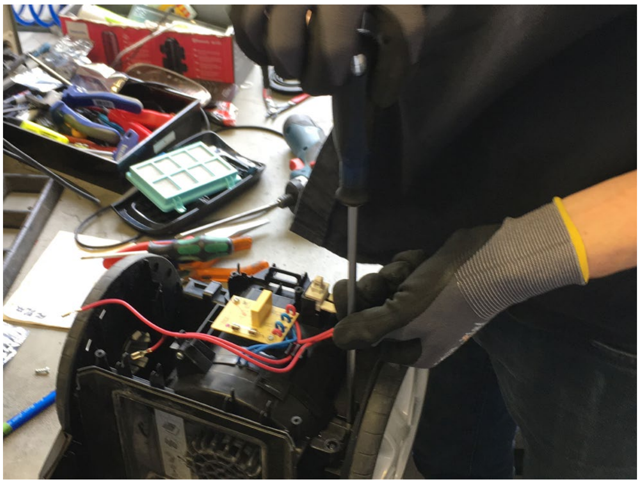


Fig. 34, Official repairer using a long screw driver (un-common tool)

3.11 Type and availability of RRU information assessment methodology

Availability of information is essential for product repairability and upgradability. The most important information related to product repairs is:

- Correct disassembly sequence to reach priority parts, essential to speed up the disassembly procedure and to disassemble in a non-destructive way the product.
- Correct type of tool required for the disassembly of a certain part, which helps to avoid parts breakage or fasteners head wear.
- Electronic schematics to identify electric connections and components on the electric boards
- Troubleshooting guide, which can help to diagnose the problem
- Spare parts serial codes, to purchase the correct spare part

Usually, the type of information provided to private consumer and authorized repairer is very different (Bracquené et al., 2018). Cordella et al. (2019) provide in the JRC scoring system final report past/fail criterions and scoring guidelines based on these two different target groups. In particular, 1pt is assigned if all the type of information just listed is publicly available, and 0,5pt is it is available just to registered official repairers.

3.12 Spare parts availability assessment methodology

According to the JRC scoring system, the pass/fail criterion for the assessment of spare parts availability is that manufacturer, importers or representatives have to ensure the availability of spare parts for a defined period (Cordella et al., 2019). Complete list of spare parts, prices and ordering system have to be publicly disclosed on the manufacturer or representatives' websites. Moreover, spare parts should be provided to the consumer within 15 days from the purchase (Cordella et al., 2019). The JRC defined the scoring thresholds for this parameter based on the product life-span. As introduced before, the average life-span of vacuum cleaners is between 5 and 9 year (Bobba et al., 2015; Bracquené et al., 2018; Kemna & Boorn, 2016; Rames et al., 2018; Reisch et al., 2010). Based on the 8 years average life-span identified by Bracquené et al. (2018), the JRC determined the following rating:

- The manufacturer ensures that spare parts (or compatible parts) are available for at least 8 years = 1 pt;
- The manufacturer ensures that spare parts (or compatible parts) are available for at least 5 years = 0.5 pt.

Further distinction has been made based on the target group receiving the spare parts:

- The spare parts are available publicly = 1 pt;
- The spare parts are available to professional repairers = 0.5 pt.

This further distinction has been added in the final version of the scoring system (Cordella et al., 2019), and it was necessary since many stakeholders presented difficulties in providing all the priority parts analysed in the study to private consumers (e.g. motor, PCBA, Cord-winder). This was also pointed out by Philips during interviews to different stakeholders. The final score is calculated multiplying the two scores.

4. Assessment Results:

Seven vacuum cleaners side by side

4.1 Introduction

In this chapter the results of the RRU assessment carried out on seven different products are presented.
As explained in detail in Chapter 3, products have been analysed based on:

- Disassembly sequence/Depth
- Fasteners re-usability
- Disassembly tools
- Disassembly time
- Type and availability of information
- Spare parts availability
- Commercial guarantee

Comparability tables have been created to identify easily differences and commonalities between different products, parameters and priority components. Eventually, calculation tables used to determine the final aggregation of scores are shared at the end of the chapter.

These assessments have been carried out to investigate the following research objectives:

- **RO.2 Determining how much repairable Philips consumer products currently are**
- **RO.3 Comparing different product architectures, identifying the most optimised structures for product repairability and upgradability**
- **RO.4 Identifying design aspects which might obstruct product repairability**

4.2 Disassembly sequence/ depth assessment results

Table 10 shows the disassembly depth of each different priority part in different product models. The reference values are highlighted in green, while the worst values are highlighted in pink. Disassembly steps have been counted and assessed using the "Disassembly map" tool, presented in Chapter 6. A Disassembly map is a design tool which helps designers to represents in a clear and effective way the architecture of a product, highlighting the depth of different priority component.

Priority parts which could not be disassembled (for instance motor brushes) scored 0 points, while the score of priority parts which could be just partially disassembled have been penalised subtracting 0,25 points (for instance, hoses not disassemblable from handles).

From this table it is possible to observe that:

- Even in this case, the Philips bag canister model FC8924 is the product which scored the longest disassembly depth for almost all the priority parts;
- The bagless canister Samsung SC8835 and the bag canister Siemens VS06A111/12 are the products which scored the shortest disassembly depth for almost all the priority parts;

Table 10, Disassembly depth/sequence of different vacuum cleaners

Disassembly sequence/depth (number of steps)

Priority part	Philips FC6812/01 Stick	Philips FC8924/01 High-end bag	Philips FC9934/07 High-end bagless	Philips FC9569/01 Mid-end bagless	Rowenta RO6963EA Mid-end bagless	Samsung SC8835 Mid-end bagless	Siemens VS06A111/12 Low-end bag
Nozzle	1	1	1	1	1	1	1
Hose	Not present	1 (with handle)	1 (with handle)	1	1	1	1
Filter	2	3	2	2	2	2	2
Cord-winder	Not present	14	11	10	9	5	5
Motor	11 (with PCBA)	16	10	13	9	5	5
PCBA	11 (with motor)	17	11	14	8	3	5
Wheels	1	15	10	12	1	2	1
Motor brushes	Not present	Not disassemblable	Not disassemblable	15	11	7	7
Battery	2	Not present	Not present	Not present	Not present	Not present	Not present
Battery charger	0	Not present	Not present	Not present	Not present	Not present	Not present
Active nozzle motor belt	8	Not present	Not present	Not present	Not present	Not present	Not present
External housing	13	9	3	4	4	2	3

- It is not possible to disassemble motor brushes in two of the Philips vacuum cleaners analysed (high-end bag and bagless models), while this was possible in the 3 competitors' products.
- In the Philips stick vacuum cleaner, it is not possible to divide PCBA from the motor. For this reason, the score for this priority part has been penalised subtracting 0,25 points.
- The hose of the Philips bag canister FC8924 and bagless FC9934, cannot be disconnected from the hose handle. For this reason, the score for this priority part has been penalised subtracting 0,25 points.
- The only model equipped with a nozzle motor belt is the Philips stick FC6812.

4.3 Fasteners re-usability assessment results

In all the vacuum cleaners analysed, all the fastening systems can be reused. In fact, even if many snap fits broke during the disassembly procedures (see Disassembly Maps in Chapter 6), all the components can be reassembled again, without requiring to fix or replace the broken connectors. This is because a high number of snap fits is present in these type of products, and the breakage of some of them do not obstruct reassembly of parts. In some cases, for instance in the bagless FC9569/01, to disassemble the wheels the total breakage of the fasteners is necessary. However, fasteners replacements are included in the spare part. Therefore, following the guidelines provided by Cordella et al. (2019), 1 pt has to be assigned also in this case.

Other aspects of the fastening systems are considered in the assessment of disassembly time. In fact, hidden connectors, or fasteners that require high intensity force increase the total time required to reach a priority part and repairing the product.

4.4 Disassembly tools assessment results

Table 11 shows the tools used in order to reach the priority parts in the different models assessed. Torx 15 screws (ISO10664) are commonly used in canister vacuum cleaners, followed by Philips 2 and 1 screws (ISO8764). In some cases, uncommon tools had to be used. This happened in three canister vacuum cleaners (FC9934/07, FC8924/01, FC9569/01), where the screws that fasten the motor housing to the lower housing, are too deep to be reached with normal length screw drivers. This was also found by the Benelux study (Bracquené et al., 2018), which assessed a canister vacuum cleaner very similar to those included in this research. These connectors have been scored as Level II connectors (Cordella et al., 2019), therefore with 0,66 pt (highlighted in pink in Table 11). What has been indicated as spudger was mainly a slotted head screwdriver (ISO2380). Eventually, the table shows how certain priority parts required many different tools, while others required just one tool (often just the hand). When the number of different tools used increases, also the disassembly time raises. This is due to the time required to change the tool, that has been considered in the eDIM calculation. Therefore, the number of different tools required do not influence this parameter, but it has been considered in the assessment of parameter 4.

The specific type of tools required for the disassembly of the different components is not always indicated in Philips Service Manuals. Despite this, all the component can be disassembled.

In Table 11 the white cells scored 1 pt, while those in orange and pink 0,66 pt.

4.5 Disassembly time assessment results

Table 12 shows the disassembly time calculated for each different priority part in different product models. The reference values are highlighted in green, while the worst values are highlighted in pink.

Priority parts which could not be disassembled (for instance motor brushes) scored 0 points, while the score of priority parts which could be just partially disassembled have been penalised by subtracting 0,25 points (for instance, hoses not disassemblable from handles).

From this table it is possible to observe that:

- The Philips bag canister model FC8924 is the product which scored the longest disassembly time for almost all the priority parts;
- The bag canister Siemens VS06A111/12 is the product which scored the shortest disassembly time for almost all the priority parts;
- It is not possible to disassemble motor brushes for two of the high-end Philips vacuum cleaners analysed (FC8924 and FC9934), while this was possible for the 3 canister competitors;
- In the Philips stick vacuum cleaner, it is not possible to disassemble the PCBA from the motor. The Floor Care department explained that this choice was due to the specific supplier providing the motor assy. They were willing to sell the motor just if in combination with the PCBA. Therefore, these two components currently cannot be independently replaced. However, this might change in future models;
- The hose of the Philips bag canister FC8924 and bagless FC9934, cannot be disconnected

from the hose handle. This service component is provided by the same external suppliers, and it is very likely that commercial agreements with external OEM’s determined this un-disassemblable design (Jungbluth, Philips Service Product Engineer). This design determined a lower disassembly time for hose-handle assemblies, since only simple hand disassembly was required. On the contrary, the disassembly time is higher if the hose can be disconnected from the handle, since this procedure usually requires the use of a spudger. For this reason, as introduced before, the score for this un-disassemblable hose design has been penalised subtracting 0,25 pt.

- The only model equipped with a nozzle motor belt is the Philips stick FC86812.

The eDiM spread sheets used for the calculation of disassembly time for each product analysed can be found in Appendix H.

4.6 Type and availability of information assessment results

Information provided to private consumers

The available information for private consumers is usually composed by:

- Brochure: this is a commercial documentation and includes the description of the main feature of the product. It is usually included in the product packaging, and it can also be retrieved online. It does not include any relevant information related to product repairability or upgradability. However, it usually indicates clearly the warranty period.
- User manual: this document contains more detailed information compared to the brochure. It includes:
  - Basic instructions about how to assemble components like nozzles, hose and dust bag (for bag canisters)

Table 11, Disassembly tools used for the disassembly of priority components

Disassembly tools							
Priority part	Philips FC6812/01 Stick	Philips FC8924/01 High-end bag	Philips FC9934/07 High-end bagless	Philips FC9569/01 Mid-end bagless	Rowenta RO6963EA Mid-end bagless	Samsung SC8835 Mid-end bagless	Siemens VS06A111/12 Low-end bag
Nozzle	Hand	Hand	Hand	Hand	Hand	Hand	Hand
Hose	Hand	Hand	Hand	Hand Spudger	Spudger	Hand Spudger	Hand
Filter	Hand	Hand	Hand	Hand	Hand	Hand	Hand
Cord-winder	Not present	Hand Torx 15 Spudger	Hand Torx 15 Spudger	Hand Phillips 2 Spudger	Hand Torx 15 Spudger	Hand Phillips 2 Spudger	Hand Torx 15 Spudger
Motor	Hand Phillips 1 Spudger	Hand extended Torx 15 Spudger	Hand extended Torx 15 Spudger	Hand Too deep Phillips 2 Spudger	Hand Torx 15 Spudger	Hand Phillips 2 Spudger	Hand Torx 15 Spudger
PCBA	Hand Phillips 1 Spudger	Hand extended Torx 15 Spudger	Hand extended Torx 15 Spudger	Hand Too deep Phillips 2 Spudger	Hand Torx 15 Spudger	Hand Phillips 2 Spudger	Hand Torx 15 Spudger
Wheels	Not present	Hand extended Torx 15 Spudger	Hand extended Torx 15 Spudger	Hand Too deep Phillips 2 Spudger	Spudger	Phillips 2 Spudger	Spudger
Motor brushes	Not present	Not disassemblable	Not disassemblable	Hand Too deep Phillips 2 Spudger	Hand Torx 15 Spudger	Hand Phillips 2 Spudger	Hand Torx 15 Spudger Pliers
Battery	Hand Phillips 1	Not present	Not present	Not present	Not present	Not present	Not present
Battery charger	None	Not present	Not present	Not present	Not present	Not present	Not present
Active nozzle motor belt	Hand Phillips 2	Not present	Not present	Not present	Not present	Not present	Not present
External housing	Hand Phillips 1 Spudger	Hand Torx 15 Spudger	Spudger	Hand Phillips 2 Spudger	Hand Torx 15 Spudger	Hand Phillips 2	Hand Spudger

  - Proper use guidelines, which explain how to properly use the vacuum cleaner using pictograms
  - User maintenance procedures, that usually include dust bag and outlet filter replacement, and filter and nozzle brushes cleaning.
- Important information manual: this document could be included in the user manual depending on the different models. It usually includes:
  - Safety information
  - Indication about where to buy spare parts (usually directing to the manufacturer website). The use of not-original spare parts is not recommended in most of the user documentation analysed, independently from the product brand;
  - Limited troubleshooting, which usually suggest the cleaning of the filters as main solution to general suction problems;
  - Disposal information, which includes disposal of dust bags for bag canisters, but also correct disposal of the product packaging and old appliances.
  - Product warranty policy and contact information for support (usually a call centre number or a website url)

Unequivocal identification of the machine, correct installation, user maintenance procedures, contact for official repair services are indicated in the information provided to the consumer by Philips. Consumer repair parts (CRP) and the related cost can be found on the official website. Costs involved in a repair, like shipping, research cost and quotation limit are also indicated on the official website (Philips.nl, 2019b). However, neither the minimum period of spare parts availability nor the price of spare parts of internal priority components (e.g. motor, PCBA, cord-winder, wheels, nozzle motor belt, motor brushes) are included in the information provided to the consumer.

Information provided to official repairers

The available information for Philips official repairer usually includes:

- Service manual. This is the most important informative document for a repairer. It includes:
  - Exploded view of the product
  - BOM of most of the components
  - Service codes to order spare parts
  - Troubleshooting guide. This is not always included and sometimes it is very limited.
  - Main electric board schematic
  - Disassembly steps. The disassembly sequences can be indicated using pictograms or pictures, followed by short descriptions about how to carry out the different procedures. Sometimes, the information provided is not enough; in particular it is difficult to understand how

Table 12, Disassembly times of different vacuum cleaners

Disassembly Time (s)							
Priority part	Philips FC6812/01 Stick	Philips FC8924/01 High-end bag	Philips FC9934/07 High-end bagless	Philips FC9569/01 Mid-end bagless	Rowenta RO6963EA Mid-end bagless	Samsung SC8835 Mid-end bagless	Siemens VS06A111/12 Low-end bag
Nozzle	6	5	5	6	6	6	4
Hose	Not present	9 (with handle)	9 (with handle)	27	24	18	5
Filter	17	17	13	13	13	16	16
Cord-winder	Not present	573	370	396	574	108	176
Motor	245 (with PCBA)	750	693	576	675	238	174
PCBA	245 (with motor)	756	707	616	544	108	176
Wheels	26	689	602	539	37	28	10
Motor brushes	Not present	Not disassemblable	Not disassemblable	607	740	273	193
Battery	60	Not present	Not present	Not present	Not present	Not present	Not present
Battery charger	0	Not present	Not present	Not present	Not present	Not present	Not present
Active nozzle motor belt	206	Not present	Not present	Not present	Not present	Not present	Not present
External housing	352	347	50	222	221	79	26

to place correctly a spudger in order to disconnect hidden snap fits.
- Position and number of screws. This is clearly indicated in the exploded view and in the disassembly procedure description. Usually the screws are named using letters. Despite this, it is never indicated the specific type of screw head, or which tools should be used to remove them.

Philips has recently started to use a standard framework to create the service manuals. The guide used to create these new guidelines has been provided by Philips Consumer Care. All service manuals will probably become more standardised in the future. A possible recommendation for the manufacturer could be to follow the IEEE 1874-2013, Standard for Documentation Schema for Repair and Assembly of Electronic Devices (IEEE Std, 2014).

- Repair check list. This is a document meant to guide the official Philips repairer during the repair procedures. It is a list of actions that have to be carried out during the repair, ensuring a complete check of the product. This document is confidential, and no further information can be shared. It can be found in Confidential Appendix C.
- SDA, also called symptoms/cures (s/c). In this document technical issues are pointed out, and repair advices and procedures are presented.
- GDA, a document containing general service information, CTN independent. This information is communicated to all the official repairers through a Philips website called “At your service”. The website includes overview of service information updates, advice for disassembly and remarks. In this section, information about post-production high failure rates of specific components or model recalls are communicated to repairers. This website is not publicly reachable, but a user account and passwords are required.

Final score calculated for Philips products

Although Philips provides much information to repairer, some important data, required by the JRC scoring system, is missing. In particular clear information about:

- Minimum period of spare parts availability to private consumers
- Costs of spare parts of each priority component (only those of nozzle, filter and hose are provided) to private consumers
- Type of tools required for product disassembly and repair in the service manual
- Service manual layout not yet standardized for all the models currently available on the market.
- Eventually, the service manuals are not made publicly available. However, the same practice is followed by many other manufacturers.

For all these reasons, this parameter has been scored with 0,5 pt out of 1 pt.

Assessment of competitors’ products

It was not possible to check the information provided by other brands to official repairer (e.g. service manuals), since they are not publicly available. Despite this, it is arguable that also the other brands assessed (Samsung, Rowenta and Siemens), provide similar documentation to authorized repair centres.

On the contrary, consumer information was checked, retrieving user and important information manuals on the manufacturers’ websites. The main findings are:

- Rowenta promotes on its website a serious commitment to product repairability. They clearly inform the consumers about a period of spare parts availability of 10 years, and a spare parts price 30% lower than a new product. According to their web-page, the long spare parts availability is achieved thanks to a large stock of components and 3D printing (Rowenta.com, 2019).
- On the Samsung website (Samsung.com, 2019a) it is possible to access easily a very complete support page, which includes:
    - Basic troubleshooting for private consumers
    - Location of official repairers and online request for a product repair
    - Online support live chat
- Siemens indicates in a clear way repair prices, timing, and a spare parts availability time of 10 years (Siemens-home, 2019a). Moreover, it is even possible to find the price of all the product components, and any spare part, including internal components (e.g. motor, PCBA, cord-winder, wheels) can be purchased online (Siemens-home, 2019c).

Since only partial information about competitors was retrieved, their products scored also 0,5 pt, allowing comparability of other parameters more reliably assessable. The only exception is Siemens, which received 1/1 pt, since they make publicly available all the spare parts and their prices, respecting fully the JRC requirements.

4.7 Spare parts availability assessment results

Spare parts availability period for Philips products

According to Erwin Smeets, Manager Service Parts

Europe, the spare parts availability period changes based on different models. There is not a defined period of time that has to be respected, but Philips always tries to provide spare parts till the demand for them exists. Moreover, the department which manages spare part provision does not receive insights concerning product sales; for this reason, they do not know when the commercial sale of a certain model stops. A big last order of spare parts is made with the announcement of End of Production of a model (EoP). In this case, a Last Time Buy purchase order (also called LTP PO, final order, All Time Buy) is made based on pareto analysis. However, usually spare parts are provided for 6-7 years, reaching in some cases 7-8 years after LTP.

Spare parts 3D printing was also considered in the past by Philips. However, it was preferred to just raise the number of spare parts ordered during the LTB, ensuring a good spare part availability coverage.

To conclude, Philips usually provides spare parts for 6-7 years after end of production, not end of sales. However, Erwin Smeets affirms that Philips always tries to satisfy the demand of spare parts for as long as possible.

Since Philips cannot provide a clear spare parts availability period, and the estimation proposed by Erwin Smeets is of 6-7 years after EoP, all the Philips products scored 0,5 pt (spare parts available for at least 5 years).

Competitors’ spare parts availability period

Samsung does not provide any specific information on their website on spare parts availability period as well. Moreover, less components seem to be available on the Samsung online spare parts portfolio with some CRP parts missing (e.g. hose) (Samsung.com, 2019b). Despite this, it was possible to find CRP genuine parts on other websites.

Table 13, Spare parts availability assessment for different models

Spare parts availability							
Priority part	Philips FC6812/01 Stick	Philips FC8924/01 High-end bag	Philips FC9934/07 High-end bagless	Philips FC9569/01 Mid-end bagless	Rowenta RO6963EA Mid-end bagless	Samsung SC8835 Mid-end bagless	Siemens VS06A111/12 Low-end bag
Nozzle	<8 years, CRP	<8 years, CRP	<8 years, CRP	<8 years, CRP	>8 years, CRP	<8 years, CRP	>8 years, CRP
Hose	<8 years, CRP	<8 years, CRP	<8 years, CRP	<8 years, CRP	>8 years, CRP	<8 years, CRP	>8 years, CRP
Filter	<8 years, CRP	<8 years, CRP	<8 years, CRP	<8 years, CRP	>8 years, CRP	<8 years, CRP	>8 years, CRP
Cord-winder	Not present	<8 years, Repairers	<8 years, Repairers	<8 years, Repairers	>8 years, ND	<8 years, ND	>8 years, CRP
Motor	<8 years, Repairers	<8 years, Repairers	<8 years, Repairers	<8 years, Repairers	>8 years, ND	<8 years, ND	>8 years, CRP
PCBA	<8 years, Repairers	<8 years, Repairers	<8 years, Repairers	<8 years, Repairers	>8 years, ND	<8 years, ND	>8 years, CRP
Wheels	Not present	<8 years, Repairers	<8 years, Repairers	<8 years, Repairers	>8 years, ND	<8 years, ND	>8 years, CRP
Motor brushes	Not present	Not disassemblable	Not disassemblable	Not available	>8 years, ND	<8 years, ND	>8 years, CRP
Battery	<8 years, Repairers	Not present	Not present	Not present	Not present	Not present	Not present
Battery charger	<8 years, CRP	Not present	Not present	Not present	Not present	Not present	Not present
Active nozzle motor belt	Not available	Not present	Not present	Not present	Not present	Not present	Not present
External housing	Not available	<8 years, Repairers	<8 years, Repairers	<8 years, Repairers	ND	ND	>8 years, CRP

On the contrary, Rowenta and Siemens clearly state on their website a spare parts availability period of 10 years (Rowenta.com, 2019; Siemens-home, 2019a). For this reason, their spare parts availability period was assessed with 1 pt (spare parts available for at least 8 years).

Spare parts provisions to private consumers and official repairer

Not all spare parts of priority components are publicly available for almost all the vacuum cleaners analysed. Especially internal components like motor, PCBA and cord-winder, can be purchased only by authorized repairers. Only Siemens provides publicly, even to private consumers, all the priority parts. On their website almost all the components of the Siemens VS06A111/12 analysed in this research are available, including internal components like motor, cord-winder and PCBA. Only motor brushes are not available singularly, but they are provided together with the motor (Siemens-home, 2019b).

Philips provided confidential documentation (Confidential Appendix D) which proves how spare parts for all the priority components are made available to official repairer. This documentation clearly identifies spare parts publicly commercialized (CRP), and spare parts available just for official repairer. It was not possible to retrieve the same type of documentation from the other brands; in this case their websites have been used to determine whether a part is publicly available or not. It has been assumed that components not present on the official website are supplied only to official repairers. However, It was not possible to check this assumption.

The final results can be seen in Table 13. The green cells scored 1 pt, those in light orange 0,5pt, the dark orange ones 0,25pt and the red cells 0pt.

4.8 Commercial guarantee assessment results

Commercial guarantee is assessed once for the entire product, independently from the single priority components. In fact, according to the JRC, the pass/fail criterion is that the entire product has to be covered by at least a 2 year warranty period (Cordella et al., 2019). This was the case for all the vacuum cleaners assessed in this research. Philips offers a 5 years warranty on the motor of some high-end canister models if the user registers the product on the official website (Fig.35). Since this initiative involves just one component, and not the entire product, this extended guarantee period is not considered in the assessment (as defined by Cordella et al. (2019)). Information about the commercial guarantee period is usually provided in the brochure/ commercial leaflet, on the product packaging (Fig. 36) and on the manufacturer website.

All the products assessed, Philips' and competitors', scored 0 pt (fulfilling only the minimum legal requirements of 2 years).

5 jaar garantie

Registreer binnen 3 maanden na aankoop op philips.com/welcome en krijg gratis 5 jaar garantie op de motor!

Fig. 35, Motor guarantee extension (Philips.nl, 2019b)

Fig. 36, Clear guarantee period indication on the product packaging

4.9 Final scores aggregation

Scoring calculation framework

As introduced in the Chapter 3, the JRC scoring system (Cordella et al., 2019) suggests the use of a specific framework for the aggregation of different parameters scores, characterized by the use of different weights for each parameters and priority components. This framework is presented again in Table 14.

Moreover, this framework allows to define different partial scores:

- Disassembly index; this score combines the assessment of the first four assessment parameters, which concern mainly physical product design features.
- RRU Process index; this score considers the assessment of parameters from 5 to 11, mainly related to system and service aspects which influence product repair and upgrade.
- Overall RRU index; this score represents the total product score based on re-usability, repairability and upgradability and it involves almost all the parameters (1 to 11), except for Commercial guarantee (parameter 12)
- Commercial guarantee index; this score specifically assesses commercial guarantee. This parameter does not have any weight, it is calculated once for the entire product and it is not included in the overall RRU index
- RRU indices for parts; these scores are meant to assess singularly repairability and upgradability of all the priority parts. The calculation of these scores involves all the parameters, except for commercial guarantee (1 to 11).

This framework has been adopted during this research as well, and the final scores aggregation tables for the seven products analysed can be seen in the following pages.

For each model the final score has been calculated twice, considering and excluding disassembly time.

Table 14, Aggregation of scores (Cordella et al., 2019)

Parameter	**Score [0 -1] for priority part 1 (and weight)**	**...**	**Score [0 -1] for priority part N (and weight)**	**Parameter Score [0 - 1]**	**Parameter Weight**	**RRU indices for product** [0 -1]
#1 Disassembly depth / sequence	$S_{1,1}$ (ω_1)		$S_{1,N}$ (ω_N)	$S_1 = \sum_1^N \frac{S_{1,i} \cdot \omega_i}{\omega_i}$	W_1	Disassemblability Index $(I_D) = \frac{\sum_1^4 S_j \cdot W_j}{\sum_1^4 W_j}$
#2 Fasteners	$S_{2,1}$ (ω_1)	...	$S_{2,N}$ (ω_N)	$S_2 = \sum_1^N \frac{S_{2,i} \cdot \omega_i}{\omega_i}$	W_2	
#3 Tools	$S_{3,1}$ (ω_1)	...	$S_{3,N}$ (ω_N)	$S_3 = \sum_1^N \frac{S_{3,i} \cdot \omega_i}{\omega_i}$	W_3	
#4 Disassembly time	$S_{4,1}$ (ω_1)	...	$S_{4,N}$ (ω_N)	$S_4 = \sum_1^N \frac{S_{4,i} \cdot \omega_i}{\omega_i}$	W_4	
#5 Diagnosis support and interfaces	S_5	...	S_5	S_5	W_5	RRU Process Index $(I_P) = \frac{\sum_5^{11} S_j \cdot W_j}{\sum_5^{11} W_j}$
#6 Type and availability of information	S_6	...	S_6	S_6	W_6	
#7 Spare parts	$S_{7,1}$ (ω_1)	...	$S_{7,N}$ (ω_N)	$S_7 = \sum_1^N \frac{S_{7,i} \cdot \omega_i}{\omega_i}$	W_7	
#8 Software and firmware	S_8	...	S_8	S_8	W_8	
#9 Safety, skills and working environment	$S_{9,1}$ (ω_1)	...	$S_{9,N}$ (ω_N)	$S_9 = \sum_1^N \frac{S_{9,i} \cdot \omega_i}{\omega_i}$	W_9	
#10 Data transfer and deletion	S_{10}	...	S_{10}	S_{10}	W_{10}	Overall RRU Index $(I_{RRU}) = \frac{\sum_1^{11} S_j \cdot W_j}{\sum_1^{11} W_j}$
#11 Password reset and restoration of factory settings	S_{11}	...	S_{11}	S_{11}	W_{11}	
#12 Commercial guarantee	S_{12}	...	S_{12}	S_{12}	Not applied	Commercial guarantee Index $(I_{CG}) = S_{12}$
RRU indices for parts	$I_{RRU,1} = \sum_1^{12} \frac{S_{j,1} \cdot W_j}{W_j}$		$I_{RRU,N} = \sum_1^{12} \frac{S_{j,N} \cdot W_j}{W_j}$			

Scores aggregation framework for the Philips FC6812/01, without considering disassembly time

Philips FC6812/01	PART 1	PART WEIGHT	PART 2	PART WEIGHT	PART 3	PART WEIGHT	PART 4	PART WEIGHT	PART 5	PART WEIGHT	PART 6	PART WEIGHT	PART 7	PART WEIGHT	PART 8	PART WEIGHT		
PARAMETER	MOTOR	3	FILTER	3	NOZZLE MOTOR BELT	3	WHEELS	1	PCBA	1	NOZZLE	1	BATTERY PACK	3	BATTERY CHARGER	1	PARAMETER SCORE	PARAMETER WEIGHT
#1 Disassembly depth / sequence	0,20		1,00		0,50		1,00		0,20		1,00		0,75		1,00		6,59	2,00
#2 Fasteners	1,00		1,00		1,00		1,00		1,00		1,00		1,00		1,00		10,00	2,00
#3 Tools	1,00		1,00		1,00		1,00		1,00		1,00		1,00		1,00		10,00	2,00
#6 Type and availability of information	0,50		0,50		0,50		0,50		0,50		0,50		0,50		0,50		5,00	2,00
#7 Spare parts	0,25		0,50		0,00		0,25		0,25		0,50		0,25		0,50		2,81	2,00
#12 Commercial guarantee	0,00		0,00		0,00		0,00		0,00		0,00		0,00		0,00		0,00	/
RRU indices for parts	5,9		8		6		7,5		5,9		8		7		8			

Disassembly index	RRU Process index	OVERALL RRU	Commercial guarantee
8,9	3,9	6,9	0,00

Scores aggregation framework for the Philips FC6812/01, considering disassembly time

Philips FC6812/01	PART 1	PART WEIGHT	PART 2	PART WEIGHT	PART 3	PART WEIGHT	PART 4	PART WEIGHT	PART 5	PART WEIGHT	PART 6	PART WEIGHT	PART 7	PART WEIGHT	PART 8	PART WEIGHT		
PARAMETER	MOTOR	3	FILTER	3	NOZZLE MOTOR BELT	3	WHEELS	1	PCBA	1	NOZZLE	1	BATTERY PACK	3	BATTERY CHARGER	1	PARAMETER SCORE	PARAMETER WEIGHT
#4 Disassembly time	0,46		0,96		0,50		0,40		0,20		0,56		0,75		1,00		6,36	2,00
#1 Disassembly depth / sequence	0,20		1,00		0,50		1,00		0,20		1,00		0,75		1,00		6,59	2,00
#2 Fasteners	1,00		1,00		1,00		1,00		1,00		1,00		1,00		1,00		10,00	2,00
#3 Tools	1,00		1,00		1,00		1,00		1,00		1,00		1,00		1,00		10,00	2,00
#6 Type and availability of information	0,50		0,50		0,50		0,50		0,50		0,50		0,50		0,50		5,00	2,00
#7 Spare parts	0,25		0,50		0,00		0,25		0,25		0,50		0,25		0,50		2,81	2,00
#12 Commercial guarantee	0,00		0,00		0,00		0,00		0,00		0,00		0,00		0,00		0,00	/
RRU indices for parts	5,7		8,3		5,8		6,9		5,3		7,6		7,1		8,3			

Disassembly index	RRU Process index	OVERALL RRU	Commercial guarantee
8,2	3,9	6,8	0,00

Scores aggregation framework for the Philips FC8924/01, without considering disassembly time

Philips FC8924/01	PART 1	PART WEIGHT	PART 2	PART WEIGHT	PART 3	PART WEIGHT	PART 4	PART WEIGHT	PART 5	PART WEIGHT	PART 6	PART WEIGHT	PART 7	PART WEIGHT	PART 8	PART WEIGHT		
PARAMETER	MOTOR	3	MOTOR BRUSHES	3	FILTER	3	HOSE	3	POWER CABLE	3	WHEELS	1	PCBA	1	NOZZLES	1	PARAMETER SCORE	PARAMETER WEIGHT
#1 Disassembly depth / sequence	0,31		0,00		1,00		0,75		0,36		0,07		0,18		1,00		4,73	2,00
#2 Fasteners	1,00		0,00		1,00		1,00		1,00		1,00		1,00		1,00		8,33	2,00
#3 Tools	0,66		0,00		1,00		1,00		0,66		0,66		0,66		1,00		6,82	2,00
#6 Type and availability of information	0,50		0,00		0,50		0,50		0,50		0,50		0,50		0,50		4,17	2,00
#7 Spare parts	0,25		0,00		0,50		0,50		0,25		0,25		0,25		0,50		3,06	2,00
#12 Commercial guarantee	0,00		0,00		0,00		0,00		0,00		0,00		0,00		0,00		0,00	/
RRU indices for parts	5,4		0		8		7,5		5,5		5		5,1		8			

Disassembly index	RRU Process index	OVERALL RRU	COMMERCIAL
6,6	3,6	5,4	0,00

Scores aggregation framework for the Philips FC8924/01, considering disassembly time

Philips FC8924/01	PART 1	PART WEIGHT	PART 2	PART WEIGHT	PART 3	PART WEIGHT	PART 4	PART WEIGHT	PART 5	PART WEIGHT	PART 6	PART WEIGHT	PART 7	PART WEIGHT	PART 8	PART WEIGHT		
PARAMETER	MOTOR	3	MOTOR BRUSHES	3	FILTER	3	HOSE	3	POWER CABLE	3	WHEELS	1	PCBA	1	NOZZLES	1	PARAMETER SCORE	PARAMETER WEIGHT
#4 Disassembly time	0,23		0,00		0,75		0,33		0,20		0,01		0,14		0,70		2,99	2,00
#1 Disassembly depth / sequence	0,31		0,00		1,00		0,75		0,36		0,07		0,18		1,00		4,73	2,00
#2 Fasteners	1,00		0,00		1,00		1,00		1,00		1,00		1,00		1,00		8,33	2,00
#3 Tools	0,66		0,00		1,00		1,00		0,66		0,66		0,66		1,00		6,82	2,00
#6 Type and availability of information	0,50		0,00		0,50		0,50		0,50		0,50		0,50		0,50		4,17	2,00
#7 Spare parts	0,25		0,00		0,50		0,50		0,25		0,25		0,25		0,50		3,06	2,00
#12 Commercial guarantee	0,00		0,00		0,00		0,00		0,00		0,00		0,00		0,00		0,00	/
RRU indices for parts	4,9		0		7,9		6,8		5		4,2		4,6		7,8			

Disassembly index	RRU Process index	OVERALL RRU	COMMERCIAL
5,7	3,6	5	0,00

Scores aggregation framework for the Philips FC9934/07, without considering disassembly time

Philips FC9934/07	PART 1	PART WEIGHT	PART 2	PART WEIGHT	PART 3	PART WEIGHT	PART 4	PART WEIGHT	PART 5	PART WEIGHT	PART 6	PART WEIGHT	PART 7	PART WEIGHT	PART 8	PART WEIGHT		
PARAMETER	MOTOR	3	MOTOR BRUSHES	3	FILTER	3	HOSE	3	POWER CABLE	3	WHEELS	1	PCBA	1	NOZZLES	1	PARAMETER SCORE	PARAMETER WEIGHT
#1 Disassembly depth / sequence	0,50		0,00		1,00		0,75		0,45		0,10		0,45		1,00		5,36	2,00
#2 Fasteners	1,00		0,00		1,00		1,00		1,00		1,00		1,00		1,00		8,33	2,00
#3 Tools	0,33		0,00		1,00		1,00		0,66		0,33		0,33		1,00		5,91	2,00
#6 Type and availability of information	0,50		0,00		0,50		0,50		0,50		0,50		0,50		0,50		4,17	2,00
#7 Spare parts	0,25		0,00		0,50		0,50		0,25		0,25		0,25		0,50		3,06	2,00
#12 Commercial guarantee	0,00		0,00		0,00		0,00		0,00		0,00		0,00		0,00		0,00	/
RRU indices for parts	5,2		0		8		7,5		5,7		4,4		5		8			

Disassembly index	RRU Process index	OVERALL RRU	COMMERCIAL
6,5	3,6	5,4	0,00

Scores aggregation framework for the Philips FC9934/07, considering disassembly time

Philips FC9934/07	PART 1	PART WEIGHT	PART 2	PART WEIGHT	PART 3	PART WEIGHT	PART 4	PART WEIGHT	PART 5	PART WEIGHT	PART 6	PART WEIGHT	PART 7	PART WEIGHT	PART 8	PART WEIGHT		
PARAMETER	MOTOR	3	MOTOR BRUSHES	3	FILTER	3	HOSE	3	POWER CABLE	3	WHEELS	1	PCBA	1	NOZZLES	1	PARAMETER SCORE	PARAMETER WEIGHT
#4 Disassembly time	0,25		0,00		0,71		0,33		0,29		0,02		0,15		0,70		3,12	2,00
#1 Disassembly depth / sequence	0,50		0,00		1,00		0,75		0,45		0,10		0,45		1,00		5,36	2,00
#2 Fasteners	1,00		0,00		1,00		1,00		1,00		1,00		1,00		1,00		8,33	2,00
#3 Tools	0,66		0,00		1,00		1,00		0,66		0,66		0,66		1,00		6,82	2,00
#6 Type and availability of information	0,50		0,00		0,50		0,50		0,50		0,50		0,50		0,50		4,17	2,00
#7 Spare parts	0,25		0,00		0,50		0,50		0,25		0,25		0,25		0,50		3,06	2,00
#12 Commercial guarantee	0,00		0,00		0,00		0,00		0,00		0,00		0,00		0,00		0,00	/
RRU indices for parts	5,3		0		7,9		6,8		5,3		4,2		5		7,8			

Disassembly index	RRU Process index	OVERALL RRU	COMMERCIAL
5,9	3,6	5,1	0,00

Scores aggregation framework for the Philips FC9569/01, without considering disassembly time

Philips FC9569/01	PART 1	PART WEIGHT	PART 2	PART WEIGHT	PART 3	PART WEIGHT	PART 4	PART WEIGHT	PART 5	PART WEIGHT	PART 6	PART WEIGHT	PART 7	PART WEIGHT	PART 8	PART WEIGHT		
PARAMETER	MOTOR	3	MOTOR BRUSHES	3	FILTERS	3	HOSE	3	POWER CABLE	3	WHEELS	1	PCBA	1	NOZZLES	1	PARAMETER SCORE	PARAMETER WEIGHT
#1 Disassembly depth / sequence	0,38		0,47		1,00		1,00		0,45		0,08		0,21		1,00		6,22	2,00
#2 Fasteners	1,00		1,00		1,00		1,00		1,00		1,00		1,00		1,00		10,00	2,00
#3 Tools	0,66		0,66		1,00		1,00		1,00		0,66		0,66		1,00		8,49	2,00
#6 Type and availability of information	0,50		0,50		0,50		0,50		0,50		0,50		0,50		0,50		5,00	2,00
#7 Spare parts	0,25		0,00		0,50		0,50		0,25		0,25		0,25		0,50		3,06	2,00
#12 Commercial guarantee	0,00		0,00		0,00		0,00		0,00		0,00		0,00		0,00		0,00	/

RRU indices for parts								
	5,6	5,3	8	8	6,4	5	5,2	8

Disassembly index	RRU Process index	OVERALL RRU	Commercial Guarantee
8,2	4	6,6	0,00

Scores aggregation framework for the Philips FC9569/01, considering disassembly time

Philips FC9569/01	PART 1	PART WEIGHT	PART 2	PART WEIGHT	PART 3	PART WEIGHT	PART 4	PART WEIGHT	PART 5	PART WEIGHT	PART 6	PART WEIGHT	PART 7	PART WEIGHT	PART 8	PART WEIGHT		
PARAMETER	MOTOR	3	MOTOR BRUSHES	3	FILTERS	3	HOSE	3	POWER CABLE	3	WHEELS	1	PCBA	1	NOZZLES	1	PARAMETER SCORE	PARAMETER WEIGHT
#4 Disassembly time	0,30		0,31		1,00		0,56		0,27		0,02		0,17		0,56		4,48	2,00
#1 Disassembly depth / sequence	0,38		0,47		1,00		1,00		0,45		0,08		0,21		1,00		6,22	2,00
#2 Fasteners	1,00		1,00		1,00		1,00		1,00		1,00		1,00		1,00		10,00	2,00
#3 Tools	0,66		0,66		1,00		1,00		1,00		0,66		0,66		1,00		8,49	2,00
#6 Type and availability of information	0,50		0,50		0,50		0,50		0,50		0,50		0,50		0,50		5,00	2,00
#7 Spare parts	0,25		0,00		0,50		0,50		0,25		0,25		0,25		0,50		3,06	2,00
#12 Commercial guarantee	0,00		0,00		0,00		0,00		0,00		0,00		0,00		0,00		0,00	/

RRU indices for parts								
	5,15	4,9	8,3	7,6	5,8	4,2	4,7	7,6

Disassembly index	RRU Process index	OVERALL RRU	Commercial Guarantee
7,3	4	6,2	0,00

Scores aggregation framework for the Rowenta RO6963EA, without considering disassembly time

Rowenta RO6963EA	PART 1	PART WEIGHT	PART 2	PART WEIGHT	PART 3	PART WEIGHT	PART 4	PART WEIGHT	PART 5	PART WEIGHT	PART 6	PART WEIGHT	PART 7	PART WEIGHT	PART 8	PART WEIGHT		
PARAMETER	MOTOR	3	MOTOR BRUSHES	3	FILTERS	3	HOSE	3	POWER CABLE	3	WHEELS	1	PCBA	1	NOZZLES	1	PARAMETER SCORE	PARAMETER WEIGHT
#1 Disassembly depth / sequence	0,56		0,64		1,00		1,00		0,38		1,00		0,63		1,00		7,43	2,00
#2 Fasteners	1,00		1,00		1,00		1,00		1,00		1,00		1,00		1,00		10,00	2,00
#3 Tools	0,66		0,66		1,00		1,00		0,66		1,00		0,66		1,00		8,11	2,00
#6 Type and availability of information	0,50		0,50		0,50		0,50		0,50		0,50		0,50		0,50		5,00	2,00
#7 Spare parts	0,50		0,50		1,00		1,00		0,50		0,50		0,50		1,00		6,94	2,00
#12 Commercial guarantee	0,00		0,00		0,00		0,00		0,00		0,00		0,00		0,00		0,00	/
RRU indices for parts	6,4		6,6		9		9		6		8		6,6		9			

Disassembly index	RRU Process index	OVERALL RRU	Commercial Guarantee
8,5	6	7,5	0,00

Scores aggregation framework for the Rowenta RO6963EA, considering disassembly time

Rowenta RO6963EA	PART 1	PART WEIGHT	PART 2	PART WEIGHT	PART 3	PART WEIGHT	PART 4	PART WEIGHT	PART 5	PART WEIGHT	PART 6	PART WEIGHT	PART 7	PART WEIGHT	PART 8	PART WEIGHT		
PARAMETER	MOTOR	3	MOTOR BRUSHES	3	FILTERS	3	HOSE	3	POWER CABLE	3	WHEELS	1	PCBA	1	NOZZLES	1	PARAMETER SCORE	PARAMETER WEIGHT
#4 Disassembly time	0,26		0,26		1,00		0,20		0,20		0,27		0,20		0,56		3,77	2,00
#1 Disassembly depth / sequence	0,56		0,64		1,00		1,00		0,38		1,00		0,63		1,00		7,43	2,00
#2 Fasteners	1,00		1,00		1,00		1,00		1,00		1,00		1,00		1,00		10,00	2,00
#3 Tools	0,66		0,66		1,00		1,00		0,66		1,00		0,66		1,00		8,11	2,00
#6 Type and availability of information	0,50		0,50		0,50		0,50		0,50		0,50		0,50		0,50		5,00	2,00
#7 Spare parts	0,50		0,50		1,00		1,00		0,50		0,50		0,50		1,00		6,94	2,00
#12 Commercial guarantee	0,00		0,00		0,00		0,00		0,00		0,00		0,00		0,00		0,00	/
RRU indices for parts	5,8		5,9		9,2		7,8		5,4		7,1		5,8		8,4			

Disassembly index	RRU Process index	OVERALL RRU	Commercial Guarantee
7,3	6	6,9	0,00

Scores aggregation framework for the Samsung SC8835, without considering disassembly time

Samsung SC8835	PART 1	PART WEIGHT	PART 2	PART WEIGHT	PART 3	PART WEIGHT	PART 4	PART WEIGHT	PART 5	PART WEIGHT	PART 6	PART WEIGHT	PART 7	PART WEIGHT	PART 8	PART WEIGHT		
PARAMETER	MOTOR	3	MOTOR BRUSHES	3	FILTERS	3	HOSE	3	POWER CABLE	3	WHEELS	1	PCBA	1	NOZZLES	1	PARAMETER SCORE	PARAMETER WEIGHT
#1 Disassembly depth / sequence	1,00		1,00		1,00		1,00		1,00		0,50		1,00		1,00		9,72	2,00
#2 Fasteners	1,00		1,00		1,00		1,00		1,00		1,00		1,00		1,00		10,00	2,00
#3 Tools	1,00		1,00		1,00		1,00		1,00		1,00		1,00		1,00		10,00	2,00
#6 Type and availability of information	0,50		0,50		0,50		0,50		0,50		0,50		0,50		0,50		5,00	2,00
#7 Spare parts	0,25		0,25		0,50		0,50		0,25		0,25		0,25		0,50		3,47	2,00
#12 Commercial guarantee	0,00		0,00		0,00		0,00		0,00		0,00		0,00		0,00		0,00	/
RRU indices for parts	7,5		7,5		8		8		7,5		6,5		7,5		8			

Disassembly index	RRU Process index	OVERALL RRU	Commercial Guarantee
9,9	4,2	7,6	0,00

Scores aggregation framework for the Samsung SC8835, considering disassembly time

Samsung SC8835	PART 1	PART WEIGHT	PART 2	PART WEIGHT	PART 3	PART WEIGHT	PART 4	PART WEIGHT	PART 5	PART WEIGHT	PART 6	PART WEIGHT	PART 7	PART WEIGHT	PART 8	PART WEIGHT		
PARAMETER	MOTOR	3	MOTOR BRUSHES	3	FILTERS	3	HOSE	3	POWER CABLE	3	WHEELS	1	PCBA	1	NOZZLES	1	PARAMETER SCORE	PARAMETER WEIGHT
#4 Disassembly time	0,73		0,71		0,78		0,28		1,00		0,40		1,00		0,56		6,92	2,00
#1 Disassembly depth / sequence	1,00		1,00		1,00		1,00		1,00		0,50		1,00		1,00		9,72	2,00
#2 Fasteners	1,00		1,00		1,00		1,00		1,00		1,00		1,00		1,00		10,00	2,00
#3 Tools	1,00		1,00		1,00		1,00		1,00		1,00		1,00		1,00		10,00	2,00
#6 Type and availability of information	0,50		0,50		0,50		0,50		0,50		0,50		0,50		0,50		5,00	2,00
#7 Spare parts	0,25		0,25		0,50		0,50		0,25		0,25		0,25		0,50		3,47	2,00
#12 Commercial guarantee	0,00		0,00		0,00		0,00		0,00		0,00		0,00		0,00		0,00	/
RRU indices for parts	7,5		7,4		8		7,1		7,9		6,1		7,9		7,6			

Disassembly index	RRU Process index	OVERALL RRU	Commercial Guarantee
9,2	4,2	7,5	0,00

Scores aggregation framework for the Siemens VS06A111/12, without considering disassembly time

Siemens VS06A111/12	PART 1	PART WEIGHT	PART 2	PART WEIGHT	PART 3	PART WEIGHT	PART 4	PART WEIGHT	PART 5	PART WEIGHT	PART 6	PART WEIGHT	PART 7	PART WEIGHT	PART 8	PART WEIGHT		
PARAMETER	MOTOR	3	MOTOR BRUSHES	3	FILTERS	3	HOSE	3	POWER CABLE	3	WHEELS	1	PCBA	1	NOZZLES	1	PARAMETER SCORE	PARAMETER WEIGHT
#1 Disassembly depth / sequence	1,00		1,00		1,00		1,00		1,00		1,00		0,60		1,00		9,78	2,00
#2 Fasteners	1,00		1,00		1,00		1,00		1,00		1,00		1,00		1,00		10,00	2,00
#3 Tools	0,66		0,66		1,00		1,00		0,66		1,00		0,66		1,00		8,11	2,00
#6 Type and availability of information	1,00		1,00		1,00		1,00		1,00		1,00		1,00		1,00		10,00	2,00
#7 Spare parts	1,00		1,00		1,00		1,00		1,00		1,00		1,00		1,00		10,00	2,00
#12 Commercial guarantee	0,00		0,00		0,00		0,00		0,00		0,00		0,00		0,00		0,00	/
RRU indices for parts	9,3		9,3		10		10		9,3		10		8,5		10			

Disassembly index	RRU Process index	OVERALL RRU	Commercial Guarantee
9,3	10	9,6	0,00

Scores aggregation framework for the Siemens VS06A111/12, considering disassembly time

Siemens VS06A111/12	PART 1	PART WEIGHT	PART 2	PART WEIGHT	PART 3	PART WEIGHT	PART 4	PART WEIGHT	PART 5	PART WEIGHT	PART 6	PART WEIGHT	PART 7	PART WEIGHT	PART 8	PART WEIGHT		
PARAMETER	MOTOR	3	MOTOR BRUSHES	3	FILTERS	3	HOSE	3	POWER CABLE	3	WHEELS	1	PCBA	1	NOZZLES	1	PARAMETER SCORE	PARAMETER WEIGHT
#4 Disassembly time	1,00		1,00		0,78		1,00		0,61		1,00		0,61		1,00		8,77	2,00
#1 Disassembly depth / sequence	1,00		1,00		1,00		1,00		1,00		1,00		0,60		1,00		9,78	2,00
#2 Fasteners	1,00		1,00		1,00		1,00		1,00		1,00		1,00		1,00		10,00	2,00
#3 Tools	0,66		0,66		1,00		1,00		0,66		1,00		0,66		1,00		8,11	2,00
#6 Type and availability of information	1,00		1,00		1,00		1,00		1,00		1,00		1,00		1,00		10,00	2,00
#7 Spare parts	1,00		1,00		1,00		1,00		1,00		1,00		1,00		1,00		10,00	2,00
#12 Commercial guarantee	0,00		0,00		0,00		0,00		0,00		0,00		0,00		0,00		0,00	/
RRU indices for parts	9,4		9,4		9,6		10		8,8		10		8,1		10			

Disassembly index	RRU Process index	OVERALL RRU	Commercial Guarantee
9,2	10	9,4	0,00

5. Discussion and conclusions on the assessment results

5.1 Introduction

In this chapter the results gathered in Chapter 4, calculated using the research methodology presented in Chapter 3, are further analysed. The main aim is to define recommendations for the manufacturer, Philips, which can help the company improving repairability of their products. Moreover, many of these insights are used in Chapter 7 as well, where a representative vacuum cleaner model is redesigned.
Additional observations are presented in the form of feedback for the Joint Research Centre scoring system. In fact, testing this new methodology for the assessment of seven different products allowed to collect interesting recommendations which could be further explored to optimise the assessment system.

5.2 Results analysis

Radar charts

Two radar charts have been created for each model using the scores aggregation tables presented at the end of Chapter 4. They can be found in the next pages. In the first radar charts the scores achieved by each model for each single parameter assessed can be easily read. In the second chart, the RRU indices per priority part can be seen as well; in this case, Disassembly times has been included in the analysis, allowing to compare it to the scores assessed for disassembly depth, tools and fasteners. On the contrary, Type and availability of information and commercial guarantee have been excluded from the second radar since these parameters are assessed at the product level and it does not change based on single priority components (Codella et al., 2019). Fasteners reusability has been excluded as well, since all the products scored 1 pt for each priority component.

The worst models

From these charts and the scores aggregation tables presented at the end of the last chapter it is possible to see how the products which scored the lowest disassembly index are two high end Philips vacuum cleaners: the bag canister FC8924/01 and the bagless FC9934/07 (5,4 out of 10). This is mainly due to:

- The high number of steps required to reach priority parts (caused by a higher number of internal components)
- Not disassemblable motor brushes
- Use of un-common tools
- Limited availability of information to the public concerning spare parts costs and availability
- Limited spare parts availability period (6-7 years, against the 8 recommended by Cordella et al. (2019)) and limited number of spare parts publicly purchasable (only CRP parts, such as nozzle, hose and filter)

The official repairers interviewed at the ERC confirmed that these models are the most difficult to disassemble (Appendix J).
As observed by Bracquené et al. (2018) as well, it was found that product complexity increases when more electric components are included in the design. This usually happens in more expensive vacuum cleaners, where sensors controllers and screens are added to the design.

The best models

On the contrary, the Samsung SC8835 and the Siemens VS06A111/12 are the models which received the best score for disassembly index (9,9 and 9,3 out of 10) and overall (7,6 and 9,6 out of 10). These models present a very simple internal design, with few plastic layers that obstruct the accessibility of the internal components. In particular the Samsung SC8835 presents a big clump which groups all the plastic aesthetic covers together, and allows to remove them all in one single step, just by unscrewing 5 fasteners.

The best Philips model analysed is the stick FC6812, where many of the priority parts are very easy to reach (as confirmed also by the official repairers interviewed, Appendix J). However, in this model it is not possible to disconnect the PCBA from the motor, and this has been penalised during the assessment.

RRU process index

From the radar charts it is clearly visible how the Siemens scored the best RRU process index, with a very high score in:

- Type and availability of information, due to the fact that the company clearly communicates spare parts availability period and prices
- Spare parts availability, due to the fact that the company makes all the inner priority components publicly available for purchase on its official website.

On the contrary, almost all the other products scored a low RRU process index. This is mainly due to lack of information concerning spare parts availability period and price and limited catalogue of spare parts purchasable by the public.
Compared to Philips and Samsung products, which received the worst score, Rowenta provides specific and public information about spare parts availability period (10 years); on the other hand, they do not communicate prices of all the spare parts. The only exception is Siemens, who shares complete information about spare parts availability period and price; it is even possible to buy all the priority parts on the website.

Commercial guarantee

As it is possible to see from the radar charts, all the products scored 0 out of 10 concerning commercial guarantee, since they all provide just the two years guarantee period required by European law. The following conclusions have been identified during this research:

- Many manufactures are not providing a commercial guarantee aligned with the life-span of the product itself.
- Extending the current commercial guarantee would probably improve product repairability and durability, since manufacturers defines their list of priority components based on call rates created by analysing mainly product returned in warranty period
- The rating proposed by Cordella et al. (2019) for this parameter might be too strict for the current manufacturing scenario. It is very unlikely that OEM's will raise their warranty period from 2 to 8 years in the near future. The assessment of this parameter might have to be revised.

Components to be optimized

As it is clearly indicated in the radar charts, the single components which scored the worst Disassembly index are:

- Motor
- PCBA
- Cord-winder

This means that, while external components such as nozzle, hose and filter are always easily accessible, the disassembly of inner components is the most problematic one. Therefore, product architectures should be optimised focusing on inner components accessibility.

eDiM data reliability

Philips carried out in 2016-2017 a disassembly time stop-watch analysis. They analysed 312 repair procedures, carried out on bag, bagless and robot vacuum cleaners, checking the time necessary to repair different priority components. The complete data set can be found in Confidential Appendix E. The disassembly time values calculated in this study using the eDIM methods have been compared with the one provided by Philips. The specific time values cannot be publicly share; in general the disassembly time stop-watched by Philips is higher, but comparable with those calculated in this research. This is because Philips took in account repair procedures not considered by the eDiM metric, such as:

- Un-boxing of the product
- Placement of the product on the working surface
- Product testing
- Re-packing of the product in the original box

Unofficial spare parts assessment

Spare parts of internal priority components (e.g. motor, PCBA, cord-winder) have been found on unofficial websites, which do not state clearly if parts are original. These selling channels do not represent either official manufacturer, importers or representatives and it is not clear if the quality of the parts sold is comparable to original ones. Therefore, these sources have not been considered in this study.

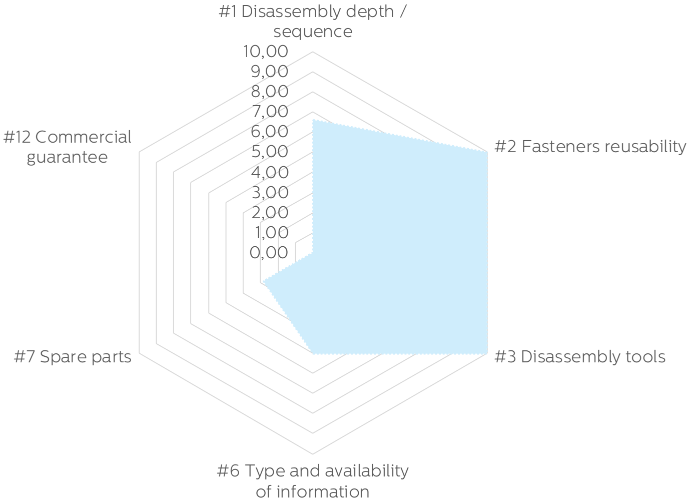
Exceptions made for Pass/Fail criterions

As it is possible to observe from Table 13 in Chapter 4, Philips vacuum cleaners are the only products which presents not disassemblable priority parts (e.g. motor brushes, active nozzle motor belt). In this research they scored 0pt for those specific components. However, Cordella et al. (2019) actually consider the availability of spare parts for each priority component as pass/fail criterion. The main reason why these parts are not disassemblable is a discrepancy between the spare parts list proposed by the JRC and the one defined by Philips according to their internal call rates.

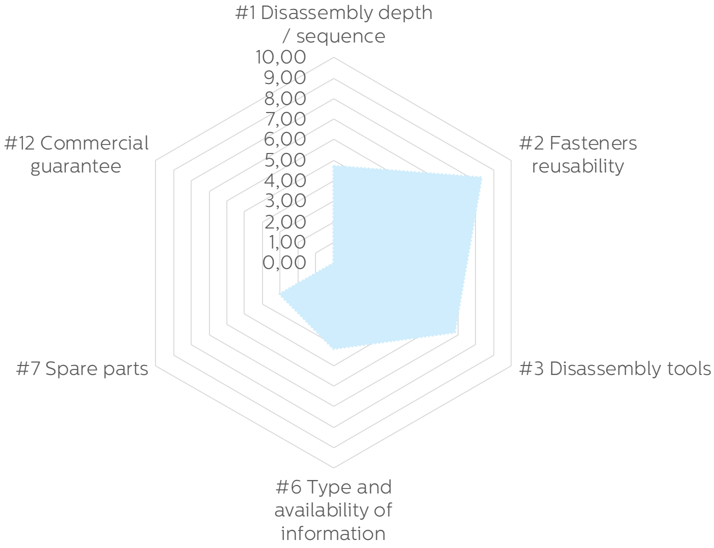
Another exception has been made for Pass/fail criteria which determines that the cost of all spare parts should be communicate to the public. This is not respected by most of the products assessed, except for the Siemens model. In fact, just few components are usually sold to private consumers, sharing publicly their prices (Nozzles, hose and filter). In most cases, inner components are available just for registered repairers, and their price is not indicated on the website. In order to complete the assessment and analyse the outcomes, this pass/fail criteria has been ignored for all the products.

Radar diagram of parameters scores at the product level

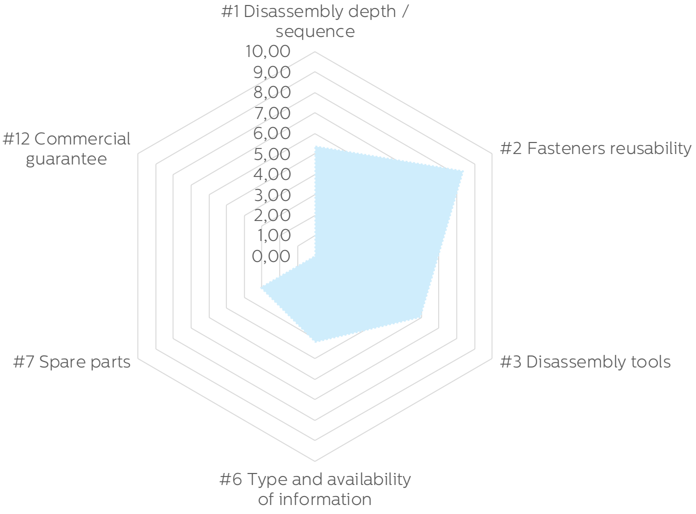
PHILIPS FC6812/01



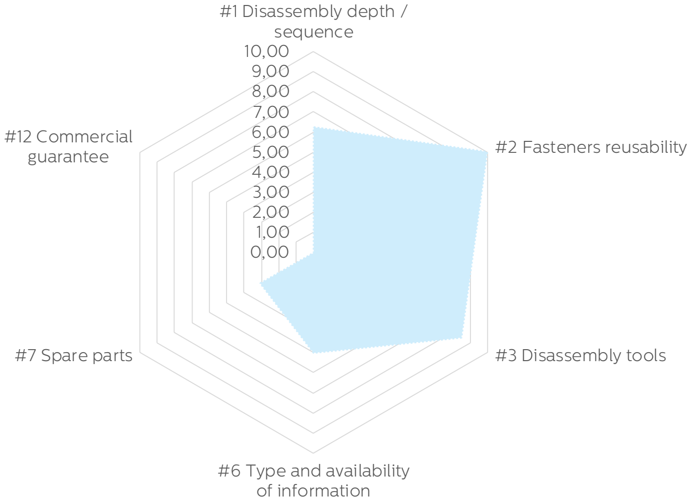
PHILIPS FC8924/01



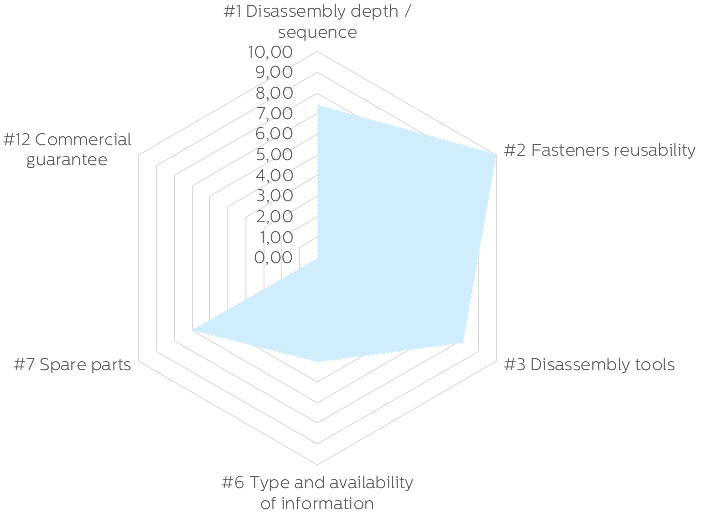
PHILIPS FC9934/07



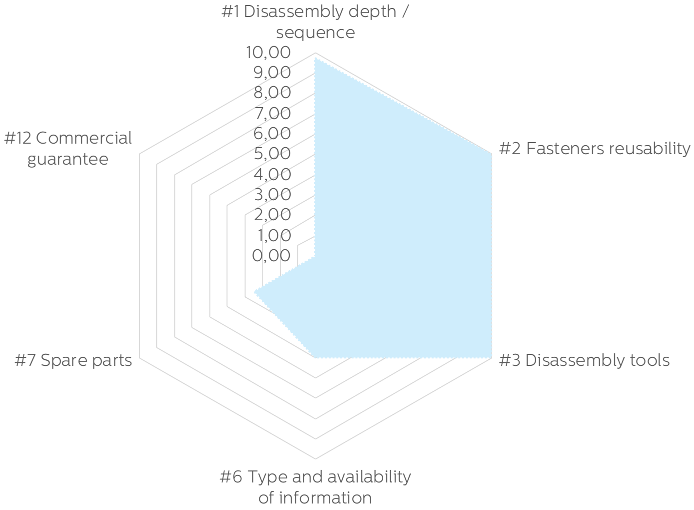
PHILIPS FC9569/01



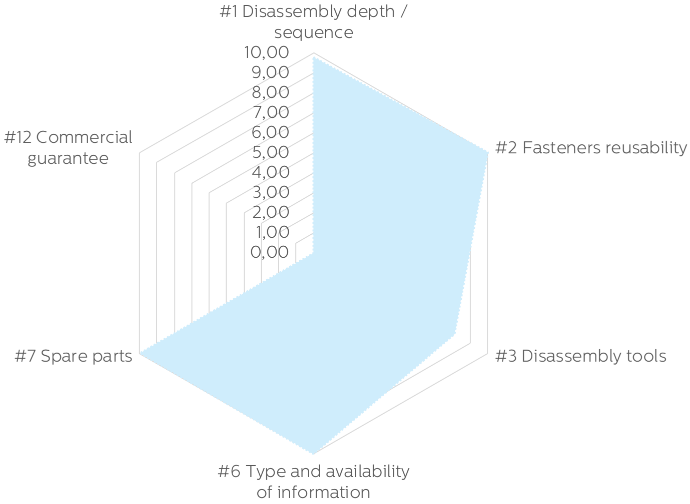
ROWENTA RO6963EA



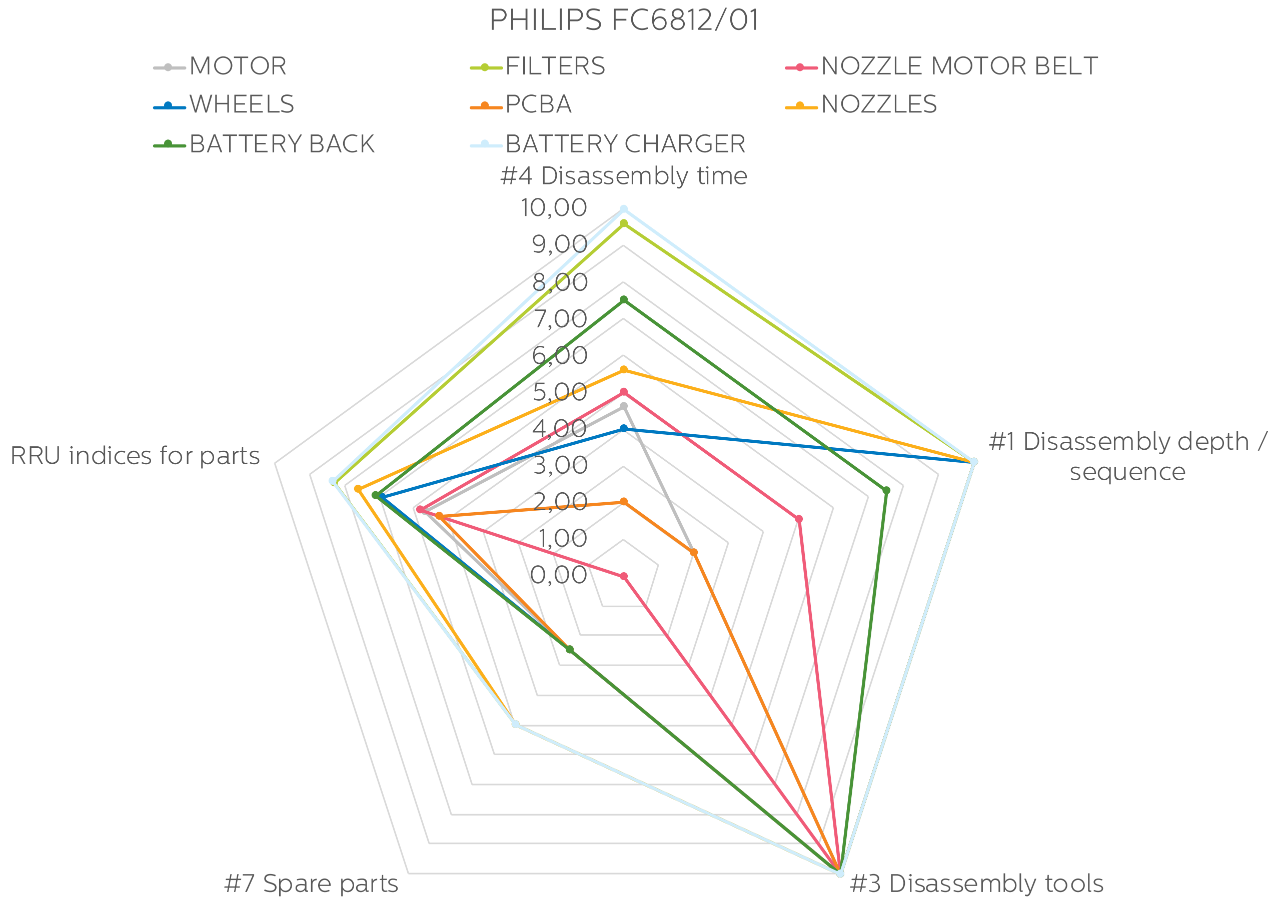
SAMSUNG SC8835

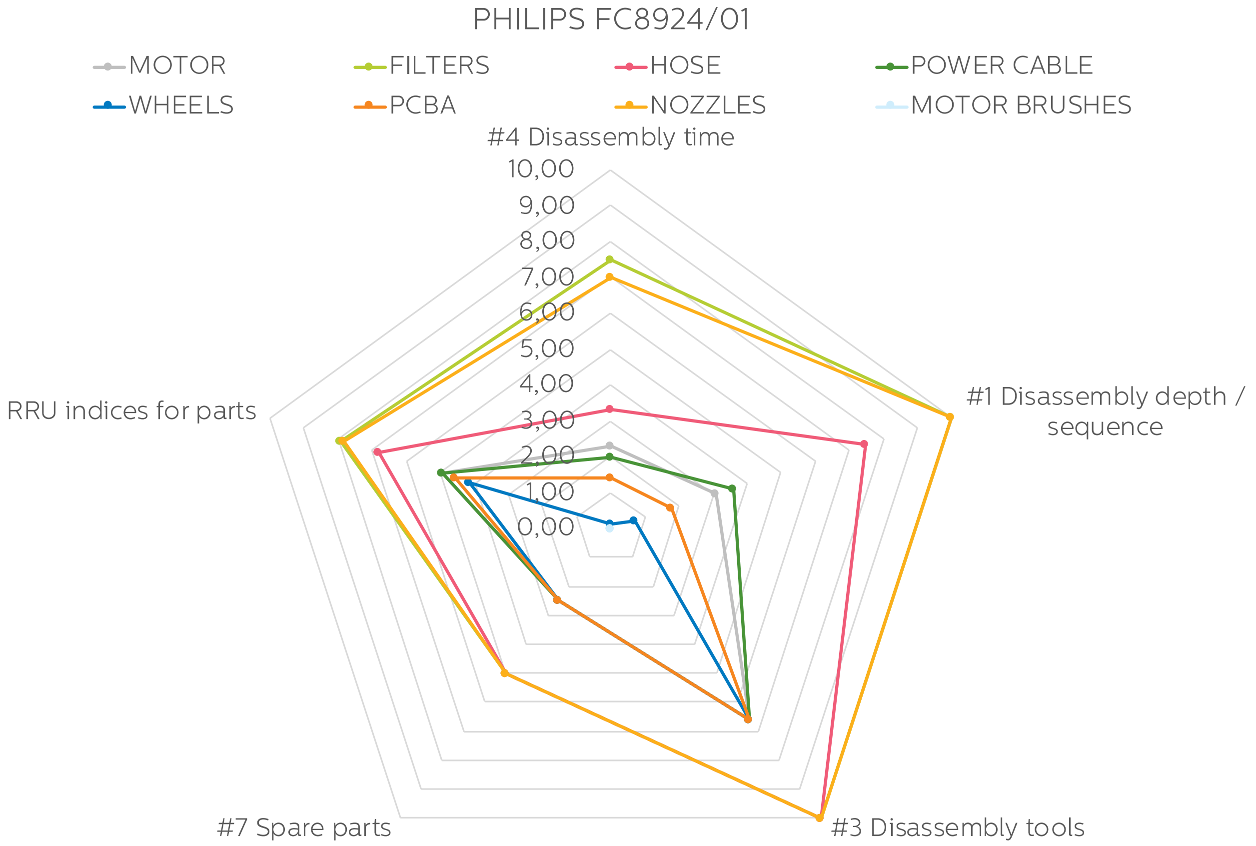


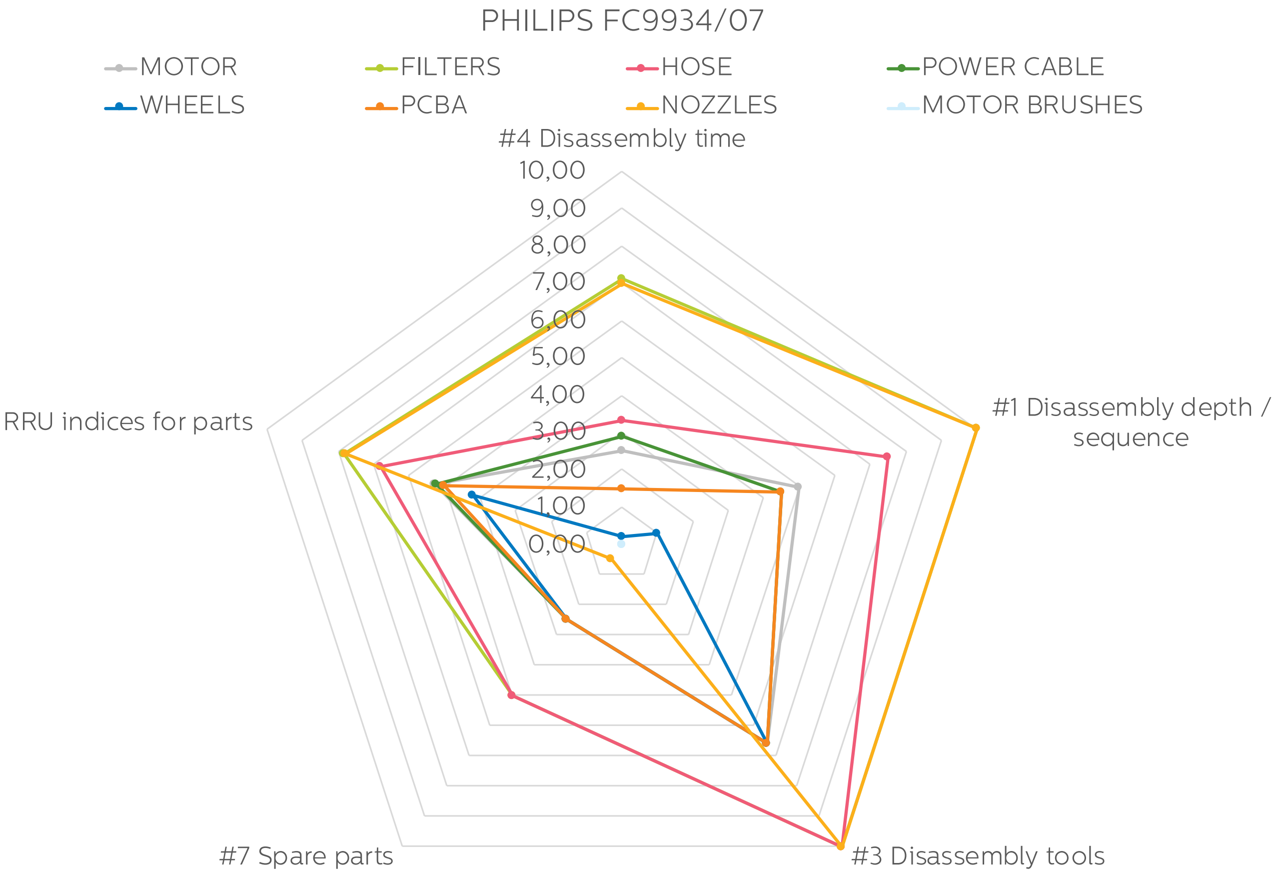
SIEMENS VS06A111/12

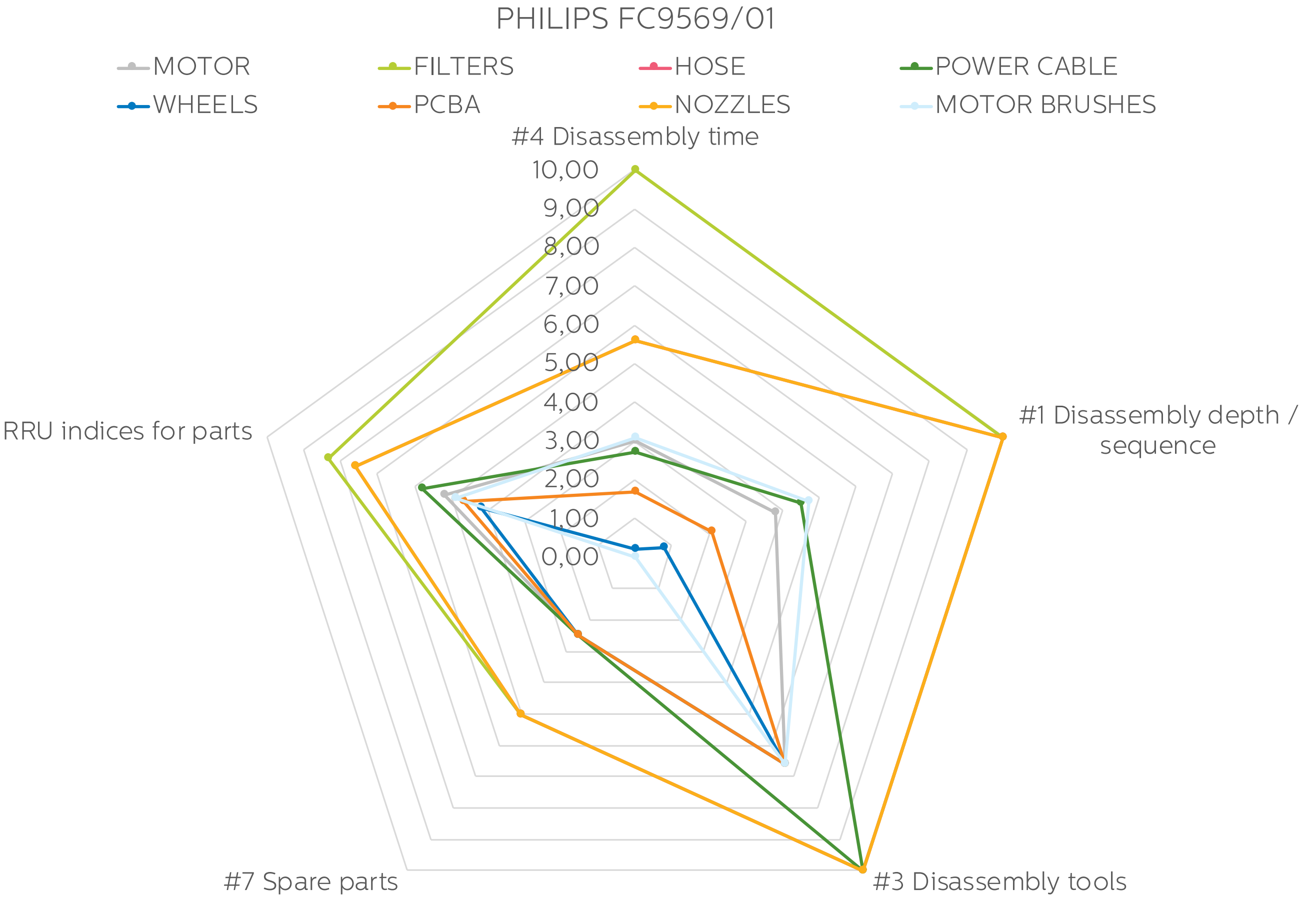


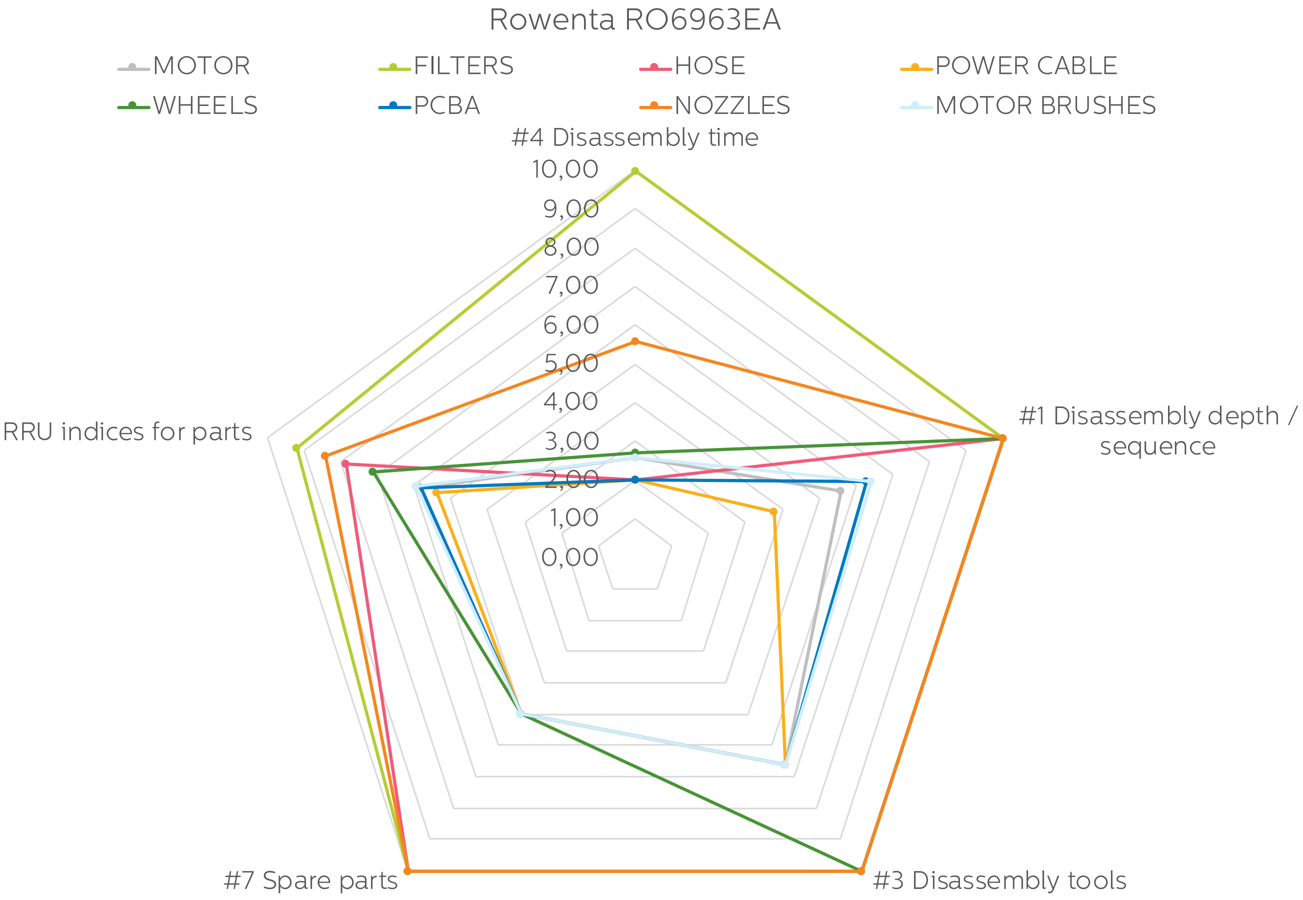
Radar diagram of parameters scores for each priority component

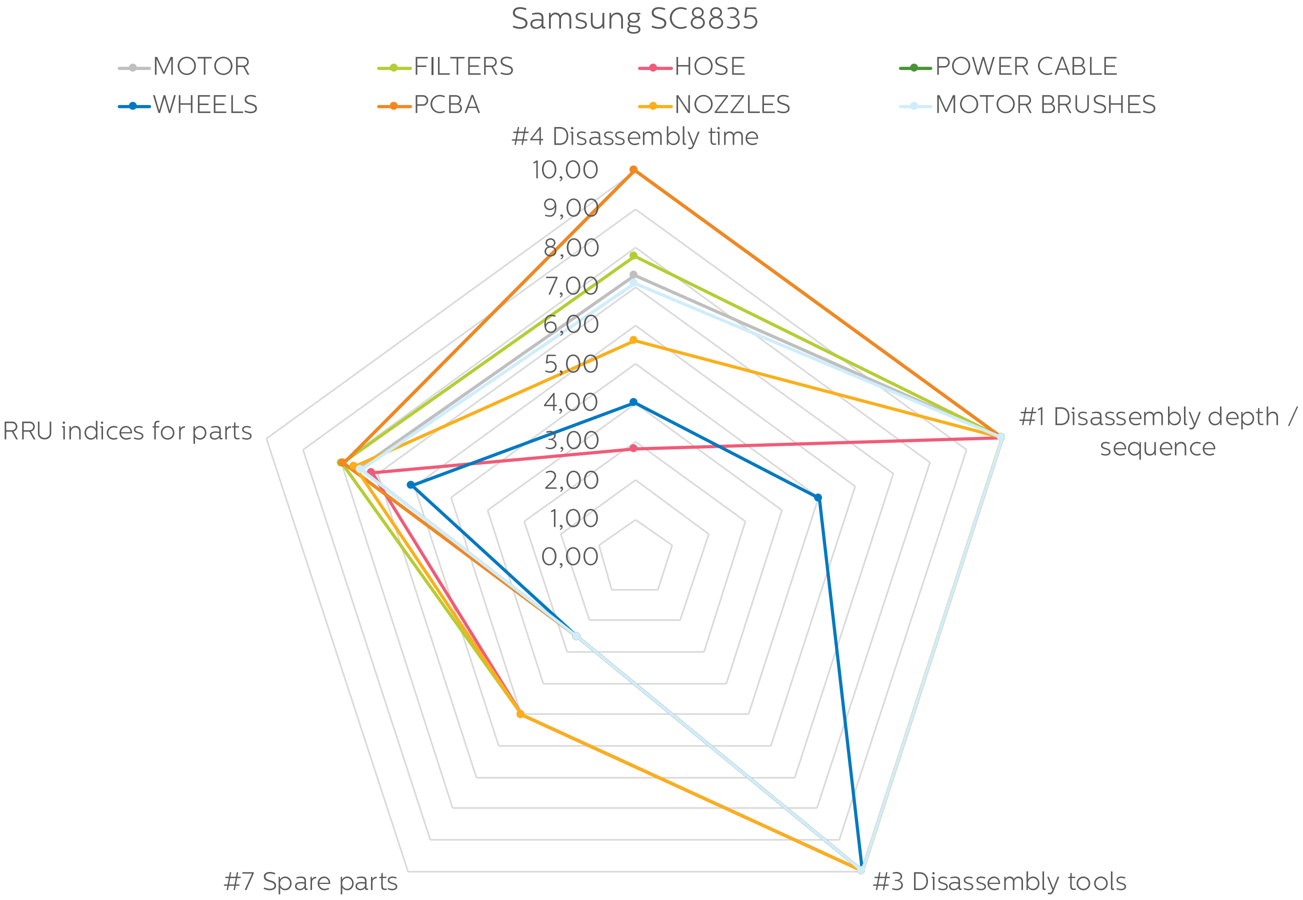


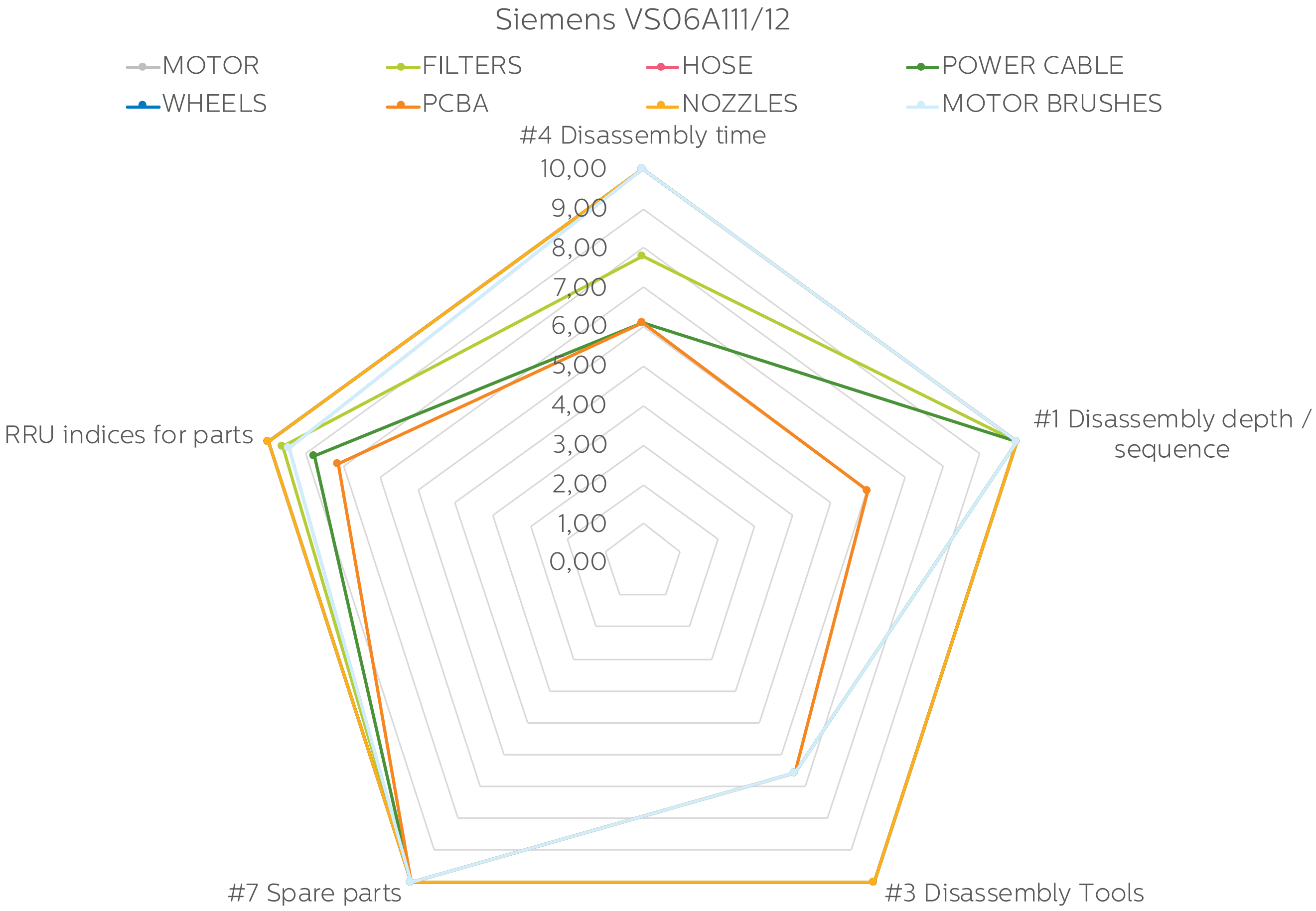



PHILIPS FC9934/07
MOTOR
FILTERS
HOSE
POWER CABLE
WHEELS
PCBA
NOZZLES
MOTOR BRUSHES
#4 Disassembly time
10,00
9,00
8,00
7,00
6,00
5,00
4,00
3,00
2,00
1,00
0,00
#1 Disassembly depth / sequence
#3 Disassembly tools
#7 Spare parts
RRU indices for parts


PHILIPS FC9569/01
MOTOR
FILTERS
HOSE
POWER CABLE
WHEELS
PCBA
NOZZLES
MOTOR BRUSHES
#4 Disassembly time
10,00
9,00
8,00
7,00
6,00
5,00
4,00
3,00
2,00
1,00
0,00
#1 Disassembly depth / sequence
#3 Disassembly tools
#7 Spare parts
RRU indices for parts


Rowenta RO6963EA
MOTOR
FILTERS
HOSE
POWER CABLE
WHEELS
PCBA
NOZZLES
MOTOR BRUSHES
#4 Disassembly time
10,00
9,00
8,00
7,00
6,00
5,00
4,00
3,00
2,00
1,00
0,00
#1 Disassembly depth / sequence
#3 Disassembly tools
#7 Spare parts
RRU indices for parts


Samsung SC8835
MOTOR
FILTERS
HOSE
POWER CABLE
WHEELS
PCBA
NOZZLES
MOTOR BRUSHES
#4 Disassembly time
10,00
9,00
8,00
7,00
6,00
5,00
4,00
3,00
2,00
1,00
0,00
#1 Disassembly depth / sequence
#3 Disassembly tools
#7 Spare parts
RRU indices for parts


Siemens VS06A111/12
MOTOR
FILTERS
HOSE
POWER CABLE
WHEELS
PCBA
NOZZLES
MOTOR BRUSHES
#4 Disassembly time
10,00
9,00
8,00
7,00
6,00
5,00
4,00
3,00
2,00
1,00
0,00
#1 Disassembly depth / sequence
#3 Disassembly Tools
#7 Spare parts
RRU indices for parts

5.3 Conclusion

The repairability assessment carried out in Chapter 4 and now discussed allowed to investigate the following research objective:

- **RO.2 Determining how much repairable Philips consumer products currently are**
- **RO.3 Comparing different product architectures, identifying the most optimised structures for product repairability and upgradability**
- **RO.4 Identifying design aspects which might obstruct product repairability**

Repairability assessment results

Philips vacuum cleaners repairability was scored between 5,4/10 and 6,8/10 according to the JRC scoring system (Cordella et al., 2019). Three competitors' received higher score (Rowenta bagless canister 7,5/10, Samsung bagless canister 7,6/10, Siemens bag canister 9,6/10).

Product architecture features which influence repairability

The main difference found between the product architecture of Philips vacuum cleaners and competitors' is how single components are organised and assembled together. Inner priority components, such as PCBA, Motor and Cord-winder are the most difficult to access during repair procedures. These are covered by many different plastic components, which usually define the outer product aesthetics. While in competitors' vacuum cleaners all these parts are generally clumped together, forming one single sub-assembly which can be removed in one step, Philips vacuum cleaners present a more complex assembly architecture, where all the outer plastic components have to be removed one by one in long sequential dependent disassembly procedures. This is the main reason found for the low score obtained in disassembly sequence/depth and time by Philips products.

Design aspects which obstruct product repairability

Apart from the general unoptimized product architecture, other design features which limits Philips vacuum cleaners disassembly index are:

- Screws used to fasten motor housing to lower housing in Philips vacuum cleaners are often too deep, and they cannot be unfastened using a common length screw driver (as defined by the prEN45554)
- Wires which connect motor and cord-winder to the PCBA are soldered on the board and cannot be disconnected. This makes the disassembly of the PCBA sequential dependent from the disassembly of the other two components
- In some models motor brushes cannot be disassembled. Cordella et al. (2019) define them as priority components. Therefore, this design aspect was penalised

System features which limit the RRU Process index are:

- Information about price and spare part availability period of many priority components is not publicly shared
- The spare parts availability period for registered repairs is limited to 6-7 years. This is lower compared to the 8 years used as rating by Cordella et. al. (2019).

Strategies to improve the overall score

All the products analysed, independently from the brand, scored a low RRU process index.
Therefore, it could be argued that the best way to improve the overall RRU score would be to focus on spare parts and information availability instead of enhancing design for product disassembly. However, in order to improve the RRU process index relevant changes at the organizational level would be required, such as:

- Bigger stock of spare parts
- Commercial, logistic and legal agreements for the sale of inner priority components to private consumers
- Consequent provision of possible guidelines for self-repairs of inner component publicly sold

On the contrary, the Disassembly index could be improved with less invasive changes for the business, optimizing product architectures for inner priority components accessibility in early and pre-production design stages. This solution might be preferable for many companies, including Philips.
However, both aspects should be investigated in order to substantially enhance product repairability and upgradability.

5.4 Recommendations for Royal Philips

More detailed recommendations for the manufacturer have been further developed. In fact, Philips expressed particular interest in receiving guidelines specifically related to its products in order to improve the current state of repairability in its consumer products portfolio. This is reflected in the research objective **RO.5 Defining and testing new guidelines or methodologies that can guide designers to design for product repairability.**

The recommendations now presented have been developed further in Chapter 7, where a representative model of Philips canister vacuum cleaners has been redesigned together with the Floor Care I&D department. The outcomes achieved convinced the manufacturer to include some of these recommendations in the official department database of design requirements, ensuring the application of these guidelines in the development of future canister products.

The most important insight learned during this research is:

> “Repairability is not about making all the components disassemblable. On the contrary, a repairable product requires to disassemble as few components as possible in the shortest time in order to reach priority parts”

The development team should consider priority components and their accessibility from an early stage of the design process. The overall product architecture should be designed around the concept of making them easy to reach and replace.

Recommendations to optimize disassembly time and sequence

- During the products assessment, it was observed a high number of hidden snap fit connectors in Philips vacuum cleaners, where they are mainly used to fasten plastic external covers. A high number of hidden snap fits increases disassembly time, since the repairer has to look for them and it is unclear how to position the tool in order to disconnect them. Even using the service manual, this can become a complex procedure. As explained by the official repairer interviewed at the ERC (Appendix J), experience is required to learn how to disassemble them without causing components and fasteners breakage.
- All the non-priority parts should be grouped together in sub-assemblies which can be easily disassembled in a short time. In Philips vacuum cleaners, there are usually many plastic layers that have to be removed one by one, making the removal of plastic components the most time-consuming procedure. Repairability is not about making everything disassemblable, but it is about facilitating the disassembly of priority components. Good examples of component clumping can be found in the Samsung SC8835 and the Siemens VS06A111/12.
- The positioning of hidden screws beneath on-off and cord-winder buttons should be avoided. This configuration determines an additional disassembly step (disassembly of the buttons) which could be easily skipped by placing the screws on the back of the rear housing (like those observed in the FC9934)
- Two connectors should be added to the PCBA, in such a way that motor and cord-winder can be easily disconnected. Currently, in order to disassemble the electric board, motor and cord-winder have to be disassembled as well
- Motor housing and cord-winder could be independently disassemblable if the last one is mounted on the lower housing and more space is left between these two components. This design has been already used by Philips in the FC85XX bag canister series
- Since both PCBA and motor are priority components, it should always be possible to disassemble them from each other. A not disassemblable configuration increases the use of spare parts and increases disassembly time (since they depend on each other).
- The use of different types of tools in the same design should be avoided, since changing tool during repair operations increases disassembly time.

Recommendations concerning tools and fasteners

- Snap fits connectors are faster to disconnect compared to screws. However, this is not the case when they are hidden. The time required to identify their position automatically makes screws faster to disassemble. Furthermore, it is often unclear how to apply correctly force with the disassembly tool; this is the main cause of snap fit breakage. Their position should be clearly indicated in order to avoid both long research time and broken snap fits.
- Screws should not be positioned too deep in the product. This is often the case with the screws used to fasten the motor housing to the lower housing. This design requires the use of non-common tools, like screw driver extension, penalised by the standard prEN45554.

Recommendations concerning type of available information

- Service manuals should be made publicly available. However, it is known that legal complications would be involved in that, and that most of the manufacturers do not publish them as well

- A minimum spare parts availability period should be defined and declared publicly to consumers on the manufacturer website. It is important for consumers to know this information. This information is assessed by the ADEME "Critères de l'indice réparabilité" as well (Appendix B). Group SEB's "Product 10Y Repairable" label (Groupeseb.co.uk, 2019) represents a good example of how Philips could effectively communicate to consumers their interest and attention towards product repairability.
- Prices of all the priority components should be made publicly available.
- The specific type of tools required for the disassembly of screws and special connectors should be clearly indicated in the service manuals. This is assessed by the ADEME "Critères de l'indice réparabilité" as well (Appendix B).
- A concise but complete troubleshooting guide should be included in all the service manuals. It is known that a complete guide can be found on "At your service", but the repairers might save some time if the troubleshooting is already included in the Service manual.

Recommendations concerning spare parts availability

- Spare parts of all the priority components should be made publicly available on the website. This includes inner components, such as PCBA, Cord-winder and Motor
- Spare parts should be made available for at least 8 years
- A standardised design should be adopted, at least for priority parts and at least for the same product family (bag, bagless, stick). Standardized and modular design is assessed by the ADEME "Critères de l'indice réparabilité" as well (Appendix B).

Recommendations concerning commercial guarantee

- According to the JRC scoring system, the guarantee period for vacuum cleaners should be calculated according to the average product life-span; therefore, it should be extended to 8 years (Cordella et al., 2019).

5.5 Recommendations for the JRC scoring system

By testing the scoring system proposed by Cordella et al. (2019) on seven different products, insights which could be used for a possible future improvement of this assessment system have been gathered. These remarks concern:

- Definition of key parameters for the assessment of vacuum cleaners
- eDiM disassembly sequences library
- Priority parts list definition for vacuum cleaners
- Definition of common tools
- Limitations of the continuous rating system

Key parameters for the assessment of vacuum cleaners

The JRC scoring system does not consider parameter 4, disassembly time, for the assessment of vacuum cleaners. This parameter has been left out by Cordella et al. (2019) since a standardised and reliable method to assess this parameter has not been defined yet. In fact, even if the eDiM metric represents a valuable and comprehensive solution, its library of disassembly action sequences is still incomplete and it might not be suitable for all product groups yet. Moreover, a more extensive research should be carried out in order to define reference parameters for a discrete rating assessment. In addition, the JRC argues that disassembly time is indirectly described by the assessment of disassembly depth, tools, fasteners and availability of repair information (Cordella et al., 2019).

These argumentations are mostly shared by this research. However, disassembly time was investigated as well, since it was a very important information for the calculation of possible savings determined by a more repairable design in Chapter 7. In addition, the eDIM method, used for the calculation of disassembly time, provided useful insights for the creation of a new design tool (Chapter 6). Eventually, by considering disassembly time it was easier to highlight differences between different product architectures, identifying the best features to enhance repairability.

The assumption made by the JRC affirming that "disassembly time is also covered indirectly by other parameters (e.g. disassembly depth, fasteners, tools, availability of repair information)" (Cordella et al., 2019) was further investigated in this research. In total, 60 different priority parts disassembly sequences have been analysed in this research. Disassembly time and depth registered for each of them have been plotted in Chart 1.

Although correlation has been found between these two different parameters (coefficient of correlation 0,92), a high standard deviation and variation resulted from the analysis of the average time per step calculated for each disassembly sequence (average time per step 30s, standard deviation 20s, variation 415). In other words, this confirms that an increase in the number of disassembly steps usually determines an increase in disassembly time. Nevertheless, the disassembly time per step can vary a lot based on the type of connectors unfastened during the specific step. Therefore, considering only disassembly depth without taking in account disassembly time can lead to a wrong assessment. This is because the same number of steps counted for two different vacuum cleaners, could require very different disassembly times.

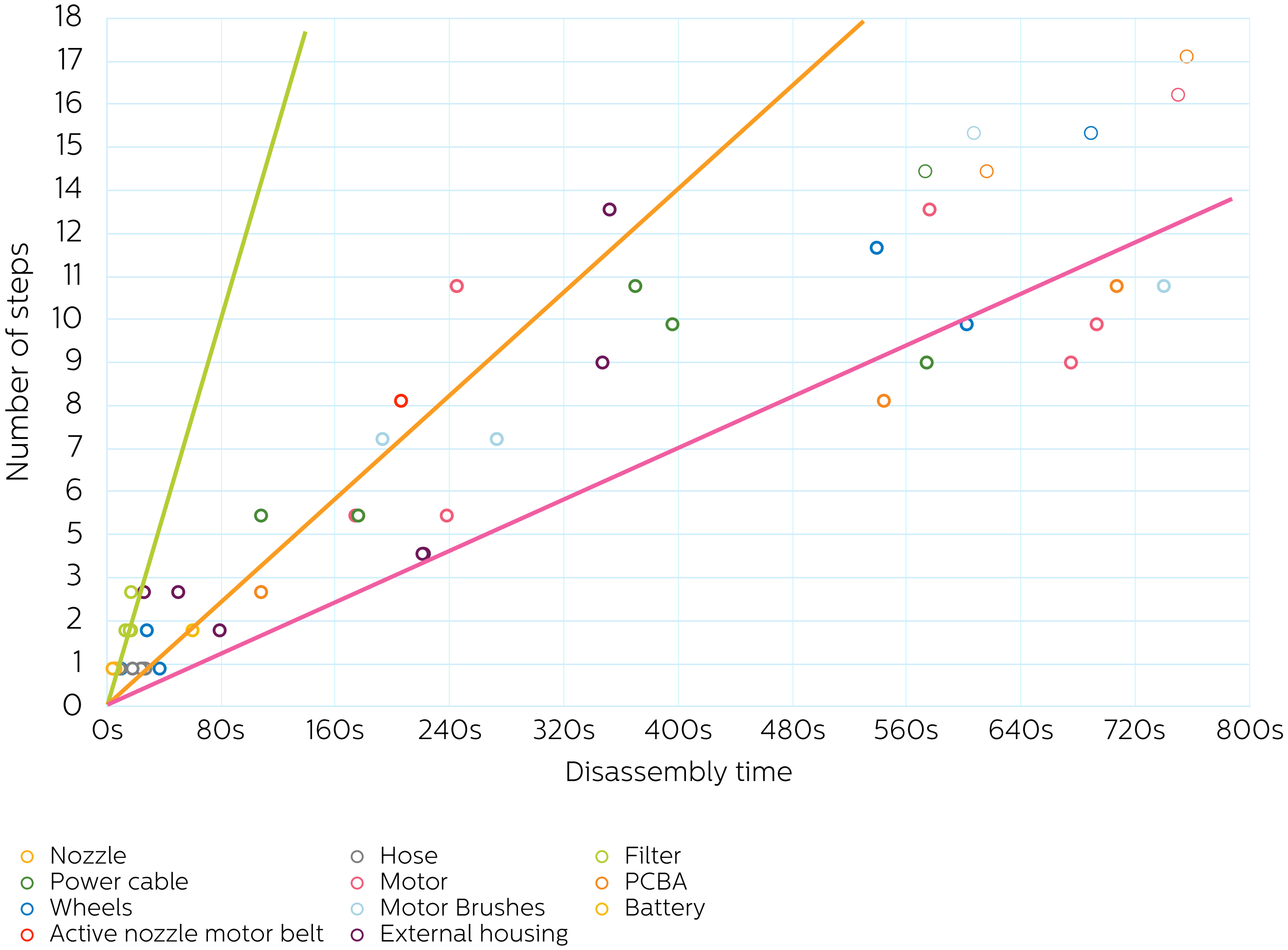
A clear example can be seen in the comparability tables 15 and 16, analysing two bagless canister from the same brand: Philips FC9934 and Philips FC9569. By comparing the disassembly of the inner priority parts of these two vacuum cleaners, it is possible to notice that:

- The cord-winder requires 11 disassembly steps in the FC9934 and 10 in the FC9569. However, the disassembly time is respectively 370 s in the first case and 396 s in the second model. This is because the disassembly of the upper plastic layers takes more time in the FC9569 because of hidden, high force intensity, snap fits
- On the other hand, the disassembly of the motor requires 10 steps in the FC9934, and 13 in the FC9569. However, the disassembly times are 693 s and 576 s, since more screws are used to fasten the motor housing to the lower housing in the FC9934.
- The PCBA requires 11 steps in the FC9934, and 14 in the FC9569. However, the disassembly times are 707 s and 616 s, caused by the longer disassembly time required to reach the motor in the FC9934

To conclude, the data gathered in this research prove that disassembly depth/sequence does not always truly describe disassembly time. This is because the average disassembly time per single step can vary a lot, based on the nature of the fasteners to be removed.

Average disassembly time per step might be an interesting parameter to include in the assessment framework. As illustrated in Chart 1 by the green, orange and pink line, the optimal situation would be to have a high number of steps carried out in

Chart. 1 Correlation between number of steps and disassembly time



a short time, therefore a low average disassembly time per step (green line).

Further proof are two different scoring frameworks presented at the end of Chapter 4: the first tables calculate the final score without considering disassembly time, while the second calculation tables consider also disassembly time. Important variations have been found in the final scores; for instance, the Philips FC9569/01 scores a Disassembly Index of 8,2/10 in the first table and 7,1/10 in the second one, which considers disassembly time. By considering disassembly time, the scores change in all the models, but with different intensity based on different architectures.

eDIM disassembly sequences library

The eDIM methodology is a powerful tool to assess disassembly time in an objective way. However, the list of connectors currently included in the eDIM disassembly sequences library is limited. During this study, new MOST sequences have been created, based on:

- Two new types of connectors (snap fits and friction fits)
- Three different force intensity ranges
- Two different disconnection tools (using bare hands or a spudger).

An extensive and standardized library, which includes all the disassembly actions necessary to truly describe the disassembly of different product groups should be created before any official assessment is done following the JRC scoring system. The use of different MOST sequences to describe the same connectors would lead to different assessment outcomes, even by using the same assessment framework.

Priority parts defined for vacuum cleaners

Motor brushes

In the final version of the Repairability scoring system (Cordella et al., 2019), motor brushes have been added to the priority part list with weight 3. This component was not included neither in the first draft, nor in the priority part list proposed by the Benelux study (Bracquené et al., 2018). However, Bracquené et al. (2018) expressed interest in it as well, explaining how carbon brushes are fundamental for the working principle of brushed motors, and how their malfunctioning is usually the main cause of motor’s end of life. The JRC included motor brushes in the list based on stakeholders interviews, while the Benelux study expressed interest quoting the “Work on Preparatory Studies for Eco-Design Requirements of EuPs (II) Lot 17 Vacuum Cleaners” (Reisch et al., 2010). However, other researches from the European Commission argued that the average life-span of general brushed motors, is around 500-600 hours (Bobba et al., 2015; Rames et al., 2018). Besides, the European Commission imposed a minimum life-span of this part of 500 hours, with the Commission Regulation (EU) No 666/2013 of 8 July 2013 (Directive 2009/125/EC of the European Parliament and of the Council with Regard to Ecodesign Requirements for Vacuum Cleaners) (Bracquené et al., 2018). Assuming 50 hours of usage per year (Rames et al., 2018), the general life span of this component is 12 years, exceeding by far the average 5-8 years life-span of vacuum cleaners (Bracquené et al., 2018; Rames et al., 2018). Philips argued that the design of the their motor brushes ensures at least 600h of work, after which they fail in a safe way. If they were replaced, extending the lifespan of the motor over 12 years, possible untested and unsafe motor breakage could happen. Moreover, the repair involving the replacement of the motor carbon brushes can be time consuming and complex. The brushes are usually hidden inside the motor housing, and they have to be recalibrated and realigned with the motor if replaced (Rames et al., 2018). Furthermore, more and more motors implemented in vacuum cleaners are brushless, eliminating the problem of brushes deterioration (Bracquené et al., 2018). In addition, Philips pointed out three other causes of motor malfunctioning, which are more frequent than carbon brushes deterioration according to their official repair centres:

- Dust accumulated inside the motor
- Water accumulated inside the motor, caused by the users who clean the filter with water and place it back before it is completely dry.
- Breakage of an overheating fuse in the motor body causing clogged filters not correctly cleaned, which limit the airflow supposed to cool down the motor

The same insights were suggested by the two professional repairers interviewed at the ERC (Appendix J)

In addition, the Repair Café monitor 2017 (Appendix D), indicates that motor failure were registered only 6% of times (2 cases out of 33) over all 2017, and on vacuum cleaners with an average life-span of 10 years.

From the literature analysed and the insights gathered from the manufacturer, it appears clear that motor brushes replacement is not a relevant aspect to be considered in order to enhance product repairability of vacuum cleaners. To conclude, motor brushes should be excluded from the priority parts list or included with a low weight (e.g. 1).

Filters

The filter has been included by Cordella et al. (2019) in the priority parts list, with a high weight: 3. However, although dirty and clogged filters

Table 15, Disassembly depth/sequence of different vacuum cleaners

Disassembly sequence/depth (number of steps)							
Priority part	Philips FC6812/01 Stick	Philips FC8924/01 High-end bag	Philips FC9934/07 High-end bagless	Philips FC9569/01 Mid-end bagless	Rowenta RO6963EA Mid-end bagless	Samsung SC8835 Mid-end bagless	Siemens VS06A111/12 Low-end bag
Nozzle	1	1	1	1	1	1	1
Hose	Not present	1 (with handle)	1 (with handle)	1	1	1	1
Filter	2	3	2	2	2	2	2
Cord-winder	Not present	14	11	10	9	5	5
Motor	11 (with PCBA)	16	10	13	9	5	5
PCBA	11 (with motor)	17	11	14	8	3	5
Wheels	1	15	10	12	1	2	1
Motor brushes	Not present	Not disassemblable	Not disassemblable	15	11	7	7
Battery	2	Not present	Not present	Not present	Not present	Not present	Not present
Battery charger	0	Not present	Not present	Not present	Not present	Not present	Not present
Active nozzle motor belt	8	Not present	Not present	Not present	Not present	Not present	Not present
External housing	13	9	3	4	4	2	3

Table 16, Disassembly times of different vacuum cleaners

Disassembly Time (s)							
Priority part	Philips FC6812/01 Stick	Philips FC8924/01 High-end bag	Philips FC9934/07 High-end bagless	Philips FC9569/01 Mid-end bagless	Rowenta RO6963EA Mid-end bagless	Samsung SC8835 Mid-end bagless	Siemens VS06A111/12 Low-end bag
Nozzle	6	5	5	6	6	6	4
Hose	Not present	9 (with handle)	9 (with handle)	27	24	18	5
Filter	17	17	13	13	13	16	16
Cord-winder	Not present	573	370	396	574	108	176
Motor	245 (with PCBA)	750	693	576	675	238	174
PCBA	245 (with motor)	756	707	616	544	108	176
Wheels	26	689	602	539	37	28	10
Motor brushes	Not present	Not disassemblable	Not disassemblable	607	740	273	193
Battery	60	Not present	Not present	Not present	Not present	Not present	Not present
Battery charger	0	Not present	Not present	Not present	Not present	Not present	Not present
Active nozzle motor belt	206	Not present	Not present	Not present	Not present	Not present	Not present
External housing	352	347	50	222	221	79	26

are one of the main causes of vacuum cleaners malfunctioning (Bobba et al., 2015; Bracquené et al., 2018; Rames et al., 2018), their cleaning could be considered user maintenance and not a repair activity (Bracquené et al., 2018). Moreover, as shown by the repairability assessment in Chapter 4, the disassembly of filters is usually very simple, requiring just one or two disassembly steps which can be carried out manually, without using any tool.

Considering the filter a priority part in a possible future scoring system for a repairability label can be beneficial to ensure that filters will always be easily accessible and replaceable. Despite this, the weight of this part should be lower than 3, since the design of this component is already optimized for easy removal, and it should not have the same influence on the final score as other components which generally requires further attention (e.g. motor, PCBA, cord-winder).

Definition of common tools

Cordella et al. (2019), suggest to use the list of common tools defined by the standard prEN45554 (CEN/CLC TC10 European Standard, 2017) in order to assess the type of tools required for disassembly. Although Torx 15 is defined as common tool by the prEN45554, this is penalised by the JRC in the assessment of the vacuum cleaners. Torx screw drivers are defined as a Level II tool, and it is scored with 0,66pt instead of 1pt. The suggested score has been applied in this research as well, obtaining Overall RRU scores which fully reflect the official JRC dispositions. However, this decision is not shared by this research: a common tool list has to be defined independently from the product group analysed.
Torx 15 screws (ISO10664) are commonly used in canister vacuum cleaners (Table 11), followed by Phillips 2 and 1 screws (ISO8764). The three competitors' products also show the same fastener types. A Philips Service Product Engineer explained how Torx 15 are preferable over traditional Phillips 2 and 1, because more robust and wear resistant. Therefore, this connector should be considered as Level I tool and assessed with 1 pt.

Limitations of the continuous rating system

During the assessment carried out in this research, a continuous rating system has been used for the assessment of disassembly depth/sequence and disassembly time. Opposite to what suggested by the prEN45554, the best sequences have been used as references in the calculation, since it was found easier to spot very good vacuum cleaners on the market, deserving 1/1 pt, instead of very bad ones which could determine the lower score (as explained in depth in Chapter 3).
However, this system showed some limitations: while the best values used as reference received the maximum score, the other values were rapidly penalised. For instance, the fastest nozzle disassembly (4 seconds) have been calculated for the Siemens SyncroPower. On the contrary, 5/6 seconds have been calculated for all the other vacuum cleaners (Table 16). This is due to the fact that while the Siemens nozzle is just pushed inside the hose tube, in the other products there is usually a hinge or a button that has to be opened or pressed in order to release the nozzle. Whereas the disassembly of the nozzle is quite easy in all the products assessed, only the best product received 1/1 pt for its disassembly. All the others scored 40 to 60% less just because of few additional seconds required for the disassembly. Although the disassembly of the nozzle actually takes more time in some products compared to others, the difference is of just few seconds and it should not be so strongly penalised. In fact, few additional disassembly seconds do not influence considerably product repairability.

To conclude, it might be better to avoid the use of a continuous rating system, favouring a discrete one. Possible values (X,Y,Z), for the discrete rating assessment of vacuum cleaners are proposed in Chapter 8.

6. Disassembly map:

A new design tool

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6.1 Introduction

In order to assess disassembly depth and sequence, it is important to have a clear overview of all the different steps required to completely disassemble a priority part. This can be done by disassembling and reassembling the product for each part analysed, without compromising the correct count of steps. Another method consists in creating a diagram which shows all the different connections and procedures required to disassemble all the priority parts of a product. This product architecture “map” would require to disassemble the product just once, and it can be used as a design tool to represent the complexity of a design. This chapter reviews methods already in place to represent disassembly procedures. All these different representation systems have been further developed and combined in a new updated methodology, called “Disassembly map”. This is a practical design tool; an important asset meant for designers. Disassembly maps have been created for all the vacuum cleaners previously analysed, and they have been used to assess disassembly depth. Furthermore, the disassembly map of the FC9569 has been used as design aid for the redesign of the product (presented in the next chapters).
The Disassembly Map answers to the research objective:
RO.5 Defining and testing new guidelines or methodologies that can guide designers to design for product repairability

6.2 Review of current disassembly representation methods

Reverse fish bone diagram

A well known method to represent the disassembly of a product was developed in the nineties by Kosuke Ishii and Burton Lee, and it is called Reverse fish-bone diagram (Ishii & Lee, 1996). This methodology was developed starting from a much older method called Design for Manufacturability (DFM). DFM has allowed American manufacturer to improve dramatically products manufacturability, optimizing their assembly sequences, reducing costs and accelerating developing cycles (Hinckley & Barkan, 1993). With the introduction of recycling processes and the first LCA methods, sustainability became a relevant aspect to be considered in the design process of consumer products. Still in the nineties, the design focus started to shift from just design for manufacturing to design for environment (DFE) (Allenby, 1991), which focuses not only on manufacturing, but considers the entire life-cycle of a product (Fig. 37). Ishii et al., introduced in 1994 Design for Product Retirement (DFPR), a new design methodology that presents the concept of “simultaneous planning for post-life use of a product in early stages of design” (Ishii et al., 1994).

Ishii identifies as the main challenge of the DFPR the advance planning of effective product disassembly, considering EoF scenarios in early stages of the design process (Ishii & Lee, 1996). In Philips, product repairability is tested just after the first main design stages are completed, which means after the realization of a functional prototype. Repairability is tested just checking if all the service components can be reached without breaking the product, without considering optimization of disassembly sequences, disassembly time or type of fasteners and tools required. It is then too late to implement radical design changes, and only small adjustments and improvement can be applied.
The reverse fish-bone diagram was developed to provide a design tool which can guide designers and engineers in the product disassembly architecture in the early stages of product development. Disassembly is different from reverse assembly, since ideally a product should be disassembled as little as possible to be repaired, refurbished or recycled, removing just big “clumps” of assembled

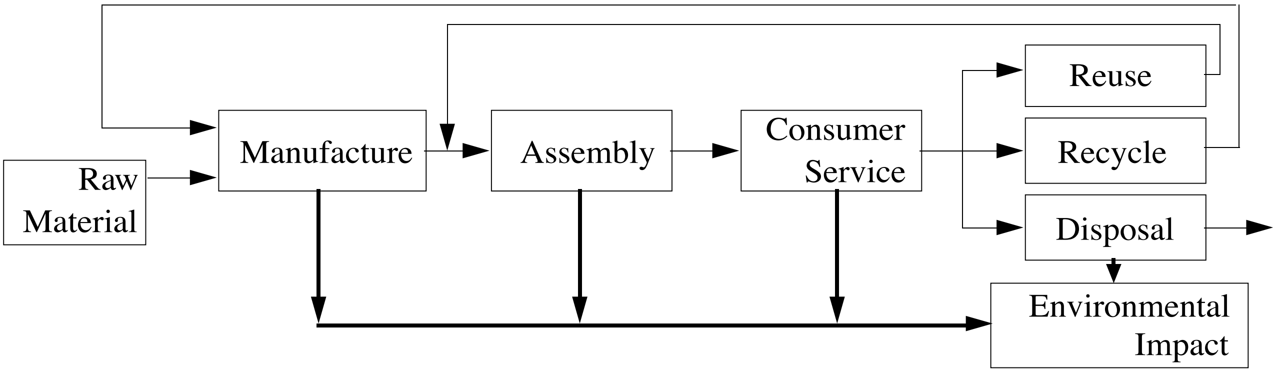


Fig. 37, Product life-cycle (Bryan et al., 1992) single components (Ishii & Lee, 1996). Single components should be grouped in the same big "clumps" according to their functional importance, failure priority, life-span, material compatibility and EoF scenario, facilitating DFPR activities.

In 1995 Ishii developed the assembly fish-bone diagram (Ishii & Kmenta, 1995), a design tool meant to guide designers and engineers through the manufacturing assembly process of a product, in a more intuitive and understandable way compared to detailed flow-chat's and process lists developed by engineers often after the design of a product. Assembly actions would be represented in a serial way (Fig. 38), adding components to each other, till the final complete assembly. The use of symbols (Fig. 39) would facilitate the reading of the diagram, identifying specific design features with a positive or negative influence on the assembly procedures.

In 1992-1993, Ishii and Marks combined studies concerning layout design for manufacturing and life-cycle serviceability (Ishii et al., 1993) with DFPR (Marks et al., 1993), developing a map called "Linker" (Fig. 40) and improving it grouping assembly components sharing the same post-life intents (clumps): primary or secondary recycling, refurbishing, incineration of energy recovery, landfill (Ishii & Lee, 1996).

At that time, they suggested that as the number of single clumps increase, the disassembly costs rise, while the reprocessing cost decrease (Fig. 41). On the contrary, when the number of clumps decreases, the cost of reprocessing would grow, while the disassembly costs would decrease, since fewer single components are actually separated from the main assembly (Ishii & Lee, 1996).
Eventually the reverse fish-bone diagram was created, modifying the assembly fish-bone diagram in a disassembly diagram and implementing DFPR elements initially explored in the Linker structural representation (Fig. 42).

This diagram is a design tool, meant to be used in the layout design stage of a project, when designers are still in time to identify disassembly complications and difficulties, taking in consideration the different product retirement scenarios for each component (Ishii & Lee, 1996) and creating possible assembly "clumps" sharing the same fate. As already discussed, this diagram is not meant to guide to a complete disassembly of a product; in fact, as few parts as possible should be disassembled, leaving together all those components that can be defined as "System carcass", meant to be grinded together at the end of their life. The designer role is to ensure that the system carcass is composed by parts that

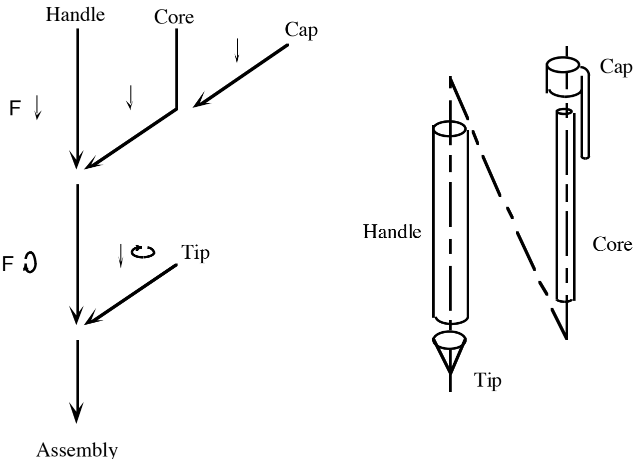


Fig. 38, Assembly sequence diagram for a mechanical pencil (Ishii & Kmenta, 1995)

F	Fixture
↻	Rotation (flip assembly or screwing action)
↓	Straight-down attachment
↙	Attachment at an angle
↑	Attachment from below
←	Attachment from the side

Fig. 39, Symbols proposed by Ishii for the reverse fish bone diagram (Ishii & Lee, 1996)

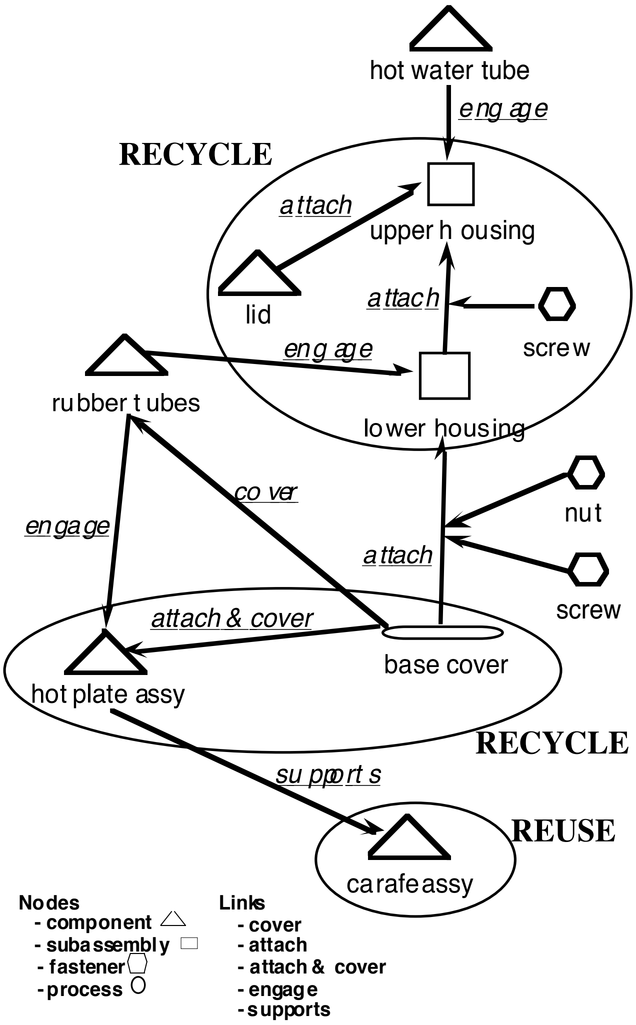


Fig. 40, Linker structural representation (Marks et al., 1993) can be recycled if grinded together, when they do not include any priority part or any component that can be reused, or any material that can be harmful for the environment. The diagram is composed by sequential disassembly actions, illustrated on the vertical level, and sequence independent steps, placed on a horizontal level. Type of connectors are indicated between the disassembly of each part, and different EoL scenarios can be indicated for each disassembled component. The diagram is completed when all components with a fate different from “System grind” have been removed (Ishii & Lee, 1996).

Sequence independent disassembly is preferable to sequential disassembly, since they allow overhead operations which make the disassembly of single components independent from the disassembly of others, and save disassembly time when a specific target part is predefined. On the contrary, sequential disassembly requires to follow a specific disassembly step sequence, which usually slows down disassembly and repairs procedures, and implies a deeper knowledge of the disassembly procedure to follow (Fig. 43). The ideal disassembly sequence would be composed just by parallel, sequence independent assemblies and architectures; however, sequence dependent assembly, also called layer assembly, are usually preferred for easy of assembly (Ishii & Lee, 1996).

As it can be seen in Fig. 44, the reverse fish-bone diagram presents some limitations. Although it introduced the definition of sequence dependent and independent disassembles, the general structure remains a basic sequence of actions Fig. 45, interrupted in some cases by actions that can be carried out in parallel, for then starting again a serial disassembly sequence.

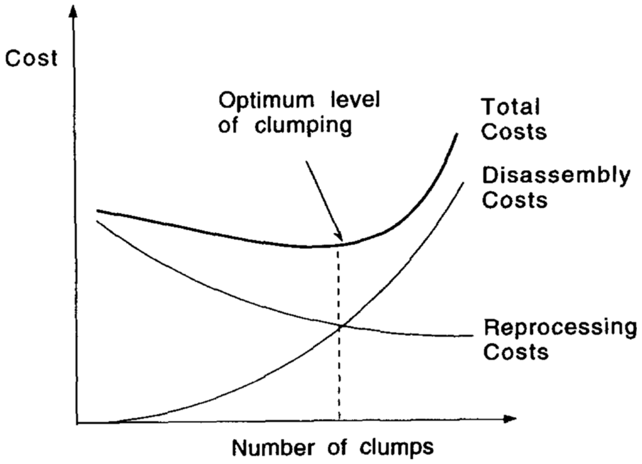


Fig. 41, Reverse Fish-bone Diagram. Initial concept (Ishii & Lee, 1996)

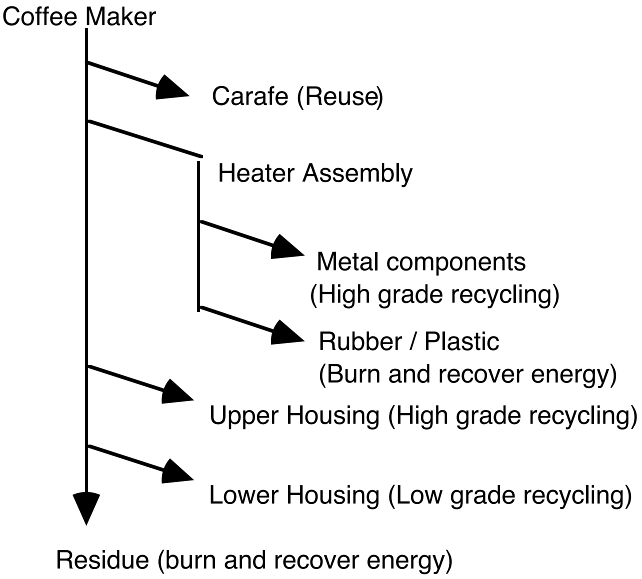


Fig. 42, Effect of clumping on disassembly and reprocessing costs (Ishii et al., 1994)

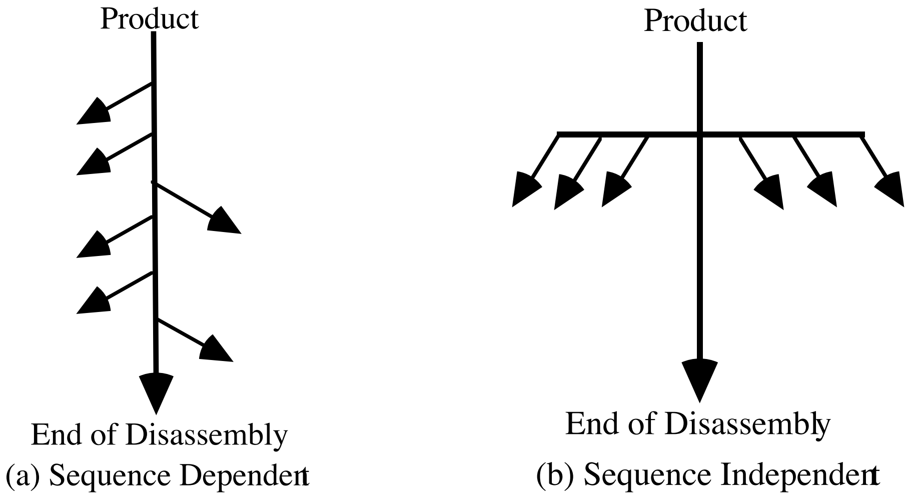


Fig. 43, Sequence dependent and sequence independent disassembly’s (Ishii & Lee, 1996)

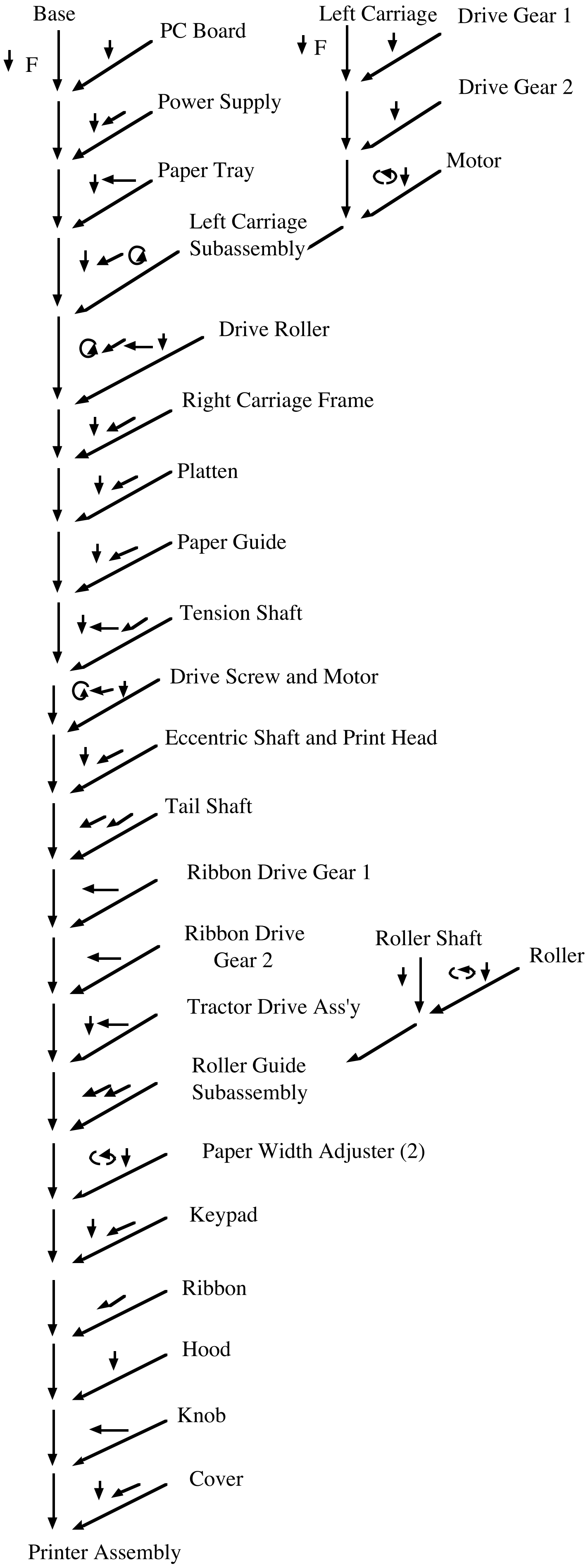


Fig. 44, Example of assembly fish-bone diagram of a IBM printer (Ishii & Lee, 1996)

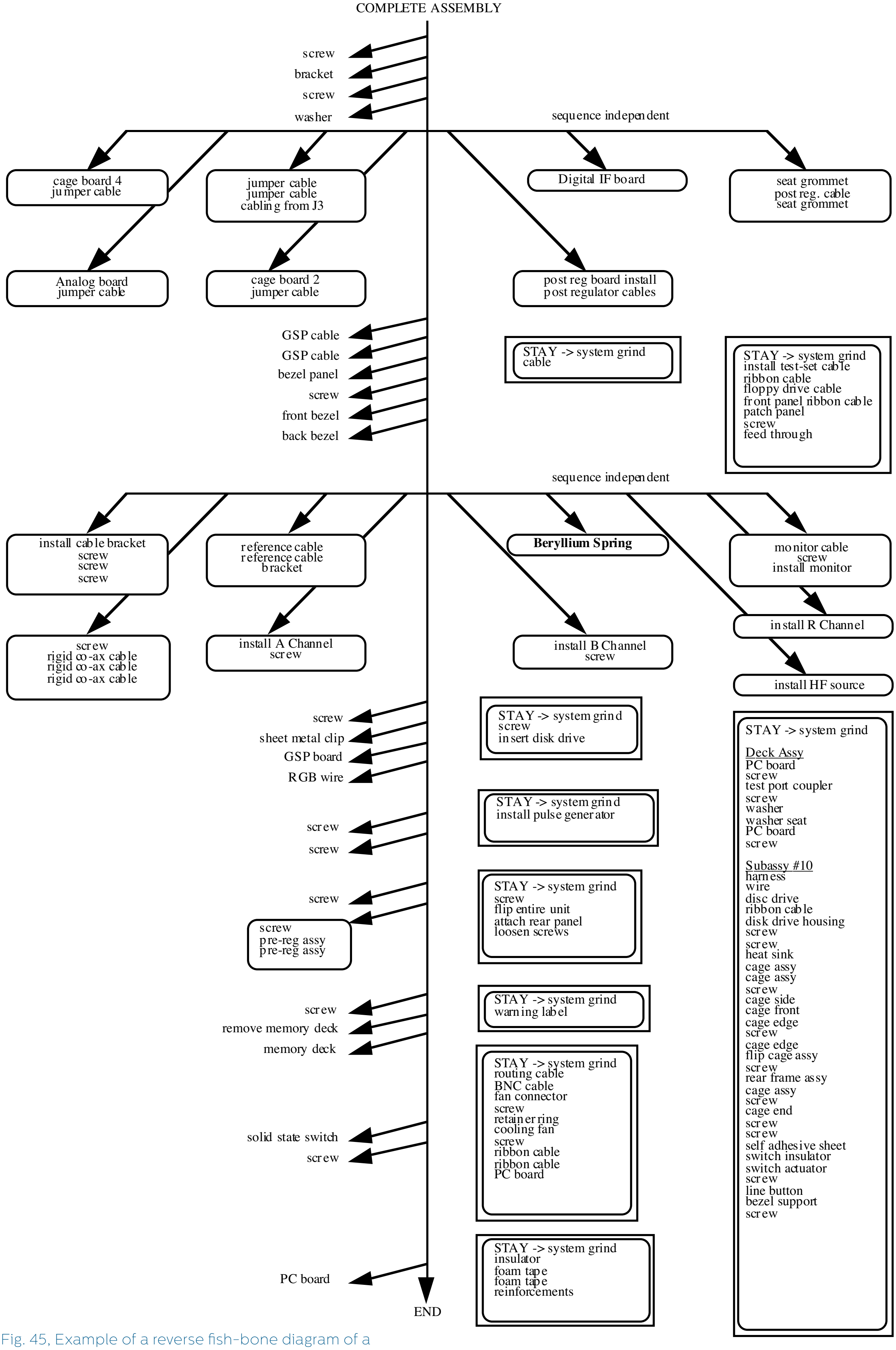


Fig. 45, Example of a reverse fish-bone diagram of a commercial electronic product (Ishii & Lee, 1996)

Liaison, state and AND/OR diagrams

Before the Ishii's fish-bone diagram, many other representation systems meant to illustrate the disassembly assembly steps of a product have been developed. In most cases, the aim of these diagrams was to identify the optimal assembly sequence of a complex product assembly using an algorithm. In fact, the number of possible assembly combinations rises exponentially with the increase of the number of components. Disassembly presents more constraints compared to assembly, therefore the number of alternative sequences is lower (Kuo, 1997). Bourjault (1984) was the first one to introduce a method to map the assembly sequences of a product. He introduced the concept of "liaisons " (Kuo, 1997), user-defined relations connecting all the single components. In his liaison diagram part are indicated as nodes and liaisons as lines connecting all the nodes (Fig. 46).

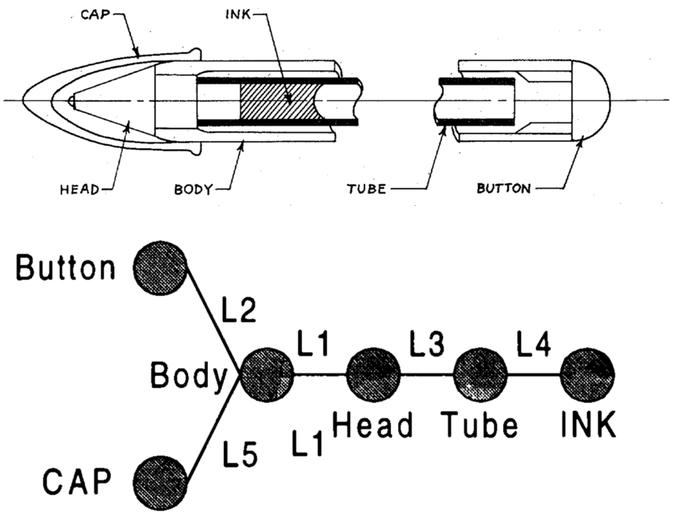


Fig. 46, Bourjault's liaison diagram (Kuo, 1997)

The aim of Bourjault was to define the liaisons logic between component through user's answers. The question and answer approach (Fig. 47) aims to determine the relations between different components asking "yes-no" questions. The answers represented assembly rules and constraints, which could be analysed through an algorithm, able to calculate the optimal assembly sequence. In Bourjault's representations, single components are indicated with their real name, while liaisons are indicated with letters and numbers. The correct sequence is determined asking whether or not a disassembly sequence can happen with or without a previous disassembly of another component.

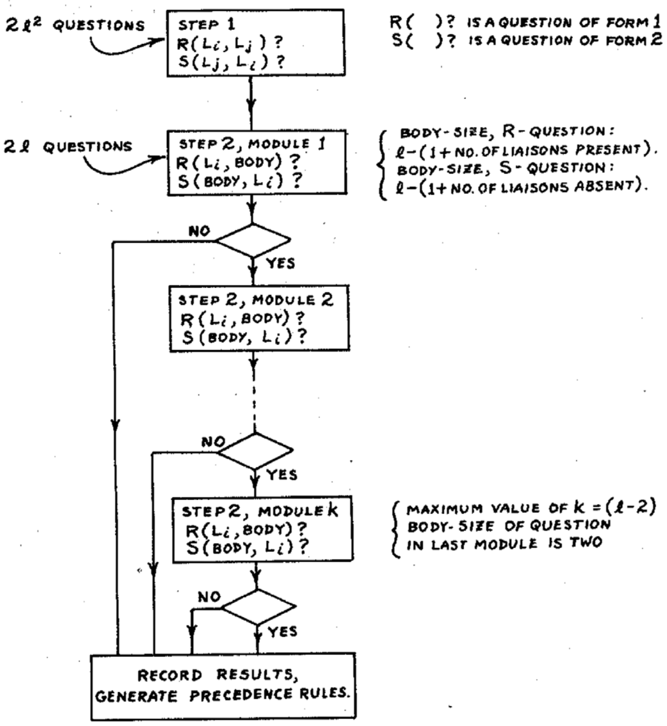


Fig. 47, Logic flow-chart of the question and answer approach (De Fazio & Whitney, 1987)

De Fazio and Whitney (1987) optimized Bourjault algorithm for more complex assembly, introducing a lower number of questions to determine the liaisons and a more effective and compact representation diagram. In their diagram every disassembly state is represented not more than once, each box represents a state, containing a number of cells representing liaisons (Fig. 49). A white cell indicates that the related liaison is established, while a marked cell implies that specific liaison has been established. A completely white box represents a completely assembled product, while a black box represents the completion of the disassembly. Lines connecting the boxes represent possible state transitions. Interesting is the introduction of Ranks, defined as the depth level of disassembly. Each rank is determined by the representation of a liaison (De Fazio & Whitney, 1987). The two questions used in their algorithm to determine the nature of the liaisons are:

- What liaisons must be done prior to doing liaison i?
- What liaisons must be left to be Done after doing liaison i?

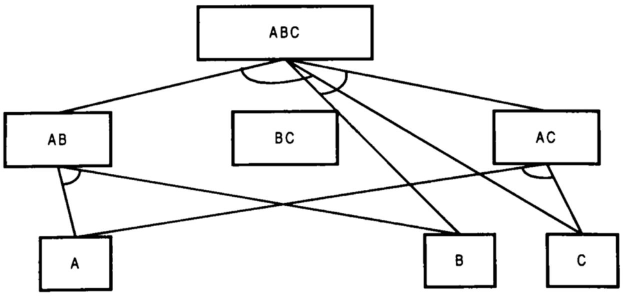


Fig. 48, And/Or Diagram (De Mello & Sanderson, 1991)

De Mello and Sanderson (1991) introduced the representation of AND/OR logic in disassembly diagrams (Fig. 48). Their graph is generated trying all the possible different ways (also called cut-sets) necessary to disassemble all the product components. This method is very accurate and it clearly represents all the different stages of a disassembly. However, identifying all the cut sets and logic connections can be very time consuming and complex, making this method not suitable for very large and complex assemblies.

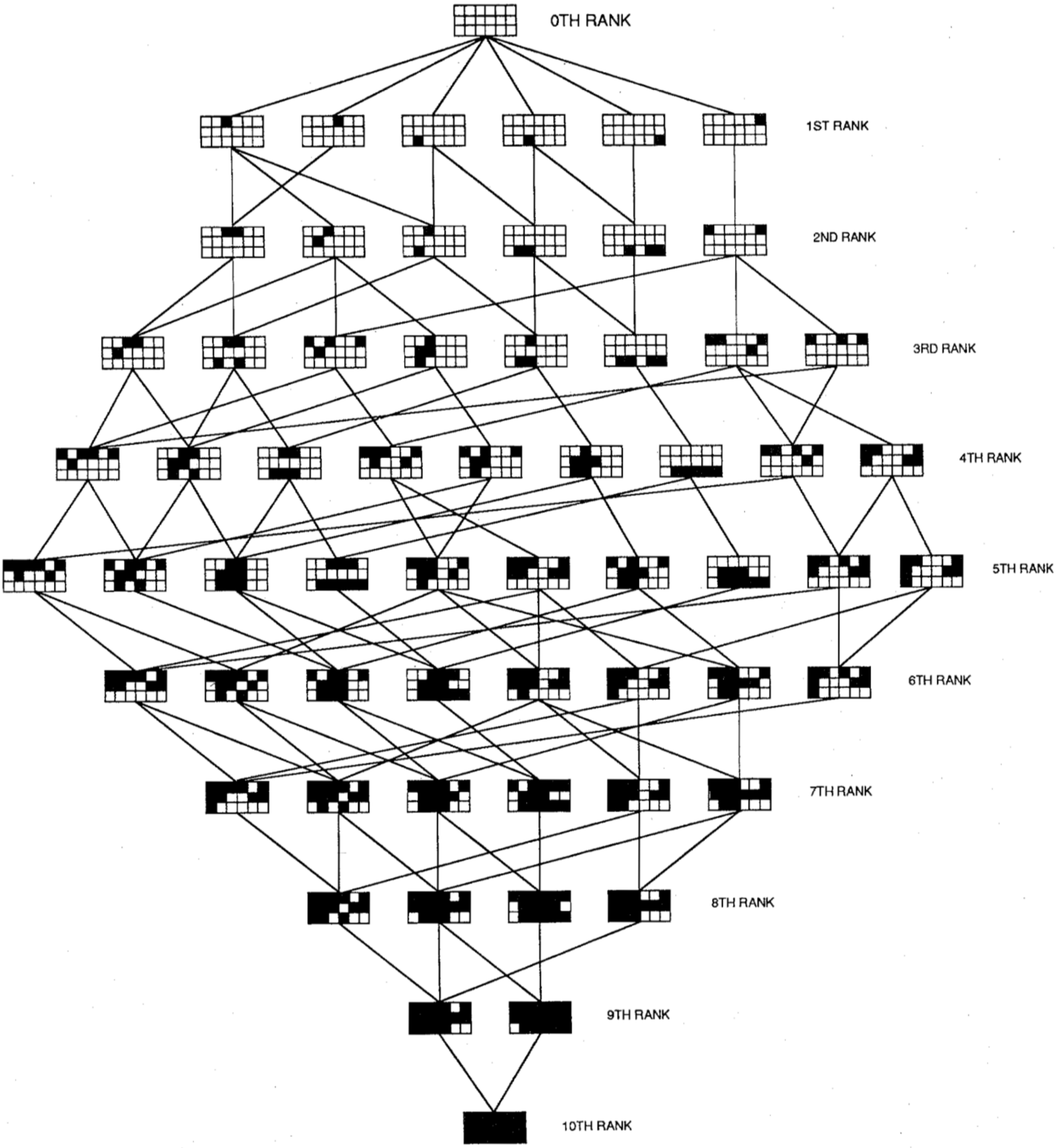


Fig. 49, Disassembly state diagram (De Fazio & Whitney, 1987)

6.3 Disassembly Map: a new methodology

During the disassembly analysis of the 7 vacuum cleaners assessed in this research, it was observed how the total disassembly procedure of a product is composed by many different alternative “paths”, based on the specific component that has to be reached. For example, some components can be disassembled independently from others (independent sequence), but their disassembly could be required to get to a part that needs other previous disassembly. This logic leads to an intricate map of alternative ways of partially disassembly a product, based on the specific component interested by the procedure. It is extremely important to define the fastest sequence to get to a priority component, in order to define a correct score in the JRC assessment framework. For this reason, the reverse fish-bone diagram has been modified and optimized in order to represent in a single diagram all the different disassembly sequences. The disassembly map is the result of the combination of the four disassembly representation graphs previously presented:

- As the reverse fish-bone diagram, the disassembly map wants to be a design tool. It has to be simple, clear and its ultimate aim is to lure designers, architects and engineers to go through the disassembly sequence of a product, identifying possible problems and complex sequences.
- The disassembly map is based on the concept of liaison introduced by Bourjault (1984). It is important that the connection between different components is clearly visualized, and that the different fastening systems are indicated between each different component.
- Each disassembly state has to be clearly indicated, as in the state diagram of De Fazio and Whitney (1987). The position of the different components has to be clear, and the map has to communicate a sense of disassembly depth as expressed by the ranks of the state graph.
- Eventually, the logic AND/OR, introduced by De Mello and Sanderson (1991), is fundamental to easily represent and identify all the realistic and alternative disassembly sequences.

Sub-assembly blocks

A geometric example can be seen in Fig. 50. According to the methodology developed by Ishii, K., & Lee, B. (1996) the number of steps required to disassemble part A would be 4, by removing sequentially part B-C-D-A (Fig. 50). However, this sequence is far from reality. In fact, the shortest way to disassemble the priority part “A” involves the disassembly of a block of different parts sub-assembled (e.g. assembly BCD). If the scope is to disassemble just part A, there is no interest in disassembling each single component of the block (e.g. C from D from B), and they would just be removed all together in one disassembly step. On the contrary, if the priority part that has to be disassembled is B the disassembly of the clump BCD is required (Fig. 51). Both these two alternative sequences should be represented in the disassembly map, since they are the fastest sequences to get to two different components, related to each other, but which do not require mutual disassembly. This can be easily done representing alternative and not sequential paths (Fig. 52). The representation of these “sub-assembly blocks” is extremely important, since their design could simplify disassembly procedures, by grouping together parts that share the same EoL scenario or failure rates. “Ideally, one should disassemble as little as possible, and process large “clumps” for effective reuse or recycling” (Ishii & Lee, 1996).

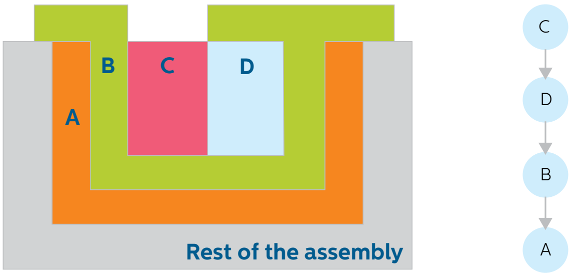


Fig. 50, Geometric example and its disassembly representation according to Ishii

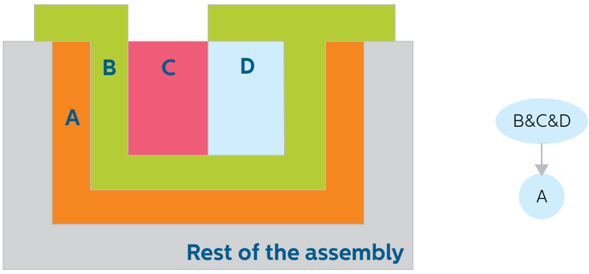


Fig. 51, Disassembly representation considering components clumping

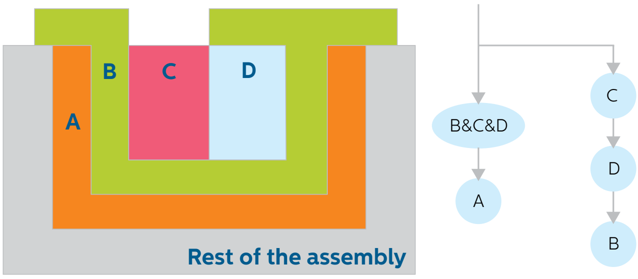


Fig. 52, Representation of clumping and alternative path for the disassemble of single components part of the clump

Parts precedence

Smaller and less meaningful components (e.g. B1) are often attached to bigger, but not priority component (e.g. B) (Fig. 53). The correct representation of this disassembly would involve the use of the logic "AND" (represented in Fig. 53 with the symbol "&"): in order to show how to disassemble the pure component B, also the disassembly of B1 is required. These situations occur very often and are widely spread along the product architecture. These small components could be the springs beneath the buttons (Fig. 55) or small plastic parts (Fig. 56) The presence of many of these less meaningful components can actually over complicate the general disassembly map of a product. Therefore, in order to simplify the disassembly diagram, the disassembly of small components, which are not related to any priority component disassembly, can be neglected (Fig. 54). This choice simplifies dramatically the final diagram, improving readability without influencing the reliability of the representation of the most important priority part disassembly.

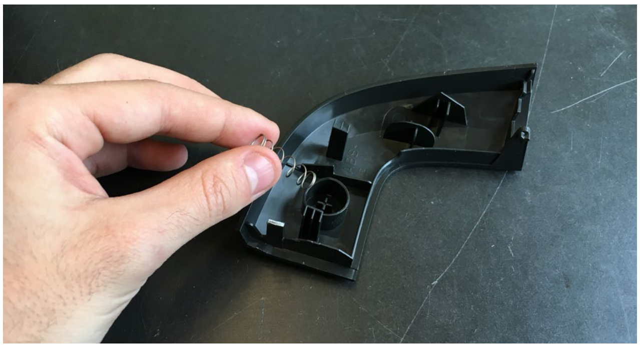


Fig. 55, Button spring: example of less meaningful component which can be left out from the disassembly map representation

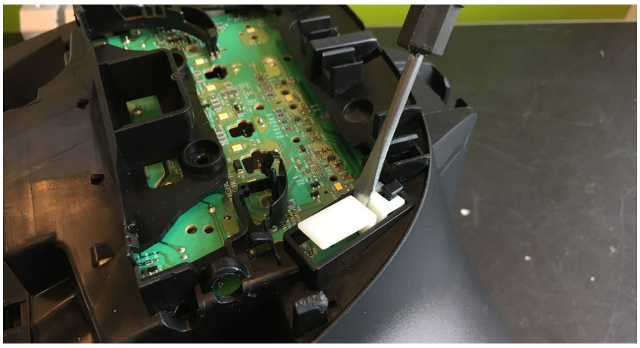


Fig. 56, Button plastic lever: example of less meaningful component which can be left out from the disassembly map representation

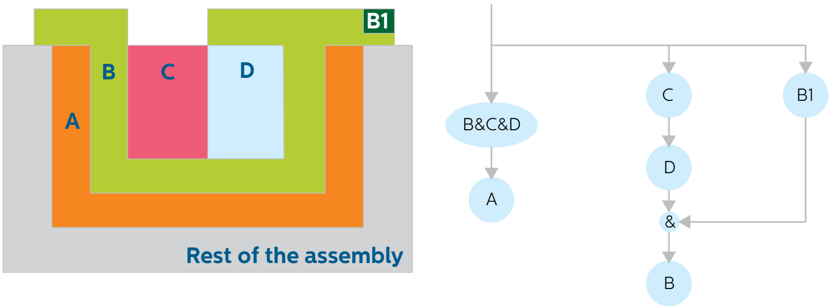


Fig. 53, Correct representation of the disassembly of component B1

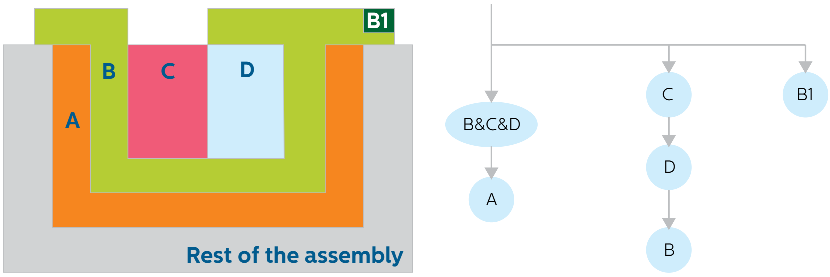


Fig. 54, Simplified representation of the disassembly of B1

And/or logic, disassembly procedures and sequence

The disassembly map created during this research has been ideated to be as simple and intuitive as possible. The structure of the map was inspired by software flow-charts, characterized by:

- Clear order and sequence of steps sequentially listed from a starting point to an end
- Use of arrows to show the steps sequence order
- Use of different text container shapes to express different logical values (Table 17)
- Use of AND/OR logic, which generates alternative logic paths

In the disassembly map, the **Starting block** is replaced by “complete assembly”. It represents the starting point of any disassembly assessment.

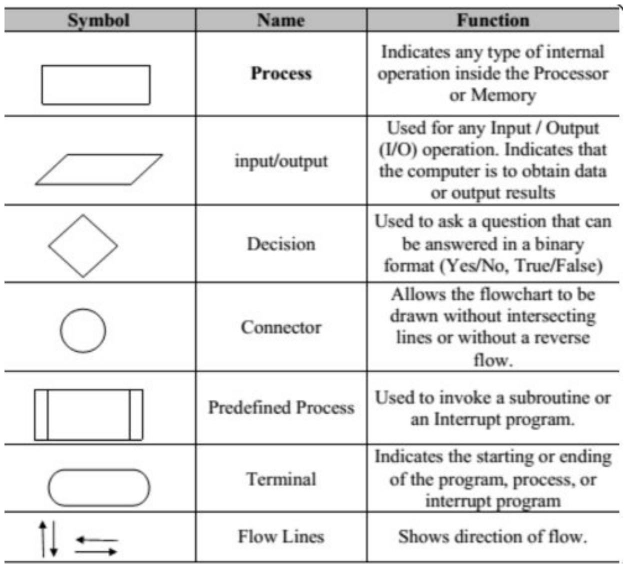
The memory processes become **disassembly action blocks**. These disassembly actions are defined by:

- **Type of tool** used (based on which the shape of the text container changes)
- **Intensity of force** (which is indicated by changing the colour tonality of the text container shape)
- **Type of connector** (written in the action shape) (Fig. 57).

These attributes have been defined based on the Ease of Disassembly Metric (Vanegas et al., 2016; Peeters et al., 2018) and the new eDIM sequences calculated in chapter 3.
In particular, the three different force intensity levels have been defined as:

- Low force intensity, approximately between 0 to 5 N (Vanegas et al., 2016; Peeters et al., 2018). The action can be carried out applying a light force, with confidence, and without the risk of breaking any component.
- Moderate force intensity, approximately between 5 to 20 N (Vanegas et al., 2016; Peeters et al., 2018). The action can be carried out applying a moderate force, with confidence, and without the risk of breaking any component.
- High force intensity, approximately higher than 20 N (Vanegas et al., 2016; Peeters et al., 2018). The action requires to apply a high force, with the risk of breaking components; therefore, without feeling confident.

Each single component is indicated only after all the disassembly actions required for its disassembly (Fig. 58). The single product parts are indicated with **numbered bubbles**, containing the official service number or alternatively the name of the part. As clarified by the Commission Decision (EU) 2016/1371 of 10 August 2016
“A step consists of an operation that finishes with the removal of a part, and/or with a change of tool” (Cordella et al., 2019). Based on this definition, a



Symbol	Name	Function
▭	Process	Indicates any type of internal operation inside the Processor or Memory
▱	input/output	Used for any Input / Output (I/O) operation. Indicates that the computer is to obtain data or output results
◇	Decision	Used to ask a question that can be answered in a binary format (Yes/No, True/False)
○	Connector	Allows the flowchart to be drawn without intersecting lines or without a reverse flow.
▥	Predefined Process	Used to invoke a subroutine or an Interrupt program.
⬭	Terminal	Indicates the starting or ending of the program, process, or interrupt program
⇅ ⇄	Flow Lines	Shows direction of flow.

Table 17, Symbols commonly used in flow-charts and their meaning (Gangoda, 2018)

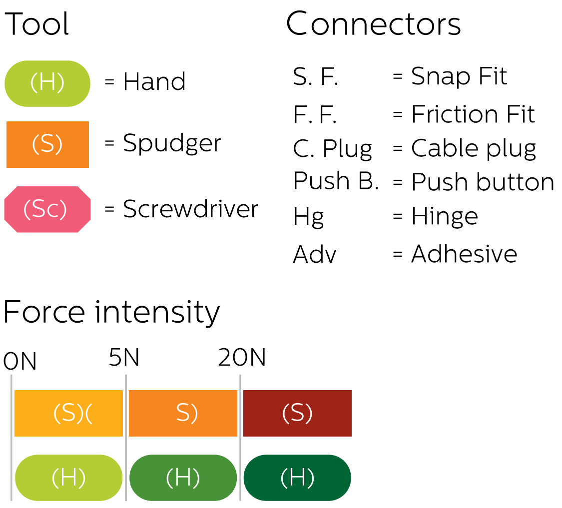


Fig. 57, Disassembly actions attributes

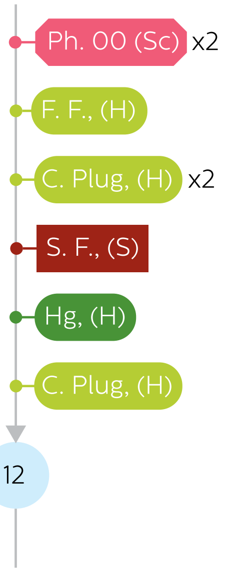


Fig. 58, Series of disassembly actions required for the disassembly of component 12 step is indicated in the disassembly map by each single sphere containing the number of a part.

The **logic OR** is simply indicated by the bifurcation of a path in two different directions. The **use of arrows** is fundamental to indicate clearly the direction of the disassembly paths. The bifurcation can also start from a component "bubble" if this can improve the readability of the map (Fig. 59).

The **logic AND** is illustrated using the symbol "&" (Fig. 60). In this case, all the single part bubbles connected to the "&" symbol are required for the disassembly of the components indicated after the "&". Even in this case the use of arrows is very important, to indicate clearly which components are inputs and which components are outputs of the logic operation. Vertical positioning can also be used to clarify complex and multiples connections: usually inputs are located at the top, before the "&" symbol, while the outputs are indicated after it, at a lower level.

Since one of the most important aims of this diagram is to express disassembly depth, it is important to represent sequential disassembly sequences in a **vertical direction**, while parallel sequences **horizontally**. This will clearly communicate the depth of a part in the product disassembly (Fig. 61).

An action could be shared by two different steps. An example is presented in Fig. 62, showing the Philips bag canister FC8924.
In order to extract the bag holder (Fig. 63), it is necessary to open the canister cover assy first (Fig. 62). However, the opening of the canister cover assy is also needed in order to disassemble the dust chamber insert (Fig. 64). The opening of the cover assy cannot be indicated as a step, since the assy is not actually removed, therefore **no part bubble can be added** to the disassembly map. On the contrary, the part is just opened, therefore it is an action (snap fit type 1, hand). This action is carried out just once for both the disassembly of the dust chamber insert and the bag holder, hence it has to be indicated as a shared action. Fig. 65 shows a possible representation of the **shared action**, where "8&9" represents the bag holder and "25" the dust chamber insert.

Finally, **penalties icons** can be added next to disassembly actions, to indicate that a disassembly penalties happened during that specific step (Fig. 66).

Recommendations for a correct use of the disassembly map

The following recommendation list has been created in order to guide in the use of the disassembly map. The use of this set of "rules" has

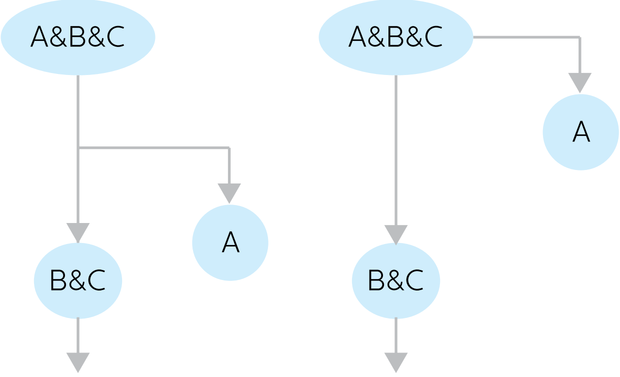


Fig. 59 Two different representation of OR logic

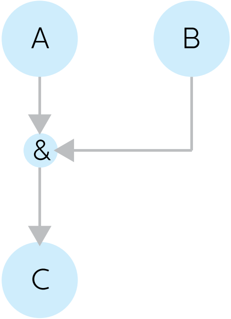


Fig. 60, Illustration of the AND logic

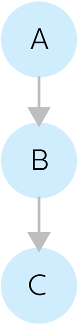


Fig. 61, Vertical representation of sequential disassembly

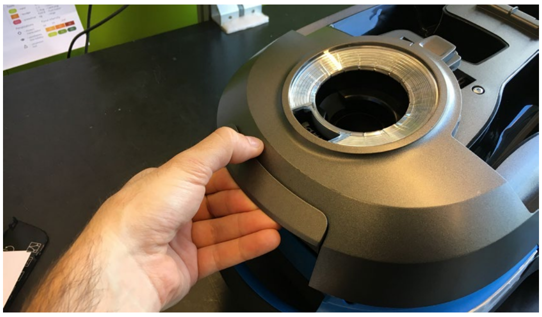


Fig. 62, Opening of the cover assy

Fig. 63, Bag holder extraction.

Fig. 64, Cover assy disassembly

been necessary in this research to assess all the products in the same way, ensuring comparability. They suggest how to deal with unclear situations, where the assessment of disassembly time and steps could be wrongly calculated:

1. By illustrating alternative disassembly paths, a connector could be indicated multiple times in different alternative sequences (Fig. 67). In case the counting of the total number of connectors presented in the products is necessary, the same connector illustrated multiple times on the alternative paths has to be counted as 1 connector. In the map it is indicated multiple times, but in reality, it is just one connector.
2. The same is valid of sub-assembly/clumps composed by different components. If two or more parts are indicated twice in the map (as single components and as clumps), they have to be counted just once in the total number of disassembly steps and components. For instance, if part 8 and part 9 are indicated in one part of the map, while the clump 8&9 is indicated on another path in order to get to a deeper component, part 8 and 9 represents two components, while the clump 8&9 is not considered again (Fig. 68).
3. If two parts are assembled together, and the last step required to disassemble them completely is just dividing one from the other, the dividing action is counted as one action, not twice (Fig. 69)

Implementation of the HotSpot Mapping tool

The HotSpot mapping tool, developed by Bas Flipsen, identifies the most important components that have to be considered while redesigning the architecture of a product for DFPR. As in the eDiM methodology, each component, disassembly action and disassembly time have to be listed in a calculation sheet (Table 18). Compared to the eDiM, in this case it is also required to indicate the weight and material of each part. Based on this data, the tool calculates automatically different indicators for each component:

- **Time indicator**, which spots the components that require high disassembly time;
- **Critical component indicator**, which indicates the priority components based on probability of failure;
- **Critical activity indicator**, which indicates the components that require complex disassembly activities;
- **Environmental indicator**, which highlights the components that have a high environmental impact;
- **Economic indicator**, which shows the parts that have high economical value;

These indicators are represented by red and yellow flags, defining two levels of prioritization (Table

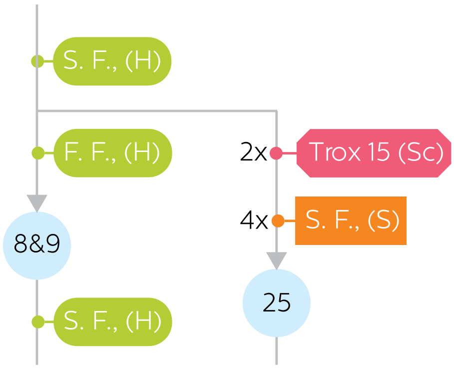


Fig. 65, Representation of an action shared by two components

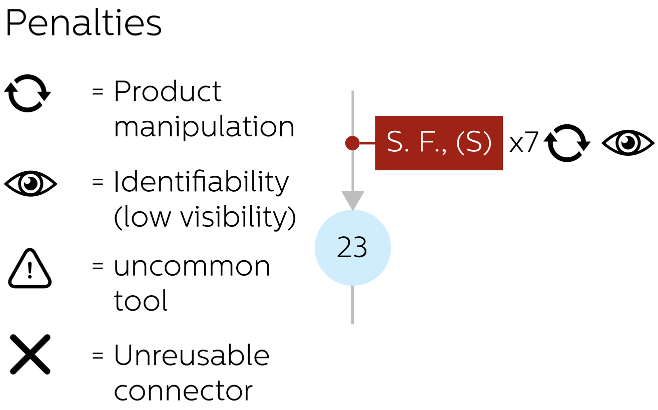


Fig. 66, Penalties icons and their representation next to an action

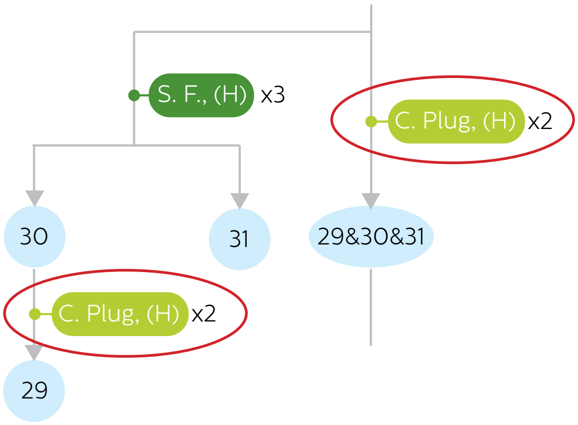


Fig. 67, The same connector represented multiple times

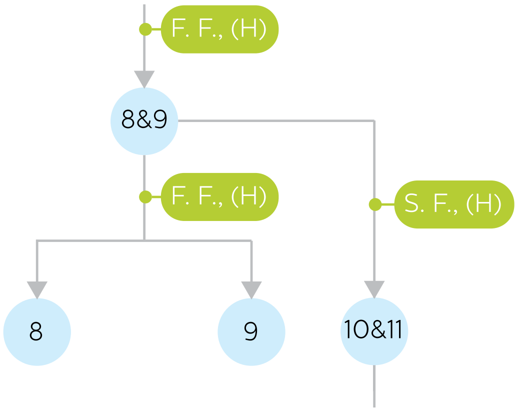


Fig. 68, The same components represented multiple times

18). This tool does not provide an absolute impact assessment, but it rather compares the impact of all the different components analysed and highlights which part could be further improved. The red flags indicate those components with the highest impact and importance for DFPR (>80 percentile for economic impact and >90 percentile for the environmental impact), while the yellow flags indicate components with moderate, but still relevant, importance for DFPR (>60 percentile for economic impact indicator and >80 percentile for the environmental impact indicator)(Table 18).
The calculation metric behind the HotSpot Mapping tool will not be discussed in this research since it will be further explored in a future academic publication by Bas Flipsen.

This tool expands the constraints defined by most of the RRU assessment systems analysed, which consider only parameters directly related to product repairability. In this case, also environmental and economic aspects are tackled, since they are important for product recyclability, refurbishing and harvesting.
Five HotSpot indicators (Fig. 70) have been implemented in the first version of the disassembly map, helping designers to spot immediately the most important components for DFPR in the general map. Priority component indicators are actually defined according to the JRC guidelines, while environmental and economical indicators are based on the HotSpot Mapping tool.
Time and critical activity indicators have not been implemented in the Disassembly map tool, since these two features had already been considered and represented based on the eDiM analysis (through disassembly activity blocks). Moreover, the time indicator considers only single step disassembly time, ignoring all the previous steps required to actually disassemble a part.

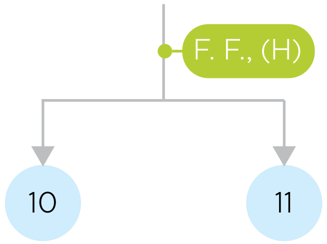


Fig. 69, Disassembly representation of two components connected to each other

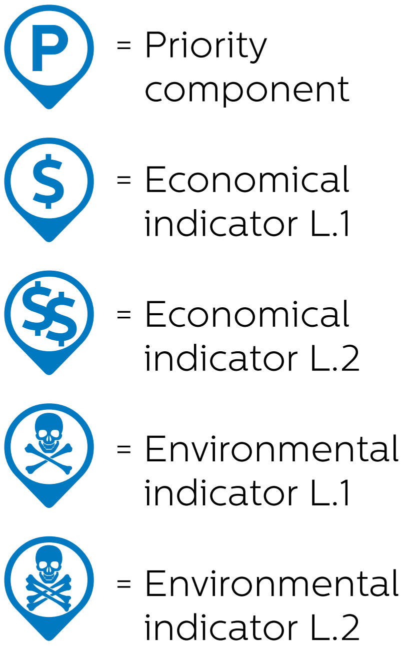


Fig. 70, HotSpot indicators

Step number	Part name	Activity	Required tool	Tool size	Number of task repeats	Time to disconnect (seconds)	Force	Accessibility
1	6. Tri-Active+ LC nozzle	Disconnect snapjoint	Hands	x	1	3,16	light resistance	Clear
2	3. Crevice nozzle Zephyr	Remove	Hands	x	1	1,76	light resistance	Clear
3	4. Tube clip Zephyr	Disconnect snapjoint	Hands	x	1	2,48	moderate resistance	Clear
4	2. 2-Piece T.T. Tube	Disconnect snapjoint	Hands	x	1	3,16	light resistance	Clear
5	110. C-Bend + Integrated brush	Disconnect snapjoint	Lever / Prybar	x	2	7,88	moderate resistance	Clear
6	111. Hose assy Zephyr	Disconnect snapjoint	Fingers	x	1	3,16	light resistance	Clear
7	7&8	Disconnect snapjoint	Hands	x	1	3,16	light resistance	Clear
8	7. Dust bucket Lid	Disconnect snapjoint	Lever / Prybar	x	1	4,64	light resistance	Clear
9	8. Dust bucket assy incl. Vortex						light resistance	Clear
10	9. Integrated filter	Disconnect snapjoint	Fingers	x	1	3,16	light resistance	Clear
11	15. Exhaust grill	Disconnect snapjoint	Fingers	x	1	3,16	light resistance	Clear
12	16. Exhaust filter Zephyr LP	Disconnect snapjoint	Fingers	x	1	3,16	light resistance	Clear
13	22. Casterwheel assy	Remove	Lever / Prybar	x	1	7,16	moderate resistance	Clear
14	12. On/off button	Disconnect snapjoint	Lever / Prybar	x	3	26,24	heavy resistance	Obstructed
15		Disconnect snapjoint	Hands	x	1	1,76	light resistance	Clear
16	12. CW button	Disconnect snapjoint	lever / Prybar	x	3	27,68	heavy resistance	obstructed
17	11. Top cover	Unscrew	Screwdriver	Ph 1	6	37,4	light resistance	Clear
18		Disconnect snapjoint	Lever / Prybar	x	2	18	heavy resistance	Obstructed
19	10. Lower handle cover	Unscrew	Screwdriver	Ph 1	2	14,36	light resistance	clear
20	24. Middle housing	Remove	Hands	x	1	1,76	light resistance	clear
21	28. Power slider assembly	Disconnect snapjoint	Lever / Prybar	x	2	7,88	moderate resistance	clear
22	17. Frame Right	Disconnect snapjoint	Hands	x	2	4,96	moderate resistance	clear
23	18. Frame Left	Disconnect snapjoint	Hands	x	2	4,96	moderate resistance	clear
24	21. Hose connector	Remove	Hands	x	1	1,76	light resistance	clear
25	30&31 Rear housing cover and power slider PCBA	Unscrew	Screwdriver	Ph 1	4	25,88	light resistance	clear
26		Unscrew	Screwdriver	Ph 1	2	11,52	light resistance	clear
27		Disconnect snapjoint	Lever / Prybar	x	2	18	heavy resistance	Obstructed
28		Unplug connector	Fingers	x	1	2,16	light resistance	clear
29	13. Cord outlet	Unscrew	Screwdriver	Ph 1	1	8,6	light resistance	clear
30	32. Cordwinder Zephyr	Disconnect snapjoint	Hands	x	2	4,96	moderate resistance	clear
31		Unplug connector	Hands	x	2	4,32	light resistance	clear
32	35. Switch	Unplug connector	Hands	x	2	5,72	light resistance	clear
33	36. Motor housing seal	Remove	Lever / Prybar	x	1	3,24	light resistance	clear
34		Unscrew	screwdriver	Ph 1	4	25,88	moderate resistance	clear
35		Unscrew	screwdriver	Ph 1	2	13,32	moderate resistance	Obstructed
36		Remove	Hands	x	1	2,48	moderate resistance	clear
37	41. Rearwheel assy RX	Disconnect snapjoint	Lever / Prybar	x	5	28,04	heavy resistance	Obstructed
38	41. Rearwheel assy LX	Disconnect snapjoint	Lever / Prybar	x	5	26,6	Heavy resistance	Obstructed
39	49. Motor housing lid	Unscrew	screwdriver	Ph 1	3	20,12	moderate resistance	Clear
40		Disconnect snapjoint	Lever / Prybar	x	4	13,32	moderate resistance	Clear
41	37. Safety Valve assy HP	disconnect snapjoint	Lever / Prybar	x	1	3,2	light resistance	clear
42	45. CDS Motor CDS-EY29-008 1800 W	Remove	Hands	x	1	1,76	light resistance	clear
43		Unplug connector	Hands	x	2	6,12	light resistance	clear
44	31. PCBA	Disconnect snapjoint	Hands	x	1	6,08	Heavy resistance	Clear
45		Unscrew	Screwdriver	Ph 1	2	12,96	light resistance	Clear
46	50. Motor back housing	Remove	Hands	x	1		light resistance	Clear
47	40. Lower housing	Remove	Hands	x	1		light resistance	Clear
48	45.x Motor Brushes	Unscrew	Screwdriver	Ph 1	2	28,1	heavy resistance	Clear

Positioning	Maintenance component	Critical Component (CC)	Material group	Weight (g)	Time indicator	Critical Component indicator	Critical Activity indicator	Environmental indicator	Economic indicator
Easy	part wears during use	Yes	Polymer	479,6	3,2	4	0	1,439	1,439
Easy	low maintenance part	No	Polymer	19,4	1,8	0	0	0,058	0,058
Easy	low maintenance part	No	Polymer	30	2,5	0	0	0,090	0,090
Easy	low maintenance part	No	Aluminium	521,6	3,2	0	0	7,824	1,043
Easy	part wears during use	No	Polymer	195,4	7,9	2	0	0,586	0,586
Easy	part wears during use	Yes	Polymer	355,4	3,2	4	0	1,066	1,066
Easy	low maintenance part	No, needed to reach CC	Polymer		3,2	1	0	0,000	0,000
Easy	low maintenance part	No	Polymer	151,4	4,6	0	0	0,454	0,454
Easy	low maintenance part	No	Polymer	532,6	0	0	0	1,598	1,598
Easy	part wears during use	Yes	Polymer	73,6	3,2	4	0	0,221	0,221
Easy	low maintenance part	No, needed to reach CC	Polymer	99,4	3,2	1	0	0,298	0,298
Easy	low maintenance part	No	Polymer	50,8	3,2	0	0	0,152	0,152
Extra hand needed	Low maintenance part	No	Polymer	26,6	7,2	0	1	0,080	0,080
Difficult angle	low maintenance part	No, needed to reach CC	Polymer	24,6	26	1	3	0,074	0,074
Easy	low maintenance part	No, needed to reach CC	Polymer		1,8	1	0	0,000	0,000
difficult angle	low maintenance part	No, needed to reach CC	Polymer	25,2	28	1	3	0,076	0,076
Easy	part wears during use	Yes	Polymer	143,2	37	4	0	0,430	0,430
Difficult angle	low maintenance part	No, needed to reach CC	Polymer		18	1	3	0,000	0,000
easy	low maintenance part	No, needed to reach CC	Polymer	30,6	14	1	0	0,092	0,092
easy	low maintenance part	No, needed to reach CC	Polymer	64,8	1,8	1	0	0,194	0,194
easy	low maintenance part	No, needed to reach CC	Polymer	28,8	7,9	1	0	0,086	0,086
easy	low maintenance part	No	Polymer	24,2	5	0	0	0,073	0,073
easy	low maintenance part	No	Polymer	25	5	0	0	0,075	0,075
Easy	low maintenance part	No	Polymer	54	1,8	0	0	0,162	0,162
Easy	low maintenance part	No, needed to reach CC	Polymer	224,6	26	1	0	0,674	0,674
Easy	part wears during use	Yes	PCB	16,4	12	4	0	2,624	9,840
Difficult angle	low maintenance part	No, needed to reach CC	Polymer		18	1	3	0,000	0,000
Easy	low maintenance part	No, needed to reach CC			2,2	1	0		
Easy	low maintenance part	No, needed to reach CC	Polymer	44,6	8,6	1	0	0,134	0,134
Easy	high chance of breaking	Yes	Polymer	595,6	5	4	0	1,787	1,787
Easy	low maintenance part	No, needed to reach CC	Polymer		4,3	1	0	0,000	0,000
Easy	low maintenance part	No	Polymer	4,2	5,7	0	0	0,013	0,013
Easy	low maintenance part	No	Polymer	13	3,2	0	0	0,039	0,039
Easy	low maintenance part	No, needed to reach CC			26	1	0		
Extra hand needed	low maintenance part	No, needed to reach CC			13	1	2		
Easy	Low maintenance part	No, needed to reach CC			2,5	1	0		
Extra hand needed	part wears during use	Yes	Polymer	158,2	28	4	3	0,475	0,475
Extra hand needed	part wears during use	Yes	Polymer	158,2	27	4	3	0,475	0,475
Easy	low maintenance part	No, needed to reach CC	Polymer	200,4	20	1	0	0,601	0,601
Extra hand needed	low maintenance part	No, needed to reach CC	Polymer		13	1	1	0,000	0,000
easy	low maintenance part	No	Polymer	8,8	3,2	0	0	0,026	0,026
Extra hand needed	high chance of breaking	Yes	Other Electronics	1406,6	1,8	4	1	7,033	210,990
Easy	low maintenance part	No, needed to reach CC	Polymer		6,1	1	0	0,000	0,000
Extra hand needed	high chance of breaking	Yes	PCB	49,8	6,1	4	2	7,968	29,880
Easy	low maintenance part	No, needed to reach CC			13	1	0		
Easy	low maintenance part	No	Polymer	336,2	0	0	0	1,009	1,009
Easy	Low maintenance part	No	Polymer	353	0	0	0	1,059	1,059
Extra hand needed	part wears during use	Yes	Other Electronics	50	28	4	2	0,250	7,500

Table 18, HotSpot Mapping calculation sheet

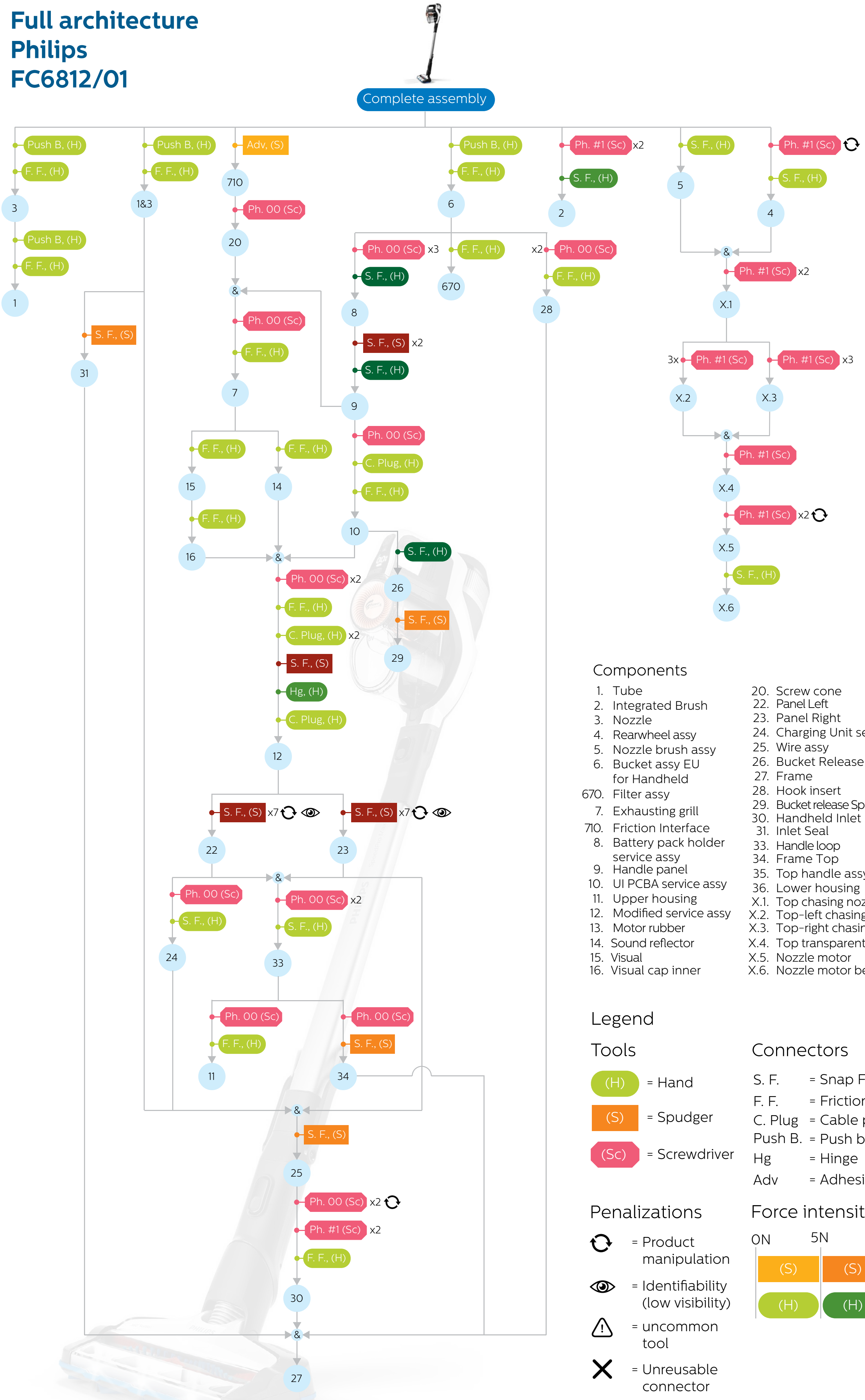
6.4 Results: application of the disassembly map on seven products

The disassembly map tool has been tested on the seven different vacuum cleaners analysed during this research. According to Ishii & Lee (1996), not all the product architecture should be mapped, but a disassembly diagram should be limited to the representation of the disassembly procedures related to priority components. However, the priority parts identified by DFPR, therefore by the HotSpot mapping tool, can differ from those identified for RRU (as also pointed out by Cordella et al. (2019)). This is because RRU does not consider environmental and economic impact in the parameters that define priority components as such. In order to test properly this method, and because of time limitations, the architecture of the seven products has been analysed with different system boundary levels:

- The architecture of all four Philips vacuum cleaners has been fully represented, and not limited to the disassembly of priority components
- The architecture of three competitor products (Samsung, Rowenta, Siemens) has been represented considering only the disassembly procedures required for priority components defined by the JRC (therefore RRU)
- The architecture of the Philips FC9569 has been further analysed using the HotSpot mapping tool (therefore considering DFPR priority components)

The maps are presented in the following pages.

Full architecture Philips FC6812/01



Components

1. Tube
2. Integrated Brush
3. Nozzle
4. Rearwheel assy
5. Nozzle brush assy
6. Bucket assy EU for Handheld
670. Filter assy
7. Exhausting grill
710. Friction Interface
8. Battery pack holder service assy
9. Handle panel
10. UI PCBA service assy
11. Upper housing
12. Modified service assy
13. Motor rubber
14. Sound reflector
15. Visual
16. Visual cap inner
20. Screw cone
22. Panel Left
23. Panel Right
24. Charging Unit service assy
25. Wire assy
26. Bucket Release Button
27. Frame
28. Hook insert
29. Bucket release Spring + Lever
30. Handheld Inlet
31. Inlet Seal
33. Handle loop
34. Frame Top
35. Top handle assy PAT
36. Lower housing
X.1. Top chasing nozzle 6
X.2. Top-left chasing nozzle 6
X.3. Top-right chasing nozzle 6
X.4. Top transparent chasing nozzle 6
X.5. Nozzle motor
X.6. Nozzle motor belt

Legend

Tools

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

Connectors

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

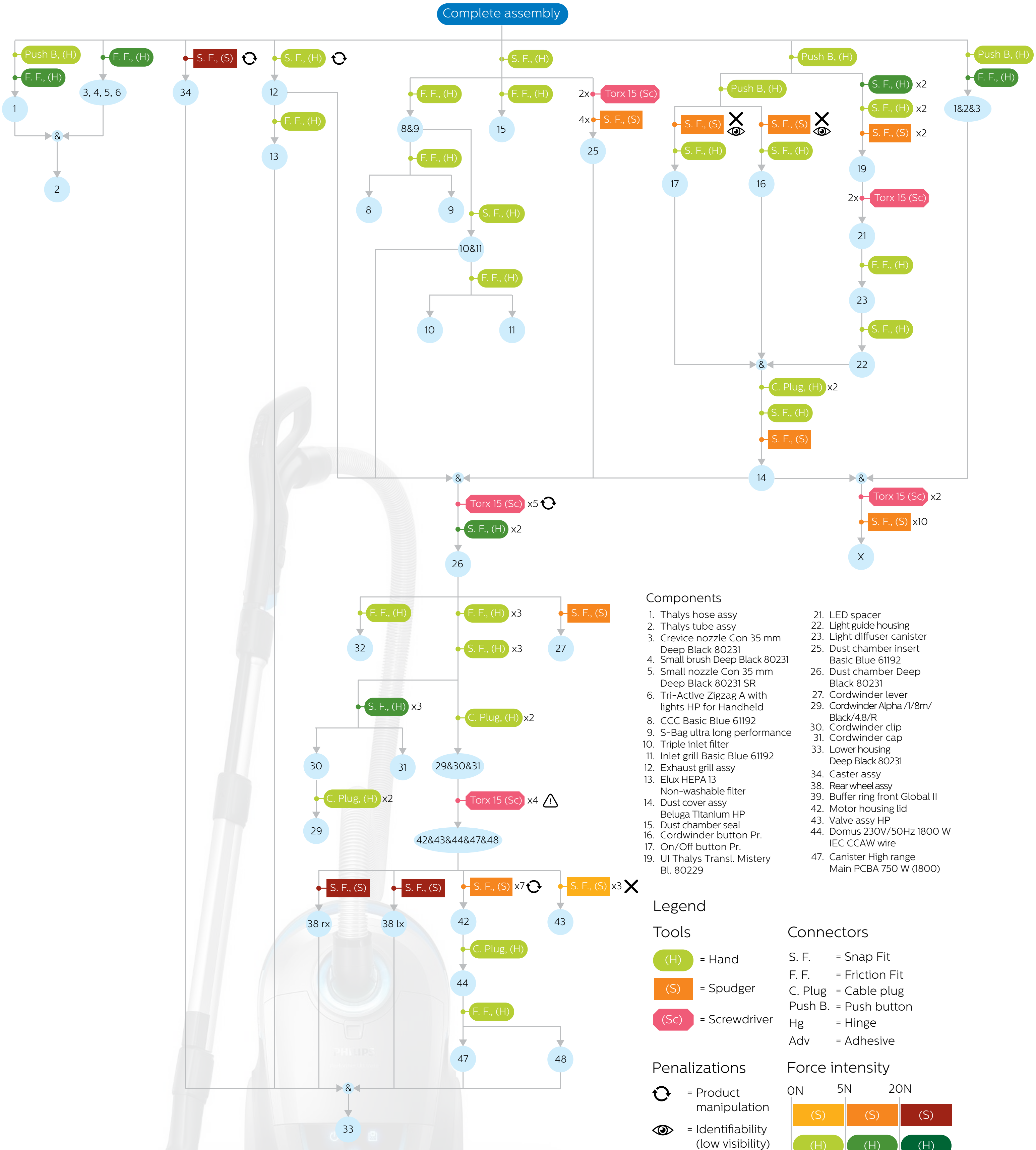
Penalizations

⟳ = Product manipulation
👁 = Identifiability (low visibility)
⚠ = uncommon tool
✕ = Unreusable connector

Force intensity

0N	5N	20N
(S)	(S)	(S)
(H)	(H)	(H)

Full architecture
Philips
FC8924/01



Components

1. Thalys hose assy
2. Thalys tube assy
3. Crevice nozzle Con 35 mm Deep Black 80231
4. Small brush Deep Black 80231
5. Small nozzle Con 35 mm Deep Black 80231 SR
6. Tri-Active Zigzag A with lights HP for Handheld
8. CCC Basic Blue 61192
9. S-Bag ultra long performance
10. Triple inlet filter
11. Inlet grill Basic Blue 61192
12. Exhaust grill assy
13. Elux HEPA 13 Non-washable filter
14. Dust cover assy Beluga Titanium HP
15. Dust chamber seal
16. Cordwinder button Pr.
17. On/Off button Pr.
19. UI Thalys Transl. Mistery Bl. 80229
21. LED spacer
22. Light guide housing
23. Light diffuser canister
25. Dust chamber insert Basic Blue 61192
26. Dust chamber Deep Black 80231
27. Cordwinder lever
29. Cordwinder Alpha /1/8m/ Black/4.8/R
30. Cordwinder clip
31. Cordwinder cap
33. Lower housing Deep Black 80231
34. Caster assy
38. Rear wheel assy
39. Buffer ring front Global II
42. Motor housing lid
43. Valve assy HP
44. Domus 230V/50Hz 1800 W IEC CCAW wire
47. Canister High range Main PCBA 750 W (1800)

Legend

Tools

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

Connectors

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

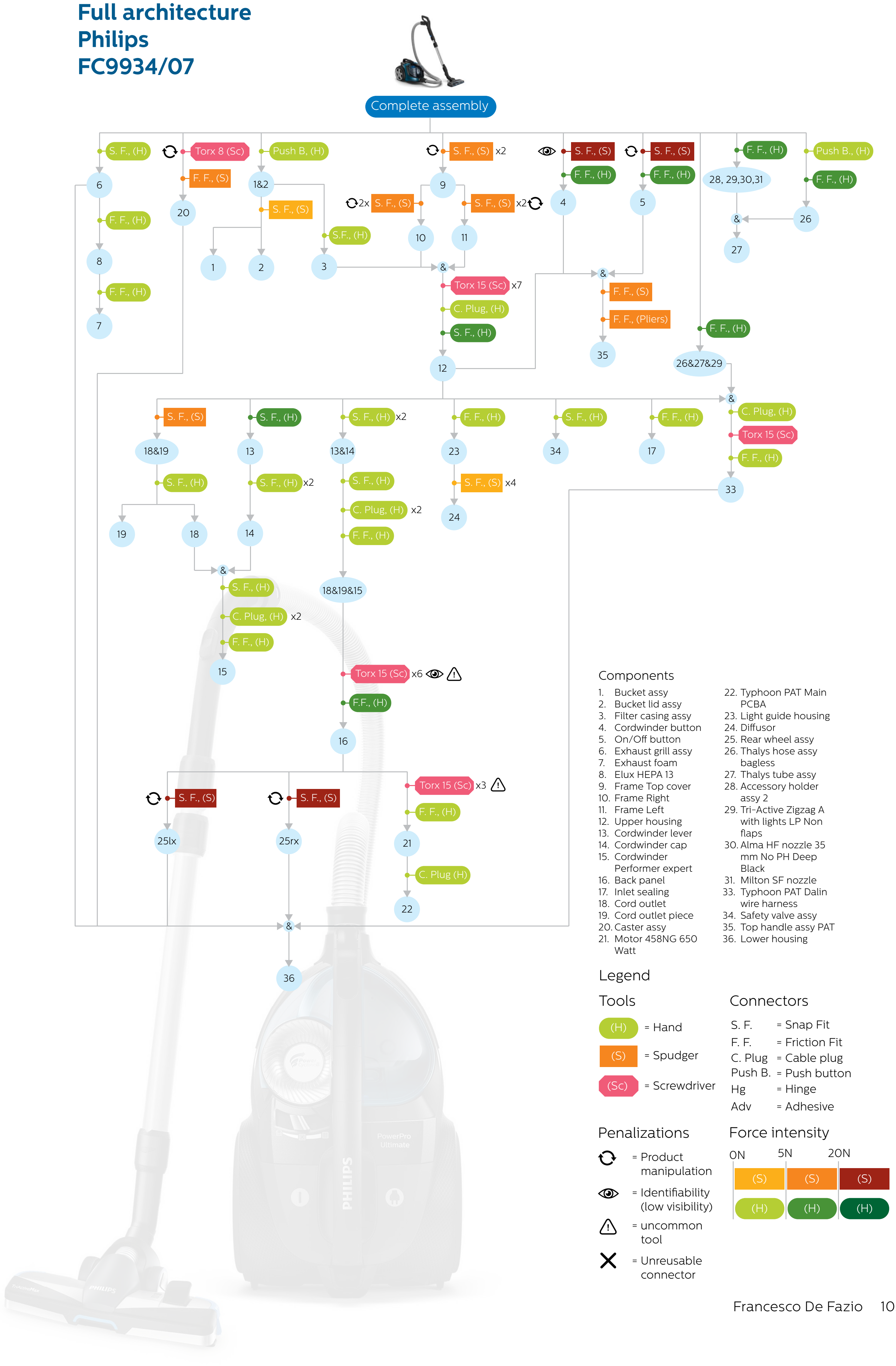
Penalizations

⟳ = Product manipulation
👁 = Identifiability (low visibility)
⚠ = uncommon tool
✕ = Unreusable connector

Force intensity

0N	5N	20N
(S)	(S)	(S)
(H)	(H)	(H)

Full architecture
Philips
FC9934/07



Components

1. Bucket assy
2. Bucket lid assy
3. Filter casing assy
4. Cordwinder button
5. On/Off button
6. Exhaust grill assy
7. Exhaust foam
8. Elux HEPA 13
9. Frame Top cover
10. Frame Right
11. Frame Left
12. Upper housing
13. Cordwinder lever
14. Cordwinder cap
15. Cordwinder Performer expert
16. Back panel
17. Inlet sealing
18. Cord outlet
19. Cord outlet piece
20. Caster assy
21. Motor 458NG 650 Watt
22. Typhoon PAT Main PCBA
23. Light guide housing
24. Diffusor
25. Rear wheel assy
26. Thalys hose assy bagless
27. Thalys tube assy
28. Accessory holder assy 2
29. Tri-Active Zigzag A with lights LP Non flaps
30. Alma HF nozzle 35 mm No PH Deep Black
31. Milton SF nozzle
33. Typhoon PAT Dalin wire harness
34. Safety valve assy
35. Top handle assy PAT
36. Lower housing

Legend

Tools

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

Connectors

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

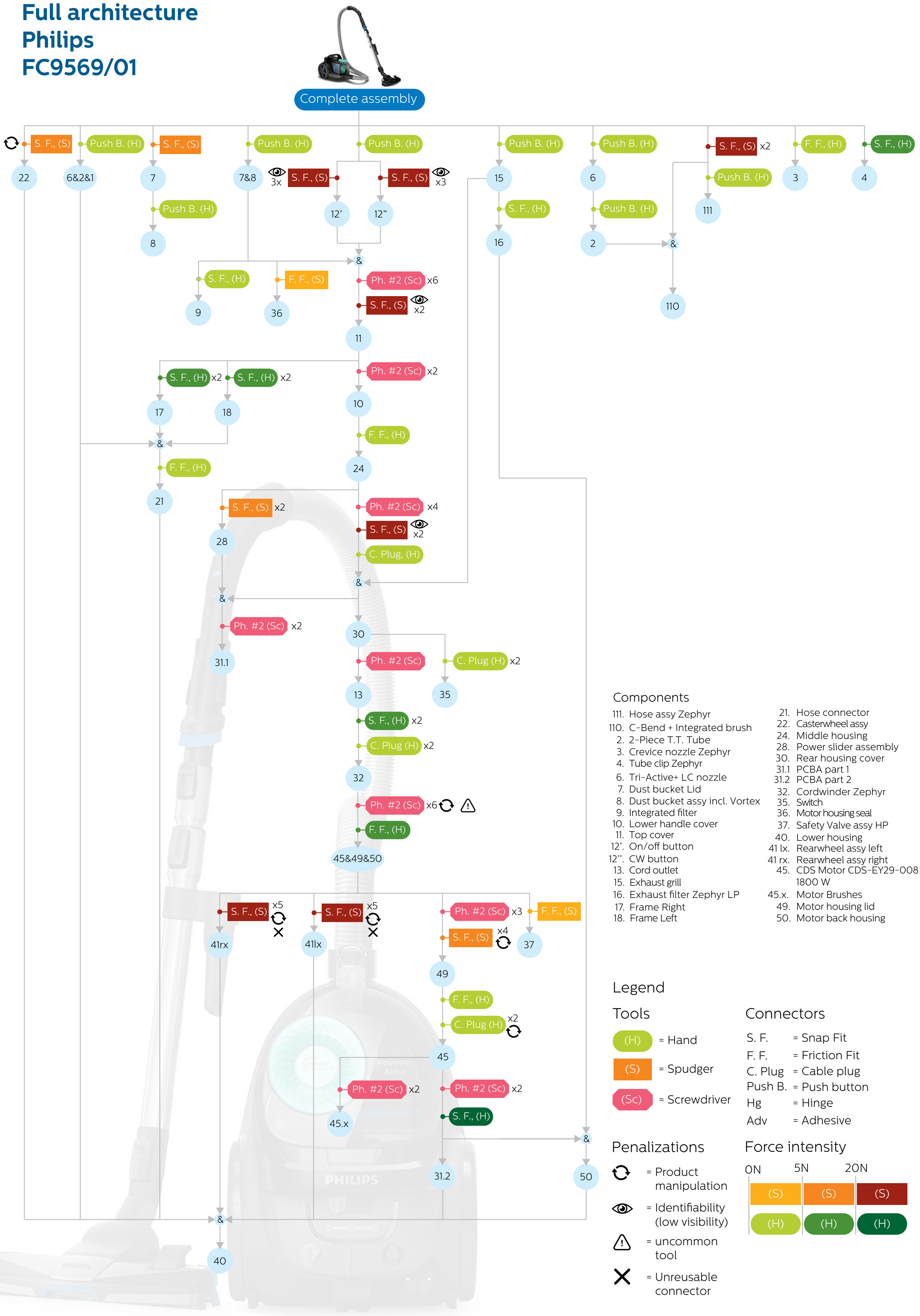
Penalizations

⟳ = Product manipulation
👁 = Identifiability (low visibility)
⚠ = uncommon tool
✕ = Unreusable connector

Force intensity

0N	5N	20N
(S)	(S)	(S)
(H)	(H)	(H)

Full architecture
Philips
FC9569/01



Components

111.	Hose assy Zephyr
110.	C-Bend + Integrated brush
2.	2-Piece T.T. Tube
3.	Crevice nozzle Zephyr
4.	Tube clip Zephyr
6.	Tri-Active+ LC nozzle
7.	Dust bucket Lid
8.	Dust bucket assy incl. Vortex
9.	Integrated filter
10.	Lower handle cover
11.	Top cover
12'.	On/off button
12''.	CW button
13.	Cord outlet
15.	Exhaust grill
16.	Exhaust filter Zephyr LP
17.	Frame Right
18.	Frame Left
21.	Hose connector
22.	Casterwheel assy
24.	Middle housing
28.	Power slider assembly
30.	Rear housing cover
31.1	PCBA part 1
31.2	PCBA part 2
32.	Cordwinder Zephyr
35.	Switch
36.	Motor housing seal
37.	Safety Valve assy HP
40.	Lower housing
41 lx.	Rearwheel assy left
41 rx.	Rearwheel assy right
45.	CDS Motor CDS-EY29-008 1800 W
45.x.	Motor Brushes
49.	Motor housing lid
50.	Motor back housing

Legend

Tools

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

Connectors

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

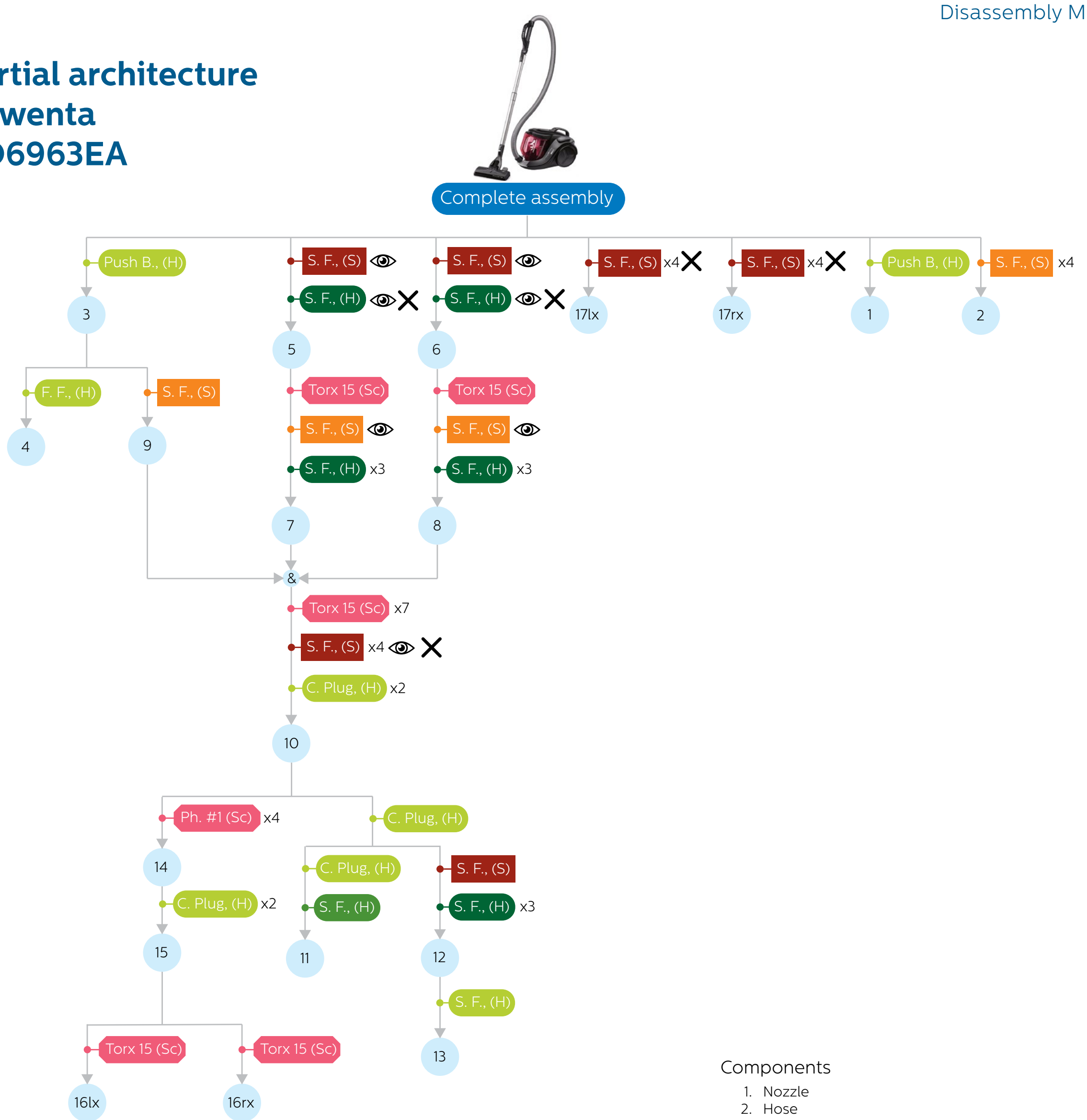
Penalizations

⟳ = Product manipulation
👁 = Identifiability (low visibility)
⚠ = uncommon tool
✕ = Unreusable connector

Force intensity

0N	5N	20N
(S)	(S)	(S)
(H)	(H)	(H)

Partial architecture Rowenta RO6963EA



Components

1. Nozzle
2. Hose
3. Dust bucket
4. Inlet filter
5. On-off button
6. Cord-winder button
7. Frame right
8. Frame left
9. Handle opening lever
10. Upper housing
11. PCBA
12. Cord outlet
13. Cord-winder
14. Motor housing lid
15. Motor

16rx. Motor bursh rx
16lx. Motor bursh lx
17rx. Wheel rx
17lx. Wheel lx

Legend

Tools

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

Connectors

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

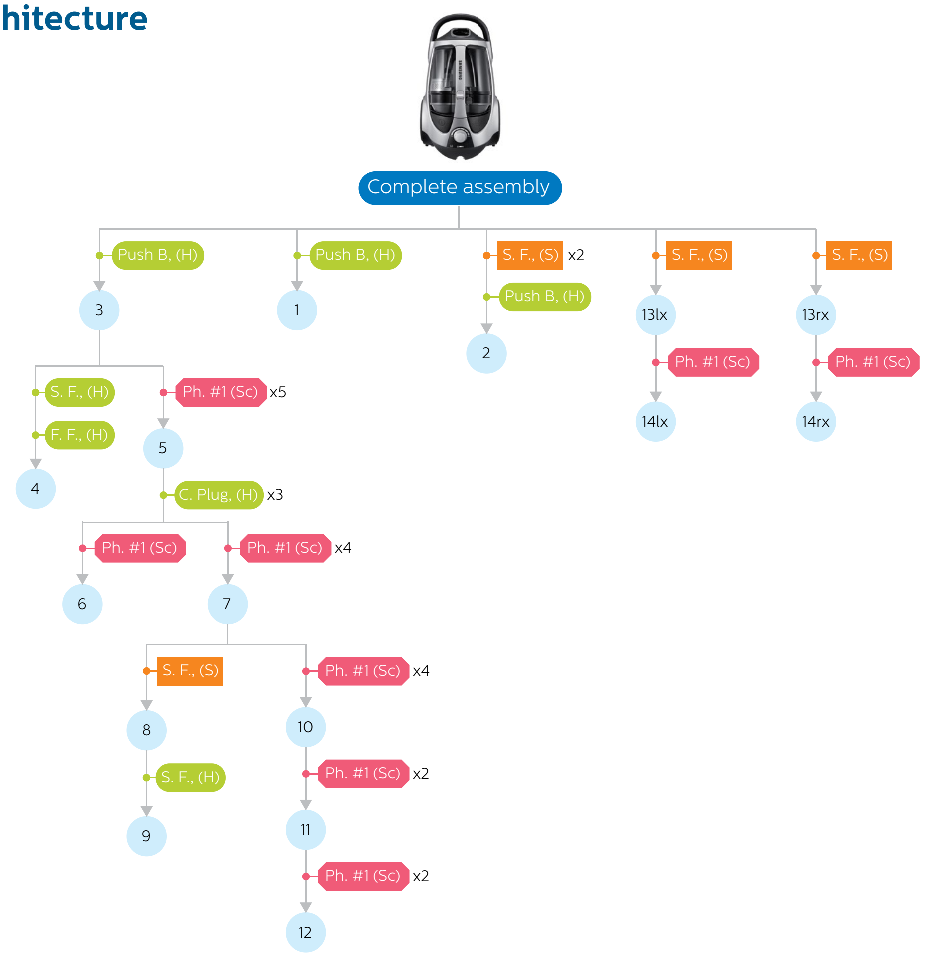
Penalizations

↻ = Product manipulation
👁 = Identifiability (low visibility)
⚠ = uncommon tool
✕ = Unreusable connector

Force intensity

0N	5N	20N
(S)	(S)	(S)
(H)	(H)	(H)

Partial architecture
Samsung
SC8835



Components

1. Nozzle
2. Hose
3. Dust Bucket
4. Inlet filter
5. Upper housing clump
6. PCBA and switches
7. Rear housing
8. Cord outlet
9. Cord-winder
10. Motor housing lid
11. Motor
12. Motor brushes

13rx. Wheel screw cover rx
13lx. Wheel screw cover lx
14rx. Wheel rx
14lx. Wheel lx

Legend

Tools

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

Connectors

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

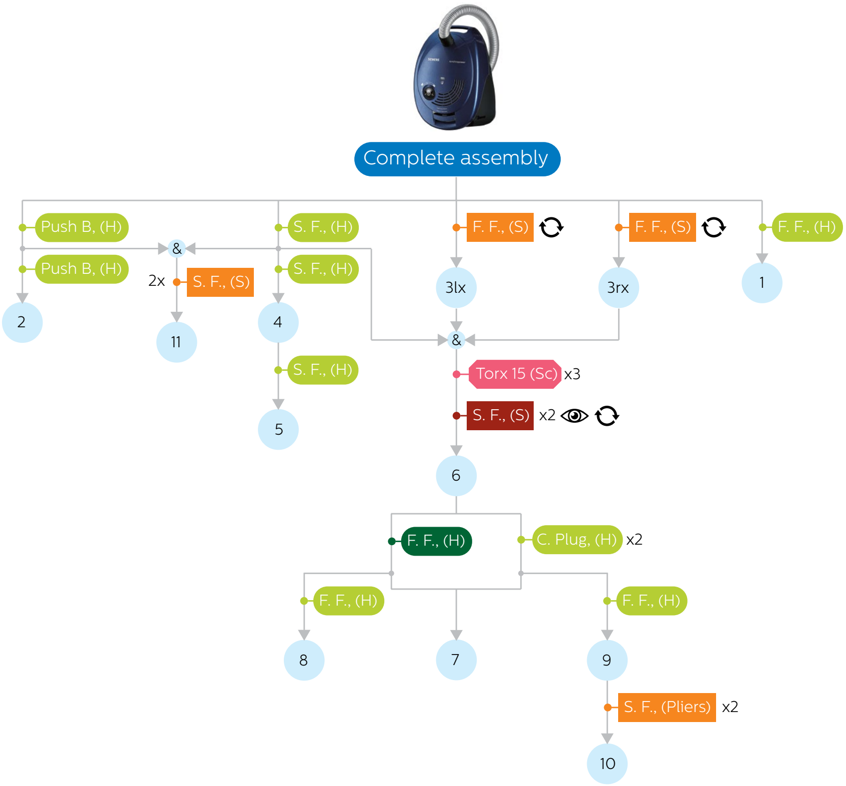
Penalizations

↻ = Product manipulation
👁 = Identifiability (low visibility)
⚠ = uncommon tool
✕ = Unreusable connector

Force intensity

0N	5N	20N
(S)	(S)	(S)
(H)	(H)	(H)

Partial architecture
Siemens
VS06A111/12



Components

1. Nozzle
2. Hose
3rx. Wheel rx
3lx. Wheel lx
4. Dust bag
5. Inlet filter
6. Rear housing
7. PCBA and switches
8. Cord-winder
9. Motor
10. Motor brushes
11. Aesthetic upper housing

Legend

Tools

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

Connectors

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

Penalizations

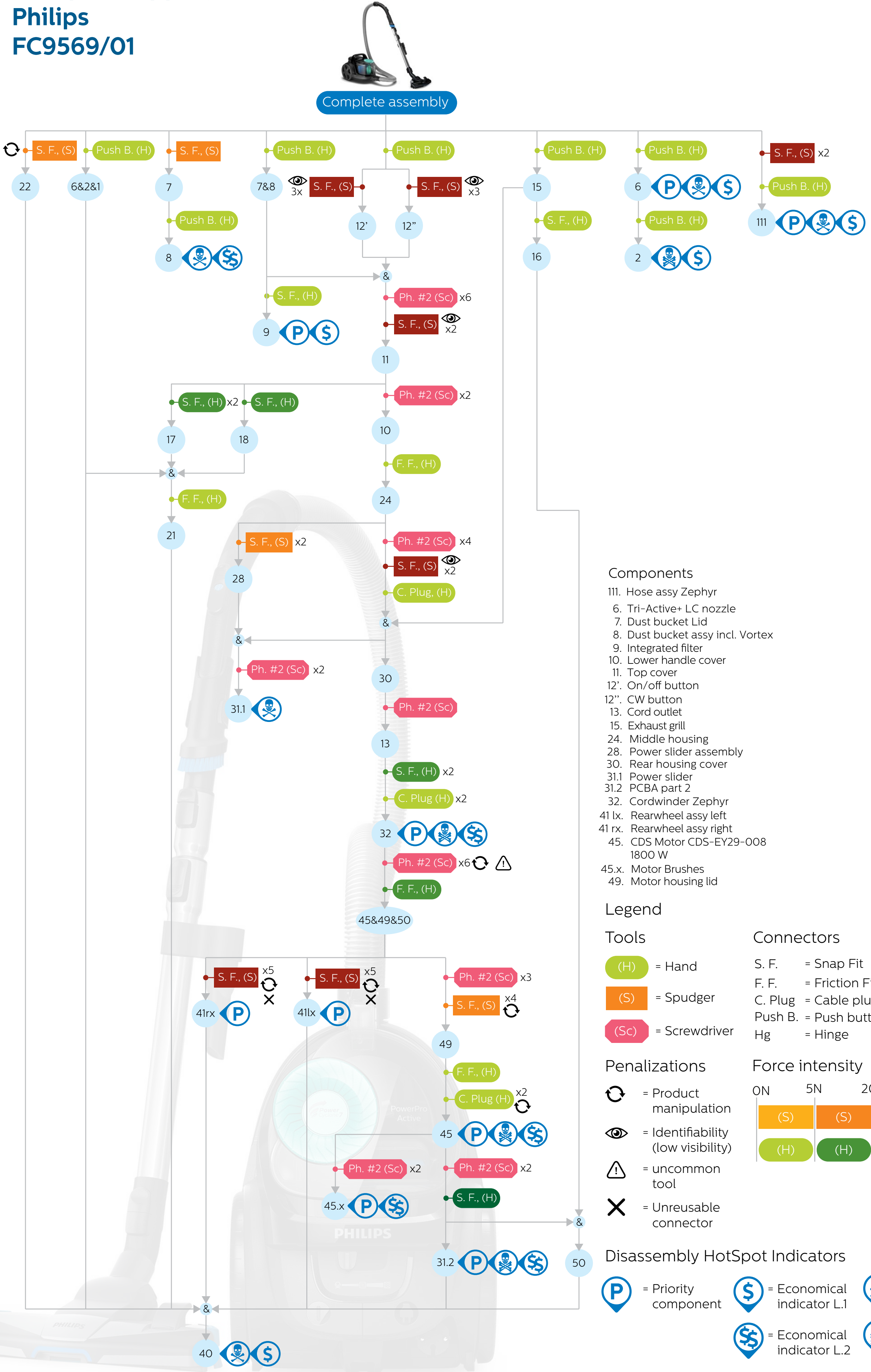
⟳ = Product manipulation
👁 = Identifiability (low visibility)
⚠ = uncommon tool
✕ = Unreusable connector

Force intensity

0N 5N 20N

(S)	(S)	(S)
(H)	(H)	(H)

HotSpot mapping tool integration
Philips
FC9569/01



Components

111. Hose assy Zephyr
6. Tri-Active+ LC nozzle
7. Dust bucket Lid
8. Dust bucket assy incl. Vortex
9. Integrated filter
10. Lower handle cover
11. Top cover
12'. On/off button
12''. CW button
13. Cord outlet
15. Exhaust grill
24. Middle housing
28. Power slider assembly
30. Rear housing cover
31.1 Power slider
31.2 PCBA part 2
32. Cordwinder Zephyr
41 lx. Rearwheel assy left
41 rx. Rearwheel assy right
45. CDS Motor CDS-EY29-008 1800 W
45.x. Motor Brushes
49. Motor housing lid

Legend

Tools

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

Connectors

S. F. = Snap Fit
F. F. = Friction Fit
C. Plug = Cable plug
Push B. = Push button
Hg = Hinge

Penalizations

⟳ = Product manipulation
👁 = Identifiability (low visibility)
⚠ = uncommon tool
✕ = Unreusable connector

Force intensity

0N	5N	20N
(S)	(S)	(S)
(H)	(H)	(H)

Disassembly HotSpot Indicators

P = Priority component
$ = Economical indicator L.1
☠ = Environmental indicator L.1
$$ = Economical indicator L.2
☠ = Environmental indicator L.2

6.5 Discussion and conclusions

The disassembly map was developed investigating the research objective **RO.5 Defining and testing new guidelines or methodologies that can guide designers to design for product repairability.** It represents a revision of the reverse fish bone diagram ideated by Ishii & Lee (1996). It is an effective method to represent the architecture of a product, highlighting different disassembly attributes which determines how repairable a product actually is. The flow-chart like structure allows to represent intricate logic paths, adopting the AND/OR logic of De Mello and Sanderson (1991). Components are indicated using bubbles, which are interconnected using liaisons, inspired by the research of Bourjault (1984). The liaisons are enriched by disassembly action blocks, which indicate important disassembly information such as type of tools, force intensity and type of connectors. The easier operations are visualised using shades of green, while more difficult procedures are indicated with tonalities of red. Consequently, the level of disassembly difficulty is understandable at first glance. Additional attributes (penalties) have been formulated mainly based on the eDiM methodology (Peeters et al., 2018; Vanegas et al., 2016).

Furthermore, the orientation of the diagram suggests the depth of the disassembly by positioning sequential disassembly operations vertically and sequence independent disassembly actions horizontally (as firstly proposed by Ishii & Lee (1996)). This also allows to compare visually the depth of different architectures, by placing side by side different disassembly maps (as presented in chapter 7). However, distances used between blocks or components bubbles were constant but not standardized, making this visual assessment of disassembly depth very approximate. Moreover, although specific rules have been formulated for a correct use of this tool, the representation of complex disassembly procedures and components interconnections might be still subject to personal interpretation. This is also valid for the identification of force intensity, penalties and type of connector, reflecting some of the problems encountered by the eDiM methodology, from which this map was also inspired. This aspect could be further analysed by asking to different designers to create the disassembly map of the same product. By comparing the different maps obtained, it would be possible to practically assess how much standardised and objective this method is, and which aspects can be instead differently interpreted.

The seven different maps created for the products analysed in this study show clear differences in product architecture between different models. The tool was flexible enough to represent complex and different disassembly procedures. Moreover, the combination of HotSpot mapping and Disassembly map represent an effective tool, which provides a clear overview of the architecture of a product and highlights the most important components on which further redesign for DFPR should take place.

By testing the method for full and partial architecture mapping it was found that considering just the disassembly of priority components makes the process easier and straight forward. The maps have been checked several times in order to guarantee their accuracy. Most of the time, partial architecture maps resulted to be correct since the first attempt, while full architecture maps required more than one iteration.

Additionally, the maps have been created using a visualization software called Illustrator, from Adobe, and their practical realization was time consuming. Possible future evolution of this tool could involve the automation of the process by using platforms like automatic flowchart maker software. Further optimization could involve image recognition and use of AI to automatically create the disassembly map from the recorded footage of the disassembly procedures.

Besides, this method has been tested only on one specific product group (vacuum cleaners). The application of this method on a different type of products might require the representation of new tools, connector and penalties attributes. This is a limitation shared also by the current eDiM methodology (Peeters et al., 2018; Vanegas et al., 2016), and it requires further research in this direction.

To conclude, the disassembly map is a tool that pushes designers to explore products from a different angle, considering attributes and features fundamental for DFPR. By using this methodology, the designer retraces each single step and action which determines the product disassembly complexity.

7. Product Redesign:

Feasible, today

7.1 Introduction

In this chapter, the Philips vacuum cleaner Power Pro Active has been further analysed, and seven different design proposals are presented. Four of them have been developed in details, assessing complete feasibility and creating physical prototypes. The last three are a recommendation for further optimization. The redesign ideas presented in this chapter have been discussed with the Philips I&D department in Drachten and aligned with the latest JRC scoring system for RRU (Cordella et al., 2019). The disassembly map tool has guided the entire design process, proving to be an optimal design aid for DFPR. The repairability score of this specific model (currently 6.3/10) has been recalculated for each different redesign, showing the objective improvement of the product architecture. Eventually, the chapter concludes showing the perfect vacuum cleaner configuration of repairability and disassembly. This configuration is then used in the next chapter to calculate discrete rating values for the assessment of canister vacuum cleaners, and for the definition of new serviceability requirements for the Philip I&D department.

This research phase investigates the following research objectives:

- **RO.5 Defining and testing new guidelines or methodologies that can guide designers to design for product repairability**
- **RO.6 Investigating the economic impact that enhanced repairability might determine**

7.2 Design process

Aim of the redesign phase

Initially, this research did not include a redesign phase, being limited to the assessment of a certain number of consumer products. However, practical redesign proposals have been reconsidered as fundamental to provide a clear idea of how a more repairable product could look like. The I&D of Philips has been involved for most of the redesign work and decisions, sharing ownership and knowledge on the final results. This has allowed to have a real impact on the company till a certain extent.

Selection of the product to be redesigned

The product analysed in the redesign phase is the Philips bagless canister **Performer Pro Active** (Fig. 71).

This model has been selected based on two main requirements:

- medium-high production volume and consequently high number of repairs in the official Repair centres;
- medium price range, ensuring its involvement in the big Philips 5R refurbishing program started in January 2018.

Moreover, the architecture of this model is very similar to the one of another high production volume canister, the Philips Power Pro Compact. Supposedly, some of the redesigns presented in the next pages could be applied also to this other model.

Design requirements

The design requirements defined for the redesign of this product are concise, but very restrictive:

- The redesign proposals should be completely feasible and manufacturable today.
- The cost of the redesign proposals should be close to zero, or lead to savings
- The redesigns should comply with the latest JRC scoring system (Cordella et al., 2019), and

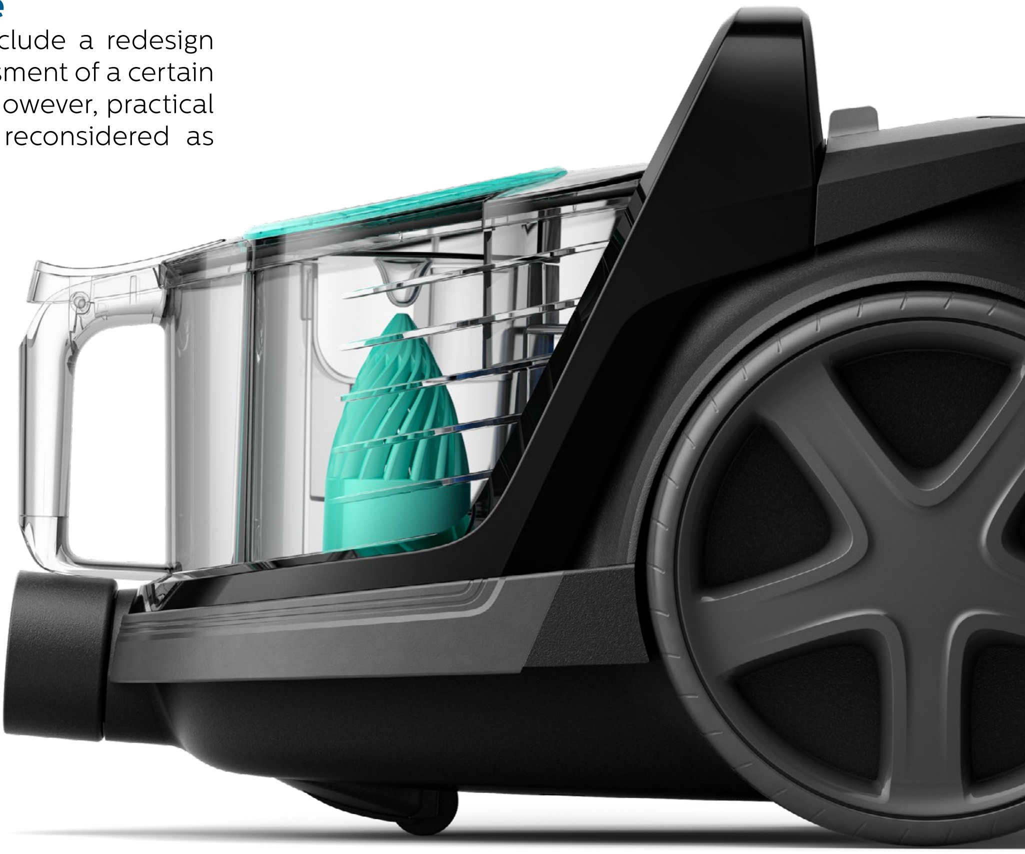


Fig. 71, Philips Performer Pro Active

determine a clear improvement in the final RRU score
- The redesigns should comply with the prEN45554
- The redesigns should not compromise the outer aesthetics of the product, respecting the official Philips Design language.
- The redesign for repairability should not increase the environmental impact of the product (e.g. by increasing quantity of material used or by compromising durability)
- Product safety should not be compromised

Design approach

Apart from the official requirements, this project wanted to have a real impact on the business, inspiring possible future design changes and rising awareness about product repairability in the company. In order to respect the strict product requirements and have a real impact on Philips, the approach applied involved:
- Redesigning a real specific product currently on the market; this makes the results more tangible and connected to the company compared to designing a completely new model.
- Working on very small, but meaningful design changes; this limit costs and manufacturability problems. Moreover, it shows clear connection with the current model and ensure comparability of the final result with the current product
- Working together with the same engineers who designed the product in the first place, discussing solution together and sharing ownership on the final result
- Implementing design solutions observed in competitor's models; they are a reliable source of inspiration, showing different, but completely feasible and manufacturable design solutions
- Focusing on redesign which improve serviceability as well, an important aspect for Philips

A workshop about product repairability has been carried out with two I&D developer engineers, one Senior Architect, two product designers and a senior manager from Philips Group Sustainability (Fig. 72, 73).

The aim of this session was:
- Raising awareness about product repairability
- Comparing different product architectures
- Gathering insights about how a more repairable product could look like
- Sharing ownership about the problem
- Testing the disassembly map tool and gathering feedbacks about it.

Different product architectures have been compared by physically disassembling different products while the disassembly map tool has been tested by filling up a incomplete map together.

The main insights gathered from this experience are:

Fig. 72, 73, Workshop about Product Repairability at the Philips I&D department.

- Hidden snap fits which also requires to apply high force with a spudger to be disassembled are one of the most difficult disassembly actions
- A design that requires the use of uncommon tools (e.g. positioning of deep screws in the product) slows down the disassembly procedure
- Competitor's products analysed during the session were easier to disassemble compared to the Philips' one. This was mainly due to easy access to fasteners and to the clumping of not priority components in one big sub-assembly block, which could be removed in one single step
- All the participants expressed positive feedback about the disassembly map tool, defining it as a useful and effective tool to map product architecture and identify product features to be improved

This session allowed to gather general insights and ideas that could improve product repairability in vacuum cleaners. However, additional one to one sessions had to be performed in order to discuss specific redesign solutions. In particular:
- Product mechanics and assembly mechanisms have been further explored in different

occasions with two developer engineers

- Redesign of the PCBA has been discussed with the Electronic and Software group leader
- Future serviceability requirements for the Philips Floor Care department have been discussed ad agreed with the Mechanical Engineering group leader and a Senior Architect.

Redesign focus

As indicated in Table 19, the Philips Power Pro Active received a repairability score of 6,2/10 (by considering disassembly time). While the disassembly index is 7,3/10, the RRU Process index is 4/10. This is a clear indication that the parameters that should be improved most are:

- Type and availability of information
- Spare parts availability

Further indications in this direction have been already pointed out in Chapter 5.

Despite this, the redesigns presented in this chapter focus on the improvement of the design for disassembly index. The main reasons are:

- This research wants to provide further insights and solution for the application of DFPR.
- The improvement of the disassembly index might result easier to the company compared to improving the RRU process one. In fact, while the first one mainly involves the adoption of a new design approach by designers and engineers, the second one requires considerable organizational and legal changes.

By improving only the disassembly index, the score improvement of the following redesign solutions is sometimes marginal or not very meaningful. In order to drastically improve the Overall RRU score, further actions have to be taken about the RRU process index as well.

In Chart 2 it is possible to observe how the priority components which received the lowest scores

Table 19, Repairability assessment results for the Philips Power Pro Active

Philips FC9569/01	PART 1	PART WEIGHT	PART 2	PART WEIGHT	PART 3	PART WEIGHT	PART 4	PART WEIGHT	PART 5	PART WEIGHT	PART 6	PART WEIGHT	PART 7	PART WEIGHT	PART 8	PART WEIGHT		
PARAMETER	MOTOR	3	MOTOR BRUSHES	3	FILTERS	3	HOSE	3	POWER CABLE	3	WHEELS	1	PCBA	1	NOZZLES	1	PARAMETER SCORE	PARAMETER WEIGHT
#4 Disassembly time	0,30		0,31		1,00		0,56		0,27		0,02		0,17		0,56		4,48	2,00
#1 Disassembly depth / sequence	0,38		0,47		1,00		1,00		0,45		0,08		0,21		1,00		6,22	2,00
#2 Fasteners	1,00		1,00		1,00		1,00		1,00		1,00		1,00		1,00		10,00	2,00
#3 Tools	0,66		0,66		1,00		1,00		1,00		0,66		0,66		1,00		8,49	2,00
#6 Type and availability of information	0,50		0,50		0,50		0,50		0,50		0,50		0,50		0,50		5,00	2,00
#7 Spare parts	0,25		0,00		0,50		0,50		0,25		0,25		0,25		0,50		3,06	2,00
#12 Commercial guarantee	0,00		0,00		0,00		0,00		0,00		0,00		0,00		0,00		0,00	/

RRU indices for parts	5,15	4,9	8,3	7,6	5,8	4,2	4,7	7,6

Disassembly index	RRU Process index	OVERALL RRU	Commercial Guarantee
7,3	4	6,2	0,00

for disassembly time and sequence are the inner components, such as **PCBA, Motor (and motor brushes), Cord-winder and Wheels**. On the contrary, other parts are already well optimised, like the nozzle, the hose and the inlet filter. Based on the repairability assessment results, the redesign of this product will focus on enhancing disassembly of the inner components, leaving unchanged the design of the external ones.

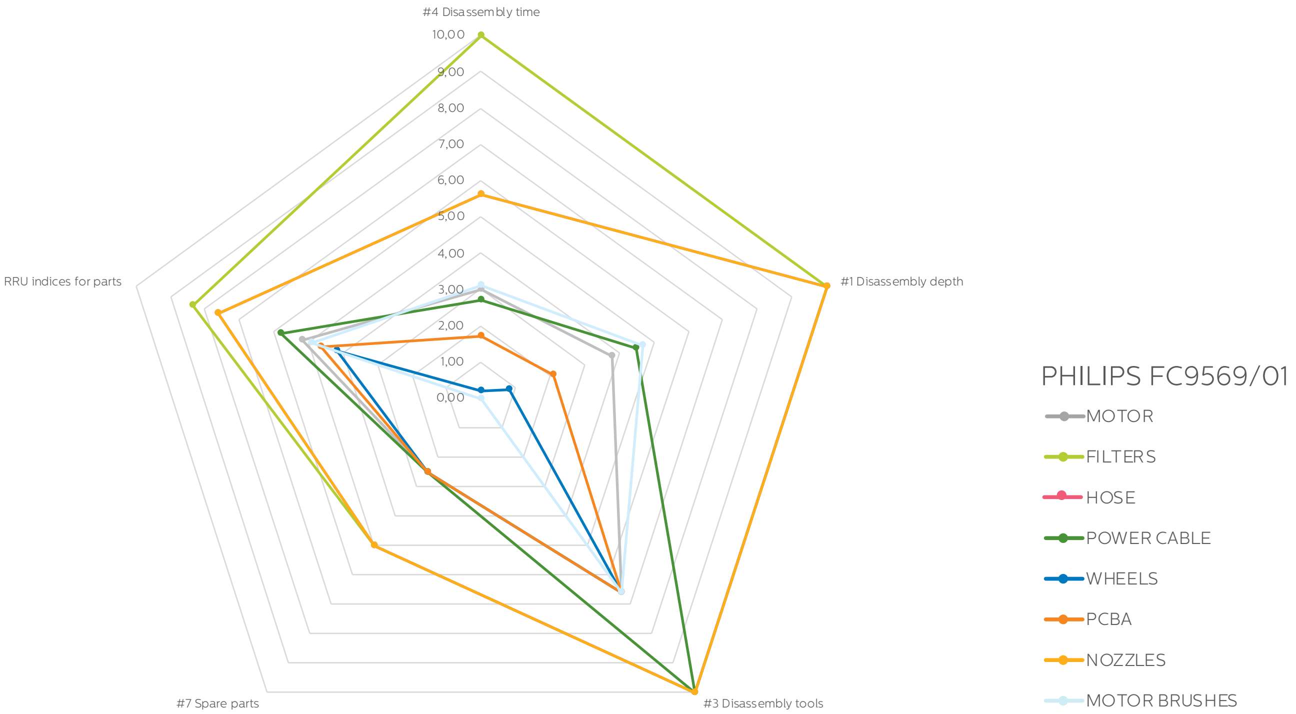
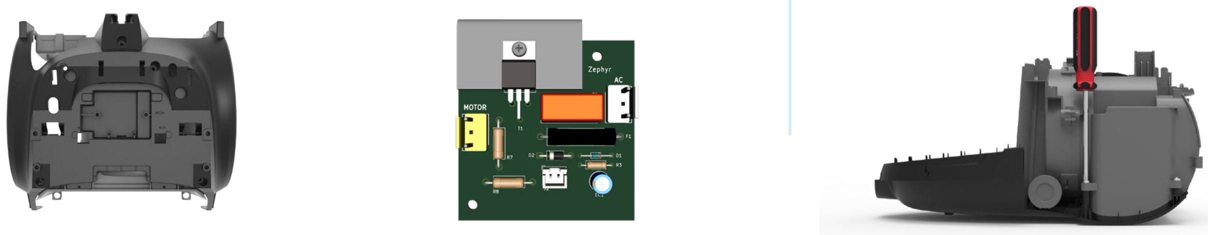


Chart 2, Repairability scores of single components, Power Pro Active

4-6 months

Short term solutions
Implementable in DFX

Feasibility



Redesign of the rear housing

Redesign of the PCBA

Screw positioning redesign

Fig. 74, Redesign clustering based on feasibility

Redesign clustering

The redesign solutions presented in this chapter can be clustered in three main categories according to feasibility (Fig. 74):

- **Short term solutions**: This solutions could be implemented in the next 4-6 months. They requires very small design changes, and they could be implemented in DFX (design revision for manufacturability).
- **Medium-term solutions**: This solutions require more consistent changes in the current design, involving modifications that could not be implemented in DFX. However, they could be easily implemented in new models that are already in advance preproduction design stage.
- **Long-term solutions**: this solutions represent more radical changes in the general product architecture of bagless canisters. In order to be implemented, they would have to be considered in an early design stage. This define a third implementation horizon of 24 months.

Two short-term and two mid-term redesign solutions have been developed extensively, while long term recommendations are presented as recommendations for future improvements. Prototypes have been made for the most feasible solutions and, in some cases, they have been physically tested. Long term recommendation have been used in order to define how the "perfect repairable vacuum cleaner" could look like. Short and mid term solutions have the main purpose of inspiring the Philips I&D department, showing how implementing product repairability and disassembly might be easier than expected. Instead, long term design recommendations have been used to define possible discrete assessment threshold for the JRC scoring system. Eventually, these discrete thresholds have been used to define new serviceability requirements for the Philips Floor Care department.

The design solutions presented in the next pages are practical examples of:

- redesign for disassembly time optimization through clumping methodology
- redesign for hotspot components accessibility through bottom-up assembly
- redesign for legislation compliance and use of common tools
- redesign for sequential independent disassembly and safer self-repiars

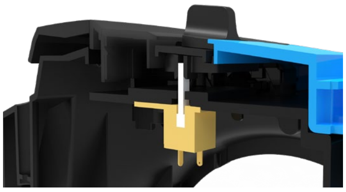
The disassembly map tool has been tested as practical redesign aid, and it has been used throughout all the redesign phase.

12 months

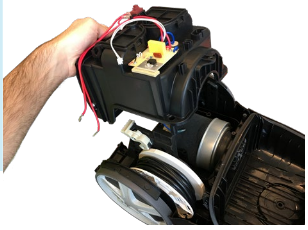
Mid-term solutions Implementable with small changes in injection molds

24 months

Long-term solutions The perfect vacuum cleaner



Redesign of the power slider assembly



Vertical disassembly of the motor housing

Independent disassembly of motor and cord-winder

External wheels disassembly

7.3 Redesign for disassembly time optimization through clumping methodology

Analysis of the current design

From the disassembly map of the Philips Power Pro Active (Fig. 75) a long sequential disassembly sequence is immediately visible. This sequence is composed by the sequential disassembly of the power and cord-winder buttons, followed by the disassembly of the upper handle, of the lower handle, the middle housing and the rear housing. These are all plastic layers which have to be disassembled in order to reach priority components positioned underneath. These parts are not priority elements, but the current architecture makes their sequential disassembly necessary in order to reach the inner components. It is also possible to notice from the map how most of this plastic casings are assembled using hidden snap fits, which require to apply high disconnection force as well. These 6 sequential steps are the main cause of the high disassembly time registered for the inner priority elements, such as PCBA, Cord-winder, Motor and Wheels. Not only they have to be removed one by one, but their disassembly is quite tricky since connectors are hidden and high force has to be applied (encircled in red in Fig. 75 and shown in Fig. 76 and 77, 81). As pointed out by the two official repairers interviewed at the European Repair Centre as well (Appendix J), this design often leads to fasteners breakage (Fig. 78) and damage of the surrounding plastic surfaces (Fig. 79).

These plastic components have to be disassembled in order to reach hidden screws, connected to the main body (Fig. 80). In fact, according to Philips Design guidelines, the use of visible screws should be avoided, ensuring a better aesthetic result.

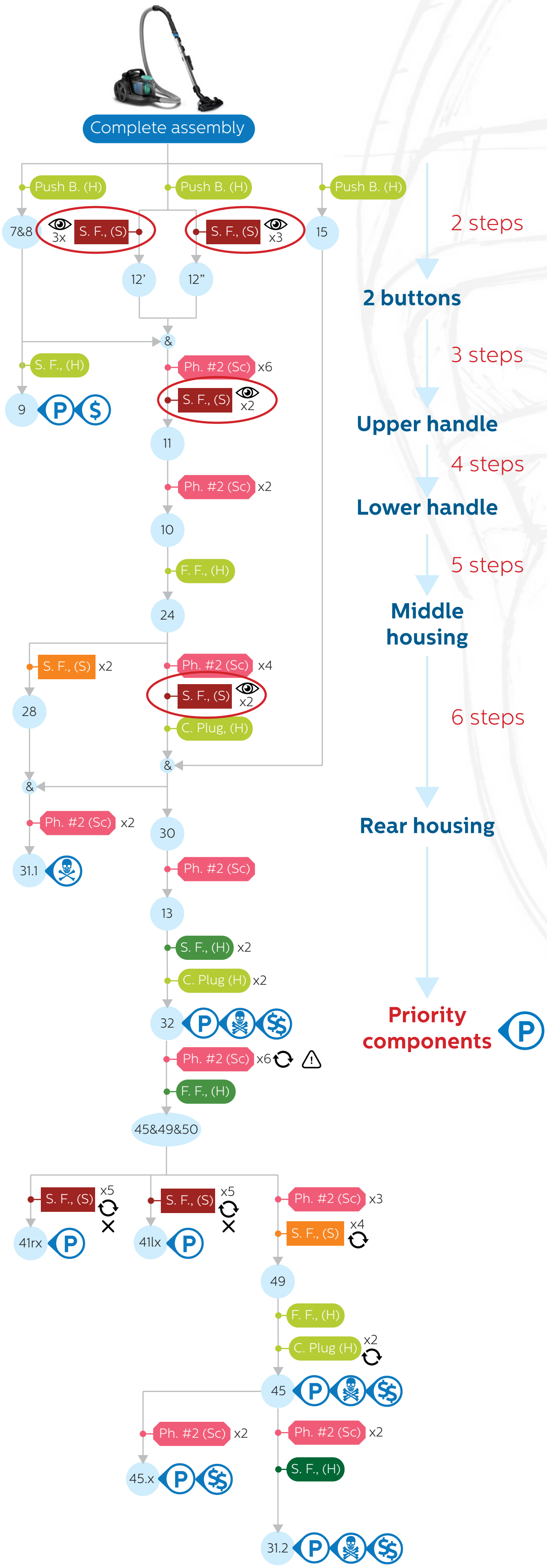


Fig. 75, Sequential disassembly of plastic layers in Philips Power Pro Active

Fig. 76, Top buttons disassembly, using a spudger (High force intensity hidden snap fit connectors)

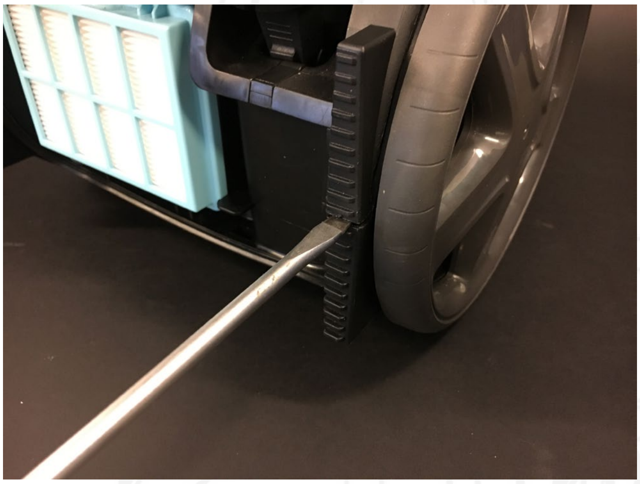


Fig. 77, Rear housing disassembly, using a spudger (High force intensity hidden snap fit connectors)

Fig. 78, Broken hidden snap fit after an official repairer tried to disassemble one of the upper buttons

Fig. 79, Ruined plastic component reassembled after product disassembly

Fig. 80, Four screws hidden beneath the two upper buttons

Fig. 81, Upper handle disassembly, using a spudger (High force intensity hidden snap fit connectors)

Clumping methodology

In order to enhance product disassembly, the clumping methodology introduced in Chapter 6 has been applied. This design technique has been firstly introduced by Marks et al. (1993), with the Linker structural representation. It was argued that, in order to enhance disassembly for product retirement, it is important to design components sub-assemblies. Parts should be grouped according to their EoF scenario and frequency of failure, facilitating repair, refurbishing, harvesting and recycling operations.

Consequently, the product architecture of the Power Pro Active has been redesigned clumping together all those plastic layers which currently have to be disassembled one by one in order to reach inner priority components. This was done taking inspiration from the architecture of the Samsung SC8835. In this model all the upper plastic covers are clumped together using hidden snap fits. However, they can be easily removed in one step by removing five screws (4 placed underneath the dust bucket and one placed on the back of the appliance) (Fig. 82). The components clumped together in this redesign are (encircled in green in Fig. (83):

1. Power button
2. Cord-winder button
3. Upper handle
4. Lower handle
5. Middle housing
6. Rear housing

In one of the first concepts, the motor housing lid was included in this clump as well (encircled in red in Fig. 83) However, this option was discarded since the redesign couldn't ensure insulation of the motor housing, fundamental for the performance of the vacuum cleaner. Despite this, the clump showed in Fig. 83 decreases the number of steps from 6 to 1 and it groups together all the four high force intensity hidden snap fits connectors, which don't have to be disassembled anymore.

Fig. 82, Upper plastic clump disassembly of the Samsung SC8835

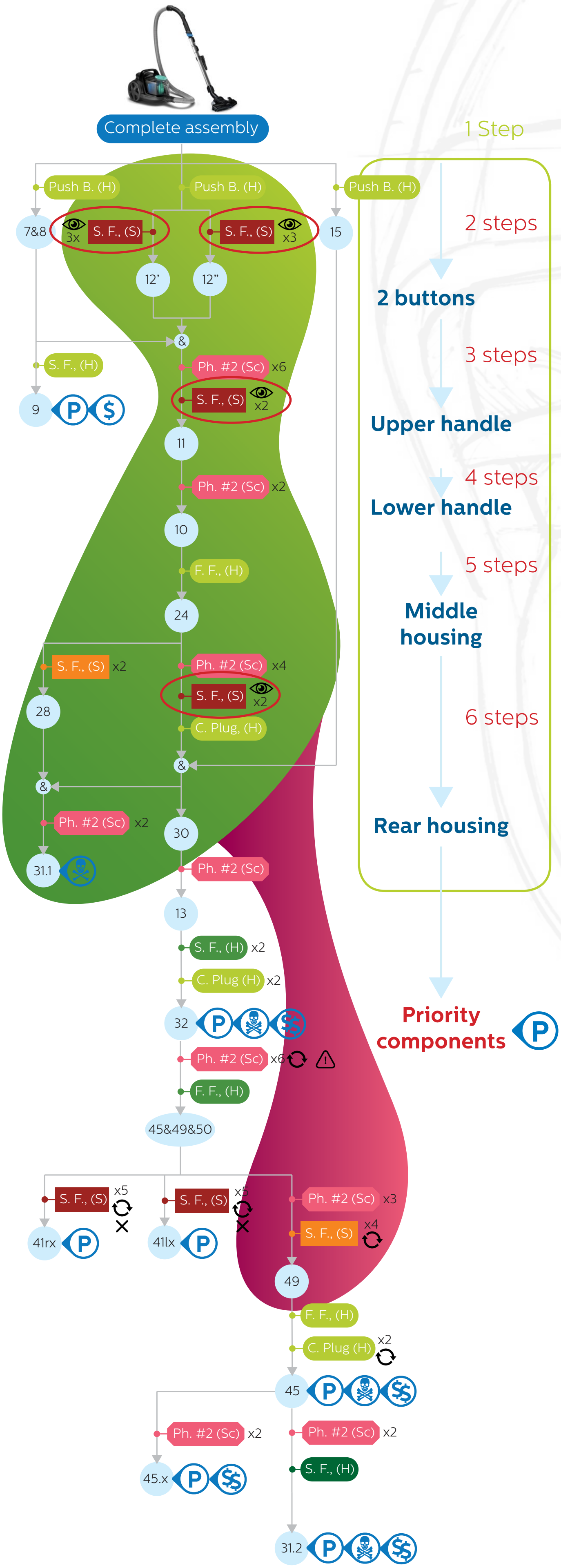


Fig. 83, Clump of 6 components, decreasing the number of steps from 6 to 1

To obtain the desired clump without increasing production cost and ensuring full manufacturability, very little of the current design has been changed. Four inner screws have been repositioned, in such a way that they can be reached from the outside, without requiring the disassembly of any of the upper plastic layers. These are screws A, which connect the motor housing lid to the rear housing, and screws B (Fig. 84), that connect the motor housing to the rear housing. Screws A have been repositioned slightly more in the centre of the product, while screws B have been unified in one single screw B' on the back of the appliance (Fig. 85). This solution make it possible to reach the repositioned screws from the outside (Fig. 86). While the repositioned screws A' are completely hidden beneath the removable dust bucket, screw B' is visible in the back of the product. This ensure minimal visibility of these fasteners, complying with the official Philips Design guidelines (Fig. 87). The new screws configuration can be seen in Fig. 85.

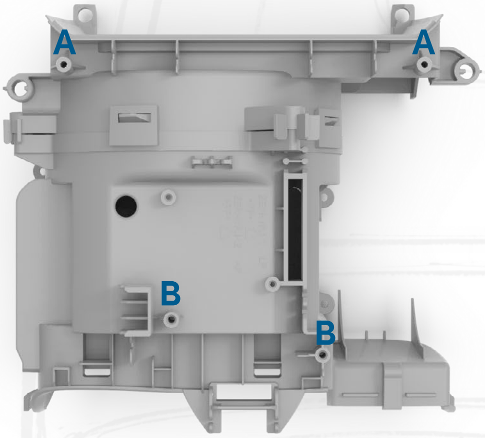


Fig. 84, Current design of motor housing and lid

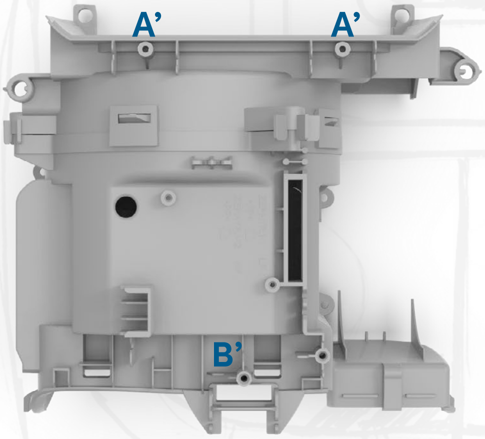


Fig. 85, Redesign of the motor housing and lid

Fig. 87, Minimal exterior aesthetic change

Fig. 86, New screws configuration

The rear housing has been redesigned as well. A new screw pole has been added in the back in order to insert screw B’ (Fig. 90). Additionally, the front part has been extended, creating two “wings” which are fastened by screws A’ (Fig. 88). This design solution makes the structure more stable and it optimize the use of the two screws, which are now fastening together motor housing, rear housing and middle housing (Fig. 89). Fastening of multiple components by means of the same screws was inspired by the architecture of the Siemens SyncroPower, where only three screws fasten the entire product (upper housing, motor housing and bottom housing).

These redesign allows to remove top buttons, upper handle, lower handle, middle housing and rear housing in one simple step, by removing 7 screws and applying a slight force on the top handle (Fig. 91).

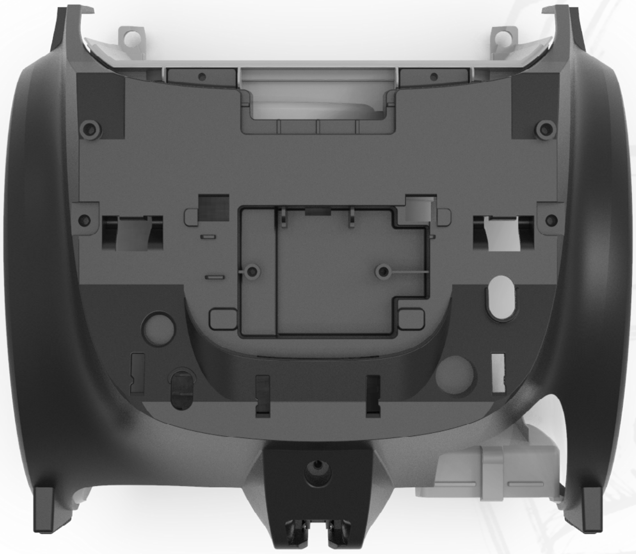


Fig. 88, Rear housing redesign (top view)

Fig. 89, Fastening of multiple components using the same screws

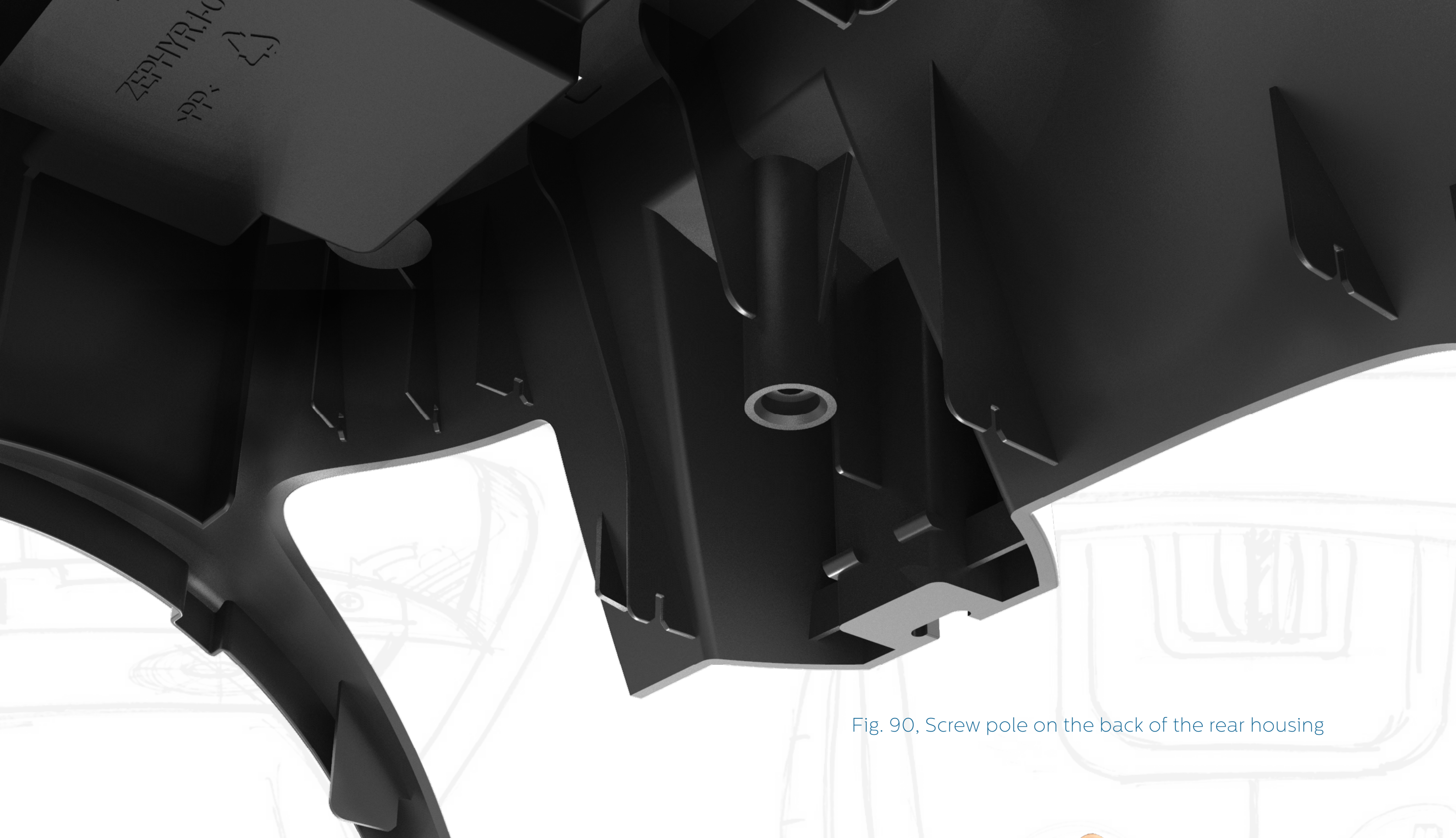


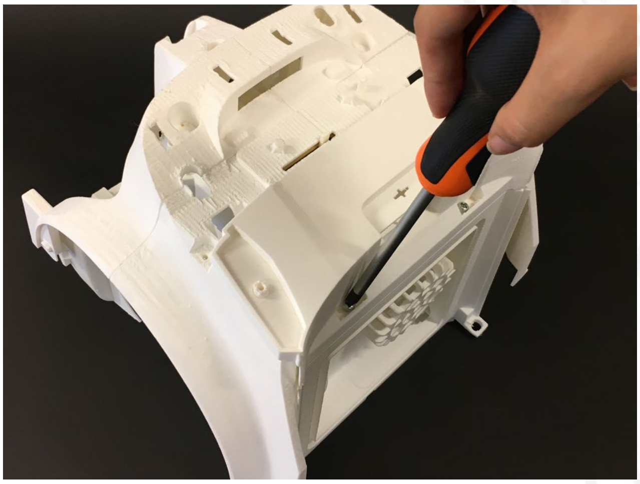
Fig. 90, Screw pole on the back of the rear housing

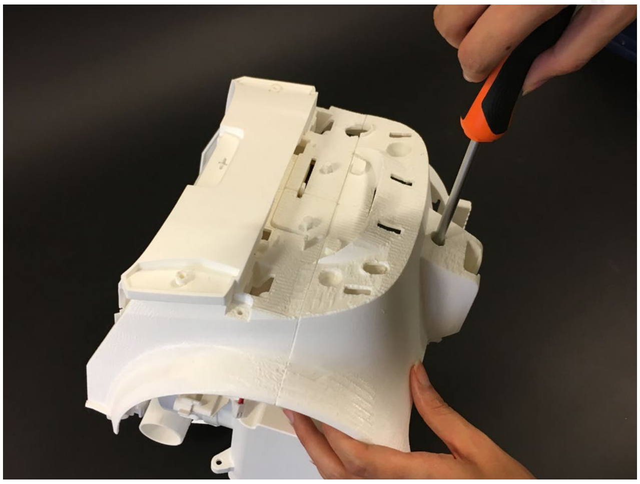
Fig. 91, One step disassembly of the top plastic cover clump

Testing of the redesign

In order to obtain a first proof of concept, the screws A and B have been removed from a model of Power Pro Active. Screws A’ and B’ have been then added to the vacuum cleaner, using an electric screw driver and self-tapping screws. This rudimentary model allowed to test the new assembly configuration, making sure that screws could fit in the indentations of the middle housing and that the dust bucked to be still hooked. This prototype has been further tested by carrying out a stress test that Philips performs on all it new canisters design. This is a pull test on the handle of the product, where a force equal to 10 times the weight of the specific model assessed is vertically applied (in this case 500 N). The test has been actually performed eight times, testing four different loads (500N, 600N, 800N and 1000N) As it can be seen by the stress analysis results shown in Graph 1, the design passed all the 8 tests, showing a maximum displacement of 11 mm at 1000N applied. Nevertheless, the test was not performed using the official Philips testing setup. On the contrary, the test has been performed on a Zwick/Roell Z010, 10 kN grips, controlled using the software testXpert® II (v. 3.6), at a testing speed of 10 mm/s and a pre-load of 60N (in order to be sure to stretch completely the chain before starting the test). The base of the vacuum cleaner has been fastened to a wooden surface using self-tapping screws, making sure just to fix the lower housing, without compromising the stress test on the rest of the assembly. A metal chain has been used to connect the product handle to the testing machine grips (Fig. 96,97,98 and 99).

3D CAD models have been modified, taking care of injection moulding tolerances, reinforcement ribs and draft angles. Eventually, the model have been then 3D printed, and components have been properly assembled using the new screw poles (Fig. 92, 93, 94 and 95).





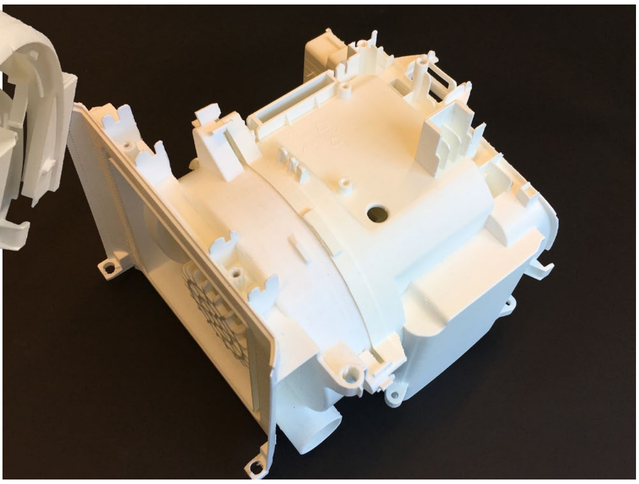


Fig. 93, 94, & 95, Testing the new screws configuration on the 3D printed model

Fig. 92, 3D printed model

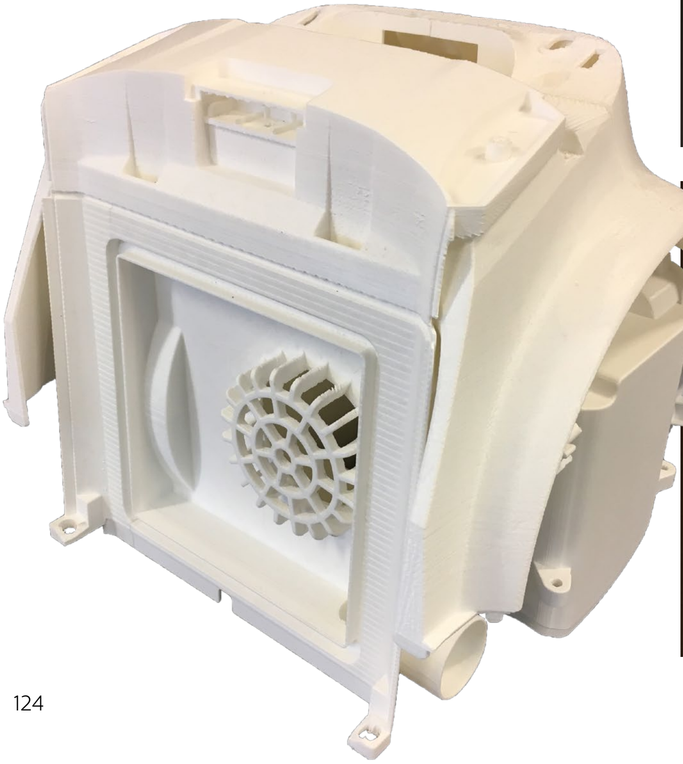
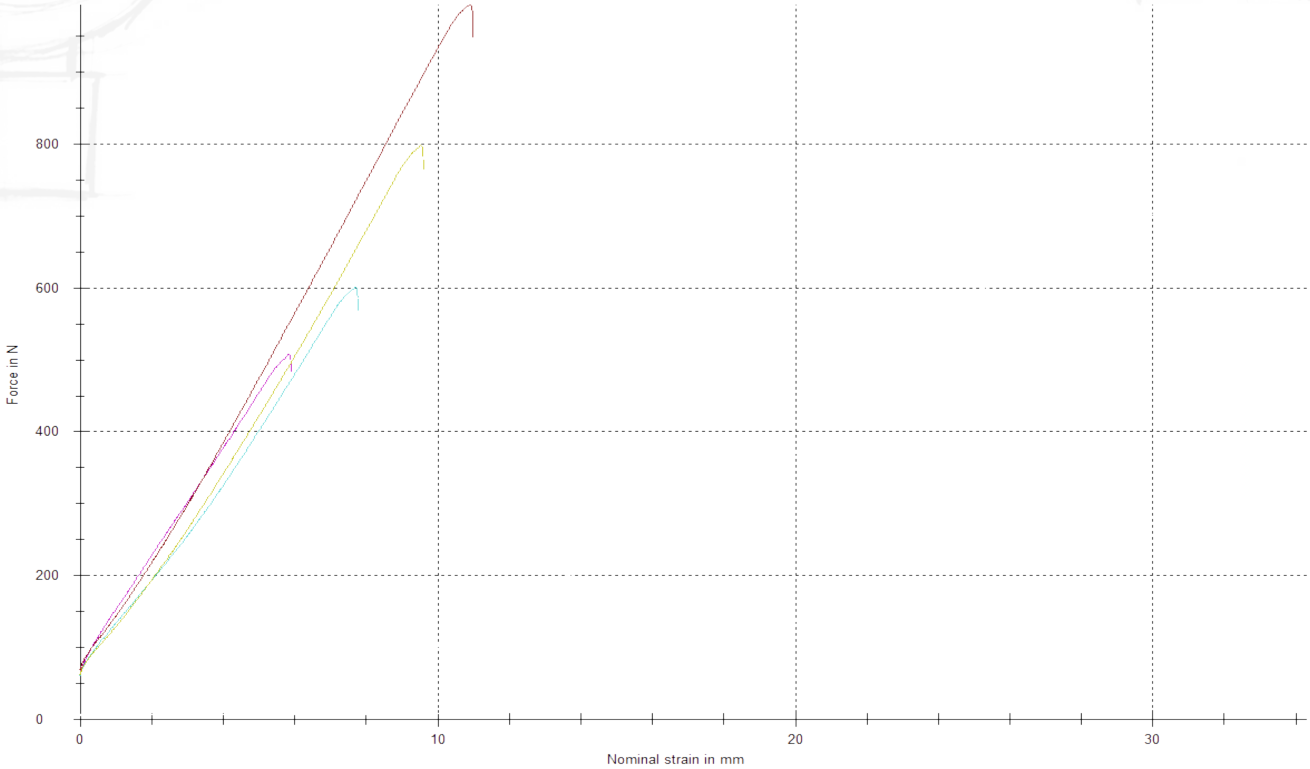


Fig. 96, 97, 98 & 99 Handle pull test setup

Graph 1, Stress test analysis results



Disassembly time improvement

This very simple redesign solution has an high impact on the disassembly time of all the inner priority components. This is due to the decrease in the number of disassembly steps, obtained clumping multiple components together, and because of the reduction of fasteners to be disconnected. In particular, the disassembly of four high force intensity hidden snap fit connectors is avoided, since they are included in the clump created. Because of the decrease in number of connectors, the number of tool changes has been reduced as well using the eDiM methodology (Table 20 and 21). The main improvements obtained are:

- 38% faster PCBA disassembly
- 41% faster Motor disassembly
- 60% faster Cord-winder disassembly

Repair service savings

These improvements have a considerable impact on the speed of repair services.

It was too early to retrieve reliable service data about the Power Pro Active, since recently launched on the market. However, the official call rates of another model assembled using the same priority components have been analysed, since very similar call rates are expected on the Power Pro Active as well. The amount of time, and labour cost, that would have been saved from 2017 (year of launch of this model) to today, if this redesign solution had been in place, has been calculated. Even so, because of confidentiality, exact values and name of priority parts cannot be share. The numbers here presented are rounded up and the components anonymous. The original calculation can be found in Confidential Appendix G. The main impact of the first redesign would be registered on three main components:

- Component 1, 250h of disassembly operations saved over three years
- Component 2, 34h of disassembly operations saved over three years
- Component 3, 9h of disassembly operations saved over three years

The faster service would have saved to Philips around 16.000 Euros over three years.

This amount of money does not represent an important quantity for the company; however, a faster service is fundamental for a better consumer experience. Moreover, the redesign presented would ensure better service quality overall by avoiding scratches on lucid plastic surfaces and the breakage of hidden snap fits connectors (as shown in the previous pages).

JRC repairability score improvement

By comparing Table 19 with Table 22, it is possible to observe how the disassembly index has been improved of 0,8 pt (from 7,3 to 8,1/10), while the overall RRU score has improved of 0,4 pt (from 6,2 to 6,8/10). This is a significant result since, as anticipated, the RRU process index remains unchanged (4/10). Furthermore, this has been achieved repositioning just four screws, leaving the rest of the product architecture untouched.

If this redesign solution had been implemented before production, its cost would have been zero. Nevertheless, according to I&D Developer Engineers, the design changes presented are so small that they could be implemented in DFX (Design for manufacturability). The new screw poles could be added to the current injection mould for a few thousand Euros, classifying this redesign as a short-term solution. However, further assessment is required and all the safety tests and quality checks should be performed on the new design again.

The comparison between the disassembly maps of current design and Redesign 1 can be seen in the next pages.

Considerations

This redesign shows how repairability could be drastically improved by applying simple design considerations. This solution, like the other three that are presented in the next pages, was extremely constrained by the current design. Even better results might be achievable if repairability was considered from early design stages.

In this case, the amount of economic savings determined by faster service operations would not be extremely relevant for the company. However, the almost 300 hours of repairs saved could have provided a faster customer service.

Eventually, the clump created is mainly composed by external aesthetic plastic casing. This configuration would allow future aesthetics changes of the upper housing without redesigning motor and lower housing. New plastic covers could just be mounted using the same fastening configuration and determining a modular architecture.

Disassembly results, Current design

Part	Steps (n.)	Tool changes (n.)	Connections (n.)	eDIM (s)	% of total disassembly time	% of total connectors	Uncommon tools
Total Disassembly	33	17	86	914	100	100	
Nozzles (6,3)	1	0	1	6	0,7	1,2	
Hose (111)	1	0	3	21	2,3	3,5	
Cordwinder (32)	10	7	31	396	43,3	36	
Wheel (41 rx or lx)	12	8	43	539	59	50	1 too deep screw
Motor (45)	13	9	48	576	63,1	55,8	1 too deep screw
PCB (31)	14	10	51	616	67,3	59,3	1 too deep screw
External casing (11)	4	3	16	228	24,9	18,6	1 too deep screw
Filter (9)	2	0	2	13	1,4	2,3	
Motor brushes (45.X)	14	10	50	607	66,4	58,1	

Table 20, Disassembly results of the current design

Disassembly results, Redesign 1

Part	Steps (n.)	Tool changes (n.)	Connections (n.)	eDIM (s)	% of total disassembly time	% of total connectors	Uncommon tools
Total Disassembly	30	17	86	914	100	100	
Nozzles (6,3)	1	0	1	6	0,7	1,2	
Hose (111)	1	0	3	21	2,3	3,5	
Cordwinder (32)	5	2	15	160	17,5	17,4	
Wheel (41 rx or lx)	7	4	27	306	33,2	31,4	1 too deep screw
Motor (45)	8	5	32	341	37,3	37,2	1 too deep screw
PCB (31)	9	6	35	380	41,6	40,7	1 too deep screw
External casing (11)	4	3	16	6	0,7	18,6	1 too deep screw
Filter (9)	2	0	2	13	1,4	2,3	
Motor brushes	9	6	34	369	40,4	39,5	

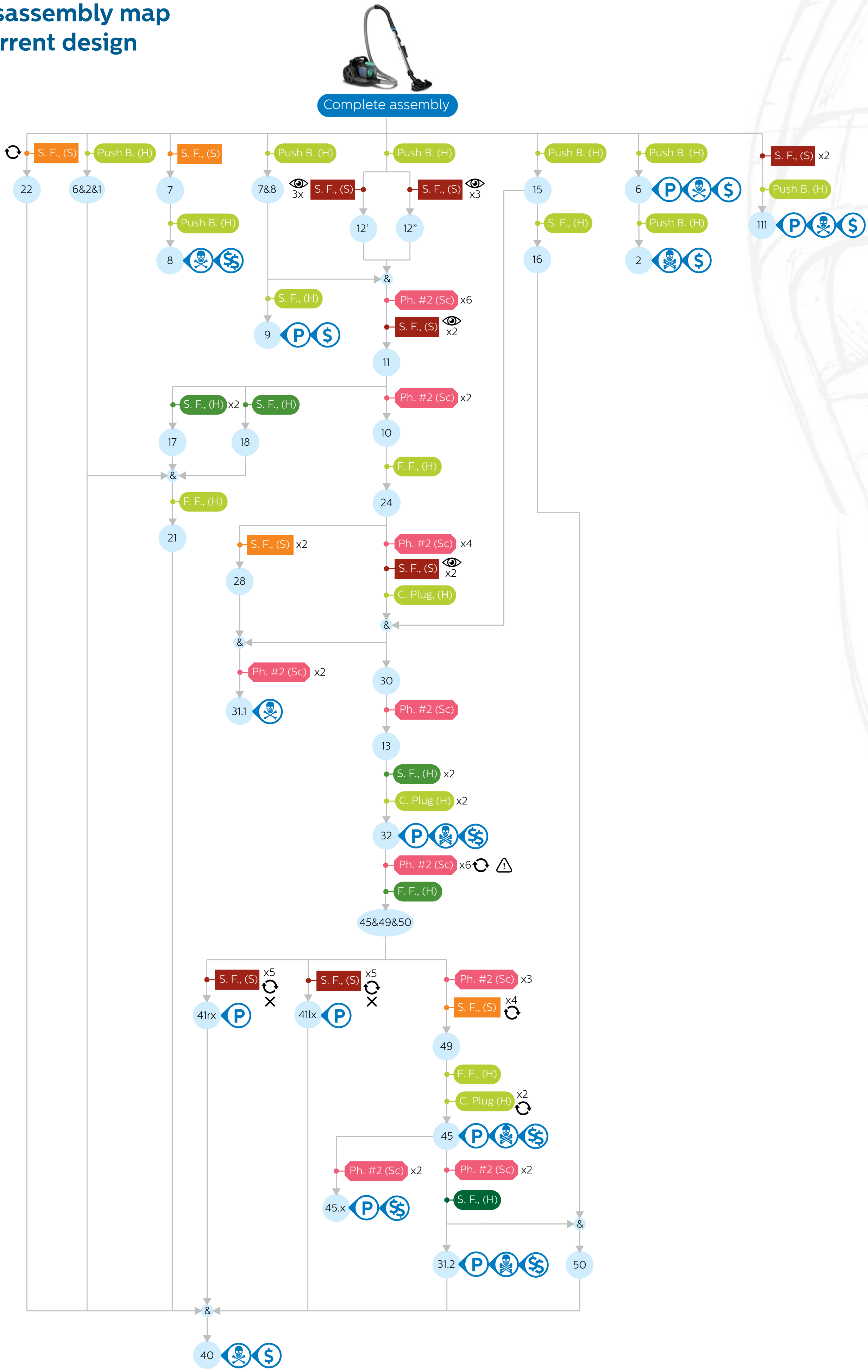
Table 21, Disassembly results of the first redesign

Philips FC9569/01	PART 1	PART WEIGHT	PART 2	PART WEIGHT	PART 3	PART WEIGHT	PART 4	PART WEIGHT	PART 5	PART WEIGHT	PART 6	PART WEIGHT	PART 7	PART WEIGHT	PART 8	PART WEIGHT		
PARAMETER	MOTOR	3	MOTOR BRUSHES	3	FILTERS	3	HOSE	3	POWER CABLE	3	WHEELS	1	PCBA	1	NOZZLES	1	PARAMETER SCORE	PARAMETER WEIGHT
#4 Disassembly time	0,51		0,52		1,00		0,56		0,67		0,03		0,31		0,56		5,93	2,00
#1 Disassembly depth / sequence	0,62		0,78		1,00		1,00		1,00		0,14		0,33		1,00		8,15	2,00
#2 Fasteners	1,00		1,00		1,00		1,00		1,00		1,00		1,00		1,00		10,00	2,00
#3 Tools	0,66		0,66		1,00		1,00		1,00		0,66		0,66		1,00		8,49	2,00
#6 Type and availability of information	0,50		0,50		0,50		0,50		0,50		0,50		0,50		0,50		5,00	2,00
#7 Spare parts	0,25		0,00		0,50		0,50		0,25		0,25		0,25		0,50		3,06	2,00
#12 Commercial guarantee	0,00		0,00		0,00		0,00		0,00		0,00		0,00		0,00		0,00	/
RRU indices for parts	5,9		5,8		8,3		7,6		7,4		4,3		5,1		7,6			

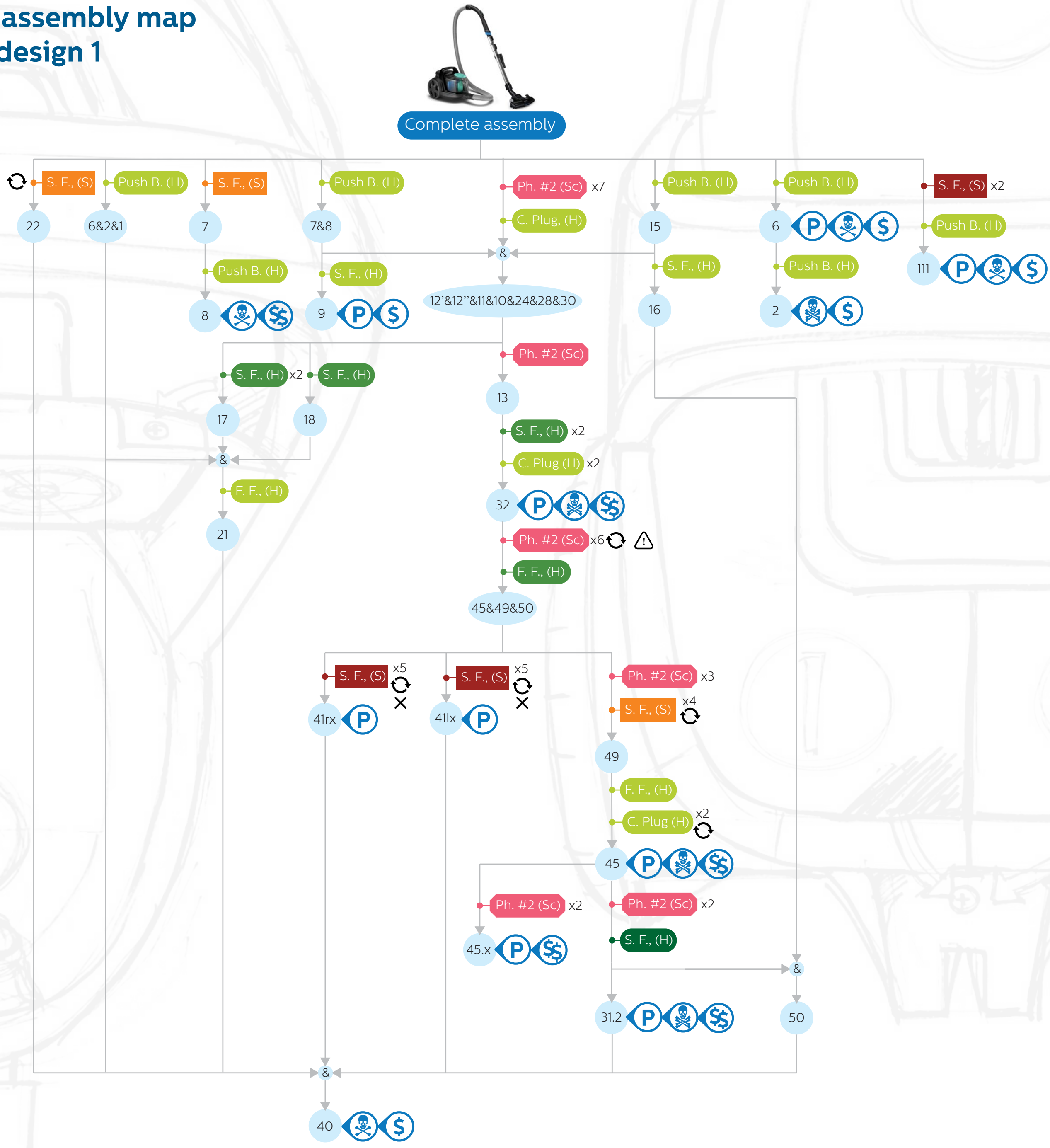
Disassembly index	RRU Process index	OVERALL RRU	Commercial Guarantee
8,1	4	6,8	0,00

Table 22, Repairability assessment results for the first redesign

Disassembly map
Current design



Disassembly map Redesign 1



Components

- 111. Hose assy Zephyr
- 6. Tri-Active+ LC nozzle
- 7. Dust bucket Lid
- 8. Dust bucket assy incl. Vortex
- 9. Integrated filter
- 10. Lower handle cover
- 11. Top cover
- 12'. On/off button
- 12''. CW button
- 13. Cord outlet
- 15. Exhaust grill
- 24. Middle housing
- 28. Power slider assembly
- 30. Rear housing cover
- 31.1 Power slider
- 31.2 PCBA part 2
- 32. Cordwinder Zephyr
- 41 lx. Rearwheel assy left
- 41 rx. Rearwheel assy right
- 45. CDS Motor CDS-EY29-008 1800 W
- 45.x. Motor Brushes
- 49. Motor housing lid

Legend

Tools

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

Connectors

S. F. = Snap Fit
F. F. = Friction Fit
C. Plug = Cable plug
Push B. = Push button
Hg = Hinge

Penalizations

⟳ = Product manipulation
👁 = Identifiability (low visibility)
⚠ = uncommon tool
✕ = Unreusable connector

Force intensity

0N	5N	20N
(S)	(S)	(S)
(H)	(H)	(H)

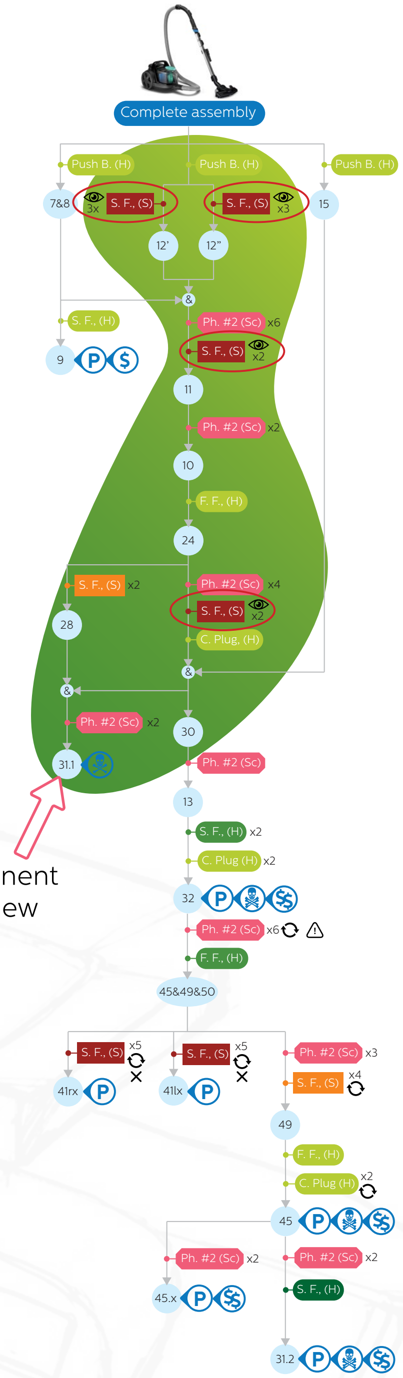
Disassembly HotSpot Indicators

P = Priority component
$ = Economical indicator L.1
☠ = Environmental indicator L.1
$$ = Economical indicator L.2
☠ = Environmental indicator L.2

7.4 Redesign for HotSpot components accessibility through bottom-up assembly

Analysis of the current design

This second redesign is directly connected with the previous one. By creating a big clump of upper plastic layers the disassembly time and depth was considerably decreased.
It could be argued that clumping methodology limit product recycling. On the contrary, as repetitively supported by Marks et al. (1993) and Ishii & Lee (1996), a properly designed clump would actually improve product recycling, by grouping together components according to their EoF scenarios. In the previous redesign, ABS and PP plastic components have been clump together. In a recycling facility this assembly can be grind together, and small metal components extracted using magnets.
However, in redesign 1 an HotSpot component in still trapped inside this new sub-assembly (Fig. 100). This is the power slider electronic shield, a component which has been identified by the HotSpot mapping tool as environmentally armful because composed by electronic components. Consequently, this has been clearly indicated on the disassembly map as well (Fig. 100). The power slider is a rather simple electronic part, which does not involve complex circuits or components. However, because of recycling processes, it might be preferable to make it easy to access and disassemble. This second redesign presents a possible solution to this problem.



HotSpot component trapped in the new clump

Fig. 100, HotSpot component included in the previous clump

Bottom-up assembly

The assembly of inner components on the bottom surface rather than top surface of plastic components have been observed in some of the vacuum cleaners disassembled. In many case this was performed in order to facilitate the removal of the fastened part, without trapping it between plastic layers. This solution might not be the most optimized one for assembly lines, since plastic assembly have to be turned retetitely. However, this design solution was already performed by Philips in previous models, like in the mid-end bag canister FC85XX series (Fig. 101).

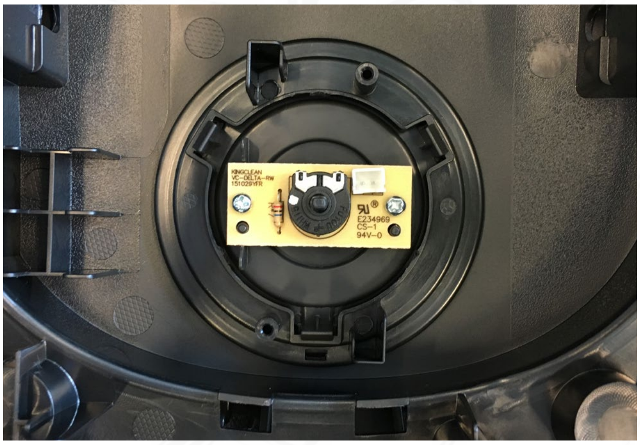


Fig. 101, Power knob assembled from the inside towards the outside in a FC85XX.

Two possible design solutions have been considered for the bottom-up assembly of the power slider:

- The component could be assembled directly on the power slider cover. This solution would involve the positioning of new screw poles on the lucid ABS cover and a big hole in the middle of the rear housing body would be necessary to reach it. This option was discarded since, according to Philips Developer engineers, it is always better to avoid to place long screw poles on aesthetic surfaces, since possible deformations might appears on the lucid finishing. Moreover, a big hole in the middle of the rear housing could compromise its stiffness and stability.
- The component could be mounted on the other side of the rear housing (Fig. 102). A small cut would be required in order to allow the power slider arm to get to the outer PP handle (Fig. 104), but this would not compromise stiffness because of its small dimension. Screw poles would be created on the PP rear housing, and they would be completely hidden by the upper ABS plastic casings (Fig. 103).

In order not to compromise the stiffness of the rear housing, avoid possible aesthetic deformations on the lucid ABS surfaces and modify as few components as possible, the second redesign solution was selected.

Fig. 103, Current design; Power slider trapped between plastic components; Rear housing redesigned, with power slider mounted from the bottom

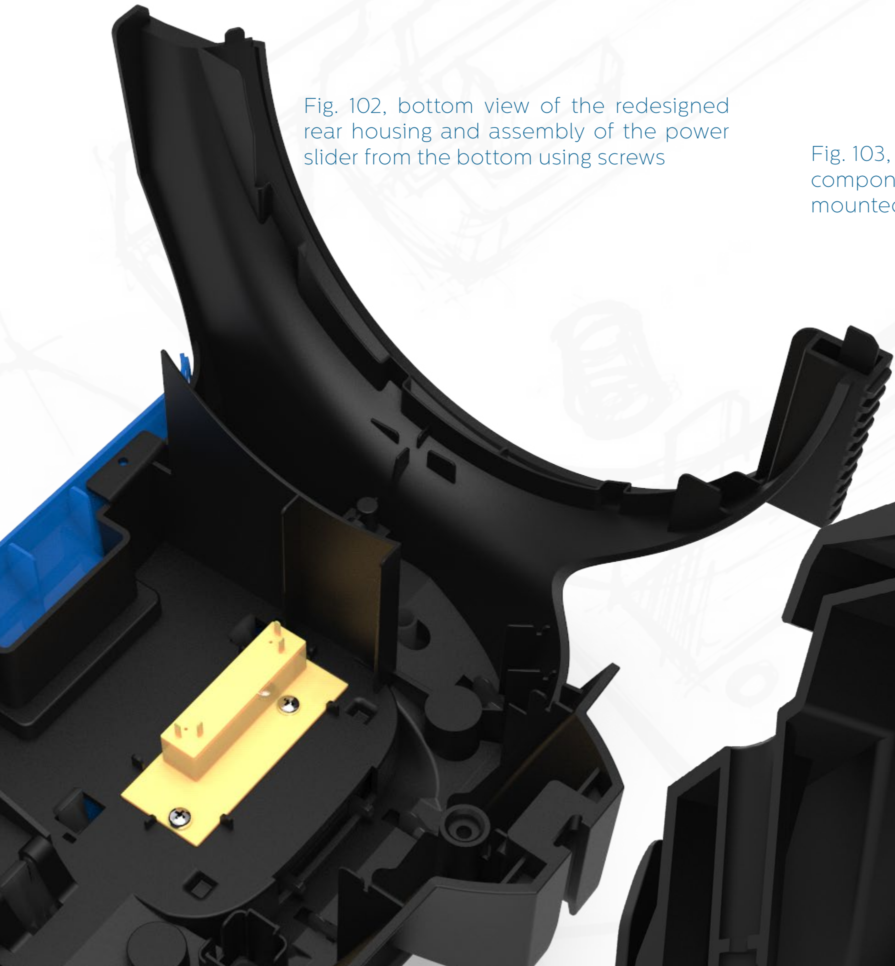


Fig. 102, bottom view of the redesigned rear housing and assembly of the power slider from the bottom using screws

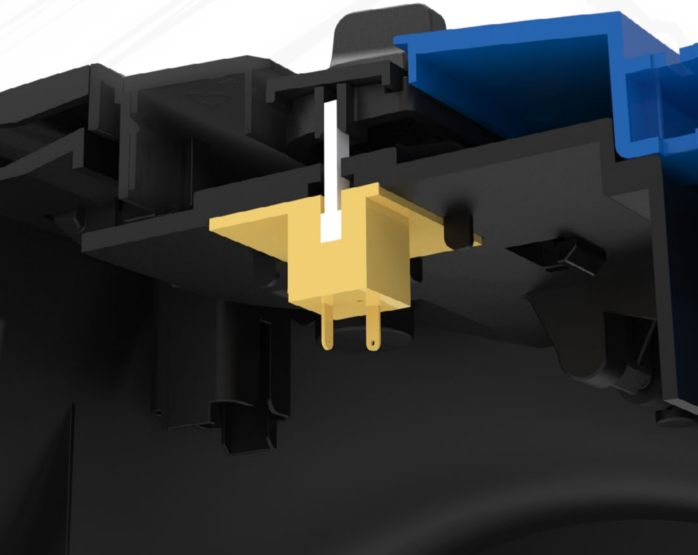


Fig. 104, Section view showing the connection between power slider and power slider ABS cover

Testing of the redesign

This redesign has been 3D printed as well. The physical model has been used to test the new bottom-up assembly configuration, assessing stability and stiffness of the fastening system (Fig. 105 and 108). The slider cover has been mounted on top, and it was checked that everything fitted correctly (Fig. 106).

Considerations

This redesign is not meant to improve the JRC score. In fact, this power slider is not included in the list of priority component assessed against repairability. However, this component should be considered for DFPR, as pointed out by the HotSpot Mapping analysis as well. Bottom-up assembly is an interesting technique, which could be often required if clumping methodology is applied. Assembling components from the inside-out might not be the best solution for assembly lines, since it requires to turn the product multiple times. However, turning upside-down light plastic clumps would not slow down considerably the total assembly time but, on the other hand, it would improve disassembly. This is clearly visible by comparing the two disassembly maps in Fig. 107.

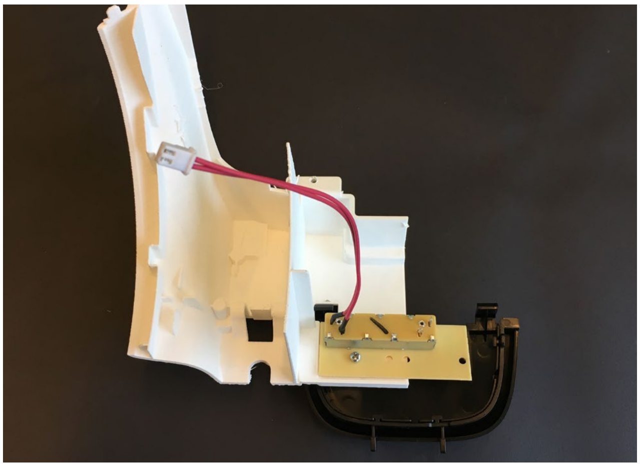


Fig. 106, Testing part of the new design of the rear housing with the top ABS cover and power slider

This second redesign could not be implemented in DFX, since it requires important changes in the injection mould of the rear housing. However, its cost would have been zero if considered while design the product in the first place. For this reasons, this is considered a medium-term solution, which could be easily implemented in future products.

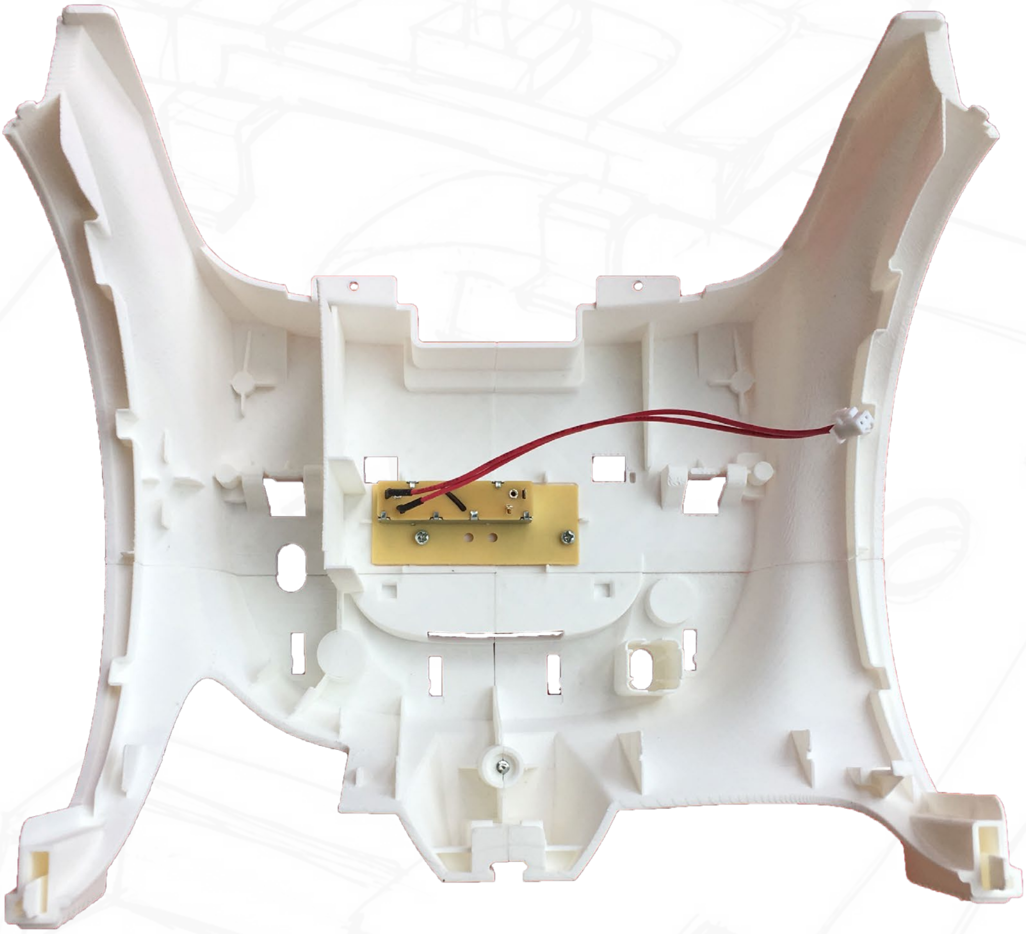


Fig. 105, bottom view of the 3D printed model of the redesigned rear housing. Bottom-up assembly of the power slider using Phillips 1 screws

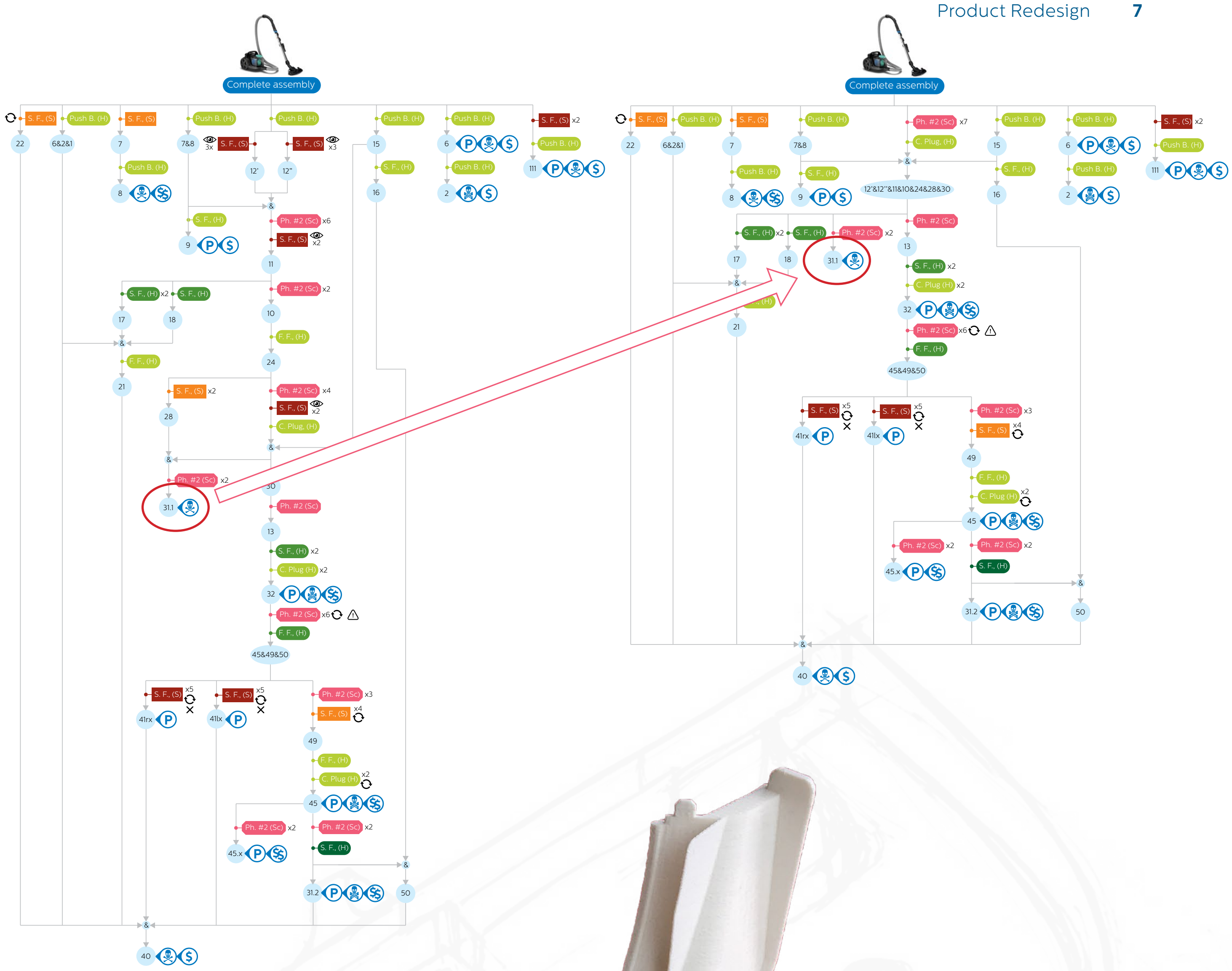


Fig. 107, Comparison of the current design disassembly map with the map showing redesign 1 and 2.

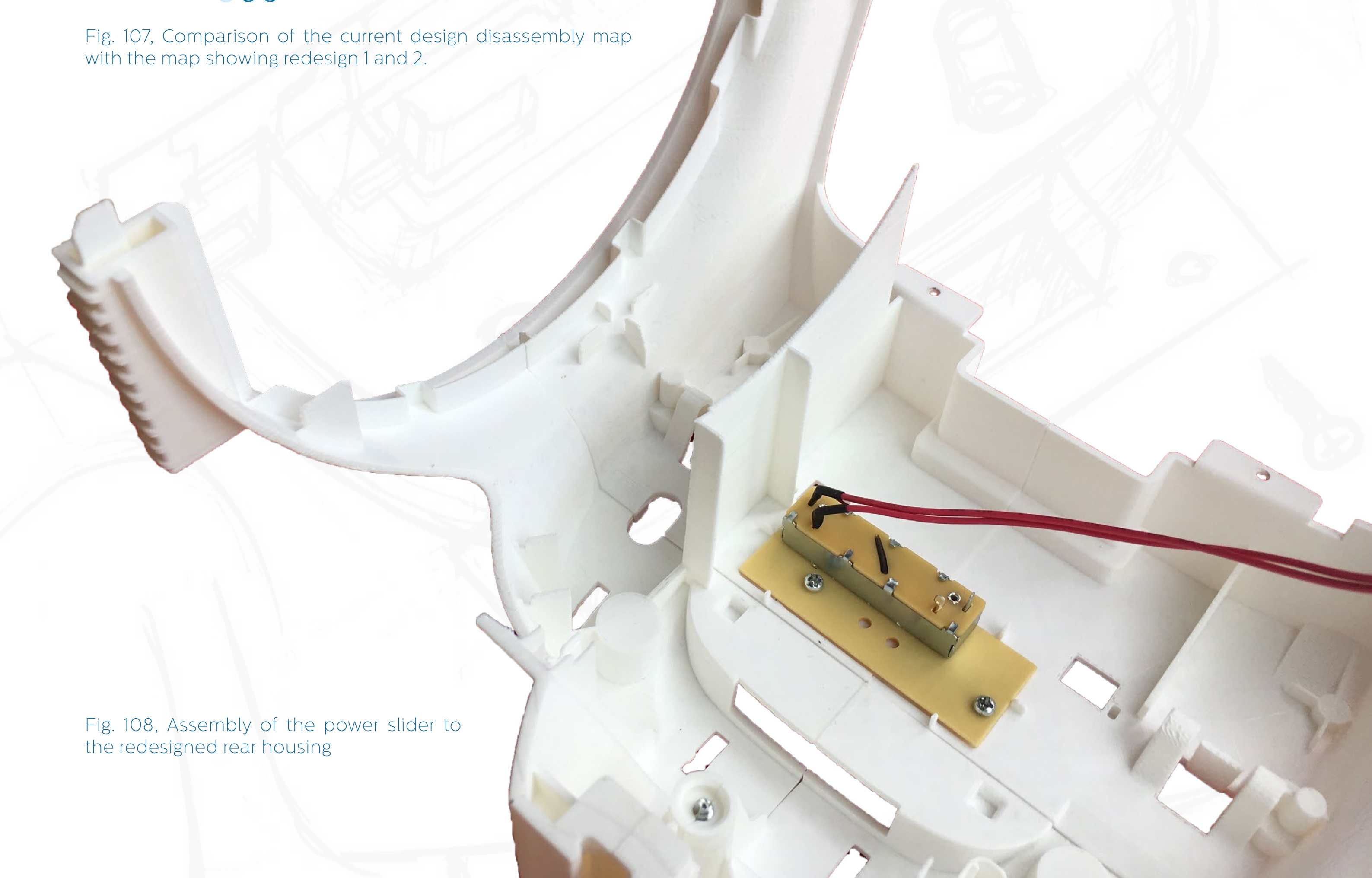


Fig. 108, Assembly of the power slider to the redesigned rear housing

7.5 Redesign for legislation compliance and use of common tools

Analysis of the current design

The preliminary draft of the standard prEN45554 (CEN/CLC TC10 European Standard, 2017) clearly defines a list of commonly available tools. The JRC scoring system for repairability uses this list as a reference in order to assess parameter 3 (Tools required for the repair operations). The prEN45554 specifies exact tooling dimensions through the ISO norms (Table 23). The Power Pro Active can be disassemble using common tools, except for the removal of one single screw which connects the motor housing to the lower housing. This situation was repeatedly observed also in other Philips canister models where, in order to fix the base of the bulky motor housing, screws are positioned too deep in the product and cannot be reached using common tools. According to a I&D developer engineer, this design choice is not meant to discourage self-repairs. On the contrary it is a functional decision since it is always advisable to use short screw poles (avoiding visible deformation on the outside of the product); moreover, all the official service centres uses very long screw drivers which can easily reach these deep fasteners. This was checked in Germany, at the European Repair Centre, where repairers were actually using very long tools to reach all the screws (Fig. 110). The screws used in this specific model are Phillips 2. According to the ISO 8764 (specified by the prEN45554 for this type of screw head), the distance between the base and the tip of the tool should not be longer than 100 mm. On of the screw holes in the Power Pro Active is positioned few millimetres higher, at 99,46 mm (Fig. 111); this means that a standard ISO screw driver can actually touch with the tip the head of the screw, but it can have enough grip on it to actually turn and remove the fastener. This was tested multiple times, proving that it was not possible to remove the screw in any way. A longer not standard screw driver had to be used instead, like those used in the service centres as well. Consequently, this has been indicated in the Disassembly Map of this model (Fig. 109) and in the calculation of the final repairability score (Table 19).

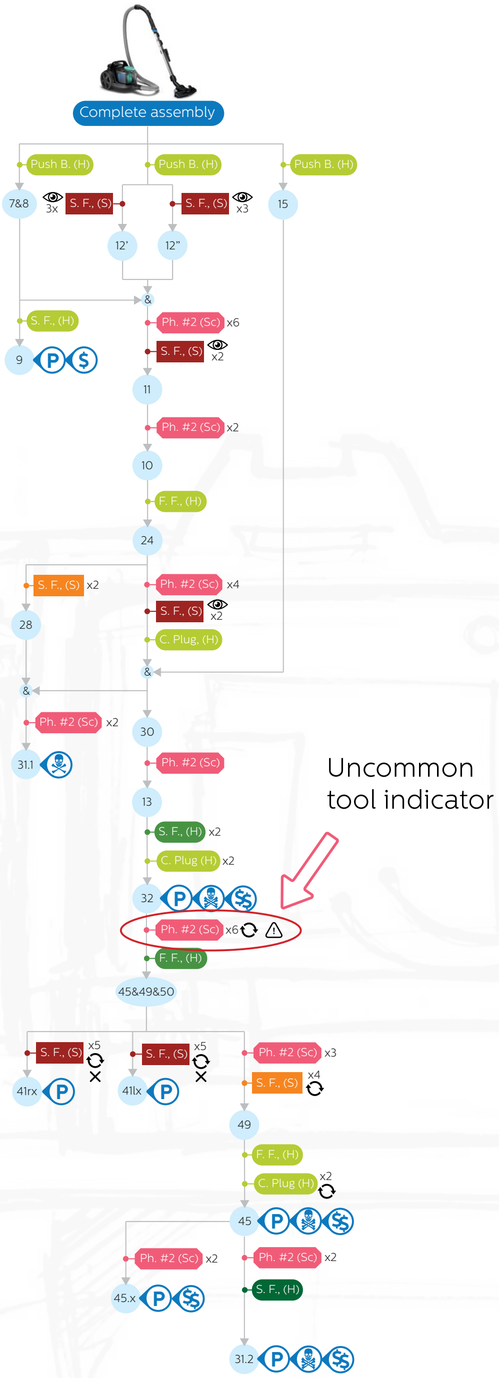


Fig. 109, Uncommon tool indicated on the Disassembly map

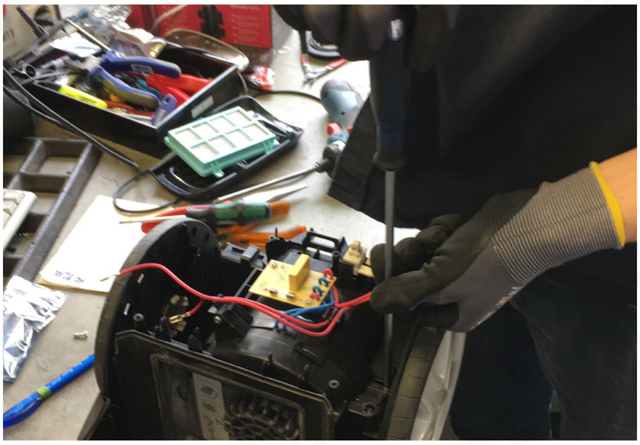


Fig. 110, Official repairer using a not standard long screw driver to reach the too deep screw

Redesign

In order to avoid the use of uncommon tools for the disassembly of this product, the motor and bottom housing have been slightly modified. The screw pole positioned on the lower housing has been extended by 15 mm, while the side walls of the motor housing has been lowered of 10 mm. In the new redesign the screw is now 74,5 mm deep and it can be reached by using not only a Philips 2, but also a Philips 1 screw driver (Fig. 113 and 114). The 25 mm saved have been spread on the lower and motor housing in such a way to avoid the creation of a too long screw pole on the back of the lower housing, since this would have likely

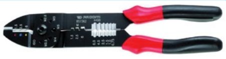
Tool type	Illustration (informative example)	Reference
Hammer, steel head		ISO15601
Combination pliers		ISO5746
Half-round nose pliers		ISO5745
Multigrip pliers (multiple slip joint pliers)		ISO8976
Diagonal cutters		ISO5749
Combination pliers for wire stripping & terminal crimping		
Combination wrench		ISO7738
Hexagon socket keys (Allen keys)		ISO2936
Screwdriver for slotted heads		ISO2380
Screwdrivers for cross-recessed (Phillips® and Pozidriv®) heads		ISO8764
Screwdrivers for hexalobular recess (Torx®) heads		ISO10664 (driving feature)
Multimeter		
Utility knife (cutter) with snap-off blades		

Table 23, List of common tools defined by the prEN45554 (CEN/CLC TC10 European Standard, 2017)

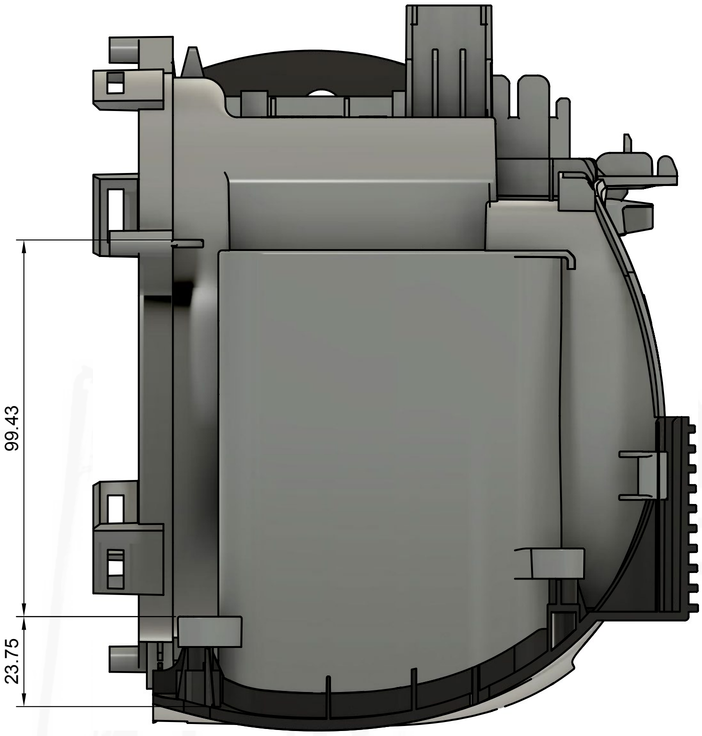


Fig. 111, Lower housing screw pole dimension and distance between screw hole and top surface in the current design

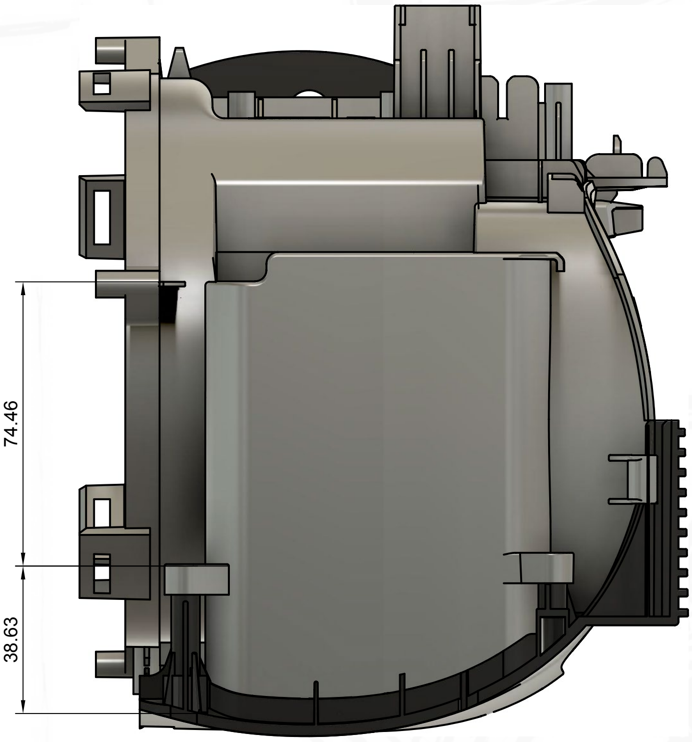


Fig. 112, Lower housing screw pole dimension and distance between screw hole and top surface in the new redesign caused visible deformations on the outside shell of the product (Fig. 112). Moreover, by modifying the motor housing as well more freedom of movement and visibility is achieved.

A physical model of this redesign has been 3D printed as well, and the new dimensions have been tested using a Phillips 1 and 2 screw drivers (Fig. 115)

JRC repairability score improvement

This very simple and feasible design change would improve the Disassembly index of 0,3 pt and the Overall scored of 0,2 pt. By comparing Table 19 to Table 24, it is possible to see how the final score has been considerably improved considering Redesign 1 and Redesign 3 together. The total improvements are 1,2 pt on the Disassembly index (from 7,3 to 8,5/10) and 0,8pt on the Overall score (from 6,2 to 7/10).

Considerations

This redesign does not substantially improve product serviceability since all the official repair centres are already equipped with long screw drivers. However, it has a considerable impact on the final repairability score. As all the other redesign presented so far, this is a very simple solution, which would not raise production costs if considered in preproduction design stage. However, implementing this redesign now would require to create a new injection mould for the motor housing. Therefore, this is a design solution which is meant to inspire the Philips I&D and that could be easily implemented in new models coming on the market in the next 12-24 months (medium-term solution). The redesign has been shown to the mechanical engineering team, which confirmed its manufacturability and feasibility.

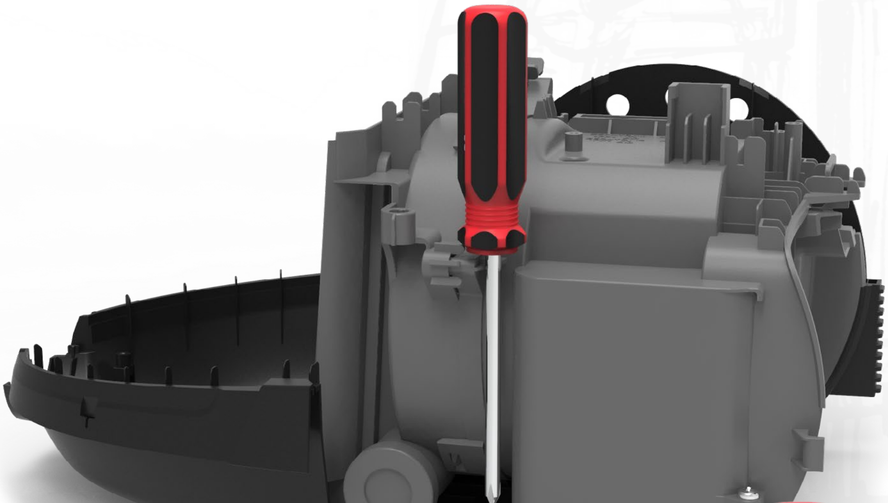


Fig. 113, Render of the current design and a Phillips 2 screwdriver

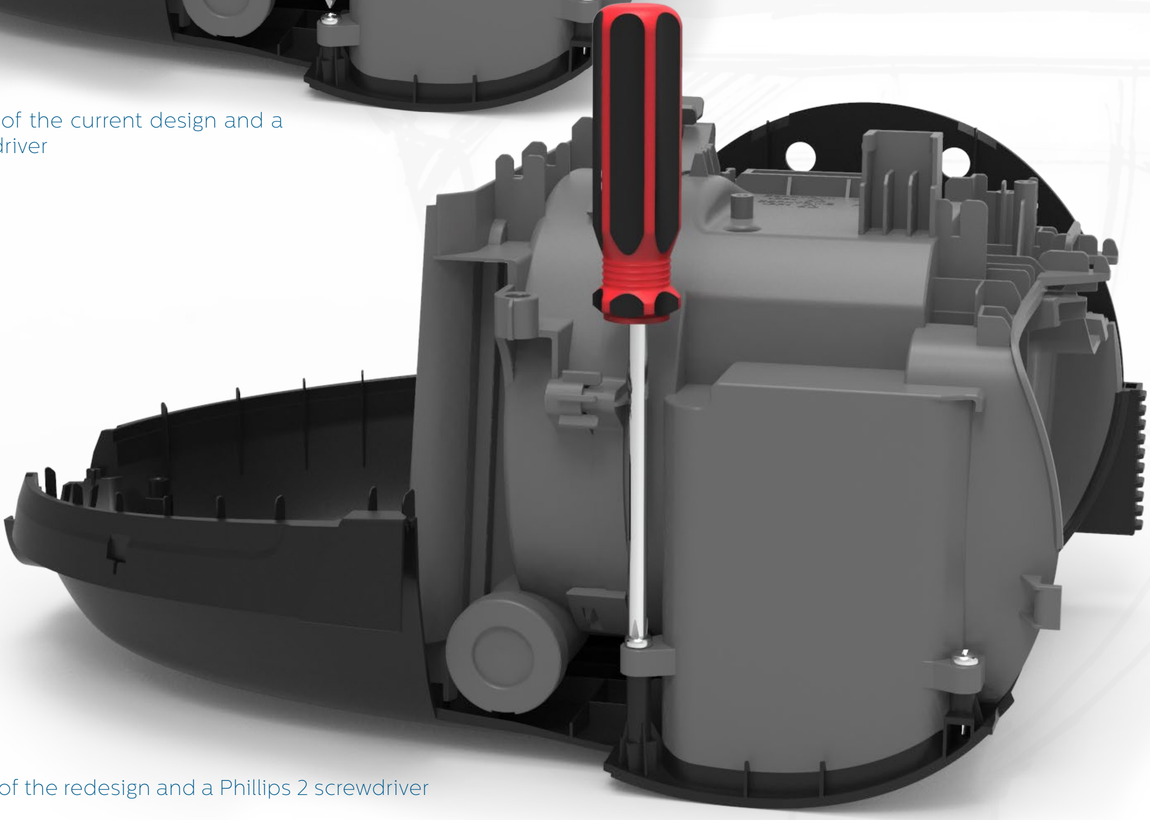


Fig. 114, Render of the redesign and a Phillips 2 screwdriver

Table 24, Repairability assessment results for the Philips Power Pro Active

Philips FC9569/01	PART 1	PART WEIGHT	PART 2	PART WEIGHT	PART 3	PART WEIGHT	PART 4	PART WEIGHT	PART 5	PART WEIGHT	PART 6	PART WEIGHT	PART 7	PART WEIGHT	PART 8	PART WEIGHT		
PARAMETER	MOTOR	3	MOTOR BRUSHES	3	FILTERS	3	HOSE	3	POWER CABLE	3	WHEELS	1	PCBA	1	NOZZLES	1	PARAMETER SCORE	PARAMETER WEIGHT
#4 Disassembly time	0,51		0,52		1,00		0,56		0,67		0,03		0,31		0,56		5,93	2,00
#1 Disassembly depth / sequence	0,62		0,78		1,00		1,00		1,00		0,14		0,33		1,00		8,15	2,00
#2 Fasteners	1,00		1,00		1,00		1,00		1,00		1,00		1,00		1,00		10,00	2,00
#3 Tools	1,00		1,00		1,00		1,00		1,00		1,00		1,00		1,00		10,00	2,00
#6 Type and availability of information	0,50		0,50		0,50		0,50		0,50		0,50		0,50		0,50		5,00	2,00
#7 Spare parts	0,25		0,00		0,50		0,50		0,25		0,25		0,25		0,50		3,06	2,00
#12 Commercial guarantee	0,00		0,00		0,00		0,00		0,00		0,00		0,00		0,00		0,00	/
RRU indices for parts	6,5		6,3		8,3		7,6		7,4		4,9		5,7		7,6			

Disassembly index	RRU Process index	OVERALL RRU	Commercial Guarantee
8,5	4	7	0

Fig. 115, 3D printed model testing using a standard Phillips 2 screwdriver

7.6 Redesign for sequence independent disassembly and safer self-repairs

Analysis of the current design

Although the product architecture has been substantially improved by the three redesign solutions presented so far, the disassembly of some priority part would still be time demanding. This is clearly shown by the improved disassembly map (Fig. 116). For instance, the disassembly of component 31,2 (PCBA), is sequential dependent, requiring 9 disassembly steps. This is due to the fact that the wires which connect the electric board to cord-winder (component 32) and motor (component 45) are soldered on the PCBA instead of being attached using connectors (Fig. 117). Philips official repair centres are not allowed to unsolder this connectors; on the contrary, they have to disassemble both cord-winder and motor, of then opening the connectors placed on these two components. Electric solders are not considered common tool by the prEN45554 as well, and it is likely that most of private consumers do not own one. All the competitors analysed presented a better configuration for the disassembly of this part: both Samsung and Rowenta placed two connectors on their PCBA's in order to easily disconnect the wires coming from cord winder and motor (Fig. 118 and 119). Siemens soldered the wires directly on the PCBA, like Philips, but the disassembly of the connectors placed on the cord-winder and motor is much easier compared to the sequential disassembly of the Philips architecture.

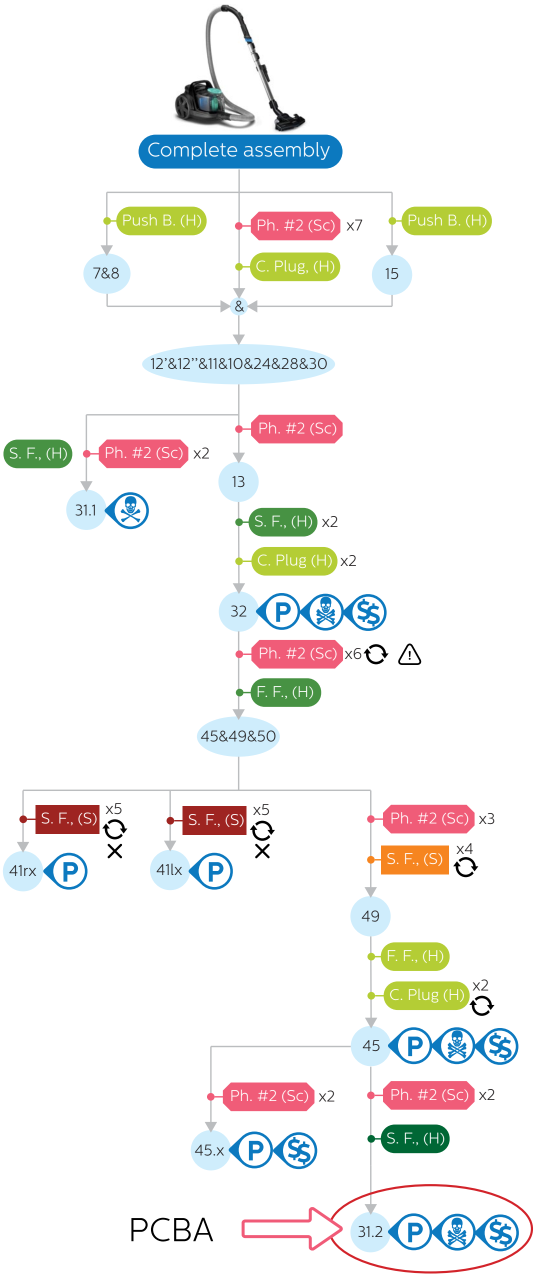


Fig. 116, Partial Disassembly map of the Power Pro Active, after redesign 1, 2 and 3 and position of the PCBA

Fig. 117, PCBA of the Power Pro Active

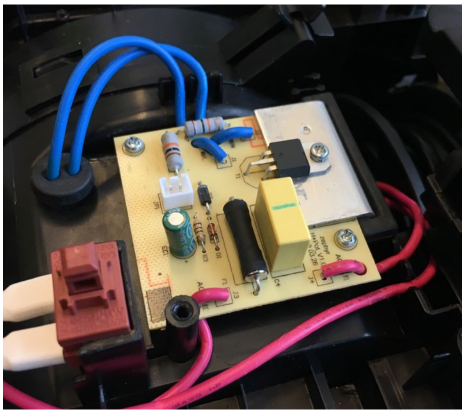


Fig. 118, PCBA of the Samsung SC8835

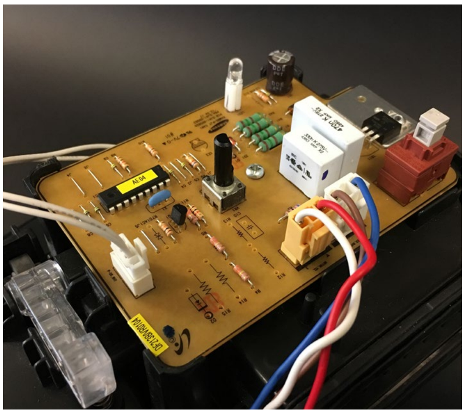
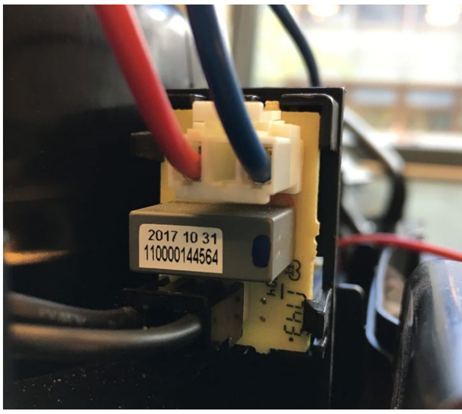


Fig. 119, PCBA of the Rowenta X-Trem



Redesign

In order to make the disassembly of the PCBA sequentially independent from cord-winder and motor, two connectors should be added on the electric board. This would allow to disconnect immediately the PCBA from the other two components, without requiring to disassemble all the vacuum cleaner. Both Samsung and Rowenta use the same type of connector: B2P3-VH from JST Sales America Inc. (JST, 2019) (Fig. 120). This is a 7,92 pitch connector, which can support up to 7A of current, making it suitable of the high current used by the AC motor of the vacuum cleaner.

In order to check if it was really feasible to implement two of these connectors in the current design, the Power Pro Active PCBA has been re-engineered (Fig. 121 and 122). In order to publicly share this information, the circuit has been reconstructed without using the official Philips schematics. This circuit is a motor driver power regulator, which uses the A/D Flash MCU with EEPROM HT66F002, designed by Holtek Semiconductor Inc (Holtek, 2017) . The IC controls a 16A triac (BTA16). The circuit schematic also redrawn; however, this will not be shared (Confidential Appendix H).Because of the high current required by the AC motor, the copper tracks have to be quite thick.

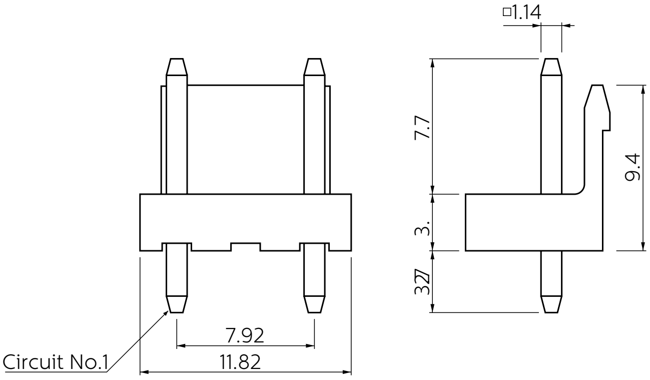


Fig. 120, 7A connector B2P3-VH (JST, 2019)

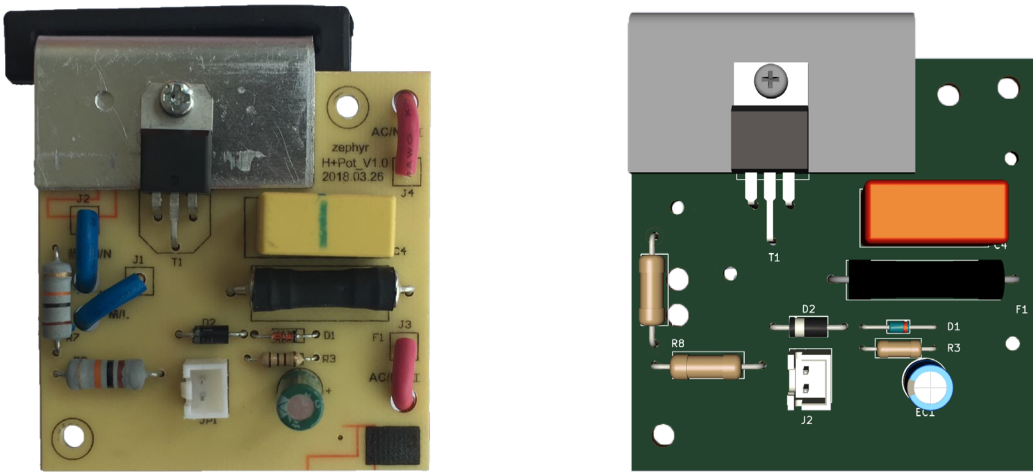


Fig. 121, PCBA Re-engineering, Top view

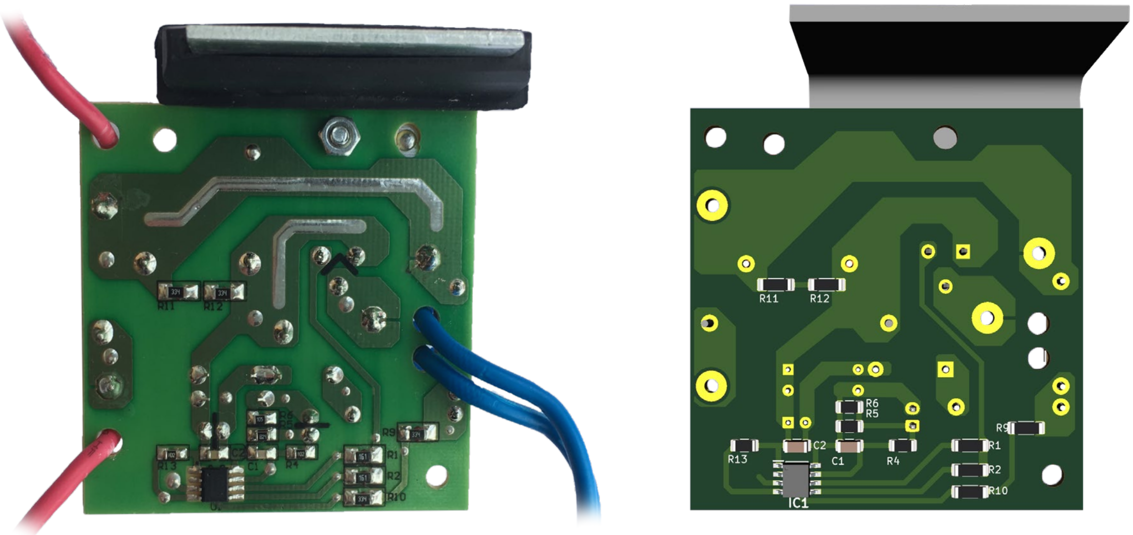


Fig. 122, PCBA Re-engineering, Bottom view

The circuit board has a dimension of 58x57 mm and a heat sink of 40x20 mm mounted on the triac. The redesigned circuit (Fig. 123)has the exact same dimensions of the original one. Most of the TH components have been left in the same position (e.g. the triac and related heat sink). The two new connectors have been positioned on the edges of the circuit, oriented according to the motor and cord-winder position (Fig. 124, 125). On the silk layer of the PCB it is clearly indicated to which component they have to be connected to (Fig. 126). Moreover, two different colours (e.g. white and yellow) could be used in order to avoid misuse. Very wide tracks have been used for the high current connections, and thermal clearance has been applied to the bigger copper zones, in order to facilitate soldering. Eventually, 3,2 mm mounting holes have been placed in the same position of those in the current design.

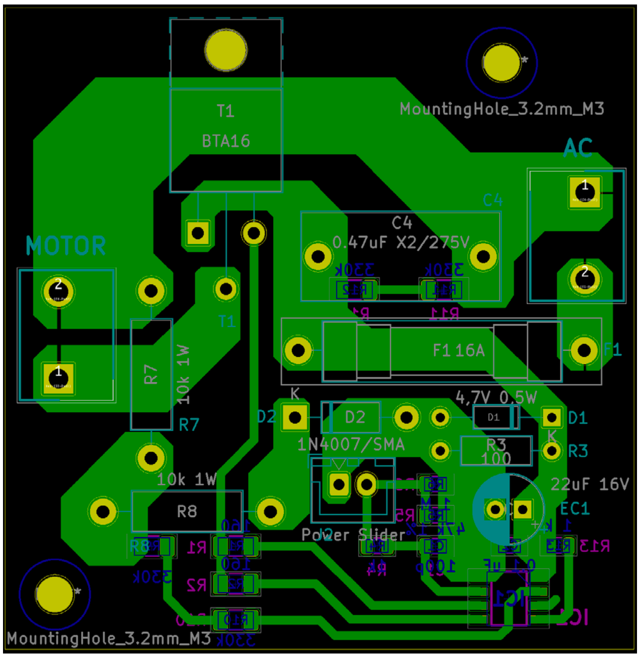


Fig. 123, PCBA redesign, CAD file

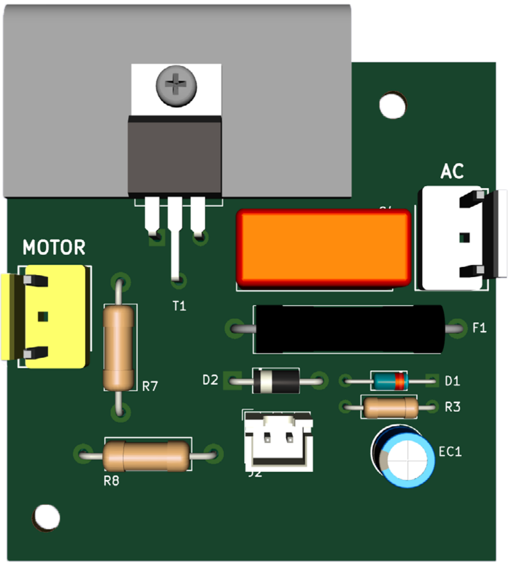


Fig. 124, PCBA redesign, Top View

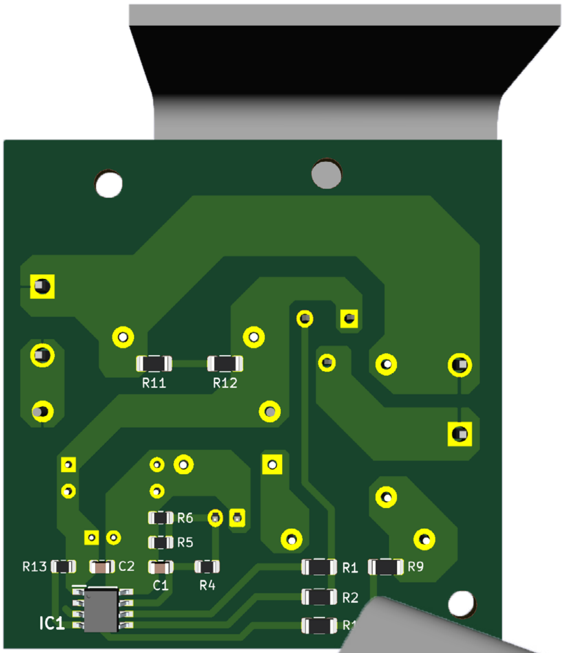


Fig. 125, PCBA redesign, Bottom View

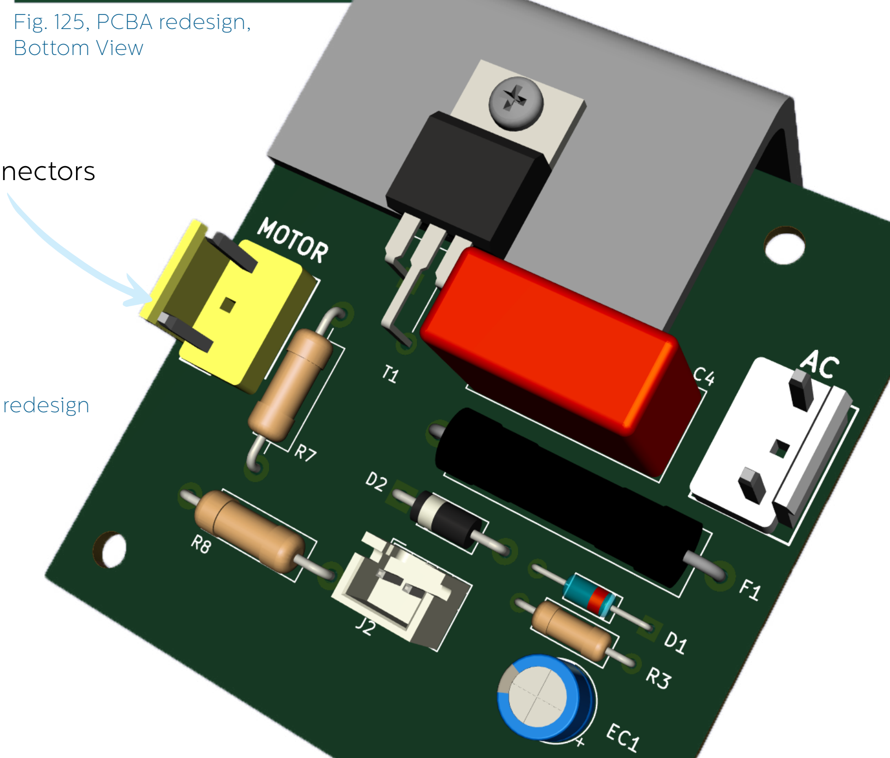


Fig. 126, PCBA redesign

Testing of the redesign

In order to test the new PCBA design, the circuit has been printed and assembled (Fig. 127, 128, 129, 130). Because of time limitations, the software could not be uploaded on the IC. Therefore, the circuit was not fully working. However, producing the electric board, allowed to check the overall dimensions and assembly of new components. It proved that adding two B2P3-VH is completely feasible and manufacturable, maintaining the same board dimensions (58x57 mm). Many different regulations are applied to consumer products' electronic circuits. For time limitations it was not possible to excecute safety tests on the circuit proposed.

Cost analysis

A complete cost analysis for the production of the redesigned PCBA has been performed together with the Electronic and Software group lead. Table 25 shows the estimated cost for each component mounted on the current design. These are not official data from Philips, but they are reliable estimations. The Electronic team shared the methodology they usually use to roughly estimate the cost of components for mass production, dividing the cost per single component (found on www.digikey.com) by 5. To the total cost of components, estimated for 1,17€, other 40 cents should be added for the production of a 30-40 cm^2 PCBA. The heat sink costs approximately 10-15 cents and the Triac requires thermal paste, which cost is be neglected in this analysis. The labour cost required for the assembly can be roughly approximated by calculating 20% of the total production cost, which is 0,34€. Another 10% should be considered as manufacturer margin. Form this analysis, the total cost of the current design would be approximately 2,26€ (Table 26).

The cost of each B2P3-VH added in the redesign is approximately 0,04€. To this cost at least the cost of the contacts (SVA-41T-P1.1), 0,02€ each, and other 0,02€ for assembly and crimping of the contact on the cord-winder and motor wires.

This analysis defines a cost of 8 cents per connector, and a total cost increment of 0,16€ Cents. By considering a possible production volume of half million products, the impact of this redesign on the total production would be 80.000€. Unlike the previous proposals the redesign of the PCBA would not be cost 0; however, the relative production cost increment would be limited (+7,1 %).

Component	Manufact	Num	Total cost (€)
Ceramic Fuse 16A 250VAC 5X20	Schurter Inc.	1	0,17
SMD Resistor 1206, 330k	Stackpole Electronics Inc.	4	0,08
SMD Resistor 1206, 160 Ohm	Stackpole Electronics Inc.	2	0,04
SMD Capacitor 0805, 0,1 uF	Wurth Electronics Inc.	1	0,02
SMD Capacitor 0805, 100 pF	Wurth Electronics Inc.	1	0,02
SMD Resistor 0805, 1k	Stackpole Electronics Inc.	2	0,04
SMD Resistor 0805, 1Mohm	Stackpole Electronics Inc.	1	0,02
SMD Resistor 0805, 47k 1%	Stackpole Electronics Inc.	1	0,02
Metal oxide TH resistor, 10k, 1 W	Stackpole Electronics Inc.	2	0,08
Triac BTA 16 600BWRG	STMicroelectronics	1	0,33
HT66F002	Holtek	1	0,08
TH resistor 100 Ohm	Stackpole Electronics Inc.	1	0,02
B2B-XH-A	JST Sales America Inc.	1	0,03
Radial Electrolytic capacitor, 6,3 mm, 220uF, 16V	KEMET	1	0,04
Rectangular capacitor0,47uF X2/275V	Panasonic Electronic Components	1	0,14
Diode DO-35, 4,7v, 500 mW	NXP	1	0,02
Diode DO-41, 1N4007-TP	Micro Commercial	1	0,02
		TOTAL	1,17

Table 25, total cost of components in the current PCBA design

Total components cost	1,17
Heat sink	0,15
PCBA printing	0,4
Labour cost	0,34
Manufacturer margin	0,2
TOTAL	2,26

Table 26, Total production cost of the current PCBA design

JRC repairability score improvement

Although this redesign would have an impact on the production cost of the product, the effect of this solution is quite considerable. By comparing Table 19 with Table 28 it is possible to see how combining redesign 1 and 4 the disassembly time of the PCBA has decreased of 80% (from 616s to 131s). Disassembly depth decreases of 10 steps (from 14 to 4) and the number of connectors diminishes from 51 to 13 (Table 27). This is due to the fact that the disassembly of this part as become sequence independent from the sequences of cord-winder and motor. The disassembly maps in Fig. 133 and Fig. 134, express quite clearly this improvement, moving component 31.2 closer to the architecture surface. Consequently, the disassembly index has improved of 0,2 pt and the overall RRU score of 0,1 pt. The improvement is relatively small because the PCBA is not considered a high weight priority part (weight of 1/3). This is also reflected in the amount of economic savings tin repair service that this redesign would have created: just around 500€ from 2017 (rough rounding up from official call rates).

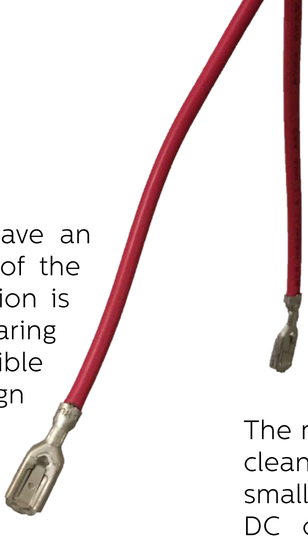


Fig. 131, Current not isolated connectors to motor and cord-winder

Safer self-repairs

The most important risk while repairing a vacuum cleaner is definitely AC current. Unlike many other smaller electronic products which uses low voltage DC current (like smart-phones, PC's, shavers, electric toothbrushes), vacuum cleaners uses big AC motors. The energy power of this component can vary from model to model, but it generally requires at least 400w. Energy is provided by the cord-winder, connected to the supply system. As just discussed, the cord-winder in connected to a PCBA, which controls the motor by modulating AC supply using a TRIAC. Touching un-insulated electric contacts with bare hands can be fatal, and this is the main reason why Philips currently does not encourage self-repairs. However, self-repairs are an important design strategy to extend product life-span, and postpone its retirement (Bakker, den Hollander, et al., 2014; Bakker, Wang, et al., 2014;

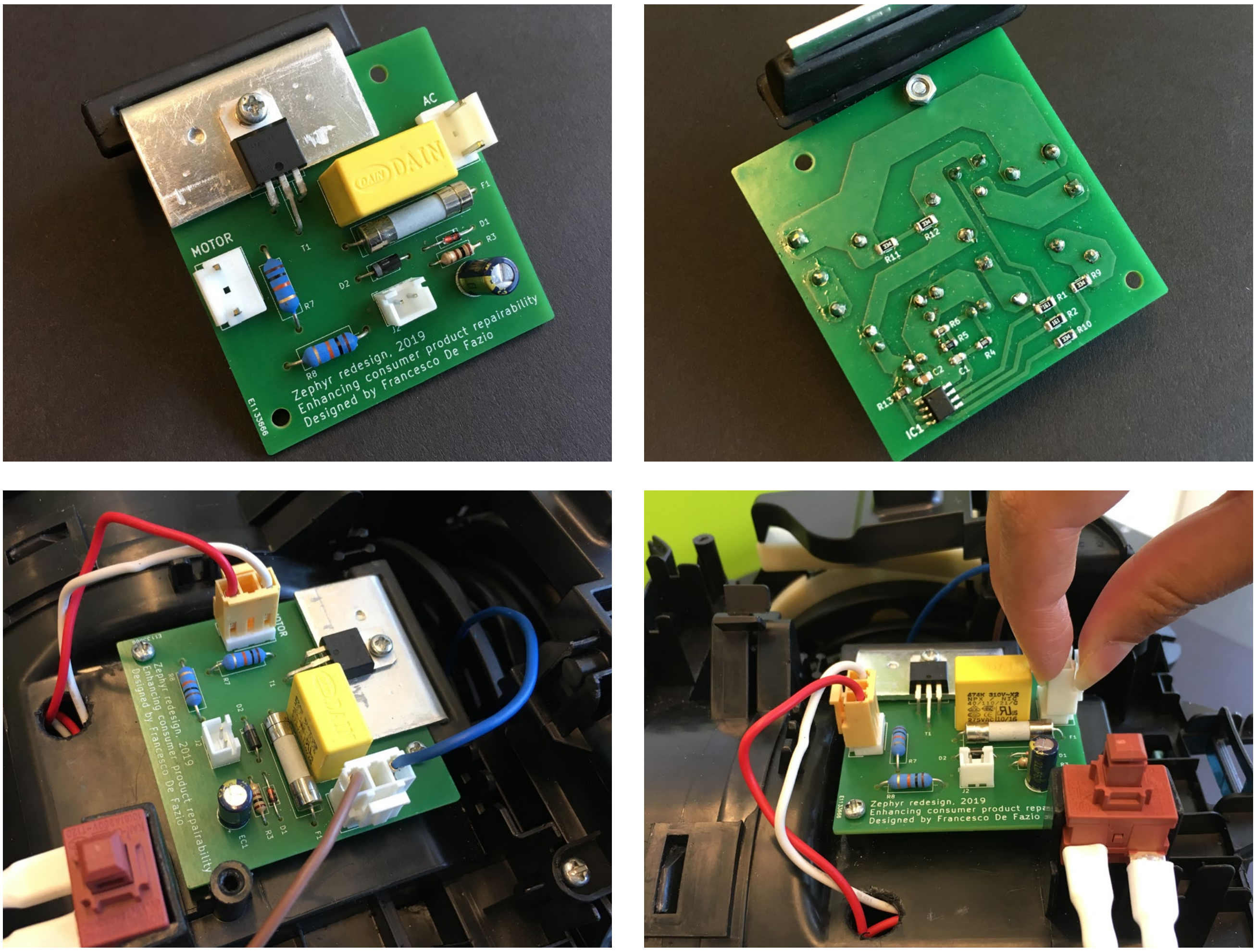


Fig. 127, 128, 129 and 130, Prototype of the PCBA redesign

Bocken et al., 2016; Flipsen et al., 2016). Moreover, self-repairs activities are likely to happen anyway after the manufacturer warranty period is expired, since the cost of an official repair is often to high compared to the cost of a new product (Flipsen et al., 2016). This was also confirmed by a Philips Repair Engineer, and already discussed in Chapter 3. The use of electric connectors B2P3-VH would ensure additional insulation of the high voltage electric contacts (Fig. 132). They would also avoid the risk of short circuit in the event the connectors were not reassembled correctly. This could be instead a serious risk with current un-insulated connectors (Fig. 131).

Considerations

This redesign would increase the production cost of 7.1% and would just slightly increase the disassembly index score (0.2 pt). However, it would drastically improve the PCBA disassembly, making it 80% faster. Moreover, it would make the product safer for self-repairs, avoiding possible short circuits determined by un-insulated connectors. Eventually, the PCBA one of the component with the Highest environmental impact. This redesign, would ficilitate recycling processes for its removal and correct disposal.

Disassembly results, Redesign 1,3&4

Part	Steps (n.)	Tool changes (n.)	Connections (n.)	eDIM (s)	% of total disassembly time	% of total connectors	Uncommon tools
Total Disassembly	30	17	86	914	100	100	
Nozzles (6,3)	1	0	1	6	0,7	1,2	
Hose (111)	1	0	3	21	2,3	3,5	
Cordwinder (32)	5	2	15	160	17,5	17,4	
Wheel (41 rx or lx)	7	4	27	306	33,2	31,4	
Motor (45)	8	5	32	341	37,3	37,2	
PCB (31)	4	2	13	131	19,8	15,1	
External casing (11)	4	3	16	6	0,7	18,6	
Filter (9)	2	0	2	13	1,4	2,3	
Motor brushes	9	6	34	369	40,4	39,5	

Table 27, Disassembly results combining Redesign 1,3 and 4.

Philips FC9569/01	PART 1	PART WEIGHT	PART 2	PART WEIGHT	PART 3	PART WEIGHT	PART 4	PART WEIGHT	PART 5	PART WEIGHT	PART 6	PART WEIGHT	PART 7	PART WEIGHT	PART 8	PART WEIGHT		
PARAMETER	MOTOR	3	MOTOR BRUSHES	3	FILTERS	3	HOSE	3	POWER CABLE	3	WHEELS	1	PCBA	1	NOZZLES	1	PARAMETER SCORE	PARAMETER WEIGHT
#4 Disassembly time	0,51		0,52		1,00		0,56		0,67		0,03		0,82		0,56		6,22	2,00
#1 Disassembly depth / sequence	0,62		0,78		1,00		1,00		1,00		0,14		1,00		1,00		8,52	2,00
#2 Fasteners	1,00		1,00		1,00		1,00		1,00		1,00		1,00		1,00		10,00	2,00
#3 Tools	1,00		1,00		1,00		1,00		1,00		1,00		1,00		1,00		10,00	2,00
#6 Type and availability of information	0,50		0,50		0,50		0,50		0,50		0,50		0,50		0,50		5,00	2,00
#7 Spare parts	0,25		0,00		0,50		0,50		0,25		0,25		0,25		0,50		3,06	2,00
#12 Commercial guarantee	0,00		0,00		0,00		0,00		0,00		0,00		0,00		0,00		0,00	[illegible]
RRU indices for parts	6,5		6,3		8,3		7,6		7,4		4,9		7,6		7,6			

Disassembly index	RRU Process index	OVERALL RRU	Commercial Guarantee
8,7	4	7,1	0,00

Table 28, Repairability assessment results for redesign 1,3 and 4 combined

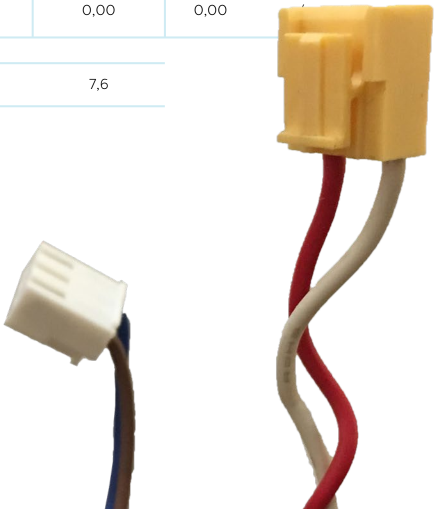


Fig. 132, JST 7A female connectors, completely isolated

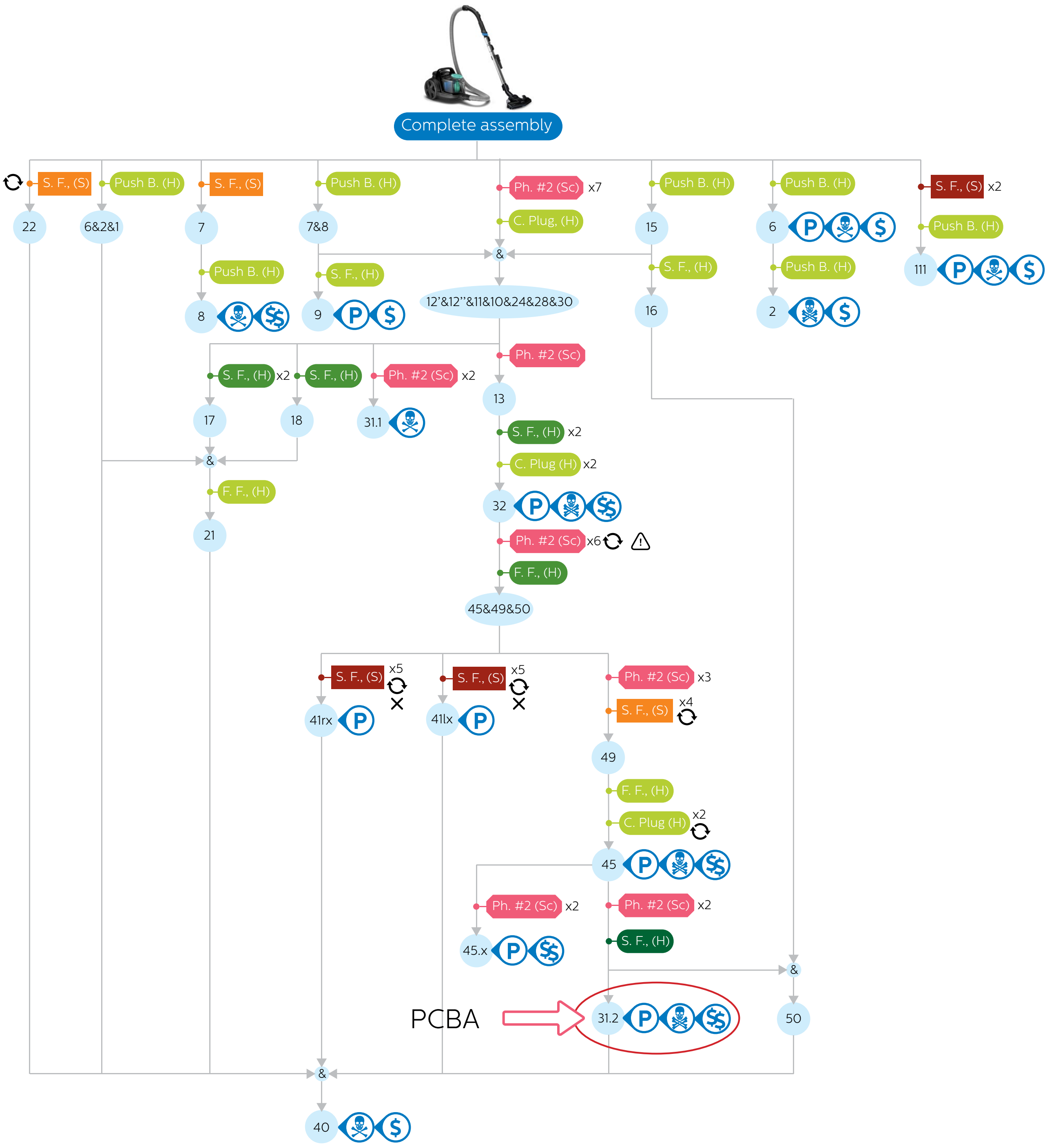


Fig. 133, Disassembly map showing the position of the PCBA after redesign 1,2 and 3

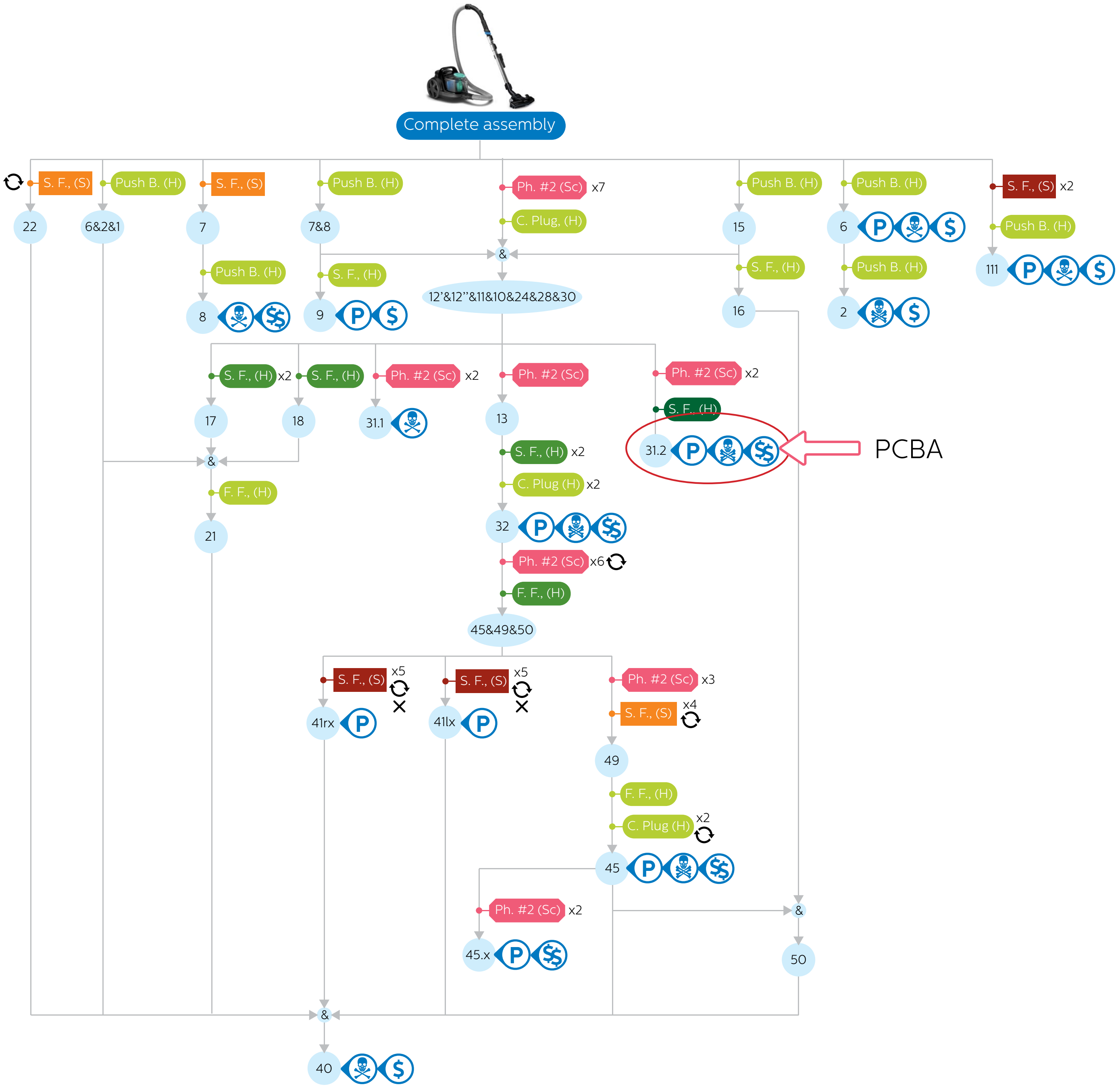


Fig. 134, Disassembly map showing the position of the PCBA after redesign 1,2,3 and 4

7.7 Recommendations for future improvements: the perfect vacuum cleaner

The architecture obtained by implementing all the redesign solutions previously presented (from 1 to 4) represents already a product which would be easy to disassemble and repair. However, additional insights for further improvement were gathered from the disassembly and comparison of different vacuum cleaners in Chapter 5. These are:

- Independent disassembly of motor and cord-winder
- Vertical disassembly of the motor housing
- External wheels disassembly

These three improvements have been used to determine “perfect” vacuum cleaners architecture for repairability. Defining the perfect product architecture was fundamental for then defining possible discrete assessment threshold for disassembly depth and time (parameters 1 and 4) for canister vacuum cleaners, presented in the next chapter.

Independent disassembly of motor and cord-winder

Fig. 138 shows the disassembly map obtained after applying the four redesign solutions previously presented. In this new configuration the disassembly of the motor (component 45) is still sequence dependent from the disassembly of the cord-winder (component 13 and 32). This is because the cord-winder is directly attached to the motor housing enclosure (Fig. 135). According to a Philips developer engineer, this design was made to limit the dimension of the product, placing motor housing and cord-winder as close as possible. Despite this, in all the competitors’ model analysed and in the Philips bag FC85XX series, the motor housing and the cord-winder mounting system are completely independent (Fig. 136, 137, 140 and 141). This allows to disassemble the motor independently by the disassembly of the cord-winder, making its disassembly faster and decreasing disassembly depth of two steps. The easier way to obtain this architecture is positioning the mouting grips that keep in place the cord-winder on the lower housing, instead of placing them on the motor housing. On the other hand, this would require to leave more space between these two components. Fig. 139 shows how the disassembly map of this product would improve if cord-winder and motors would be independently disassemblable.

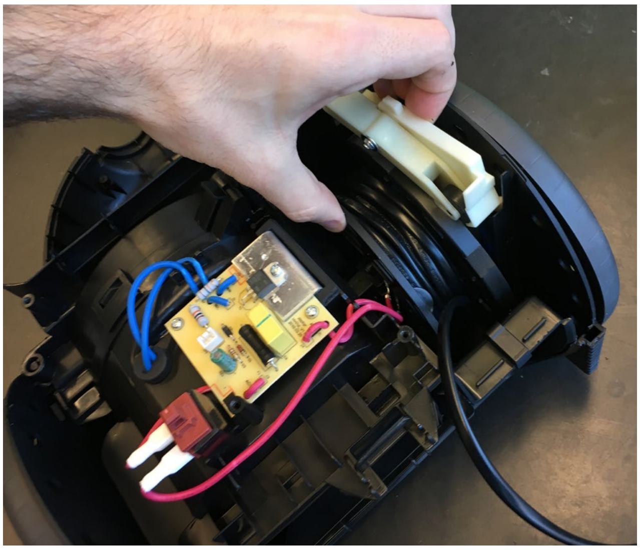


Fig. 135, Dependent disassembly of motor and cord-winder in Philips Power Pro Active

Fig. 136, Independent disassembly of motor and cord-winder in Siemens SyncroPower

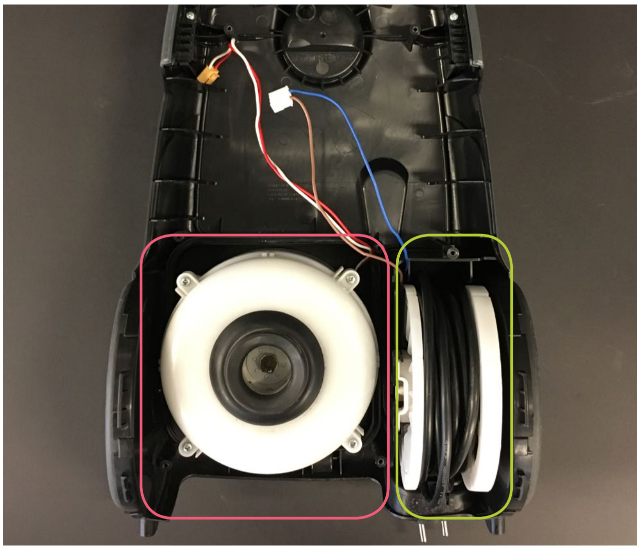


Fig. 137, Independent disassembly of motor and cord-winder in Samsung SC8835

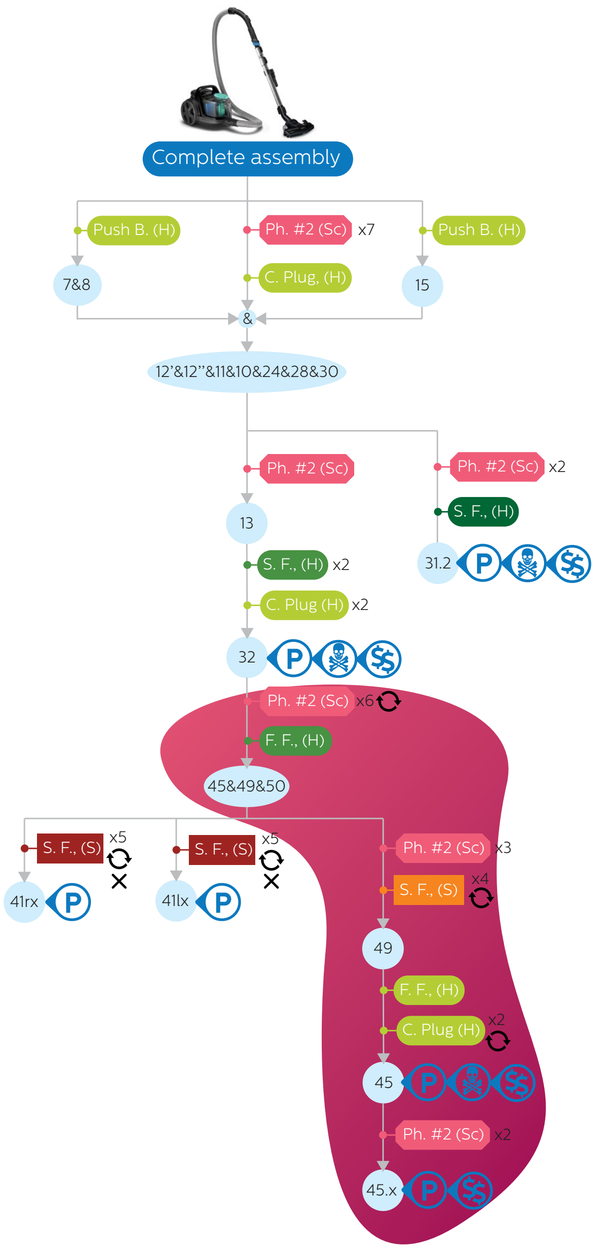


Fig. 138, Partial isassembly map of the Power Pro Active showing sequential disassembly of motor and cord-winder

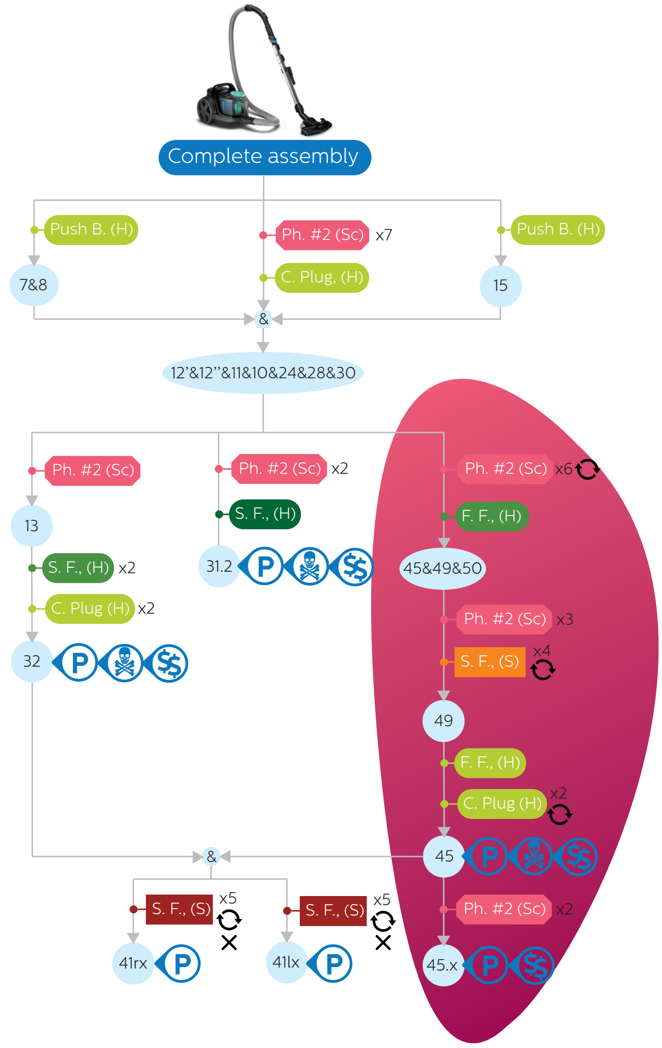


Fig. 139, Partial isassembly map of the Power Pro Active showing independent disassembly of motor and cord-winder

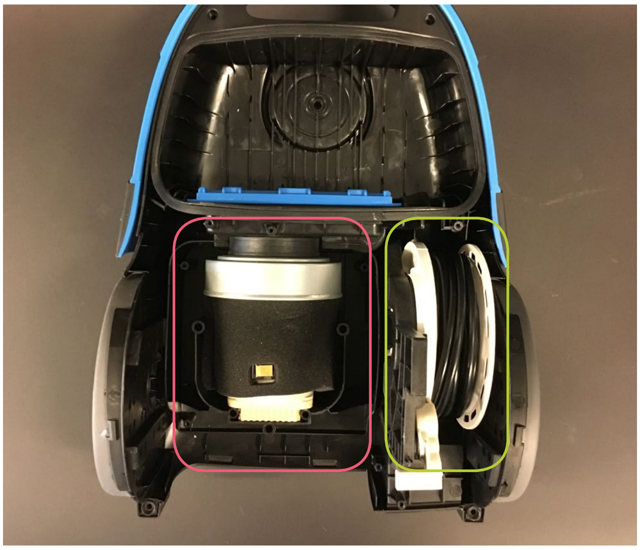


Fig. 140, Independent disassembly of motor and cord-winder in Philips FC85XX series

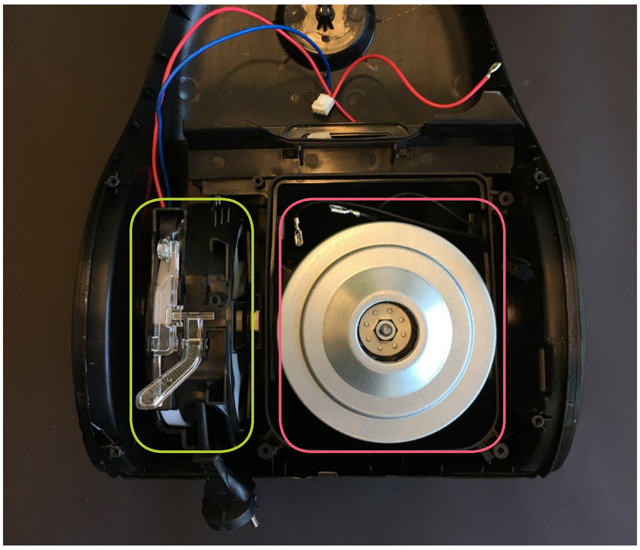


Fig. 141, Dependent disassembly of motor and cord-winder in Rowenta X-Trem

Vertical disassembly of the motor housing lid

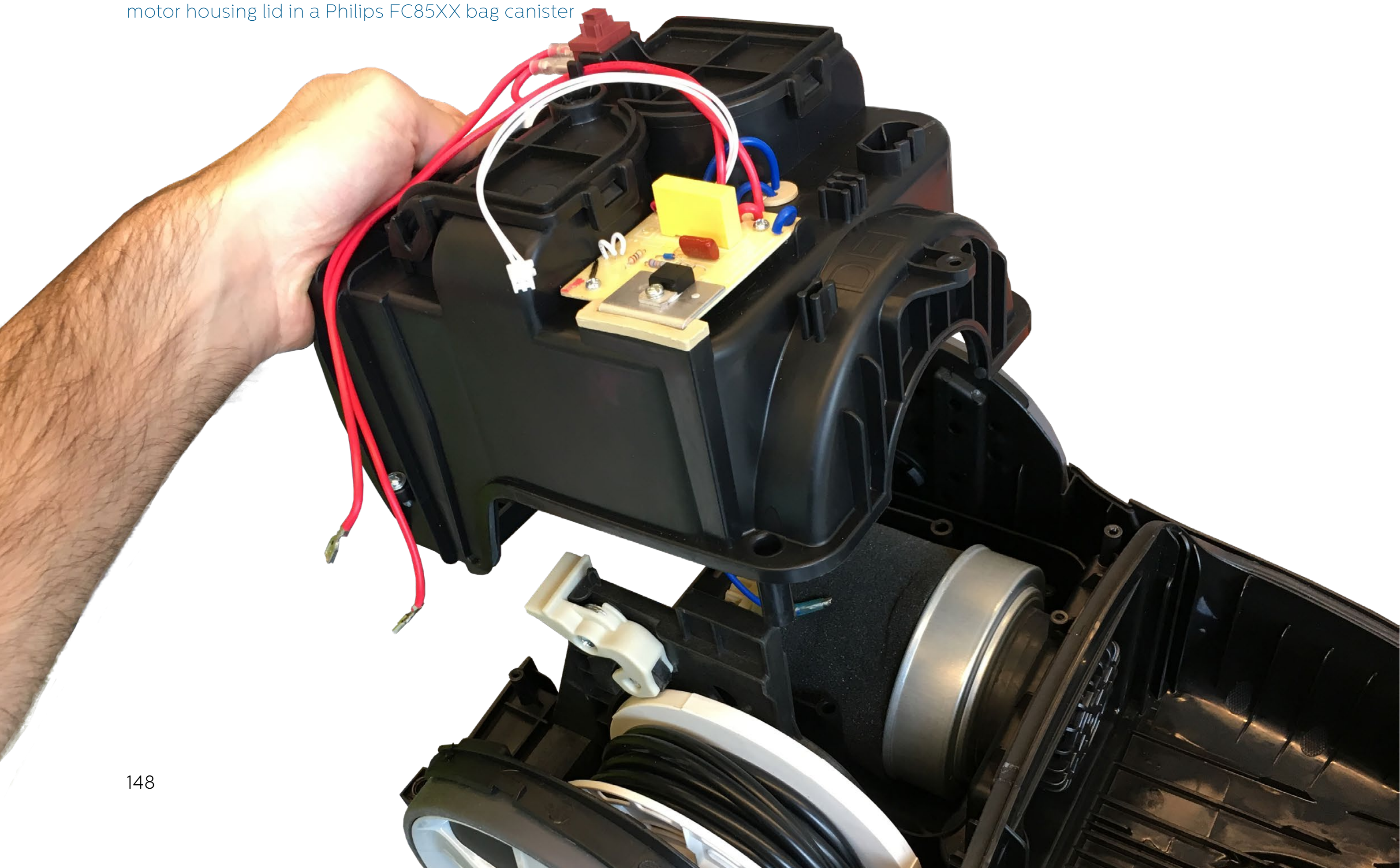
In the Philips Power Pro Active, the disassembly of the motor housing requires many sequential steps:

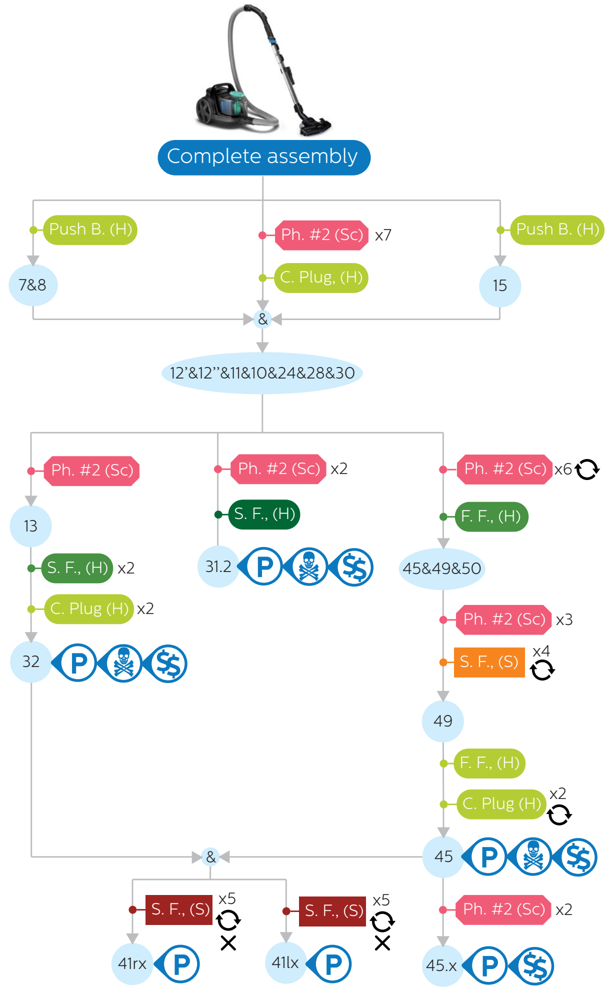
1. Firstly the motor assy, composed by Motor, Motor housing, and Motor housing lid (45&49&50) has to be disassembled from the lower housing, by removing 6 screws (Fig. 142)
2. Then the motor housing lid has to be removed (49), by opening 4 snap fits and 3 screws
3. Finally the motor (45) has to be extracted, disconnected the cables coming from the PCBA

On the contrary, in all the competitors' product analysed and in the Philips bag series FC85XX, the motor housing is incorporated in the lower housing, and the motor housing lid can be disassembled vertically in one step (Fig. 143, 146 and 147). According to a Philips developer engineer, this design was made in order to ensure optimal sealing of the motor housing, obtaining better performance. However, a vertical disassembly of the motor housing lid would make the disassembly of the motor faster and easier, by skipping the disassembly of the entire motor assy. One disassembly step would be saved, as it is possible to see from the two disassembly maps in Fig. 144 and 145, where a 4 screws motor housing lid assembly has been considered. Philips already uses this kind of design in many bag vacuum cleaners, proving that it could be actually feasible to implement this solution also on bagless canisters.

Fig. 142, 3 steps disassembly of the motor assy. Extraction of the motor assy in a Philips Power Pro Active.

Fig. 143, One step vertical disassembly of the motor housing lid in a Philips FC85XX bag canister





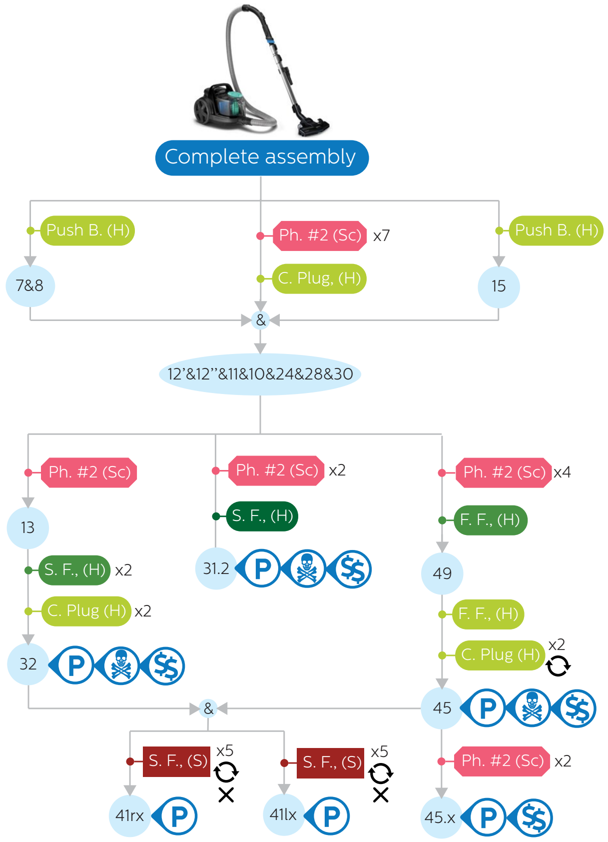


Fig. 144, Partial disassembly map of the Power Pro Active showing the disassembly of the motor assy (45&49&50) in order to get to the motor (45).

Fig. 145, Partial disassembly map of the Power Pro Active showing vertical disassembly of the motor housing lid (49), without requiring the disassembly of the motor assy.

Fig. 146, One step vertical disassembly of the motor housing lid in a Samsung SC8835

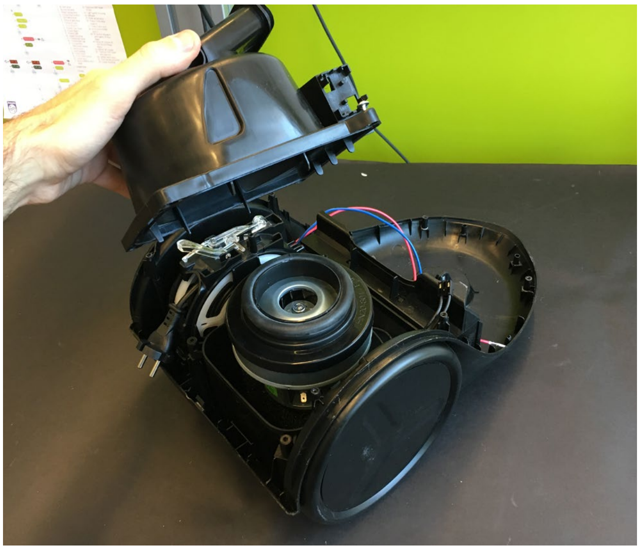


Fig. 147, One step vertical disassembly of the motor housing lid in a Rowenta X-Trem

External wheels disassembly

The last architecture improvement proposed is the external disassembly of the wheels. Philips uses two types of wheel fastening systems in its canister lines:

- A bearing fastening system, which can be disassembled from the inside of the product using a spudger. This is the most expensive system, since it is composed by a POM bearing and metal fasteners, and it is implemented just on mid or high price range canisters (Fig. 148).
- A snap fit fastening system, which is not meant to be disassembled, since it is composed by many stiff snap fits which fasten the wheel directly to the lower housing. This system is cheaper compared to using POM bearings and it is used for all the base line of bag and bagless canisters (Fig. 149).

In both cases, the disassembly of the wheels can happen only after disassembling all the inner components, since the snap fits or metal fasteners can be reached only from the inside of the product. Wheels are considered priority part by the JRC scoring system (Cordella et al., 2019); consequently, they should be easier to disassemble. A possible design solution was found in the Samsung SC 8835, where wheels are assembled from the outside of the product. A screw is hidden beneath a PC semi-transparent cover (Fig. 151), which can be disassembled using a spudger (Fig. 150). The screw fastens a POM bearing to the lower housing (Fig. 151).

As shown by the two disassembly map in Fig. 153 and 154 the accessibility of the wheels would improve quite significantly by implementing the same mechanism in the Power Pro Active. Wheels could be disassembled in two steps, removing a plastic insert first (41.1) and then the wheels (41). In another vacuum cleaner analysed, the Siemens SycroPower, the wheels can be actually disassembled in just one step. However, in this case they are caster wheels, and they have a completely different structure compared to the side wheels

Fig. 150, Semi-transparent cover, hiding the wheel screw in the Samsung SC8835

Fig. 148, Bearing wheel fastening system in the Philips Power Pro Ultimate

Fig. 151, Removal of the semi-transparent screw cover in the Samsung SC8835

Fig. 149, Snap fits wheel fastening system in the Philips Power Pro Active

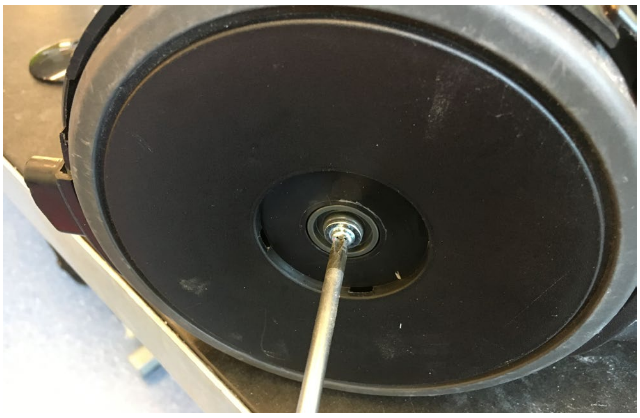


Fig. 152, External removal of the wheel in the Samsung SC8835

found in most of the other models considered. One step disassembly would be quite difficult to reach on wheels that are not caster.
This solution was discussed with the developer engineer team as well. The mechanical Group leader pointed out how the designed proposed by Samsung does not integrate an anti-wobbling mechanism, making the design less durable compared to the Philips one. According to Philips engineers, the wheels of the Power Pro Active have been designed to be very durable and break during the life-span of the product. This is confirmed by the call rates on this model.

Repairability VS Durability

Philips expressed an interesting point worth further consideration: by designing a component for a higher durability, its repairability might be compromised. Considering the environmental impact of a product, a more durable design for a priority component might be preferable compared to a more repairable but less durable one. Furthermore, it could be questionable if a component that has a longer life-span of the product itself can be defined as priority part, since its disassembly might not be really necessary. A reasonable approach could be to always consider repairability as design requirement for any priority component, making sure that this would not compromise their durability, decreasing parts life-span.
Despite this, better solutions compared to the one found in the Samsung vacuum cleaner could be found, ensuring external disassembly of vacuum cleaner wheels but avoiding wobbling.

The optimized architecture

The disassembly map in Fig. 155 shows an extremely optimized product architecture for repairability of canister vacuum cleaners. From this map it is possible to observed how all the inner priority components have been pushed towards the product architecture surface. This map is further analysed in the next chapter, where it is used to define new discrete assessment values for disassembly depth and time.

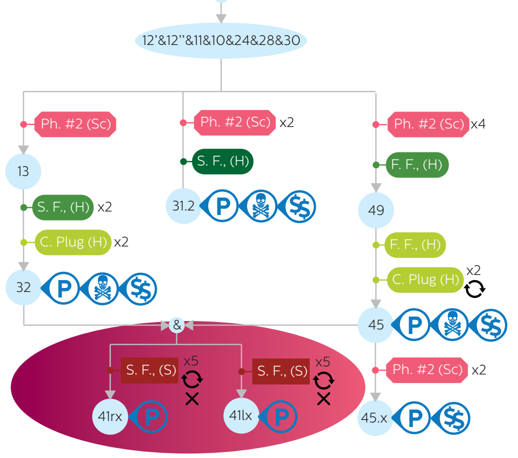


Fig. 153, Partial disassembly map of the Power Pro Active showing the disassembly depth of the wheels (41rl, 41rx) disassemblable from the inside of the product

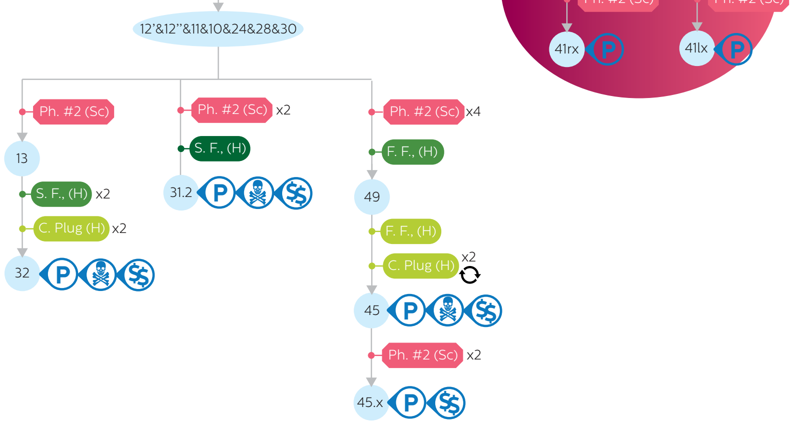


Fig. 154, Partial disassembly map of the Power Pro Active showing the disassembly depth of the wheels (41rl, 41rx) externally disassemblable

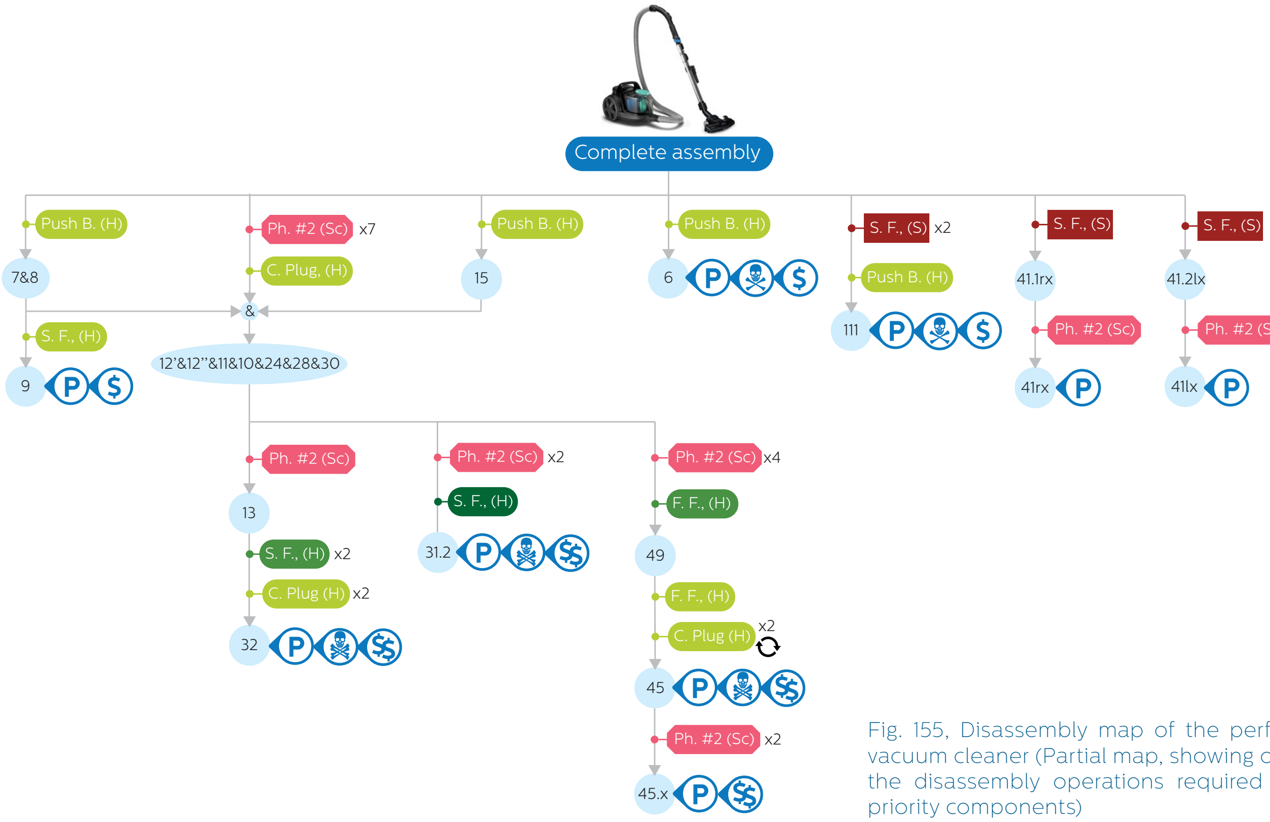


Fig. 155, Disassembly map of the perfect vacuum cleaner (Partial map, showing only the disassembly operations required for priority components)

7.8 Conclusions

In this chapter the following research objectives have been tackled:

- **RO.5 Defining and testing new guidelines or methodologies that can guide designers to design for product repairability**
- **RO.6 Investigating the economic impact that enhanced repairability might determine**

Seven different redesign solutions to enhance product repairability of the Philips Power Pro Active have been presented. Four of them have been developed in detail, by building proof of concepts and by calculating the related repairability score improvement. Three additional recommendations for future improvements have been also formulated, with the aim of inspiring possible future more radical changes in the general architecture of new Philips canister vacuum cleaners.

With **the first redesign** it was shown how the clumping methodology is a very effective design solution to enhance considerably product repairability without increasing production costs. Priority components do not have to be physically closer to the product surface; this is often not feasible, causing a complete change of the product architecture. On the contrary, they have to be moved closer to the disassembly surface, which means that few steps should be required for their disassembly. Clumping methodology is an effective way to achieve this result.

However, **the second design** showed that a possible collateral effect of clumping methodology is that some hotspot components might remain trapped in the new sub-assembly created. If this should happen, bottom-up assembly could be an effective solution to include disassembly for recycling purposes into the equation.

The third design showed how easy it can be to modify the current design in order to comply with future legislations, like the prEN45554. A fastener, which cannot be disassembled using common length screw drivers in the current design, has been easily repositioned closer to the product surface, allowing disassembly using standard tools. Eventually, a **redesign of the PCBA** has been proposed. The scope of this redesign is to allow the independent disassembly of PCBA from cord-winder and motor. Just adding two connectors to the board, the disassembly of the PCBA would require 10 steps less. On the other hand, this redesign would determine a production cost increment of 0,16€ per board, showing how, sometimes, a price has to be paid for improved repairability.

Additional future design improvements could be: independent disassembly of motor and cord winder, vertical disassembly of the motor housing lid and external disassembly of wheels. By combining these seven solutions it is possible to obtain the disassembly map shown in Fig. 155, which represents the "perfect canister vacuum cleaner". Compared to the current design (Fig. 156)

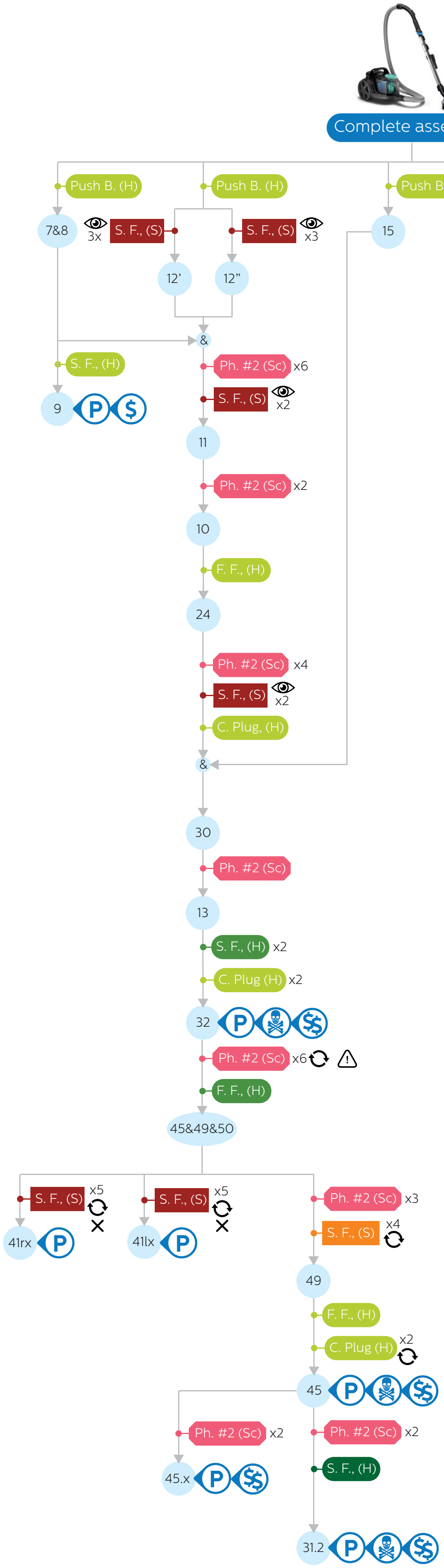


Fig. 156, Disassembly map of the Power Pro Active current design (Partial map, showing only the disassembly operations required for priority components) it is clearly visible how the general orientation of the map has changed from vertical to horizontal. Sequence dependent disassembly operations have been transformed in parallel sequence independent disassembly procedures. All the priority components have been moved closer to the product architecture surface, requiring maximum 5 disassembly steps. Further optimization would still be possible. For instance, in the Samsung SC8835, the PCBA is disassemblable in 3 steps, since the back exhausting grid does not have to be disassembled. Moreover, in the Siemens SyncroPower, the wheels are just simple caster wheels, and they can be disassembled in one step using a screw driver. However, these solutions are quite extreme, and they can be applied just in very simple designs. On the contrary, the map in Fig. 155 represents a completely feasible and realistic architecture that any canister vacuum cleaner on the market could easily adopt.

Additional insights worth of notice are:

- Enhanced repairability might not lead to relevant savings in repair service for a big company like Philips. In fact, savings for around 15.000-16.000 € over three years were calculated. Despite this, around 300 hours of service would be saved by the faster product disassembly and this might result in a faster, hence better, customer service. Moreover, most of the redesign proposed would not require any additional investment in production cost, making repairability an interesting strategy for the manufacturer.
- Designing for product repairability differs from designing for product retirement. In fact, DFPR usually involves a wider number of priority parts, which might not be completely shared by the list of priority components defined for RRU. In either cases, it was very difficult to convince the company to focus on components which do not have high priority according to their internal call rates. This might be problematic, since manufacturer call rates usually describes only the first two years of product life-span. This means that, often, only those components which fail in the short term are actually tackled and improved.
- By exploring a possible future redesign of the wheels in order to be externally disassembled, a possible contradiction between product repairability and durability has been found. A more repairable design might be less durable compared to a design which cannot be easily disassembled because of its very robust structure. A practical example is the wheels designed by Philips for the low-end canisters line. This design is meant not to break during the entire life-span of the vacuum cleaner, and this was achieved by creating a very stiff structure which cannot be disassembled if not breaking it completely. Philips pointed out that, in their opinion, redesigning this part for enhanced repairability would not have much sense, since this part is not meant to break and be replaced. It could be argued that even if this component is important to deliver primary functions (Cordella et al., 2019), its failure rate is quite low, excluding it from the priority part list. Despite this, repairability should always be considered as design requirements for all the priority components, and a good balance between repairability and durability should be investigated.

8. Practical project outcomes

8.1 Introduction

In this chapter the most important outcomes of this research are discussed. By analysing the optimized architecture for repairability obtained in the previous chapter, new discrete rating threshold values for the assessment of disassembly time and depth have been defined. These values could be a valuable outcome for further developments of the JRC scoring system. They have been already used to create new serviceability requirements for the development of future Philips canister vacuum cleaners. These new requirements have been integrated in the official requirements database of the Philips I&D department.

8.2 New discrete rating values for the JRC scoring system

The perfect vacuum cleaner

In the previous chapter 7 different redesign solutions have been proposed:

1. Redesign of the motor housing and rear housing for faster disassembly
2. Redesign of the power slider connections for hotspot components accessibility
3. Redesign of the motor housing screw depth for legislation compliance (use of common tools)
4. Redesign of the PCBA for sequence independent disassembly and safer self-repairs
5. Parallel disassembly of motor and cord-winder for faster disassembly of the motor
6. Vertical disassembly of the motor housing lid for faster disassembly of the motor
7. External disassembly of wheels, for easier and faster disassembly of the outer wheels

The combination of these seven redesigns determined an extremely optimised vacuum cleaner architecture for disassembly. It integrates all the positive design features observed over 8 vacuum cleaners, becoming the perfect vacuum cleaner structure for repairability. The Disassembly Map of this optimised assembly can be seen in Fig. 157. In this map the disassembly depth of priority components is:

- Nozzle, 1 step
- Hose, 1 step
- Filter, 2 steps
- Wheels, 2 steps
- PCBA, 4 steps
- Cord-winder, 5 steps
- Motor, 5 steps

Discrete rating assessment

The seven vacuum cleaners analysed during this research have been assessed using a continuous rating calculation for disassembly depth and time. By using a continuous rating calculation, products have been proportionally assessed based on the best vacuum cleaner analysed. For instance, if the lowest time registered for the disassembly of the PCBA is 108 seconds (Table 31), scored by the Samsung SC8835, this model receives a 1 pt/1 pt for the PCBA disassembly time. Based on this model, all the others are proportionally assessed. This means that if in another vacuum cleaner the PCBA is disassemblable in 116 seconds, the PCBA disassembly time of this model will score 0,5pt/1pt, since it took twice as much time as the Samsung model.

On the contrary, a discrete rating assessment is based on specific values (X, Y, Z) (Cordella et al., 2019) which defines different scoring thresholds. For instance, if the disassembly time calculated for a specific priority part is lower than Z, than that part scores 0,25pt. If the value is between Z and Y it receives 0,5pt, if it between Y and X it scores 0,75pt and if it is higher than X it reaches 1/1 pt (Cordella et al., 2019).

During the research phase (Chapter 3), the continuous rating system was preferred over the discrete rating system for three main reasons:

- The use of a continuous rating assessment is advised also by the prEN45554 (CEN/CLC TC10 European Standard, 2017)
- Values for a discrete rating assessment of vacuum cleaners were not defined yet by the JRC scoring system (Cordella et al., 2019)
- Since values of a discrete rating assessment were currently missing, the continuous rating assessment appeared to be the most reliable and objective methodology to be used.

Despite these considerations, the continuous rating system had some limitations: while the best values used as reference received the maximum score, the other values were rapidly penalised. For instance, the fastest nozzle disassembly (4 seconds) have been calculated for the Siemens SyncroPower. On the contrary, 5/6 seconds have been calculated for all the other vacuum cleaners (Table 31). This is due to the fact that while the Siemens nozzle is just pushed inside the hose tube, in the other products there is usually a hinge or a button that has to be opened or pressed in order to release the nozzle. Whereas the disassembly of the nozzle is quite easy in all the products assessed, only the best product received 1/1 pt for its disassembly. All the others scored 40 to 60% less just because of few additional seconds of disassembly. Although the disassembly of the nozzle actually takes more time in some products compared to others, the difference is of just few

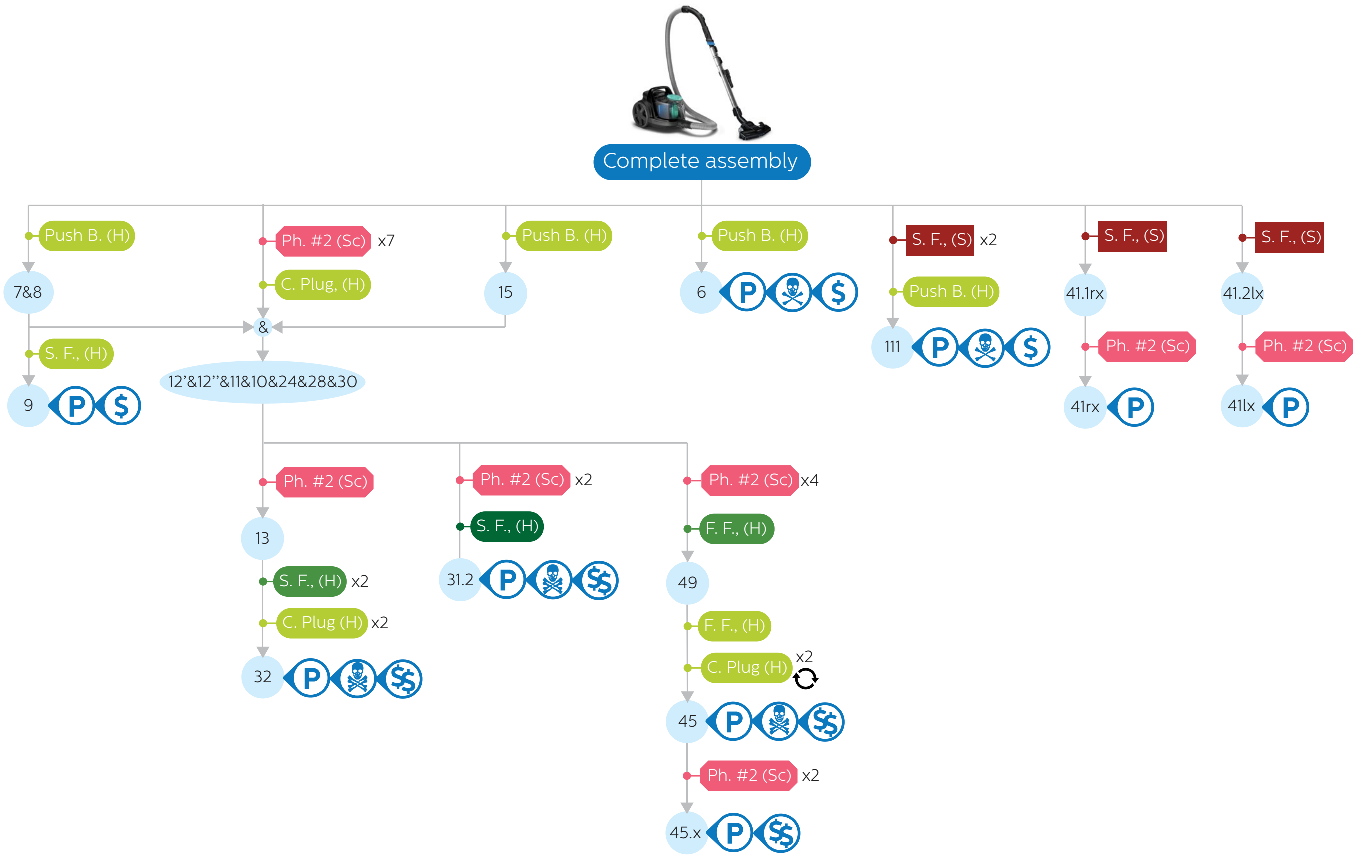


Fig. 157, Disassembly map of the perfect vacuum cleaner (Partial map, showing only the disassembly operations required for priority components)

seconds and it should not be strongly penalised. In fact, few additional disassembly seconds do not influence considerably product repairability.

This is the reason why new discrete threshold values for the assessment of canister vacuum cleaners have been calculated and presented in this chapter, hoping to provide valuable insights for future development of the JRC scoring system for repairability.
In Table 29 it is possible to see threshold values that could be used to define scores from 6 to 10. These have been calculated for all the priority components indicated by the JRC for canister vacuum cleaners, except nozzle, hose and filter. In fact, from the assessment performed on seven different products it has resulted that these three components are always easy and fast to disassemble, usually in two or three steps maximum and within one minute. They are considered by OEM's as CRP (Consumer Repair Parts); therefore, their design is already optimised for repair and replacement. In order to assess CRP components, a score of 1/1 pt could be given if the part is disassemblable within 3 steps and 30 seconds, while 0,5 pt in all the other cases. The calculation of thresholds for the other components is more complicate to define objectively, since only seven vacuum cleaners have been analysed, of which four from the same brand. The values shown in Table 29 have been defined according to the following considerations:

- The threshold values for score of 9/10 and 10/10 have been defined looking at the optimised structure defined in the last chapter and the best vacuum cleaners analysed in this research (usually the Samsung SC8835 or the Siemens SyncroPower). A gap of two steps have been used to differentiate enough each score threshold, while differences in disassembly time have been defined looking at Table 31. The Siemens SyncroPower shown an optimal architecture with a very low number of steps for most of the priority components. However, its design is quite basic and it is arguable that very few vacuum cleaners on the market can reach its simplicity. Therefore, the threshold values for a 10/10 are usually higher compared to what observed in the Siemens model.
- The disassembly of the PCBA usually requires a step less compared to the cord-winder. This is because the PCBA could be disassembled immediately after removing the rear housing if two JST connectors are used to connect it to cord-winder and motor. On the contrary, the disassembly of the cord-winder usually requires to remove a cord outlet or a upper cap before removing it completely, adding a further step. Despite this, the disassembly time of PCBA and cord-winder is very similar, since the first one requires the disassembly of multiple

connectors, while the second one requires a fast disassembly of the cord-outlet

- The disassembly of the motor usually requires at least an additional step compared to the cord-winder, since it is usually placed in a housing which ensure insulation (Table 30)
- The disassembly of the motor brushes requires one step more compared to the disassembly of the motor. This step represents the removal of a screw, which fasten the brush to the motor body and the extraction of the brush. This action requires 30s according to the eDIM methodology.
- The thresholds defined for the disassembly of the wheels are the most uncertain one, since very different design have been observed over the seven products. For a score of 9 or 10, the wheels should be externally disassemblable (2-4 steps, in less than 80 seconds). However, for lower scores, like 6 or 7, internal disassembly could be acceptable, if it does not require the complete disassembly of all the inner components. Therefore, disassembly time should be lower than the one of the motor and similar to those of PCBA and cord winder (e.g. 250s,350s,450s).

The discrete rating values X, Y, Z could be defined in the following way:

- X is the threshold which define a score of 1 pt. This could be equal to a score of 9 or higher (indicated in green in Table 29)
- Y defines the second threshold, over which 0,75 pt are assigned. This could be represented by the values defined for a score of 7/10 (indicated in orange in Table 29)
- Z is the lower threshold, and it could be represented by the score of 6/10. Product which do not reach this score would be assess with 0,25 pt. (indicated in pink in Table 29).

PARAMETER	SCORE	MOTOR	POWER CABLE	PCBA	Single WHEEL	Single MOTOR BRUSH
Disassembly Sequence (# steps)	6	13	12	11	10	14
	7	11	10	9	8	12
	8	9	8	7	6	10
	9	7	6	5	4	8
	10	5	4	3	2	6
Disassembly time (Seconds)	6	<660s	<450s	<450s	<450s	<690s
	7	<440s	<350s	<350s	<350s	<470s
	8	< 340 s	< 250 s	< 250 s	< 250 s	< 370 s
	9	< 240 s	< 180 s	< 180 s	<80s	< 270 s
	10	< 180 s	< 110 s	< 110 s	< 30 s	< 210 s

Table 29, Thresholds proposed for a discrete rating assessment of disassembly depth and time.

Disassembly sequence/depth (number of steps)

Priority part	Philips FC6812/01 Stick	Philips FC8924/01 High-end bag	Philips FC9934/07 High-end bagless	Philips FC9569/01 Mid-end bagless	Rowenta RO6963EA Mid-end bagless	Samsung SC8835 Mid-end bagless	Siemens VS06A111/12 Low-end bag
Nozzle	1	1	1	1	1	1	1
Hose	Not present	1 (with handle)	1 (with handle)	1	1	1	1
Filter	2	3	2	2	2	2	2
Cord-winder	Not present	14	11	10	9	5	5
Motor	11 (with PCBA)	16	10	13	9	5	5
PCBA	11 (with motor)	17	11	14	8	3	5
Wheels	1	15	10	12	1	2	1
Motor brushes	Not present	Not disassemblable	Not disassemblable	15	11	7	7
Battery	2	Not present	Not present	Not present	Not present	Not present	Not present
Battery charger	0	Not present	Not present	Not present	Not present	Not present	Not present
Active nozzle motor belt	8	Not present	Not present	Not present	Not present	Not present	Not present
External housing	13	9	3	4	4	2	3

Table 30, Number of disassembly steps required to reach each priority part in seven different vacuum cleaners

Disassembly Time (s)

Priority part	Philips FC6812/01 Stick	Philips FC8924/01 High-end bag	Philips FC9934/07 High-end bagless	Philips FC9569/01 Mid-end bagless	Rowenta RO6963EA Mid-end bagless	Samsung SC8835 Mid-end bagless	Siemens VS06A111/12 Low-end bag
Nozzle	6	5	5	6	6	6	4
Hose	Not present	9 (with handle)	9 (with handle)	27	24	18	5
Filter	17	17	13	13	13	16	16
Cord-winder	Not present	573	370	396	574	108	176
Motor	245 (with PCBA)	750	693	576	675	238	174
PCBA	245 (with motor)	756	707	616	544	108	176
Wheels	26	689	602	539	37	28	10
Motor brushes	Not present	Not disassemblable	Not disassemblable	607	740	273	193
Battery	60	Not present	Not present	Not present	Not present	Not present	Not present
Battery charger	0	Not present	Not present	Not present	Not present	Not present	Not present
Active nozzle motor belt	206	Not present	Not present	Not present	Not present	Not present	Not present
External housing	352	347	50	222	221	79	26

Table 31, Disassembly time required to reach each priority part in seven different vacuum cleaners

Considerations

The redesign solutions presented in the last chapter have been combined in a single optimized design, which has allowed to define the optimal disassembly depth of all the priority part of a canister vacuum cleaner. By comparing the disassembly map of the optimized structure with the one of the current design, it is possible to observe how the general orientation of the map has changed from vertically oriented to horizontal (Fig 157).

Based on this optimized design and on the other seven vacuum cleaner assessed, new discrete rating threshold values have been defined. These should be further investigated in a future development of the JRC scoring system since they are just indicative and not final. This is because only seven products have been assessed, four of which were produced by the same company. However, all the considerations that led to these indicative values have been listed, in the hope that they will be useful for future research. Moreover, it was possible to define discrete rating values just for canister vacuum cleaners, and not stick or uprights model, since just one stick appliance was analysed in this research.

8.2 New serviceability requirements for the Philips Floor Care department

After being involved in this research, the Philips I&D department focused on the development of vacuum cleaners offered the opportunity of defining new product requirements to enhance repairability of canister vacuum cleaners. Stick and uprights models have been excluded since insufficient data were gathered during this research. These requirements have been defined based on the research presented so far and on the current implementation capabilities of the department. 19 new requirements have been added to the official product requirements database and they might be already implemented on a project currently in preproduction design stage. These 19 prerequisites are clustered in four sections (Table 32):

- **Serviceability**, where more general requirements are listed. These define general features that the design should respect in order to facilitate repair operations, such as avoiding "exotic screws", glue, hidden snap fit connectors or screws, reusable fasteners and connectors on the PCBA.
- **Priority component**, where priority components are defined. It has been agreed with the department that for the moment only motor, cord-winder and PCBA will be considered. This is because nozzle, hose and filter are already considered CRP and their design is already optimized. On the contrary, wheels have been excluded since their current design extend their life-span over the one of the product itself; therefore, they are not considered important for service. Eventually, motor brushes have been excluded as well since, also in this case, their life-span is longer than the one of the motor itself (according to Philips they are designed to last at least 600 h)
- **Assembly depth**, where the maximum number of steps for motor, cord-winder and PCBA is defined according with the optimised disassembly map shown in Fig. 157. These values represent a score of 9/10 for disassembly depth in Table 29.
- **Disassembly tools**, where specific requirements related to the type of tools needed for the disassembly of the product are listed. Position and type of screw should be clearly indicated in the service manuals, and the tools required should be selected from the "common tools" list proposed by the prEN45554.

These requirements might be reviewed in the future, updating them with the latest regulations. This is just a first step towards improving product repairability, but it seems promising and it will be interesting to see how new Philips canister vacuum cleaners will look like in the future.

8.3 Conclusions

In this chapter, two practical outcomes of this research have been presented.

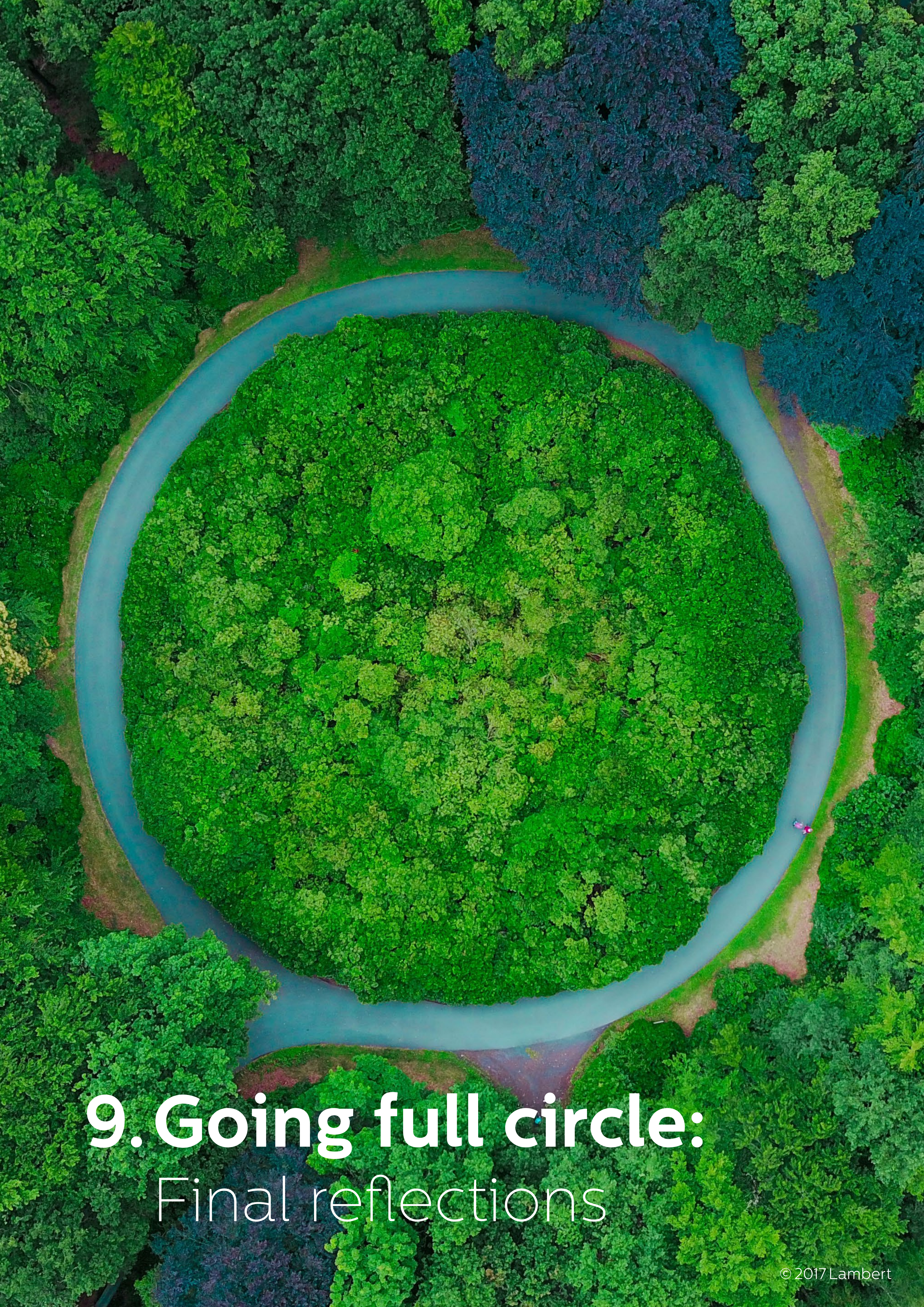
The first one concerns the definition of new threshold values (X, Y, Z) (Cordella et al., 2019) for a discrete rating of disassembly depth and time for canister vacuum cleaners. Although continuous rating assessment (CEN/CLC TC10 European Standard, 2017) was used in the first part of this research, this system proved not to be completely suitable for the assessment of product repairability. This is because while reference products were assessed with a 1/1 pt, all the other models, proportionally assessed based on the best, were rapidly penalised. For instance, few disassembly seconds more for the disassembly of the nozzle could cost almost half a point. At the beginning, this method was preferred over a discrete rating since the JRC did not provide any threshold values yet. However, after this extensive research, possible new insights in this direction have been presented. Indicative threshold values for the assessment of priority components have been calculated. Further investigation is required, since only seven vacuum cleaners have been analysed, one of which was a stick vacuum cleaner and four were produced by the same company. While the thresholds proposed

1	Serviceability
PR24	It shall be easy to disassemble and assemble the product for repair
PR25	The order in which the actions are to be carried out for repair shall be logic and clear
PR26	It shall be easy and fast to reach the components that are indicated as spare parts
PR27	No "exotic screws" shall be used, only commonly available ones
PR28	No hidden snap fits shall be used, unless they never have to be disassembled for repair
PR29	No glued parts shall be used that will hamper the opening and closing of the product
PR31	Snap on electrical connections shall be preferred above soldered connections in case they have to be disassembled and assembled in case of repair
PR32	There shall not be screw holes behind type plates
PR48	Fastener systems shall be reusable and not break during disassembly or subsequent assembly. Breakage shall only be accepted if the new fastening system is included as spare part for the repair activity
2	Priority components
PR38	High priority components shall be defined. High priority components shall be disassembled easily and independent from each other
PR34	The motor shall be a high priority component
PR35	The power cable shall be a priority component
PR36	The PCBA shall be a priority component
3	Assembly depth
PR41	The number of disassembly steps for the motor shall be ≤ 7 steps
PR42	The number of disassembly steps for the power cable shall be ≤ 6 steps
PR43	The number of disassembly steps for the PCBA shall be ≤ 5 steps
4	Disassembly tools
PR47	The position of screws and the type of screw shall be indicated in the service manual
PR45	It shall be possible to disassemble the product using common tools, as defined in prEN45554
PR46	In case tools other than defined by prEN45554 are needed, this shall be discussed in the project team and mentioned in the service manual

Table 32, New Philips Floor Care serviceability requirements

for high scores are quite certain, due to the fact that the perfect vacuum cleaner architecture was investigated in the last chapter, the lower score needs a broader analysis.

The second practical outcome of this research are new serviceability requirements for the Philips Floor Care I&D department. These are 19 product requirements, clustered in four sections: Serviceability, priority components, assembly depth and disassembly tools. Philips agreed to define these new guidelines together after the involvement in the project. These new design “rules” are meant to guide the development of future products, enhancing repairability of future canister models. Not enough data were analysed to propose requirements for stick and uprights vacuum cleaners as well, and further research in that direction should be carried out. Eventually, Philips I&D expressed clear interest in the Disassembly Map tool, and it might be used by the engineering teams in the next coming years.



9. Going full circle:

Final reflections

In this final chapter I would like to express some personal reflections about the overall project and Circular Economy. These are extremely personal considerations, and they do not necessary reflect neither the opinion of the Circular Product Design department of TU Delft, nor the one of Royal Philips. On the contrary, some of these are suggestions about how, in my vision, circularity could actually come to life with the help of both organizations.

Small, but meaningful changes

Industry has never liked radical change: it costs money, implies risks and cannot ensure success. On the other hand, Circular economy requires a lot of it, and our planet needs it soon. As Conny Bakker once said, there is “no time to waste”. However, circularity cannot happen without industry and without those stakeholders who have been at the beating heart of companies until today. Change must happen, but radical solutions might not be the answer. In order to convince Philips to act fast about product repairability, I tried a new strategy: small, but meaningful changes. Instead of proposing threateningly new and un-feasible concepts, I iterated on the work already done, adding my small brick on a big wall. I tried to find solutions as simple as possible. In most cases, the solution was still the same original product, just with some small additions. This allowed me to show how it was easy to implement the changes I was proposing and raising questions about why those changes were not there in the first place.

Stakeholder involvement

Shared ownership is the key to implement change in a company. Circularity cannot happen if just few passionate are working on it. Everybody, even the most sceptical must be involved in the change. Convincing the most reluctant can be an incredibly effective strategy to persuade everyone else. To obtain this result, solutions must be found together, discussing and confronting on different opinions. New ideas must come from the same beating heart of people who have been working in the company for many years.

Double front approach

In order to implement circular economy, all the corporate levels should be involved in the change; this includes top levels as low ones. There is the need of people able to talk with completely different types of stakeholders, from mangers to engineers. Change should be guided with both top-down and bottom-up approaches, integrating it deeply in the company identity.

Practical approaches and solutions

Circularity must become more practical. A lot has been written and discussed at high level, but very little guidance is provided on the practical one. It is often argued that product design must change to enable circular business models. Despite this, while we have clear ideas of how a circular model looks like, we are lacking in practical solutions or guidelines at the product level. “Easy to repair, to clean, to disassemble or to recycle” is not enough anymore; more articulated methodologies are necessary to make a step further.

Collaboration between academic world and industry

Circularity represents an extremely complex challenge, and the industry cannot make it without aid from the academic world. There is a strong need for research to develop new practical guidelines and methodologies for circular product development. At the same time, universities will never succeed in creating them without having the possibility of testing them practically on the field. This is a new game for everybody and, as already said, there is no time to waste.

Sustainable representatives in the design teams

Design teams in Philips involve different figures, such as designers, mechanical and production engineers, functional developers and product research engineers. The new figure of a sustainability expert should be involved as well. This is someone who can bring at the decision table matters and aspects related to the sustainable impact of the product. The use of new design methodologies, like those developed during this study, requires people with expertise and allocated time to really be able to apply them. This should be a full-time position, and not just a side task. Sustainability cannot be a nice project addition anymore, but an integrated product feature.

The importance of Top-Down legislation

A future European scoring system for product repairability and labelling system that are on the horizon were strong drivers for the manufacturer and different company stakeholders, which decided to initiate and collaborate in this project. Top-Down legislation is an incredibly powerful aid to promote a transition towards Circular Economy, and in pushing OEM’s to improve their current manufacturing systems. New legislation from the European Commission is essential in order to achieve a change in this sense at the system level in the close future.

References

Allenby, B. R. (1991). Design for environment: A tool whose time has come. SSA journal, 12(9), 5-9.

Andrews, A. (2018). Peter Mckinnon inspired camera repair photo. Retrieved on 30th August, 2019 from https://unsplash.com/photos/rt6QV85-AIE

Bakker, C., den Hollander, M., Van Hinte, E., & Zljlstra, Y. (2014). Products that last: Product design for circular business models: TU Delft Library.

Bakker, C., Wang, F., Huisman, J., & Den Hollander, M. (2014). Products that go round: exploring product life extension through design. Journal of cleaner production, 69, 10-16.

Bhatt, P. (2018). peekaboo. Retrieved on 21th August, 2019 from https://unsplash.com/photos/7URiS9J_Rh8

Bobba, S., Ardente, F., & Mathieux, F. (2015). Technical support for environmental footprinting material efficiency in product policy and the European platform on LCA—Durability assessment of vacuum cleaners. JCR Sci. Policy Rep.

Bocken, N. M., de Pauw, I., Bakker, C., & van der Grinten, B. (2016). Product design and business model strategies for a circular economy. Journal of Industrial and Production Engineering, 33(5), 308-320.

Bourjault, A. (1984). Contribution a une approche methodologique del'assemblage automatise. Sciences Physiques, Universite de Franche Comte.

Bracquené, E., Brusselaers, J., Dams, Y., Peeters, J., De Schepper, K., Duflou, J., & Dewulf, W. (2018). Repairability criteria for energy related products.

Bryan, C., Eubanks, C., & Ishii, K. (1992). Data representation for serviceability design. Paper presented at the 4 th International Conference on Design Theory and Methodology.

CEN/CLC TC10 European Standard. (2017). General methods for the assessment of the ability to repair, reuse and upgrade energy related products. DRAFT DOCUMENT. In (Vol. prEN 45554).

Chiu, M.-C., & Kremer, G. E. O. (2011). Investigation of the applicability of Design for X tools during design concept evolution: a literature review. International Journal of Product Development, 13(2), 132-167.

Ciaglo, M. (2013). A Digital Dump. Retrieved on 29th August, 2019 from http://www.michaelciaglo.com/agbogbloshie-a-digital-dump

Cordella, M., Alfieri, F., & Sanfelix, J. (2019). Analysis and development of a scoring system for repair and upgrade of products - Final Report. (EUR 29711 EN). Luxembourg: Publications Office of the European Union

Cordella, M., Sanfelix, J., & Alfieri, F. J. P. C. (2018). Development of an Approach for Assessing the Reparability and Upgradability of Energy-related Products. 69, 888-892.

De Fazio, T., & Whitney, D. (1987). Simplified generation of all mechanical assembly sequences. IEEE Journal on Robotics and Automation, 3(6), 640-658.

De Mello, L. H., & Sanderson, A. C. (1991). A correct and complete algorithm for the generation of mechanical assembly sequences. IEEE transactions on Robotics and Automation, 7(2), 228-240.

Ellen MacArthur Foundation. (2017). Global Partners: Philips. Retrieved on 17th August, 2019 from https://www.ellenmacarthurfoundation.org/our-story/partners/global/philips

European Commission. (2015). Closing the loop—An EU action plan for the circular economy. COM 614 final.

European Commission. (2016). Ecodesign Working Plan 2016-2019. COM(2016) 773 final.

Flipsen, B., Bakker, C., & van Bohemen, G. (2016). Developing a reparability indicator for electronic products. Paper presented at the 2016 Electronics Goes Green 2016+(EGG).

Gangoda, P. (2018). General rules for flowcharting. Retrieved on 12th May, 2019 from https://www.quora.com/What-is-a-flowchart-What-are-the-different-symbols-used-in-a-flowchart

Groupeseb.co.uk. (2019). Product Repairable. Retrieved on 10th May, 2019 from https://www.groupeseb.co.uk/repairable.html

Hervier, M., Logle, X., & Descos, I. (2018). Benchmark international du secteur de la réparation – ADEME Rapport - 59 p., . Retrieved from https://www.ademe.fr/sites/default/files/assets/documents/benchmark_reparation_2018_rapport.pdf

Hinckley, M., & Barkan, P. (1993). Benefits and Limitations of the DFA Structured Methodologies in Product Design. ASME Manufacturing Review, 6(3).

Holtek. (2017). Cost-Effective A/D Flash MCU with EEPROM. HT66F002/HT66F0025/HT66F003/HT66F004. Retrieved on 8th August, 2019 from https://img.ozdisan.com/ETicaret_Dosya/501741_7638301.pdf

IEEE Std. (2014). IEEE Std 1874-2013 : IEEE Standard for Documentation Schema for Repair and Assembly of Electronic Devices. In.

ifixit.com. (2019). Design for repairability. Retrieved on 10th May, 2019 from https://www.repairability.org/login

Ishii, K., Eubanks, C., & Marks, M. (1993). Evaluation methodology for post-manufacturing issues in life-cycle design. Concurrent Engineering, 1(1), 61-68.

Ishii, K., Eubanks, C. F., & Di Marco, P. (1994). Design for product retirement and material life-cycle. Materials Design, 15(4), 225-233.

Ishii, K., & Kmenta, S. (1995). Introduction to design for assembly. ME217A Course Reader, Design for Manufacturability: Product Definition, Stanford Bookstore.

Ishii, K., & Lee, B. (1996). Reverse fishbone diagram: a tool in aid of design for product retirement. Paper presented at the Proceedings of the 1996 ASME Design Technical Conference.

JST. (2019). VA CONNECTOR. 7.92mm pitch/Disconnectable Crimp style connectors. Retrieved on 7th August, 2019 from http://www.jst-mfg.com/product/pdf/eng/eVA.pdf

Kemna, R., & Boorn, R. v. d. (2016). VHK for the European Commission. Special Review - Study on durability tests - According to Article 7(2) of Commission Regulation (EU) No 666/2013 with regard to ecodesign requirements for vacuum cleaners.

Kuo, T.-C. (1997). A disassembly model for end-of-life products recycling. Texas Tech University,
labo.fnac.com. (2018). Labo Fnac lance l'indice de réparabilité des PC portables. Retrieved on 10th May, 2019

Lambert, T. (2017). Top picture of a forest in Belgium. from https://unsplash.com/photos/EhLH-WN7F7I

Lebeck, A. O. (1991). Principles and design of mechanical face seals: John Wiley & Sons.

Marks, M. D., Eubanks, C. F., & Ishii, K. (1993). Life-cycle clumping of product designs for ownership and retirement. ASME DES ENG DIV PUBL DE., ASME, NEW YORK, NY (USA), 53, 83-90.

Messler, R. W. (2004). Joining of materials and structures: from pragmatic process to enabling technology: Butterworth-Heinemann.

Natuur&Milieu. (2018). Reparatie Monitor: analyse resultaten.

Nordic Swan Ecolabel. (2019). Product groups. Retrieved on 9 March, 2019 from https://www.nordic-ecolabel.org/product-groups/

Noronha, E. (2017). Microsoft Surface Laptop Teardown. Retrieved on 20th August, 2019 from https://www.ifixit-pwa.appspot.com/guide/92915

Peeters, J., Tecchio, P., Ardente, F., Vanegas Pena, P., Coughlan, D., & Duflou, J. (2018). eDIM: further development of the method to assess the ease of disassembly and reassembly of products: Application to notebook computers.

Philips Healthcare. (2014). Refurbishing solutions for MRI systems. Retrieved on 17th August, 2019 from https://www.philips.com/a-w/about/sustainability/sustainable-planet/circular-economy/refurbished-medical-products.html

Philips.com. (2016). Healthy people, sustainable planet. Our ambition for 2020. Retrieved on 17th August, 2019 from https://www.philips.com/a-w/about/sustainability/our-approach/ambition-2020

Philips.com. (2017). SENSEO. Original goes the extra mile to use recycled plastics. Retrieved on 17th August, 2019 from https://www.philips.com/a-w/about/sustainability/sustainable-planet/circular-economy/senseo.html

Philips.nl. (2019a). Philips stofzuigers. Retrieved on 26 February 2019 from https://www.philips.nl/c-m-ho/stofzuigers

Philips.nl. (2019b). Service & Repair. Retrieved on 5th May, 2019 from https://www.philips.nl/c-w/support-home/service-en-reparatie.html

Rames, M., Gydesen, A., Huang, B., Peled, M., Maya-Drysdale, L., Kemna, R., & van den Boorn, L. (2018). Review study on vacuum cleaners for the european commission - Draft interim report (October 2018 version).

Reisch, L., Graulich, K., Degallaix, L., Maurer, S., & Bernefeld, N. (2010). Work on Preparatory Studies for Ecodesign Requirements for EuPs (III) and on Stakeholder Representation: LOT C: Stakeholder Representation: Consumers-Final Report.

Repair Café. (2019). About Repair Café. Retrieved on 17th April 2019 from https://repaircafe.org/en/about/

Rowenta.com. (2019). Rowenta is committed to repairability. Retrieved on 5th May, 2019 from https://www.rowenta.com/repairability-page

Samsung.com. (2019a). Home Appliances Support. Retrieved on 5th May, 2019 from https://www.samsung.com/us/support/home-appliances/

Samsung.com. (2019b). More for your convenience. Vacuum cleaner accessories. Retrieved on 6th May, 2019 from https://www.samsung.com/nl/vacuum-cleaners/all-vacuum-cleaners/?accessory

Santa Clara University. (2006). Design for assembly. Retrieved on 12th May, 2019 from http://www.dc.engr.scu.edu/cmdoc/dg_doc/develop/design/part/33000004.htm

Schlick, C. M. (2009). Industrial Engineering and ergonomics: visions, concepts, methods and tools festschrift in honor of Professor Holger Luczak: Springer Science & Business Media.

Siemens-home. (2019a). Siemens customer service. Retrieved on 5th May, 2019 from https://www.siemens-home.bsh-group.com/uk/customer-service

Siemens-home. (2019b). Siemens service assistent. Retrieved on 6th May, 2019 from https://www.siemens-home.bsh-group.com/nl/supportdetail/product/VS06A111/12#/Tabs=section-spareparts/Togglebox=2409/Togglebox=2411/Togglebox=tb0201/

Siemens-home. (2019c). Spare parts, cleaning products and accessories. Retrieved on 5th May, 2019 from https://www.siemens-home.bsh-group.com/uk/shop/search-parts

smlease.com. (2019). Engineering Tolerance & Fits. Retrieved on 12th May, 2019 from https://www.smlease.com/entries/tolerance/engineering-tolerance-fits/

Tres, P. A. (2017). Designing plastic parts for assembly (8th edition updated. ed.). Munich Cincinnati: Hanser Publishers
Hanser Publications.

Tukker, A. (2004). Eight types of product–service system: eight ways to sustainability? Experiences from SusProNet. Business strategy and the environment, 13(4), 246-260.

Tukker, A. (2015). Product services for a resource-efficient and circular economy–a review. Journal of cleaner production, 97, 76-91.

Tukker, A., & Tischner, U. (2017). New business for old Europe: product-service development, competitiveness and sustainability: Routledge.

Vanegas, P., Peeters, J. R., Cattrysse, D., Duflou, J. R., Tecchio, P., Mathieux, F., & Ardente, F. (2016). Study for a method to assess the ease of disassembly of electrical and electronic equipment.

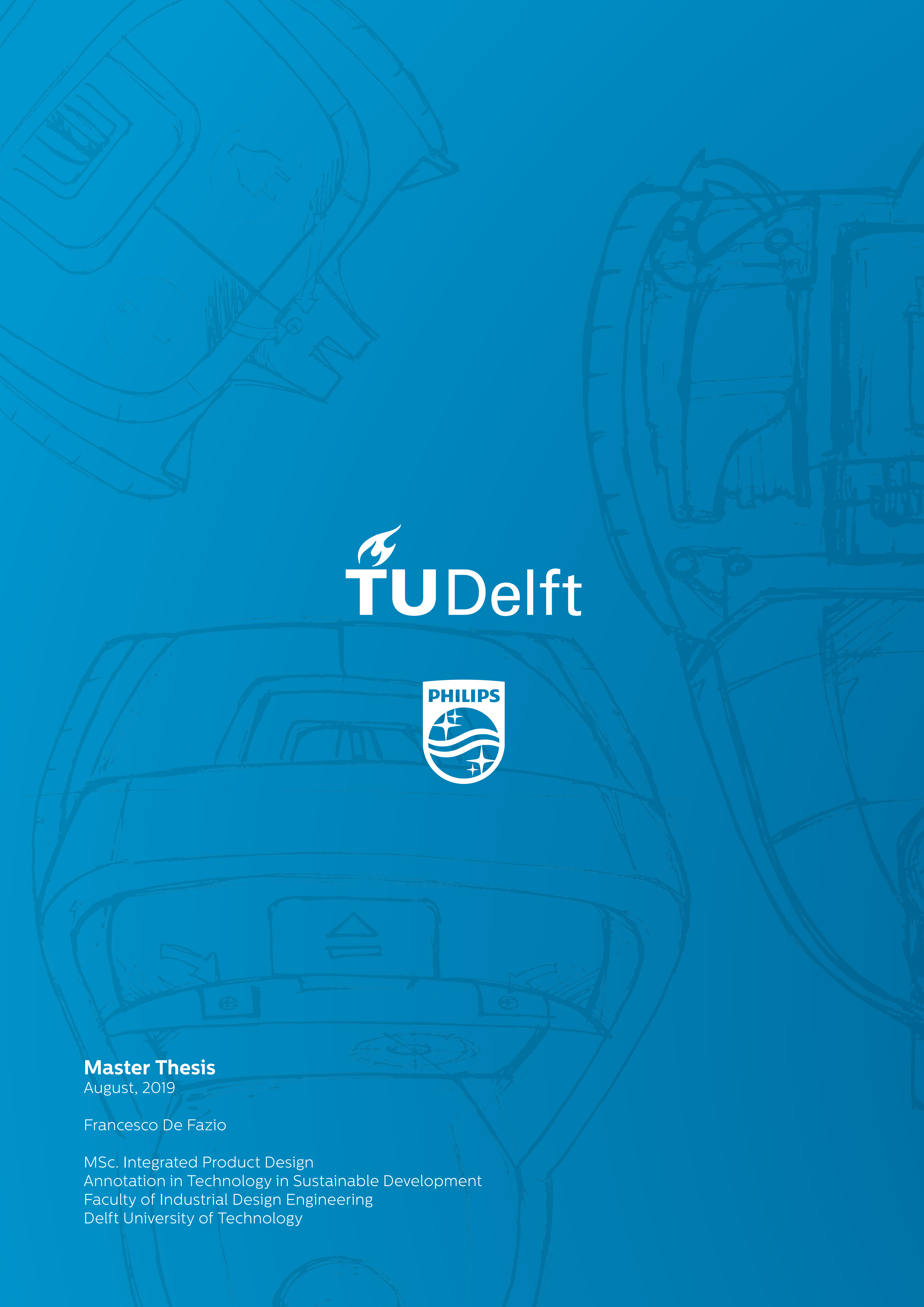
Vezzoli, C., Ceschin, F., Diehl, J. C., & Kohtala, C. (2015). New design challenges to widely implement 'Sustainable Product–Service Systems'. Journal of cleaner production, 97, 1-12.

Vezzoli, C., Kohtala, C., Srinivasan, A., Xin, L., Fusakul, M., Sateesh, D., & Diehl, J. (2017). Product-service system design for sustainability: Routledge.

Wang, F., Huisman, J., Stevels, A., & Baldé, C. P. (2013). Enhancing e-waste estimates: Improving data quality by multivariate input–output analysis. Waste management, 33(11), 2397-2407.

Way, P. L. T. (2016). Plastic Fasteners, Welding, and Bonding. Retrieved on 12th May, 2019 from https://www.lancasterschools.org/cms/lib/ny19000266/centricity/domain/1055/plastic_fasteners_welding_bonding.pdf

Zandin, K. B. (2002). MOST work measurement systems: CRC press.



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