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PROMPT

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Content

State-of-the-art of design strategies and design principles in relation to obsolescence

This deliverable presents an overview of design strategies, design principles and design features in relation to obsolescence based on literature and state-of-the-art in repair practice. The results presented are preliminary in the sense that they are the result of an initial exploration in a broad field to extract the information most promising for further research in future deliverables (Deliverable 4.1-4.5).. It provides an overview of barriers, various scoring systems, and reports from partners in order to extract design features facilitating and hampering longevity of products. Finally, using these results, an inventory of design strategies and principles, and its relation to different design features is generated and analysed. This inventory will be elaborated and built upon for the development of tests on design aspects in future deliverables (Deliverable 4.1-4.5).

1 Literature review related to product design and obsolescence

Product design affects longevity and can provide opportunities to resist, postpone and reverse product failure, but might also induce premature obsolescence. This report describes the activities over the past eight months in Task 2.3 on the setup of an inventory of design strategies and design principles in relation to obsolescence, based on both literature and actual repair cases. This report comprises a literature overview on design principles related to longevity (Chapter 1) and a State-of-the-Art overview on design features that are known to affect product longevity (Chapter 2).

In Chapter 3 the results of both approaches are compared to identify starting points for further investigation into the opportunities and barriers when using design features for evaluating different of aspects of longevity, i.e. durability, maintenance, repair and upgrading.

1.1 Introduction

A product is obsolete if it is no longer considered useful or significant to its user (Burns, 2010). This obsolescence can be categorized into different types: aesthetic, social, technological, logistical and functional obsolescence (Bartels et al., 2012; Burns, 2010; Cooper, 2010; Feldmann & Sandborn, 2007; Tomczykowski, 2001). In essence, all obsolescence ultimately is a loss of perceived value (i.e., desire or affinity) of the product and/or system, triggered, in some instances, by inadequacy at the product and/or system side (Box, 1983). It is, by definition, impossible to objectively state whether a product is obsolete or not. Obsolescence seems to be largely in the eye of the beholder. Often it is the user who determines whether or not a product is due for repair; for example, a fully functional smart phone with a crack in the screen may be considered obsolete (and thus in need of immediate repair) by someone who highly values aesthetics, whereas it may seem in perfectly good working order to someone less concerned about the product's appearance. This subjective nature of obsolescence can make it difficult to predict and determine the best design approach.

Den Hollander (2018) in this thesis on "Design principles for Resisting and Postponing and reversing obsolescence" provided a comprehensive literature overview on obsolescence for products and services in general. This thesis has been taken as the starting point for the overview and ordering of design principles as presented here. This has been made more explicit for electronic products and especially for the products directly in the scope of PROMPT. The thus obtained overview provides a starting point for design features that are interesting to be examined in a testing program

In a circular economy, a product should remain as much as possible identical to its original state, over time (Den Hollander, 2018). The extent to which a product remains identical to its original state is regarded as 'product integrity' (, 2010). For this, Stahel (2010) suggested the Inertia Principle: "*Do not repair what is not broken, do not remanufacture something that can be repaired, do not recycle a product that can be remanufactured. Replace or treat only the smallest possible part in order to maintain the existing economic value of the technical system*". (Stahel, 2010, p.195). Following the Inertia Principle, Den Hollander (2018) proposes that design priority should be given to prevent a product from becoming obsolete (resisting and postponing obsolescence), followed by recovering of resources at the highest level of integrity (reversing obsolescence). These two points are referred to as "Design for Preserving Product Integrity".

A product with high emotional and physical durability resists obsolescence. A product that could be easily maintained, repaired and upgraded could extend the use of the product, i.e. postpone obsolescence. And finally, a product that could be easily remanufactured, refurbish or used in a different context is able to reverse obsolescence. These three design aspects have been developed into a "typology for design strategies for preserving product integrity", see Table 1. The typology presents design strategies that are available for preserving product integrity by counteracting obsolescence. As PROMPT focuses on durability and reparability, the scope of this overview covers the following three areas.

- Design for Physical Durability
- Design for Maintenance and Repair
- Design for Upgrade

In this report the focus is mainly on the technological aspects of design.

Design for Product Integrity		
Design approaches for long use	Design approaches for extended use	Design approaches for recovery
Design for Physical Durability Design for Emotional Durability	Design for Maintenance and Repair Design for Upgrading	Design for Recontextualising Design for Refurbishment Design for Remanufacture
		Design for Recycling

Table 1 *Design approaches for product integrity. Taken form Bakker, Balkenende, Poppelaars (2018).*

A variety of definitions for the presented typologies can be found in scientific literature. In order to avoid misinterpretation, the following definitions are proposed to be used by the consortium (following the literature study conducted by Den Hollander (2018).

Physical Durability

"Durability of an item is the ability to withstand wear, stress and environmental degradation over a long useful life." (Den Hollander, 2018)

With regards to the ability of a product to resist obsolescence, two main concepts are presented in literatures: reliability and durability (Vezzoli & Manzini, 2008; Bijen, 2003; Keoleian & Menery, 1993). Although the two concepts are related, they are not the same. By definition, reliability is expressed in relation to a specified period of time (Moss, 1985). Products that by design have a high level of reliability for a short period of time, such as single-use medical devices or single-use rocket boosters do not necessarily have a high level of durability. Most of the literature agree that durability is about "*the possession of qualities associated with long-life*" (Frohnsdorff & Masters, 1980, p. 17) and "*staying strong and in good condition over a long period of time*" (Merriam-Webster, 2015a). A definition by Keoleian and Menery (1993) reflects the physical durability as a material quality of a product and distinguishes it from the concept of emotional durability. Products that have a high level of physical durability by design often do exhibit a high level of reliability. Although reliability can be an important contributor to an extended product lifetime, as "*unreliable products or processes, even if they are durable, are often quickly retired*" (Keoleian & Menery, 1993), the literature contains evidence indicating that in some instances, reliability has limited or no effect on the onset of obsolescence. Therefore durability (rather than reliability) could be considered the primary discriminating characteristic of design aimed at resisting obsolescence over time.

Maintenance

"Maintenance is the performance of inspection and/or servicing tasks at regular intervals, to retain a product's functional capabilities and/or cosmetic condition." (Den Hollander, 2018)

The international standard EN 13306 (EN, C., 2010) on maintenance terminology defines maintenance as the "*combination of all technical, administrative and managerial actions during the life cycle of an item intended to retain it in, or restore it to, a state in which it can perform the required function*" (p. 5). In this definition, postponing obsolescence (i.e., retaining a product in a functioning state) and reversing obsolescence (i.e., restoring a product from a non-functioning state to a functioning state) are both considered maintenance. In practice, this led to the terms preventative (or predictive) maintenance (to retain functionality) and corrective maintenance (to restore functionality) being introduced (Moss, 1985). In the typology provided in **Fehler! Verweisquelle konnte nicht gefunden werden.** designing for maintenance is limited to preventative (or predictive) maintenance and not including corrective maintenance.

Maintenance terminology was developed in the field of engineering, which is why (according to the standard definition) it focuses on technical and organizational issues. In addition to making adjustments to the settings of the original product, maintenance removes elements that are foreign to the original product, for example dust, and/or adds or replaces specific elements (consumables) that are required for the standard operation of the (durable) product, for example, fuel, filters, or lubricants. These maintenance activities are often characterized by their repetitive nature. When applied to consumer products, maintenance retains an aesthetic and/or hygienic condition, like in clothes laundering (washing and ironing).

Repair

"Repair is the correction of specific faults in an obsolete product, bringing the product back to working condition." (Den Hollander, 2018)

In a context where products are used as capital goods (e.g., manufacturing), repair is often equated with the term corrective maintenance (Moss, 1985). However, here we use a more familiar definition of repair based on Ijomah et al. (2004), but with the inclusion of a statement about the end condition of the product, as introduced by Stahel (2010) and Flexner (1987).

As Moss (1985) implies, repair is a form of maintenance, therefore there is a general agreement in the literature that maintenance and repair are closely related and guidelines for maintenance and repair are similar to each other (e.g. Moss, 1985; Lidwell et al., 2010; Kuo et. al, 2001; Vezzoli and Manzini 2008; CRR, 2009). Therefore from a design perspective, maintenance and repair have much in common and will be discussed together.

Upgrade

"Upgrading is the process of enhancing, relative to the original design specifications, a product's functional capabilities and/or cosmetic condition." (Den Hollander, 2018)

The definition of upgrading is an extension to the definition provided for maintenance, whereby retain is replaced by enhance to express the overall intent of the process of upgrading, as defined by Flexner (1987). Upgrading is usually done when a product is still in good working order, but the context of use changes, making it necessary to enhance the product's capabilities.

1.2 Design principles for Physical Durability

According to the literature, the physical durability in a product could be increased by following elements

Design complexity
Selecting a basic conceptual operating principle for performing a specific function that reduces the number of (moving) parts required for performing that particular function, thereby maximizing the simplicity and the robustness of the operating principle (CRR, 2009; Vezzoli & Manzini, 2008; Bijen, 2003 Keoleian & Menery, 1993).

Design Detailing
Detailing the basic conceptual operating principle in a way that increases the resistance to wear or stress during the performance of a particular function (Vezzoli & Manzini, 2008; Bijen, 2003; Keoleian & Menery, 1993). For example, example different types of movement, e.g., rotation versus translation, different types of connection, e.g., welding, bolting, gluing, snapping, pressing or stitching, or different production methods, e.g., casting, injection moulding, milling.

Dimensioning
Dimensioning or over dimensioning parts so that the load on the part during use will under normal conditions never exceed the load that the material that a specific part is made of can handle can help to further reduce stress during use (Bijen, 2003). Furthermore, dimensioning interfaces of moving parts to provide smooth running without excess wear could also be considered.

Material Selection
Careful matching of type and grade of components and materials with functional requirements and use environment can prevent chemical and/or mechanical and/or radiation and/or thermal degradation during the performance of a particular function (Vezzoli & Manzini, 2008; Bijen, 2003; Keoleian & Menery, 1993).

Surface treatment
Selection of the type of surface treatment to prevent chemical and/or mechanical and/or radiation and/or thermal degradation during the performance of a particular function (Bijen, 2003). It is also possible to choose treatment where wear would be alright or even an asset (e.g., patina on copper roof, leather shoes fitting better by stretching, etc.).

Use of Expendable parts
Design of the weakest link; An inexpensive part that is designed to wear out during use, thereby protecting parts that are more expensive and difficult to replace (Mulder et. al 2012) (Eg. Brake pads in the disc brakes of a car wears out much faster than disc brakes, thereby protecting disc brakes). Whist this aspect was indicated more towards design principles for maintenance and repair, it also firmly fits in the design principles of physical durability.

Use components of similar life-span
Designing components with similar life-span prevents "weakest link" in the design and assures a component doesn't fail until the rest of the product fails Bovea et. al (2018).

Encourage Maintenance
Although this aspect is partially covered by design principles for maintainability, the encouragement of maintenance does help in the longevity of the device and could be considered here. The following points fall under the design guidelines for maintenance encouragement (Autodesk, 2011).

- Make care instructions available, clear, and inviting.

- Build maintenance instructions into the product interface.
- Provide maintenance tools and supplies.
- Provide easy and affordable maintenance service.

Dirt accumulation prevention
Whilst it is possible to also design for easy clean-up of accumulated dirt, it would be more sensible to design for aspects that would prevent the accumulation of dirt entirely which may hamper the performance of products (f. . Therefore, Maria et. al (2018) suggests on "design to avoid dirt from accumulating" as one of the guidelines that focus on circular economy principles.

With regard to designing a potential for physical durability into products, Keoleian and Menery (1993), observed that "*some design actions may make a product more durable without the use of additional resources. However, enhanced durability may depend on increased resource use*" (p. 64). Keoleian and Menery (1993) therefore stressed that design interventions to increase physical durability should always be weighed against the (additional) resources required to achieve the increase in useful lifetime, this is supported by Alfieri et. al (2018) where they proposed to conduct and compare life cycle assessment of a new (more durable) design with an old (less durable) design and determine whether the environmental impact of the new design can be justified.

1.3 Design Principles for Maintenance and Repair

The following design principles with regards to maintenance (and repair) have been identified as according to the literature.

Standardization
Standardization pertains to designing products and parts in such a way that they conform to generally accepted design standards for configuration, dimensional tolerances, performance ratings and other functional design attributes (Moss, 1985, p.36). With regard to maintenance/repair, the objectives of standardization are twofold. Firstly, standardization assures compatibility between mating parts for example when replacing a faulty/expendable unit, and between the product and the common tools, test equipment, and facilities used for its maintenance. Secondly, standardization helps to minimize the number of different spare parts that must be stocked for maintenance/repair support.

Modularization
With the design principle of modularization, product is divided "into multiple, smaller self-contained systems" (Lidwell et al., 2003, p.136), that conform "to dimensional standards based on modular "*building block" units of standardized size, shape, and interface locations (i.e., locations for mating attachment or mounting points and input/ output line connectors), in order to simplify maintenance tasks by enabling the use of standardized assembly/disassembly procedures*" (Moss, 1985, p. 36).

Functional Packaging
The design principle of "*functional packaging locates all components … performing a given function in … a unit that is readily removable and replaceable as an entity*" (Moss, 1985, p.36), allowing for example maintenance/repair activities to be performed off-line.

Interchangeability
The design principle of "*interchangeability controls dimensional and functional tolerances of manufactured parts and assemblies to assure that [a part that is expected to fail (or cause failure)] soon can be replaced in the field with no physical rework required for achieving a physical fit, and with a minimum of adjustments needed for achieving proper functioning*" (Moss, 1985, p. 37).

Accessibility
The design principle of accessibility controls the spatial arrangements of parts and assemblies within a piece of equipment so that each of these items is readily accessible (Moss, 1985, p. 37) for replacement, whereby evaluation of the relative accessibility of each component of a given design must take into consideration the physical limitations of the maintenance/repair worker (human factors), and whether other items must first be removed in order to gain access to a specific item (Moss, 1985, p. 37). Arcos et al. (2019) builds on to this by recommending to "*arrange components with short lifespan and exposed to frequent wear and tear in an accessible and ergonomic disposition*" Furthermore, housings that are easy to facilitates access to the products interior for inspection (Arcos et al., 2019).

Error Codes
Malfunction annunciation serves to announce to the operator or user that a product is about (Moss, 1985, p. 37). Moss (1985) provided the example of "*warning indicator lights on the dashboard of an automobile [that] are intended to alert you to approaching malfunctions in the engine cooling system, oil system, or electrical system so one can stop before losing power or damaging the engine*". This is further supported by Maria et. al (2018) suggesting to include systems to monitor failing components.

Fault Isolation
The design principle of fault Isolation assures that an (approaching) equipment malfunction can be traced to the (soon to be) faulty part of the assembly requiring replacement, even if supplementary hardware must be provided solely for that purpose. (Moss, 1985).

Visibility
Use of transparent materials for product and component housing avoids disassembly of the product during inspection. In addition, tubular components with a straight shape and sectionable parts facilitate interior inspection at different points of its longitude (Arcos et al., 2019)

Component Identification
The design principle of identification pertains to the utilization of "*engraving, marking, or labelling for quick location of parts or assemblies from which maintenance/repair could be performed*" (Moss, 1985).

User and Product Safety
products need to be designed in such a way that injuries to those performing maintenance as well as damage to the product during maintenance activities (e.g., during disassembly and reassembly (Brennan, Gupta & Taleb, 1994) are prevented. To achieve this, Kuo et al. (2001) suggested for example to leave sufficient space around components and to avoid sharp edges, corners and protrusions in the design.

Tools
Kuo et al. (2001) stated that the need for special tools must be minimized, to help ensure tool availability (Keoleian & Menery, 1993). Ideally no tools would be required to open or remove components (Mulder et al 2012). In addition, easily usable tools should be supplied with the product.

Fasteners/Joints
Mulder et al. (2012) also suggested to use fasteners that accelerate maintenance (and repair) activities. Maria et. al (2018) further gives details on the guidelines for fasteners:

- Use standardized fasteners
- Use joints that can be disassembled rather than fixed ones
- Use screws with same metrics
- Minimize type of joints
- Use easily accessible joints

- Minimize number of joints
- Minimize number of tools to be used to disassemble the joints
- Use standardized tools
- Improve the identifiably of disassembly joints

Keying
To help speed up the maintenance process and avoid errors, Kuo et al. (2001) proposed to use keying, i.e., the use of matching geometric features (e.g., matching sizes and shapes like holes and pins) to ensure correct positioning of removable parts.

Disassembly sequence placement
The efficiency of maintenance activities can also be increased by locating part or units that require regular maintenance in such a manner that they can be accessed or removed with as little disturbance to the remainder of the product as possible, e.g., without having to first remove other parts or units and without interrupting critical functions (Kuo et al., 2001). Maria et. al (2018) further adds on this suggesting to "*avoid disassembly of parts in opposite directions*".

Instinctive Design
Kuo et al. (2001) highlighted the importance of designing adjustments to function in line with what is commonly expected, e.g., clockwise, to the right, or up, to increase, and provided them with adequate end-stops to prevent damage.

Handling
Kuo et al. (2001) advised that heavy components or units should be placed as low as possible and be equipped with handles to facilitate their handling. Additionally, Maria et. al (2018) size components to make their handling easier.

Ergonomic accessibility
Vezzoli and Manzini (2008) in their guidelines for designing for maintenance cautioned designers to avoid narrow slits and holes to facilitate access for maintenance. Arcos et. al (2019) develops this further by recommending design of tubular components with open and ergonomic internal geometry to facilitate the elimination of obstructions during maintenance process.

On-site Maintenance
Designing for maintenance must "*pre-arrange and facilitate the substitution of short-lived components*" (Vezzoli & Manzini, 2008, p. 145) and aim for maintenance actions that could easily be performed onsite.

Information Availability
Although this aspect does not directly fall under physical design of the product, providing maintenance and repair documentation could greatly facilitate maintenance (and repair) for the users (Vezzoli & Manzini, 2008).

Spare Part Availability
This point also doesn't directly fall on the physical design of the product and has not been mentioned in any of the current guidelines in literature, however as according to Sabbaghi et al. (2017) and Dewberry (2016) availability of spare part (and its price) does seem to be a significant factor in maintainability/reparability of a product.

Maintenance points positioning
Position maintenance points close proximity of one another (Mulder et. al. 2012) (e.g., boiler and pumps are located at one place).

There is general agreement in the literature on designing for maintenance that product designers must strive to minimize downtime, ensure tool and spare part availability, factor in the resources and capabilities of the actor performing maintenance, minimize the complexity of required procedures, minimize potential for error; ensure accessibility to parts, components, or system to be maintained and minimize frequency of design-dictated maintenance (Mulder,Blok, Hoekstra & Kokkeler, 2012; Vezzoli & Manzini, 2008; Kuo, Huang & Zhang, 2001; Keoleian & Menery, 1993; Moss, 1985).

1.4 Design Principles for Upgrading

As discussed earlier, upgrading is also considered an extension of maintenance, therefore many of the design principles related to maintenance and repair is also applied towards upgrading. However, whereas maintenance often is characterized by repetitive activities, expendable filters for example are replaced regularly, a specific upgrade activity such as increasing computer RAM memory from 8 Gb to 16Gb, typically is only performed once on a particular product specimen over its entire lifetime. Therefore, in addition to the principles of maintenance and repair, the following principles apply for design principles for upgrading.

Compatibility
According to Keoleian & Menery, 1993, physical dimensions and geometry, data formats, on upgrades must be consistent with those of the original product in order to achieve compatibility.

Summarizing this overview of design principles in Sections 1.2-1.4, the different design approaches for preserving product integrity (physical durability, maintenance, repair and upgrade) can be seen to overlap each other. The use of a particular design principle in support of one design approach also tends to affect other approaches. Because of this interdependency, the underlying design principles by themselves could be an insufficient basis for discrimination between design strategies for preserving product integrity. While implementing design for maintenance and/or repair, the user (layman, professional etc.) and context (home, workshop etc.) needs to be factored in to ultimately determine how underlying design principles will be applied, and to determine to what extent a manufacturer chooses to limit or allow access to the internal design and working of a products. It follows that design for preserving product integrity needs to be applied in conjunction with business models that allow the (repeated) capture of economic value over time.

2 Overview of State-of-the-Art knowledge on design features facilitating and hampering repair

While the design principles presented in previous chapter may provide a favourable direction towards creating design features that facilitate products longevity, following a design principle doesn't guarantee its effective implementation and is not directly suitable for testing purposes. However, the presence/absence of specific design features in a product is an indicator for the durability and actual ability to maintain, repair or upgrade a product. Testing for such features is therefore considered as a step towards a potentially reliable and repeatable procedure for determining longevity.

In this chapter, design features of the products that are of primary concern in PROMPT are analysed and extracted, based on different sources, in order to arrive at an overview of design features that facilitate or hamper reparability of the product. This inventory is then clustered based on the design principles from Chapter 1 and analysed by identifying gaps and deviations of the design principles with respect to the design features. This inventory will be iterated and updated as further research is conducted during the course of future deliverables (Deliverable 4.1-4.5). The following sources were analysed to extract design features that facilitate/hamper reparability of product.

1. Four Current scoring systems
2. iFixit report on market observations (iFixit, 2019)
3. Washing machine analysis by RUSZ
4. Vacuum cleaner analysis by RUSZ
5. Repair practices and observed barriers for repair by
   a. Consumer
   b. Professional repairers
   c. Repair cafés

2.1 Design Features from current scoring systems

There are different existing initiatives regarding the reparability assessment of energy related products. The rating criteria in these assessment systems are mostly based on assessing different design features within a product. The design features addressed in these ratings system provide a valuable starting point towards obtaining a general overview on design features that facilitates and hampers reparability and that are suited for implementation in a testing program.

While durability assessment systems such as long-time label (LONGTIME) and PREN 45552 (CEN/CLC European Standard. 2019) do exist, these have not been investigated yet and will be included in further evaluation of the inventory in future deliverables (Deliverable 4.1-4.5).

For a general overview, the following four scoring systems were used as they provide a comprehensive and relatively recent overview on the design features addressed for the scoring system for reparability. This list will be expanded in the course of future deliverables (Deliverable 4.1-4.5) for a comprehensive overview.

ONR 192102:2014 (Austrian standard Organization, 2014)
Published by the Australian Standard Organization, this standard is a normative composed by semi-qualitative criterions to assess product on both durability and reparability. There are 40 criteria for white goods and 57 for brown goods. The requires are divided into "general requirement" related to product design and "Service delivery" related to provision of information and services.

Benelux study on "Reparability criteria for energy related products" (Bracquene et al., 2018)
This study represents a comprehensive academic research concerning assessment of product reparability, many of the criteria investigated and proposed in this study has been later adopted by JRC scoring system (Cordella et al., 2019). The assessment framework is based on five main repair steps (product identification, failure diagnostic, disassembly and reassembly, spare parts replacement, and restoring to working condition) and three different reparability criteria (Information provision, product design, service). This framework provides clear classification of the criteria and therefore has been used as the basis for the inventory of design features in this study.

PREN45554 (CEN/CLC TC10 European Standard.,2017)
The generic method for assessment of the ability to repair, reuse and upgrade (RRU) of energy related product, is an assessment standard developed under Mandate M/543 of the European Commission. The standard aims to provide a toolbox of parameters and methods to assess the ability to repair, reuse and upgrade of energy related products. This standard provides a generic set of tools and is not tailored towards specific products.

Joint Research Centre (JRC) Scoring system (Cordella et al., 2019)
The JRC scoring system has been developed following the preliminary draft of the standard concerning general methods for the assessment of the ability to repair, reuse and upgrade energy related products (CEN/CLC TC10 European Standard, 2017) and the Benelux study on "reparability criteria for energy related products".

First, all the design features mentioned in these scoring systems are listed in an inventory according to their steps in repair, using adapted framework of Braacquene et al., 2018. (Appendix 3) shows the thus obtained inventory. Design features were further elaborated and is detailed in Table 2.

2.1.1 Reference value

JRC scoring system and PREN 45554 use a reference value for scoring of disassembly time, disassembly sequence, warranty and spare part availability. This reference value according to JRC is retrieved by analysing several products from the same product category for the related criteria and calibrating for the average achieved from the analysis. Products are then scored by comparing them to the reference values. According to Cordella et al. (2019), this calibration requires significant amount of resources.

With large variety of products in each product category, the number and choice of products selected could greatly influence the analysis and calibration of the reference value. Both JRC and prEN4554 do not show how these choices are made.

During the synthesis of a testing program, any features that would require a calibration could face a similar situation. To which extent the use of reference values is useful and how in that case choices with respect to references could be made will be further investigated in future deliverables (Deliverable 4.1-4.5).

2.1.2 Disassembly time and number of disassembly steps

The JRC argues that the criteria 'disassembly time' and 'number of disassembly steps' are already covered by three other criteria: disassembly depth/sequence, fasteners and tools. However, no study has been conducted comparing disassembly time to e.g. disassembly depth, therefore further studies into the relations between criteria are required.

Moreover, it is pointed out that a more methodological development is still required in order to create an objective and standardized process to assess disassembly time. The eDIM methodology (Peeters et alp.,2018), while one of the latest documented methodology to objectively assess disassembly time, includes a relatively limited list of connectors and only for specific ICT-products. A more extensive and preferably standardized library, which includes most of the disassembly actions necessary to truly describe the disassembly of different product groups is desirable before this methodology is implemented in an assessment system. This will be further addressed in future deliverables (Deliverable 4.1-4.5).

2.1.3 Priority Parts

Energy-related products are usually composed of many different parts, however just some parts are functionally important or are likely to be fail and/or upgraded, these parts are referred to as priority parts (Cordella et al., 2019; Bracquene et al., 2018). Among the four scoring system assessed, only ONR 192102 do not use the concept of priority parts, however when component is referred in the criteria of ONR 192102, it is assumed as priority part for this analysis.

Table 2: *Design features from Appendix III further elaborated to detailed parameters. Source column; (1: PREN 45554, 2: JRC scoring system, 3:Benelux study on "Reparability criteria for energy related products" , 4: ONR 192102)*

Design feature	**Detailed parameters**	**Source**
Diagnostic Interface	Visually intuitive interface	1,2,3,4
	Coded Interface	1,2,3,4
	Public Software Interface	1,2,3
	Proprietary interface	1,2,3
Diagnostic software could be accessed by	User	2,3
	3rd party repairers	2,3,4
	Authorised repairers	2,3,4
	Not available	2,3
Low level function	Able to function at low level after critical component malfunction	4
Accessibility in switch on position	Appliance can still be activated when opened	4
Required working environment for safety	In site repair	1
	General purpose workshop	1
	Specialized workshop	1
	Production environment	1
Safety Skill level (Repair can be only carried out by)	Layman	1,2
	Generalist	1,2
	Professional	1,2,3
	Manufacturer	1,2,3
Tool Required (for repair, maintenance and update)	Tool less	1,2,3
	Common tool	1,2,3,4
	Professional tool found in market	1,2,3,4
	Proprietary Tool	1,2,3,4
Fasteners Reusability	Reusable	1
	Non-reusable but removable	1

	Non removable fasteners	1
Fasteners Visibility	Clearly visible fasteners	1
	Not clearly visible	1
	Hidden/Behind other parts	1
Fastener standardization	Standardized fasteners	4
Disassembly time (per component) using eDIM	Cannot be disassembled	3
	More than reference value	1,2,3
	Equal to reference value	1,2,3
	Less than reference value	1,2,3
Disassembly sequence	More than reference value	1,2
	Equal to reference value	1,2
	Less than reference value	1,2
Modularity	At least 50% (by count) priority parts* can be replaced individually	3
	At least 75% (by count) of priority parts can be replaced individually	3
	All priority parts* can be replaced individually	3,4
Warranty	Long term (~10 years)	2,4
	medium term (~5 years)	2,4
	Minimum term as required by law	2
Availability duration of spare parts	Long term (~10 years)	1,2,3,4
	medium term (~5 years)	1,2,3,4
	minimum term as required by law	1,2
	no information on duration	1,2
	Not available	1,2
Spare parts available to	All interested parties	2
	Any self-employed professional	2,3,4
	Authorised Service providers	2,3,4
Cost of spare parts (% of original price)	<5%	3
	5%-10%	3
	10%-20%	3
	>20%	3
Supply of spare parts	Limited Availability	3
	Widely Available	3
	Standardized Parts	3,4
Updates (to update all product-specific key features)	Update available with no limitation of time	1,2
	Update available until reference value years	2
	Update of feature achievable in product without performing product exchange	1

	Product does not allow users to update features	
	Open source standardized software	4
Data Deletion	Built in secure data deletion functionality	1
	Secure data deletion available under request	1
	Secure data transfer and deletion not available	1
Reset Ease of identification	Integrated reset without restriction	2,3
	External reset using freely accessible software	2
	Service reset offered by manufacturer	2
	Brand and unique model version reference	3
Reset Accessibility of identification	Barcode/QR code for identification	3
	Accessible only after removal of less than 2* connections	3
	Accessible after manual operation without disconnecting components	3
Robustness of identification	written in removable labels	3
	Engraved or printed	3
Safety Signs Information medium	Clear warning signs in every dangerous component	4
	Attached to product	4
Robustness of identification	In a free printed manual	4
	Product Website	3
Safety Signs	Toll fee contact support	3,4
Information medium Information is available to	Local fee contact support	3,4
	User	2
	3rd party repairers	2
	Authorised repairers	2
	Not available	2
Information Available duration	Short term after last production	3
	Medium term after last production	3
	Long term after last production	3

Information Required About	Features being claimed in update	1
Information Available duration	Update method	1
	Documentation of time updates are offered after the point of sale	1
	repair method	1,3
Information Required About Training	Product identification	2
	exploded view	2,4
	Regular maintenance instruction	2,4
	Troubleshooting chart	2,3,4
	Repair/Upgrade service offered by the manufacturer	2
	safety measures related to use, maintenance and repair	2,3,4
	List of available updates	2
	Disassembly sequences	2,3
	Reassembly sequence	3
	Product identification	3
	Fault detection software	3
	PCB diagram	3
	Error codes	3,4
	3D printing of spare parts	3
	Reconditioning	3
	Procedure to reset to working condition	2,3,4
	Service centre accessibility	4
	Transportation instructions	4
	Circuit diagram	4
	Supplier information	4,3
	Tools required	4
	Service plan of electrical boards	4
	Maintenance plan	4
	Access to training available to all technicians	4

2.2 Design features for ICT products as evident from iFixit report

iFixit's report on Repair Market Observations (iFixit, 2019) gives examples of design feature that hamper reparability of a product. Subdivided in the categories Information Provided, Warning Information, Physical Disassembly Features and Software Restrictions, these design features are listed below.

2.2.1 Information Provided

Provision of a detailed Service Manual

The following features should be available in a service manual to assist reparability.

- Exploded diagrams of parts
- Compatibility charts
- Wiring diagrams
- step-by-step disassembly instructions
- required tools
- Product specifications
- Maintenance procedures
- Trouble shooting information
- Free accessible of the manual
- Easy accessible of the manual
- User friendly formatting
- Machine friendly formatting version
- Open-source license that allows redistribution and modification

2.2.2 Warning Information

- *"Warranty void if removed" stickers in product*: This type of warnings (although illegal in the US under the Magnuson-Moss Warranty Act of 1975) discourage users from attempting self-repair.
- *No-disassembly clauses in manual*: Adding statements similar to "do not disassemble" also discourages users from attempting self-repair.

2.2.3 Physical Disassembly Features

Fasteners

- *Using Proprietary Screws*: iFixit (2019) gives an example of Apple switching to pentalobe screws on the exterior of casing. Torx security bit in torx screws
- *Use of Adhesive*: Using adhesive makes devices difficult to open without chances of breaking it. Adhesive also hides seams in the device disincentivising users to repair their device. Examples: screen surface pro 3, glued down batteries. Both are most common failure (iFixit 2019)
- *Soldering components to board*: Soldering components directly to main board hampers repair and upgrade of the products severely. Example: soldering ram and solid-state drive directly to motherboard of Dell XPS 13 laptop (iFixit 2019). Non replaceable charging port.
- *Ultrasonic welding of the device cover*: This make the device impossible to disassemble without damaging it and severely hamper any reparability actions.

Disassembly procedure

- *Requirement of complete disassembly to replace priority part*: E.g. While disassembling screen.
- *No replacement Parts available*: Manufacturing not providing replacement parts for a device gives no option for users to repair the product. Example: iPhone X battery replacement is not provided by apple.

- *Expensive repairs*: High repair cost encourages customers from buying a new device rather that repairing (iFixit 2019). Example: Samsung galaxy 10 smartphone screens being too expensive to repair ($250).
- *Large replaceable module*: iFixit (2019) gives an example of apple laptop integrating keyboard, trackpad, battery and upper case in a single replaceable module. This means a failure in any one component in module renders the entire module to be replaced. In addition to this, replacement of such modules becomes very expensive and not cost effective. (iFixit 2019)

2.2.4 Software Restriction

- *Diagnostic Software Accessibility*: Not providing diagnostic software to repair the product outside authorized technicians would largely hamper reparability by third party and self-repairs. Example: touch ID sensor on iPhones cannot be repaired due to lack of diagnostic software (iFixit 2019)
- *Software restriction of third party repair*: A feature placed on detecting and killing devices that has undergone any third party repair: Example: apple "bricking" any phones that is repaired outside "authorized" network in 2016 (iFixit 2019).
- *Wireless Telematics Accessibility*: With smart products, data gathered can be used to maintain and repair products however preventing access to these data greatly hampers it. Example: providing consumer information that their vehicle emissions were spiking, and is able to proactively get it fixed.

2.3 Design features for washing machine as evident from RUSZ repair analysis

R.U.S.Z have tested 24 washing machines against the ONR 192102. Design analysis was conducted on the results in order to extract design features that would assist or hamper reparability of washing machines. Design features already addressed and extracted from ONR 192102 criteria was not looked further in detail. Visual examples of the results are presented in Appendix 2.

- *Tub material*: majority of the washing machines had plastic tubs, this construction of the plastic tubs plastic tubs are more susceptible to damage than stainless steel tub. According to the report, stainless steel tube are more durable and its bearings are replaceable.
- *Modularity of electronic components*: If there is a fault in the control board the entire unit has to be replaced (control board, UI board) rather than changing individual component such as capacitor. While this modularity does make the replacement slightly simpler, it also increases the price of spare part.
- *Drain pump filter accessibility*: Accessibility of drain pump from front and no tools are required to remove it greatly facilitates replacement of the filter.
- *Clip connections for tubes can detached by hand*: Presence of clip connections that could be detached by hand facilitates repair.
- *Resin coating in circuit board*: A plastic resin coating on a circuit board makes it difficult to repair. However according to the report this design elements prolongs the life of circuit board as it protects the circuit board from dust and moisture.
- *Panel mounting material*: Using plastic hooks for mounting panels hindered the ease of dismounting and remounting, in addition, this type of hooks are more prone to breakage **Fehler! Verweisquelle konnte nicht gefunden werden.**.
- *Placement of level switch*: Placement of level switch directly behind the removal panel gives easy access to level switch for its servicing . Two models of washing machine however had the level switch deep in the disassembly step hindering the ease of its replacement.
- *Tension spring material*: Tension springs for door seals made from plastic damaged after first disassembly for all the washing machine designs. This shows non removable nature of such design.
- *Shock Absorber type*: Frictional shock absorber with fat foam was observed in washing machines in cheap price range. According to the report, this type of shock absorber is reported have lower reliability than other types.

- *Large Bends in Detergent hose*: large bends in detergent hoses (180*) could cause soap deposition and could obstruct the flow of water leading to underperformance.
- *Cable tolerances*: A tight tolerances on cables could render the cable to break during when unplugging, this could mean the control board needs to be replaced as cable cannot be bought as separate part. A tolerance in the cable enough for it to be removed safely is recommended.
- *Cover panel design*: Two designs were identified for cover panels; three part design with two side plastic rails encasing plywood board in the middle and single panel design attached with glue or metal clips. The single part panel design is found to be easier to disassemble and reassemble.
- *Protection in the suspension ring*: Plastic protection between suspension springs protects the spring from wear, in designs with suspension springs directly in contact with metal (or only protected by fatty layer could result in faster wear.
- *Attachment of detergent drawer and input valve*: In general detergent drawer is connected to input valve by separate hose , however in some designs, hose and detergent drawer is constructed as a single plastic component. This means if damage occurred in either the hose or the drawer, the entire unit needs to be replaced and thus increasing the spare part price and also decreasing the reliability of the unit as a whole. In addition, the spare part must be obtained from the washing machine manufacturer (in case of separable hose, the standard hose could be bought from several suppliers.
- *Access to drain pump filter in the drum*: Creating access to drain pump filter directly from the drum reduces steps to change the filter, In addition, it is also possible to control heating in calcification from this design. However, the component is susceptible to damage during washing sessions.
- *Untrimmed edges*: sharp untrimmed edges in any part of washing machine becomes a safety hazard. This problem could be easily solved by simply trimming the edges.

2.4 Design features for vacuum cleaner as evident from RUSZ repair analysis

Similar to washing machine R.U.S.Z have tested 40 vacuum cleaner against the ONR 192102. Design analysis was conducted on the results in order to extract design features that would assist or hamper reparability of vacuum cleaners. Design features already addressed and extracted from ONR 192102 criteria was not looked further in detail. Visual examples of the results are presented in Appendix 2.

- *Snap fits*: Placement of non-reusable snap fit design either damages the component casing or the fastener during its removal and greatly hinders the reparability of the product.
- *Sharp protrusions in components that requires disassembly*: Sharp protrusions in components increases the risk to the service technician and therefore hampers the reparability process.
- *Hidden screws required to be unscrewed for disassembly of outer cover:* several vacuum cleaners had hidden screws either under buttons or wheels that needed to be removed before removal of the top, without a proper disassembly instructions it becomes increasingly difficult to locate the screws for disassembly.
- *Surface finishing*: Shiny surface in the casing was more prone to scratches than other type of surface (all the surfaces were plastic).
- *Cable reel attachment to on/off switch*: For some models on/off switch has to be replaced when replacing the cable reel, it Is not enough to just replace the cable reel. Similar to the case with detergent drawer model, if damage occurred in either the cable or the switch, the entire unit needs to be replaced and thus increasing the spare part price and also decreases the reliability of entire replacement unit.

2.5 Insights from Repair Practices

2.5.1 Framework for the repair process of household products

By analysing repair practices from various literatures Pozo Arcos et al. (2019) presents a conceptual framework of the process carried out from failure to repaired product (Figure 1). This framework contains three steps (Fault Detection, Fault Location and Fault Isolation) of fault diagnosis process before the process of repairing the product begins.
According to the paper, an approach to diagnosis of product is done by first detecting the fault using sensory observation. The fault is then located through analysing symptom to the cause, product information and history of usage/repairs. The fault can be then isolated by checking and testing the components. Once a fault is isolated the repair process can be conducted by component repair/replacement. It is observed that the fault diagnosis takes a large portion of the entire repair process and therefore can be a significant factor in determining the reparability of a product.

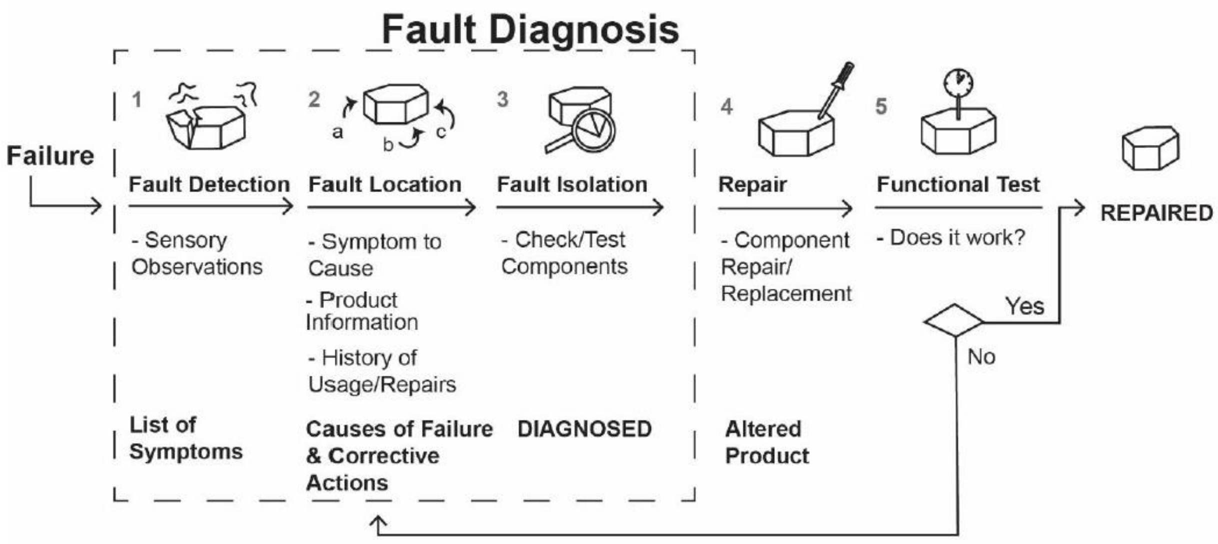

Figure 1: Framework of fault diagnosis (Pozo Arcos et al., 2019)

Pozo Arcos et al. (2019) show that non-professional users follow two distinct diagnosis approaches. First is a trial an error approach where user performs diagnosis actions which usually result in replacing a potentially defective component until the symptoms disappear. The second approach is by checking error codes. The diagnosis process in the second approach is relatively straightforward as defective part can be identified more accurately, assuming that the error codes are sufficiently descriptive.

With further analysis of diagnosis practices of a non-professional users, Pozo Acros et al. 2020 also presents a list of specific design features that influences the ability to diagnose faults in products and guide the user through the diagnosis steps depicted in Table 4. However, the effectivity of the design features to enable users to repair a product in practice has not yet been studied and is a direction that needs further research.

Table 4: *Design features affecting fault detection, location and isolation (Pozo Arcos et al., 2019)*

	(1) Fault Detection	(2) Fault Location	(3) Fault Isolation
	[Symptom Observation]	[Symptom to cause deduction]	[Component Inspections]
Interchangeability			
Connectors – backward compatibility			+
Modularity			
Component - functionally independent			+
Accessibility			
Housing – easy-to-open			+
Component – irreversible encapsulation			-
Fasteners – Deeply Recessed			-
Hose – Ergonomic geometry			+
Frequently failing components – difficult areas of access			-
Visibility			
Component – transparent material	+	+	+
Component – non-automatic	+		
Component – confined behind plates			-
Hose – sectionability			+
Hose – straight shape			+
Provision of Support to User			
Embodied signal – blinking light	+	+	+
Embodied signal – error codes	+		+
Embodied signal – sound to action		+	+
Component – switch associated with an action		+	+
Component – built-in test			+
Safety switches – unsignalled		-	-
Embodied signal – uninformative symbol		-	
User's manual – missing diagnosis information		-	
User's manual – unhelpful		-	
Autonomy			
Sensors & Control boards – difficult to test			-

2.5.2 Barriers to Repair

Barriers experienced by consumers

For deliverable 2.1 of this project, the consumer research has been carried out in Germany, France, Belgium, Spain, Italy and Portugal, to investigate why consumers are often are not repairing a broken product. The results are shown in Figure 2. Only about 10% of the respondents tried to repair the product. The largest proportion of respondents in most countries indicate that they consider repair too expensive (25%-37%). The results are further rather inconclusive as many different reasons are mentioned, but usually by less than 5% of the respondents.

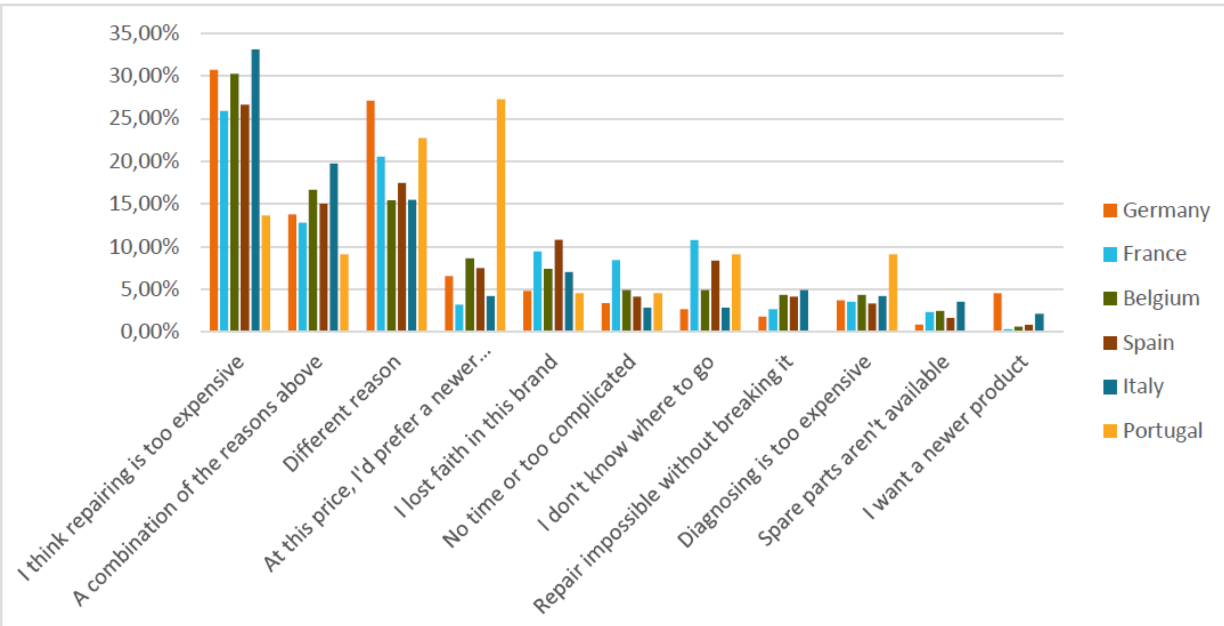

Figure 2: Reason why customers don't repair their product (Thysen, 2019)

This result is consistent with a recent paper by Victoria et. al (2018) Only 9.5% took the initiative to repair. The large majority of respondents in that study (79%) did not repair as they thought the repair price would be similar to the price of buying a new one. This was followed by small fractions of the respondents with different reasons, e.g. about 5% who didn't know where to take an appliance for repair.

In both of studies, the consumer expectation or previous knowledge towards price of repair seems the main barrier to repair. The perceived cost of repair is followed by a variety of other reasons, like losing faith in brand, not knowing where to go for repair, being unable to repair without breaking the product, no time for repair and too expensive diagnosis.

Overall, from a consumer perspective, the following barriers in repair can be extracted:
- Perceived high cost of repairing
- difficult diagnosis
- information on repair procedure
- repair time and difficulty

As the first mentioned reason is dominating, it is not clear from these studies what the effect on user behaviour would be of more physical product design related barriers to repair. Anyhow, it is clear that high cost of repair or a lack of transparency on the cost of repair combined with the fear for potentially high cost is withholding users from (professional) repair. Self-repair is hampered, which seems only to be considered by a minority of the users, is hampered by the other factors.

Barriers experienced by Professional Repairers

Analysis of repair data from Paolo et al. (2019) on washing machines shows that the most recurring failure modes were identified in electronics, shock absorbers and bearings, doors, carbon brushes and pumps (Figure 3) . Furthermore, the lowest repair rate was found in drum and tub (27% of cases) followed by electronics (47%) of cases and shock absorber and bearings at (47% of the cases). The majority (76%) of washing machines not repaired is due to customer determining that it is too expensive to repair, followed by infeasibility according to the repairer (15%) and economic non-viability (7%) of the repair (Figure 4). According to the paper, the high price of repair is mainly due to the cost of spare parts. Low rate of repair in washing machine

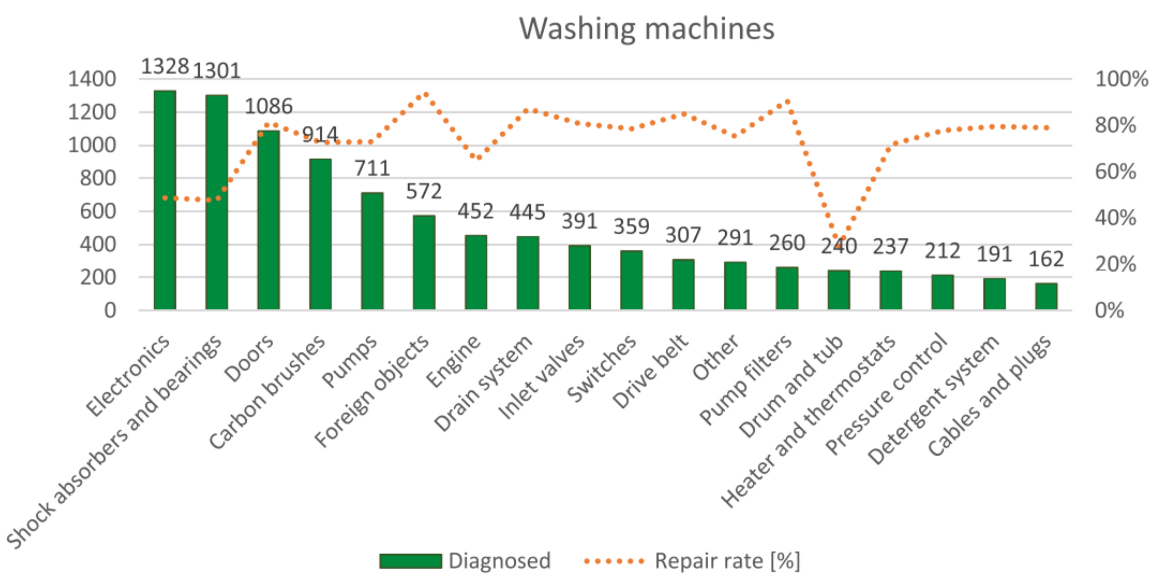

Figure 4: Most recurring failure and its repair rate (Tecchio et al., 2019)

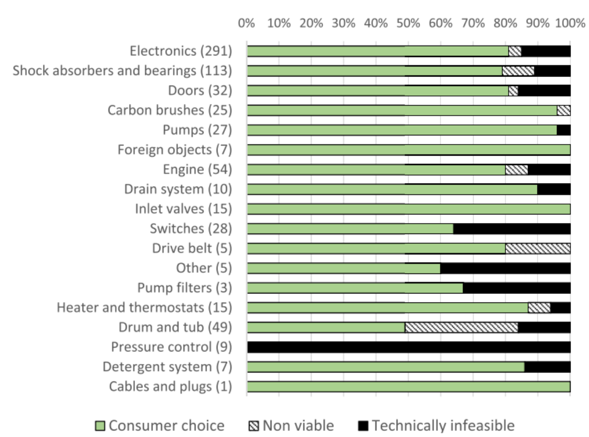

Figure 3: Reasons components are not repaired for washing machine (left) (Tecchio et al., 2019)

by professional repairers is observed in the case of a defective drum or tub, which are almost as expensive as a new washing machine or in the case of shock absorber and bearings, which is then due to a design that also necessitates replacement of the drum (Tecchio et al., 2019). In the case of the control electronics lack of accessibility of spare parts, software access and updates is often a reason that hampers repair. From the paper by Tecchio et al. (2019) the following design features that negatively affect professional reparability have been extracted.

- High cost of spare parts
- poor design for disassembly for drum , tub, shock absorber and bearings
- Inaccessibility of spare parts, software and updates

A less detailed survey on 10,000 German repair shops and workshops on what would strengthen the repair sector most gave the following result (Deloitte 2016):

- 33% easy access to spare parts with fair prices
- 23% better information to consumers about repair services
- 23% becoming authorized partner of the manufacturer
- 18% Ease of dismantle and repair
- 5% Access to recycling places to reuse electronic goods

In a study on professional repair of different categories of products, Sabbaghi (2017) held a survey among 2170 repair technician in the US, who were questioned regarding the reason for an unsuccessful repair processes. The following reasons emerge:

- Availability of spare parts
- Cost of spare parts
- Availability of tools
- Duration of repair (i.e. related to ease of repair)
- Complexity of repair (i.e. also related to ease of repair)
- Repair information (manual) unavailable.

The detailed results are shown in Table 5.

The clustering results of consumer electronics based on the reasons for their unsuccessful repair processes.

	Cluster 1	Cluster 2	Cluster 3	Cluster 4
	Solid Sate Drive, Hard Disk Drive, USB, and Modem	Laptop	TV, Monitor, LCD, Digital Camera, and Game Console	PC, Pocket Computer, Smart Phone, Printer, and Projector
Spare Parts Unavailability	14%	16%	35%	20%
Expensive Spare Parts	18%	43%	14%	28%
Required Tools Unavailability	17%	7%	6%	10%
Time-consuming Repair	11%	10%	7%	13%
Complicated Repair Process	25%	18%	26%	23%
Repair Manual Unavailability	15%	6%	12%	6%

Table 5 *Reason for unsuccessful repair process for ICT products (Sabbaghi, 2017).*

Based on Table 5, it is observed that spare part unavailability and the cost of spare parts comprises largest reason for barriers of repair for ICT products. This Is followed by unavailability of tools, time consuming repairs and complicated repair process. Unavailability of repair manual was is identified as the least important reason for unsuccessful repair product.

Barriers experienced by repair cafes

The following barriers to repair were listed from 41 semi-structured interview for repair café participants in UK (Dewberry, 2018).

- Lack of access to spare parts
- Obsolete components
- Lack of knowledge about spare parts required

- Products not designed for longevity or repair
- Products designed for manufacture, not disassembly
- Difficult to open products to repair them
- Products not looked after, are seen as disposable
- Lack of knowledge
- Lack of time
- The inconvenience of repair
- The ease of buying a new product
- Not owning the right tools
- Concerns about voiding the warranty
- Concerns that product won't work anymore
- Lack of creativity to do repair
- Lack of skill

It is noted that the reasons for non-repair by professionals in many are directly related to design features that have been mentioned in Sections 2.2-2.4. This will be a core focus of next deliverable (Deliverable 4.1-4.5). Reasons for consumers not to repair a product are currently especially related to the (perceived) price of repair, which will be focused in deliverable 5 of this project.

2.6 Reasons for product break-down

During the General Assembly of consortium partners of this projects, discussion of the primary products within the project were held with experts to establish the most important reasons for product failure and ways in which early failure in these cases could be anticipated. The top three most occurring failure rates for the chosen four products were extracted from deliverable 2.1 and the potential cause for the failure and design features that could be checked for longer lifetime were discussed during the workshop with consortium partners (see Appendix 1 for details). Furthermore, design features that help the users in determining the cause of the failure and what to do after the failure occurs, and how this can be translated to a testing program was also discussed.

The following key questions with respect to the specific failure modes highlighted in green in the table shown in Appendix 1 require further research:
- How can ease of visibility and legibility (visual ergonomics) be quantified and tested?
- How can accumulation of dust within pipes and hose be tested through design features?
- What are the design feature requirements for an IOT products and how can it be tested?
- For durability tests what are the minimum criteria that should be tested against (in the case of a test relative to a reference)
- How can the effect of different alloys and lubricant within bearings and shock absorbers be tested efficiently?
- How can material type and its durability over long period of time be tested efficiently?
- What Is the effectivity of test points within a product towards diagnosis facilitation?

In addition to the table, the following key points were raised during the workshop discussion
- Determining the desired lifespan of the product to be tested for would be crucial in order to set parameters for durability testing. User behaviour could be looked at in order to determine this.
- Making testing program specific to certain design features could hamper its future innovation. Therefore, when translating the findings to a testing program, a way to incorporate the possibility of new technology and innovation has to be considered
- Use of sensors and smart (IOT) devices for ease of failure diagnosis by user has been pointed for most of the discussed failure modes.
- At current technology, battery and motor brush has to be as "consumable" component, any component considered as "consumable" should be designed to be replaceable.

3 Inventory of design strategies and design principles in relation to obsolescence

Incorporating the design features apparent from the preceding chapters, an inventory of design guidelines with their related features has been created (Table 6). The design guidelines are clustered based on the design principles from chapter 2 and analysed by identifying gaps and deviations when relating the design principles to the observed design features.

3.1 Inventory format

Using a modified version of the format from Bracquene (2018) and through an iterative process, the following format is found to present the inventory in the most effective manner at this stage.

- The design features are clustered in columns distinguishing stages in repair and maintenance process. This way it is possible to get an overview on at what product phase the particular design feature is relevant.
- The design features are clustered in rows and are clustered with respect to the design principles presented in chapter 1.
- Each feature is grouped into one of the following categories, represented by colouring of the cell :
    - green cells: features related to physical product design.
    - yellow cells: features regarding information availability
    - Blue cells: features related to services.
- Black text colour represents design features that facilitates longevity whereas red text colour represents design features that hamper longevity of the product.
- Design features further detailed within a cell is separated by “>” sign indicating any preceding design feature in the cell facilitates reparability/maintainability of the product more than any succeeding design features.
- If a design feature is relevant to a particular product, it is indicated by the following letters preceding the text in the cell.
    - (WM) : Washing machine
    - (MP) : Mobile phone
    - (VC): Vacuum cleaner
    - (TV): Television

3.2 Overview of the inventory results

From the inventory it is observed that a wide variety of single design features is considered relevant to longevity. Specific design features are usually not linked to just a single design approach, but can often be derived from different approaches (e.g. many similar features arise from design guidelines for maintenance, repair or upgrading). Therefore, it will be important to examine how a specific design feature affects each of the lifecycle prolongation approaches. For example, resin coated circuit board hampers the disassembly of and ability to diagnose the components, however it may facilitate longevity during the use phase by providing protection against dust and moisture.

Table 6: Inventory of design guidelines with their related features Incorporating the design features apparent from the preceding chapters.

Repair/Maintenance Phase / **Design Principles**	***Identification***	***Failure Diagnostic***	***Disassembly & Reassembly***	***spare part replacement***	***Restoring to working condition***	***Update***	***Preventive Maintenance during use***
Standardization			Standardized fasteners used	Standardised priority parts		Standardised software updates	
Modularization		Functionally independent component	Priority parts can be replaced individually	Replacement module with multiple components			
			(WM) single panel design for outer cover > multiple panel design	(WM) Attachment of detergent drawer and input valve			
				(VC) Cable reel attachment to on/off switch			
Functional Packaging		Functionally independent component					
Interchangeability			Standardized fasteners used	Standardised priority parts			
Accessibility		Accessible measuring points at edge of circuit board	Sufficient cable length for connecting groups of components			ports, slots or connectors used for the update are accessible with: no tools > common tools > tools only available from manufacturers	
		Easy to open housing	Disassembly time (less than > equal to > more than) reference value				
		Irreversible encapsulation	(WM) Resin coated circuit board				

Repair/Maintenance Phase Design Principles	*Identification*	*Failure Diagnostic*	*Disassembly & Reassembly*	*spare part replacement*	*Restoring to working condition*	*Update*	*Preventive Maintenance during use*
		Deeply recessed fasteners	Disassembly sequence (less than > equal to > more than) reference value				
		Ergonomic Geometry of the hose	(WM) Access to drain pump filter in the drum				
		Component confined behind plates					
		(WM) Resin coated circuit board					
		Difficult areas of accessed for frequently failing components					
Diagnostics and monitoring provision		Diagnostic software is accessible to: (User > 3rd Party repairers > Authorised repairers > not available)					(VC) Alert mechanism to change filter - Google/Alexa reminder
		Diagnosis interface: Visually intuitive interface > Coded interface > Publically available interface >					Condition monitor app for IOT products

Repair/Maintenance Phase / Design Principles	*Identification*	*Failure Diagnostic*	*Disassembly & Reassembly*	*spare part replacement*	*Restoring to working condition*	*Update*	*Preventive Maintenance during use*
		Proprietary interface					
		Blinking light					(VC) "Wetness" Sensor for filter
		error code					(VC) Temperature indicator sensors in motor
		(MP) Phone sensor indicating water/moisture presence and location					(VC) RPM sensor
		sound to action					(MP) Transparency of battery management system
		Component switch associated with action					(MP) Optimization of battery via use-pattern data
		Error codes list					
		Accessibility of diagnostic software					
		(VC) indicator lights directly connected to priority components					
		Test method					

Repair/Maintenance Phase / Design Principles	*Identification*	*Failure Diagnostic*	*Disassembly & Reassembly*	*spare part replacement*	*Restoring to working condition*	*Update*	*Preventive Maintenance during use*
		Troubleshooting common failures					
		(VC) Temperature indicator sensors in motor					
		Test mode available in software					
Visibility		Transparent Material	Hidden screws required to be unscrewed for disassembly of outer cover				
		Non Automatic component					
		Hose sectionability					
		Straight shape hose					
		(VC) filter in visible location					
		(VC) transparent cover in filters					
		Component confined behind plates					
Component Identification	Identification Accessible after removal of only 2 connections						

Repair/Maintenance Phase / Design Principles	*Identification*	*Failure Diagnostic*	*Disassembly & Reassembly*	*spare part replacement*	*Restoring to working condition*	*Update*	*Preventive Maintenance during use*
	Product identification engraved or printed						
	Identification Accessible without disconnecting components						
User and Product Safety	Clear warning sign on dangerous components	Safety switch	Safety measures identified in accordance with Low voltage directive				Safety measures identified in accordance with Low voltage directive
			Safety measures identified in accordance with Machinery directive				Safety measures identified in accordance with Machinery directive
			Sharp protrusions in components that requires disassembly				
			Untrimmed edges				
Tools			Tools Required: Toolless> common tool > Professional tool found in market >proprietary tool				
Fasteners/Joints		Deeply recessed fasteners	Standardized fasteners used				
			Removable > Non removable				

Repair/Maintenance Phase / Design Principles	*Identification*	*Failure Diagnostic*	*Disassembly & Reassembly*	*spare part replacement*	*Restoring to working condition*	*Update*	*Preventive Maintenance during use*
			Reusable > Non reusable				
			Parts in PCB can be desoldered				
			(WM) Clip connection detachable by hand				
			List for fasteners that are non removable: one way snap fits, Adhesives, soldering, welding,				
			(WM) Use of plastic fasteners such as tension spring is easily susceptible to damage upon disassembly and reassembly				
Keying							
Disassembly sequence placement		Difficult areas of accessed for frequently failing components	Priority parts can be replaced individually				
			Placement of level switch directly behind cover panel				
Instinctive Design		Visually instinctive diagnosis					

Repair/Maintenance Phase / **Design Principles**	***Identification***	***Failure Diagnostic***	***Disassembly & Reassembly***	***spare part replacement***	***Restoring to working condition***	***Update***	***Preventive Maintenance during use***
Handling							
Ergonomic accessibility		Ergonomic Geometry of the hose	Sufficient cable length for connecting components or group of components				
			Space large enough for hand soldering				
Onsite Maintenance		Work environment (Insite repair > general purpose workshop > specialized workshop > production environment	Work environment (Insite repair > general purpose workshop > specialized workshop > production environment	Work environment (Insite repair > general purpose workshop > specialized workshop > production environment	Work environment (Insite repair > general purpose workshop > specialized workshop > production environment	Work environment (Insite repair > general purpose workshop > specialized workshop > production environment	
Information Availability	Brand and unique model	Troubleshooting common failures	Exploded Diagrams	Address	procedure to reset default factory settings	Update method	Safety measures identified in accordance with Low voltage directive (2015/35/EU)
	Barcode or QR code	Test method	List of connectors used	web shop information		list of required tools and software For update	Safety measures identified in accordance with Machinery directive (2006,42,EC)
		Error codes list	List of required tools	unique reference numbers of available spare parts		How updates will affect the original system characteristics	Regular maintenance schedule
		Required repair actions	Description of recommended disassembly steps to remove priority parts	information to 3d print spare part is available when relevant			Maintenance plan

Repair/Maintenance Phase / Design Principles	*Identification*	*Failure Diagnostic*	*Disassembly & Reassembly*	*spare part replacement*	*Restoring to working condition*	*Update*	*Preventive Maintenance during use*
		Printed circuit board diagram	Wiring diagram				Specifics of transporting the appliance attached to the unit
		Fault detection software	No-disassembly clauses in manual				Medium of information (Attached to product > in printed manual > product Website)
							User friendly formatting
Spare Part Availability			Availability of spare parts: long term availability> medium term availability> minimum term as required by law> no information > not available.				
			Cost of spare parts*				
			backwardly compatible spare parts are widely available to replace priority parts				
			compatible spare parts available				
Maintenance points positioning							Accessibility of test points
Compatibility				Compatibility charts		Compatibility charts	
		Backward compatibility of connectors		compatible spare parts available	Software restriction of third party repair	Access to software and current updates	Full compatibility with open source software is ensured

Repair/Maintenance Phase / Design Principles	***Identification***	***Failure Diagnostic***	***Disassembly & Reassembly***	***spare part replacement***	***Restoring to working condition***	***Update***	***Preventive Maintenance during use***
				backwardly compatible spare parts are widely available to replace priority parts			
After sale support	Technical support for identification for at least 10 years	Diagnostic Support available for at least 10 years after last production	support available for disassembly and reassembly for at least 10 years after last production	Recovery time for components or groups of components is same time as availability of spare parts	toll free web based contact available for reconditioning	Software/firmware updates support offered for at least X years after placing last unit on the market	
	Toll-free or web based support available for product identification	Toll-free or web based Diagnostic support available for failure diagnostic and repair	Toll-free or web based contact available for disassembly and reassembly allowing customer to access, repair and repair failed part through assisted disassembly and reassembly			Update of a feature is achievable in the product without performing a product exchange	Regular training provided to technicians from all repair shops
			Availability of spare parts: long term availability> medium term availability> minimum term as required by law> no information > not available.				
			Cost of spare parts*				

Repair/Maintenance Phase / Design Principles	*Identification*	*Failure Diagnostic*	*Disassembly & Reassembly*	*spare part replacement*	*Restoring to working condition*	*Update*	*Preventive Maintenance during use*
			backwardly compatible spare parts are widely available to replace priority parts				
Restorability					procedure to reset default factory settings		
					resetting to factory settings can be done without intervention of external/specialized device or software		
					resetting to factory settings can be done with freely accessible software		
Low level functionality		Appliance can still be activated when the cover is opened					
		product is able start despite faulty components					
		Product is still functional despite the failure of peripheral functions					
Design Guideline for longevity							
Design Complexity							
Design Detailing							(TV) Mounting stability

Repair/Maintenance Phase / Design Principles	*Identification*	*Failure Diagnostic*	*Disassembly & Reassembly*	*spare part replacement*	*Restoring to working condition*	*Update*	*Preventive Maintenance during use*
							(MP) Presence of water protection mechanism
							Brushless motor > brush motor
							(VC) bad housing finishing
							Electronics control protected against moisture, high temperature and dust
							Shock absorber type: Frictional shock absorber have lower reliability
							(WM) Resin coated circuit board
							(WM) Machine Adaptation to load
							(WM) Plastic protection in suspension ring
							(WM) Standardization of capacitors
Dimensioning							Under dimensioned Capacitors
							(WM) Under dimensioned shock absorbers
							(VC) Under dimensioned power cord
							(VC) long and good quality carbon brush
							(WM) Under dimensioned bearings

Repair/Maintenance Phase / Design Principles	*Identification*	*Failure Diagnostic*	*Disassembly & Reassembly*	*spare part replacement*	*Restoring to working condition*	*Update*	*Preventive Maintenance during use*
							(WM) Metallic parts > Plastic parts
							(WM) high rubber quality of sealing ring
Material Selection							(WM) Use of plastic fasteners in metallic panels
Surface treatment			Use of shiny surface in outer casing tend to be susceptible to scratches				Use of shiny surface in outer casing tend to be susceptible to scratches
Use of Expendable parts			(MP) Battery designed to be replaceable	(MP) Battery designed to be replaceable			(MP) Battery designed to be replaceable
			(VC/WM) Motor brush designed to be replaceable	(VC/WM) Motor brush designed to be replaceable			(VC/WM) Motor brush designed to be replaceable
Use of components with similar lifespan							
Maintenance Encouragement							(VC) Alert mechanism to change filter - Google/Alexa reminder
							Condition monitor app for IOT products
							Regular maintenance schedule
							Maintenance plan
							(VC) Temperature indicator sensors in motor
Dirt accumulation prevention							Electronics control protected against moisture, high temperature and dust

Repair/Maintenance Phase / Design Principles	*Identification*	*Failure Diagnostic*	*Disassembly & Reassembly*	*spare part replacement*	*Restoring to working condition*	*Update*	*Preventive Maintenance during use*
							(VC) Design of pipe to achieve smooth airflow

3.3 Additional insights from the structured inventory

The ordering provides by Table 6 in section 3.2 provides insight in design features and design principles that are frequently applied as well as design principles that are apparently not regularly applied. Also, a number of design features were observed that could not be categorized under one of the design principles mentioned in Chapter 1.

Some design principles were added based on the studies on actual design features as some of the design features could not be related to any of the principles listed in chapter 3. This concerns the following principles.

After sale support
The principle of after sales support ensures that the product is readily updated and information on any repair/use phase of the product could be retrieved from the manufacturers through various mediums. It is also responsible for making sure the spare parts are readily available.

Restorability of factory settings
The principle of restorability ensures that the product could be reset to default factory settings easily.

Low-level functionality
The principle of low-level functionality ensures that product is still able to perform basic functionality despite failure of critical components. This promotes the ability to diagnose of the product.

Some of the design principles from Chapter 1 could not be related to observed design features as evident from the studies evaluated here. This concerns the following design principles.

- Keying
- Handling
- Design complexity
- Using components of similar lifespan.

However, this doesn't exclude that these principles need to be addresses in the research now starting in deliverable 4. It just indicates that limited information from practice can be expected with respect to these strategies.

4 Conclusion

The inventory developed in in this task provides a starting point towards the design features that are worthwhile for examination in a testing program. This inventory will be elaborated and further developed in future deliverables (Deliverable 4.1-4.5). The inventory will be used to create specific lists of design features (per product) that affect product longevity and that can be tested (e.g. for its presence, absence or performance) in a testing program. The effectivity of those design features in the inventory to actually test the durability, maintenance, reparability and upgradability will be investigated in future deliverables (Deliverable 4.1-4.5).

From the work done in chapter 2.2 a number of gaps and questions have already been identified on topics that may contribute to the creation of an effective, reliable and repeatable testing program. These need to be further addressed:

- Development of a methodology similar to eDIM in order to expand the information ICT equipment as well as to include domestic appliances, thus incorporating the four product groups researched in PROMPT.
- Establishing the relation between disassembly time, disassembly steps and disassembly features in order to determine the most effective way of quantifying ease of disassembly
- Establishing a protocol to determine the number and type of products that needs to be tested in order to determine reference values in a testing system.
- Determine the effectivity of design features related to fault diagnosis, repair, maintenance and longevity.
- Determine how ease of visibility and legibility (visual ergonomics) can be quantified.
- Determine how accumulation of dust (e.g., within pipes and hoses) can be measured.
- Establish the requirements regarding design feature for Internet-of-Things connected products.
- Establish the set of minimum criteria that needs to be tested to obtain a representative qualification of a product.
- Establish procedures for determining the effect of multiple interacting design features (e.g., the nature of alloys and lubricant in a bearing in relation to specific shock absorbers).

Further research in future deliverables (Deliverable 4.1-4.5) is expected to elaborate on the findings reported here and will also explore new directions to establish testable design criteria in relation to longevity. The current overview and key questions are seen as a thorough foundation for this further research.

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6 Appendix 1: Inventory of failure mode analysis conducted during consortium workshop

The numbers preceding each points in column (B, C and D) represents the failure cause point addressed from column (A). ">" in column (B) represents the specific point can be applied in general to the points in column (A) for the particular failure mode. Key points that could be discussed and researched further is highlighted in green in the table and are as follows

Product	Failure mode	What are the potential causes of this failure?	How can we translate the findings to a testing program? Design recommendations for a longer lifetime?	(b) Which design features help the user in determining the cause of this failure and to decide on what to do after this failure occurs?	How can we test for the outcomes of (B)
Vacuum cleaner	Low suction	1: Blocked filters 2: Blocked Pipes 3: Reduced motor power 4: Defective power regulation 5: Turbine Clogged 6: Filter Burst 7: Nozzle deterioration (Active) 8: Battery deterioration	> Ease of Disassembly > Check Durability of washable filter 3. Motor + Battery test 2. Check pipe design - achieve smooth airflow (how can we test for it? Simulation? > Ease of maintenance - Using user manual - Using Sensors	> Voice feedback 1,6: Transparent filter cover 1,6: Filter in a visible location High visibility of filter (how do we test for it?) 1,6: Alert mechanism to change filter - Sensors - Alexa/Google Reminder 2: Separable nozzle (to check for blockages) > User manual for maintenance and repair - Do people read it? - Video instructions might be better - Contain Error codes from sensors	1: Ease of use of changing the filter - Accessibility - Legibility (How we test for it?) o Presence of signs in visible area o Divide the product into different points and create a visibility ranking for each point > Check what kinds of instructions are available - Sticker - Video vs manual > How much info does the VC tell you? - Checklist on VC design features that provide users with information o Alerts o Error codes o Display system o Sensors

					o Extent of diagnosis and repair information from the device
	Cable Failure (+ return mechanism)	1: Bad finishing/Design on the housing for "pulling area" - Sharp edges - Too much bending 2: Too much bending by user 3: Bad cable quality - Dimensioning - Fragile cable 4: Brake Failure - overuse, poor quality 5: Return spring breaks - overuse, poor quality	2,3: Roll mechanism cycle test - Bending test - Stress/Strain test 2: Snapping mechanism for cable - Could lead to thicker cable - More expensive cable 2: Cable handling instructions - Sticker (too many stickers might	> Indicator light directly connected to cable - Could be extrapolated to all the failure regions (e.g. motor, PCB) - Different colour depending on failure location (simple legend next to it) > App, condition monitor of the devices - Smart features - Sensors - How could these be standardized?	> Requirements for IOT? - standardization for connectivity o may incur privacy and security issues

			hamper the aesthetics) - Manual		
	Motor	1: overheat 2: water damage (From we filter/ Bag) 3: Clogged overheat 4: Carbon brushes - Bad connection of carbon brushes - Short carbon brushes - Motor problems due to burnout of the brush	4: Dismantle and test carbon brush length and quality - Check motor connection design 4: Brushless motor (yes/no) 1,4: Test motor in real life scenario - With dirt and bag half full	1: Temperature indicator - Sensor 2: "Wetness" Sensor for filter 3,4: Rpm measurement - Current measurement - Easy Accessible measuring points (possibly without disassembly) > For cordless vacuum cleaner - Howe to check if it is motor failure or battery problem o Battery health indicator , remaining battery capacity - sensors/IOT for diagnosis	> Checklist on the design features indicated on "b" , this can be all the other failure modes as well. > - users could be informed directly via design features of the product.

Mobile Phones	Battery	1: Lack of capacitance 2: Lack of capacity 3: Quick Charging? - Does it hamper longevity? 4: Repeated charging cycle 5: Wrong charging load 6: Bad battery management system 7: Rupture of Cells/Swelling - High temperature 8: Wrong Operating temperature 9: Poor quality of chargers	> Check quality of BMS - transparency of BMS o how doe it affect software performance o battery lifespan and capacity > Battery condition data - look at use pattern > Standard charging cycle test - What would be the minimum criteria? o check smartphone lifetime o use pattern of smartphone o % of users replacing o customize battery lifetime based on user behaviour > At some point battery capacity will run out, therefore it should be considered a consumable and therefore designed to be replaceable	> Fast battery depletion - check remaining capacitance > Sudden shutdown of phone after certain charge percentage > Indicator of battery replacement condition > Battery condition data	>Whether communication of durability a goal? Battery would be considered as a expendable component has to be designed to be removable

	Screen	1. Crack 2. Scratch 3. Dead Screen - Drops - High temperature o Hastens Ageing 4. Irresponsive touch screen - Capacitance short-circuit 5. lines - Broken circuit 6. Dead pixel - Local screen defect 7. Artefacts - Graphic chip failure	1,2,3: Drop test, pressure test, scratch test bend test o how resistant should it be? o resistant test criteria can be looked up , how do they determine what is enough? 3: Temperature stress test - Internal + external temperature - Check screen detoriation - Oled detoritas faster	> Visual inspection > Other failures linking to screen failure is rare - e.g., screen problems due to graphic chip failure	
	Water Damage	1. Splash 2. Humidity 3. Failure of Protection mechanism 4. Speaker membrane Degradation	> Standard IP testing > Presence of water protection mechanism.	>Phone sensor indicating water/moisture presence and location (already available in high end models)	
Washing machine	Electronics	1. Degradation of electronic capacitor - Hot environment - Moist environment 2. Capacitor too weak 3. Corrosion 4. Overheating of chip	> Standardization of capacitor > Index of Dimensioning > Document electrical drawing > Robustness of components > Dimensioning	> Elaborated Error Code with instruction (Not available today)	> Open data diagnostic software

	Shock Absorber + Bearings	1. Tear and wear of bearing - poor quality material - small bearings - water and dirt in bearing o due to seal getting broken . poor quality seal 2. Too high load 3. bad quality shock absorber combined with small bearing in a outer part plastic tub	> Vibration less than X after 4 cycles > Check size of bearing (Bigger the better) - Effect of lubricant and alloy? test needed > Enable replacement of shock absorber > Design choices on shock absorber placement -Drum on top of 4 shock absorber (consideration) > Machine adapts performance to bearing load 3: Material Choices - metal vs plastic	Noise	
	Door (seal, hinges and locker)	1. Material ageing - Material Durability - Chemical and thermal resistance	> Encourage user to dry sealing > Check Locker material (how?) > Construction of handle > accelerated test of sealing ring	> Leakage > Door remaining open > Loose door	
	Heater	Accumulation of cloth abrasive on heater			
Television	Screen	2. Dead Pixels 3. Burn In 4. Controller defect 5. Led Overheating 6. Mechanism defect	> Stability test for mounting > IR - Imaging of TV	> Indication by symptom > Extended trouble shooting in manual > Diagnostic software with clear information (on screen messages)	> Check for presence of the features > Accessibility of test points

	Power supply	1. Heat + Capacitors	> Standardization of capacitor > Index of Dimensioning > Document electrical drawing > Robustness of components > Dimensioning > Accelerated module test	> Test points out of hardware > Diagnostic software	
	Connectors (HDMI,..)	1. Mechanical Overload 2. Fatigue	> Indicator signal (light, tone, etc.)	> Mechanical plug test	
	Software (Firmware, Apps, Operating System)	1. Not well developed code 2. Licensing issues 3. Interdependencies and interoperability issues 4. End of software support	> Update Guarantee > Quality check on standard > Quality check on software (benchmark)	> Warning on license expiry > System on response on complaints > Display system in user interface	> Visibility?

7 Appendix 2: illustration to design features mentioned in Section 2.3

Design features for washing machine as evident from RUSZ repair analysis

A number of the design features mentioned in Section 2.3 are here illustrated for practical cases.

Panel mounting material: Using plastic hooks for mounting panels hindered the ease of dismounting and remounting, in addition, this type of hooks are more prone to breakage Figure 5.

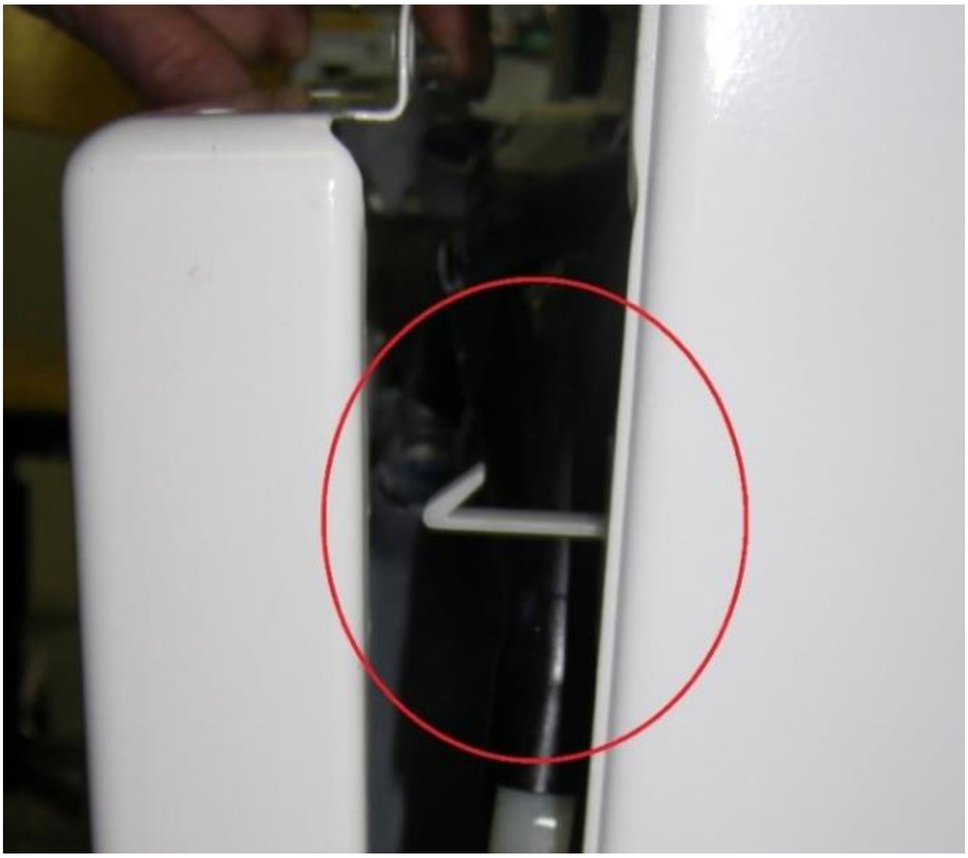

Figure 5: Use of plastic hooks for mounting panels

Placement of level switch: Placement of level switch directly behind the removal panel gives easy access to level switch for its servicing (Figure 6). Two models of washing machine however had the level switch deep in the disassembly step hindering the ease of its replacement (Figure 7).

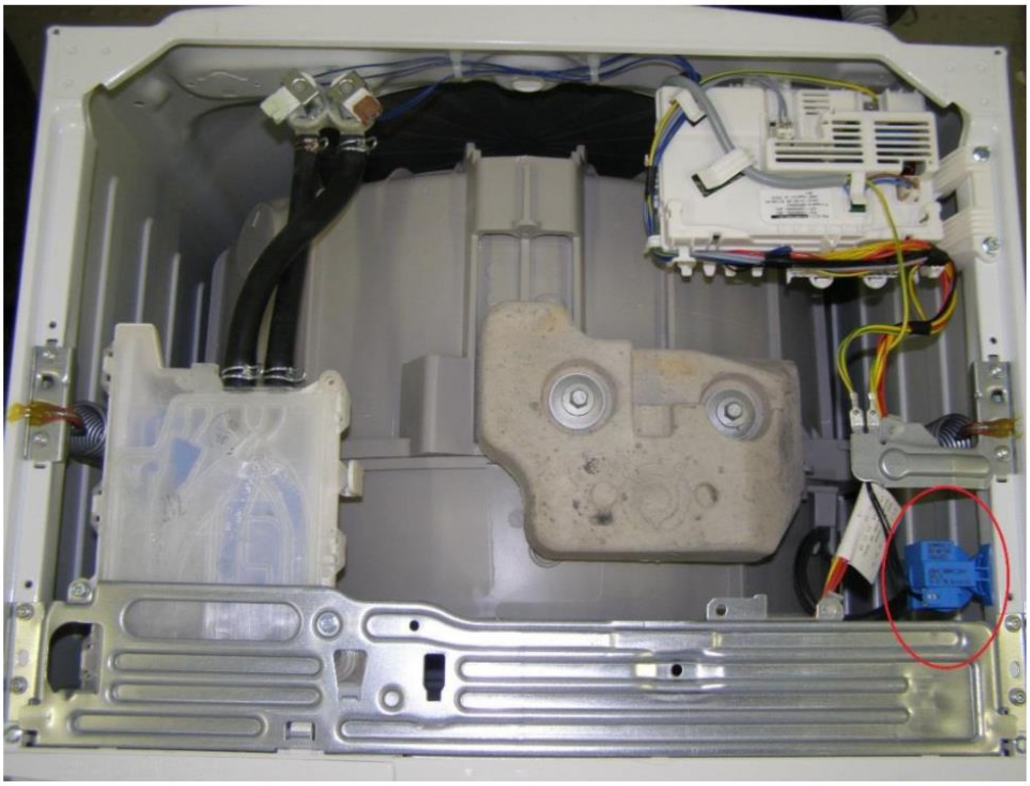

Figure 6: level switch directly behind the top cover

Figure 7: level switch deep in the disassembly step

Tension spring material: Tension springs for door seals made from plastic damaged after first disassembly for all the washing machine designs. This shows non removable nature of such design (Figure 8).

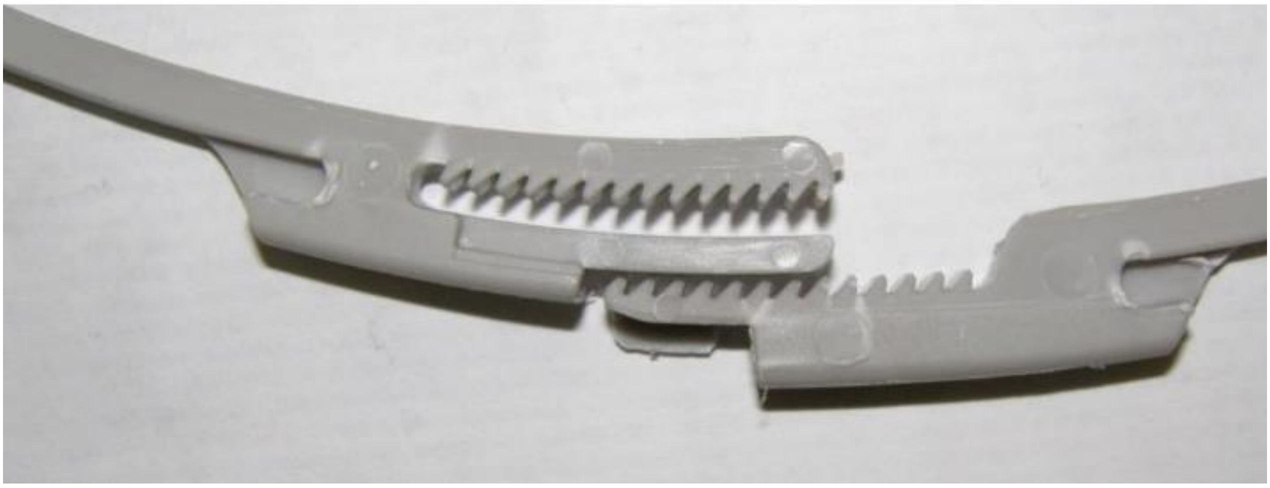

Figure 8: Damaged tension spring

Shock Absorber type: Frictional shock absorber (Figure 9) with fat foam was observed in washing machines in cheap price range. According to the report, this type of shock absorber is reported have lower reliability than

Figure 9: Frictional shock absorber

other types.

Large Bends in Detergent hose: large bends in detergent hoses (180*) (Figure 10**Fehler! Verweisquelle konnte nicht gefunden werden.**)could cause soap deposition and could obstruct the flow of water leading to underperformance .

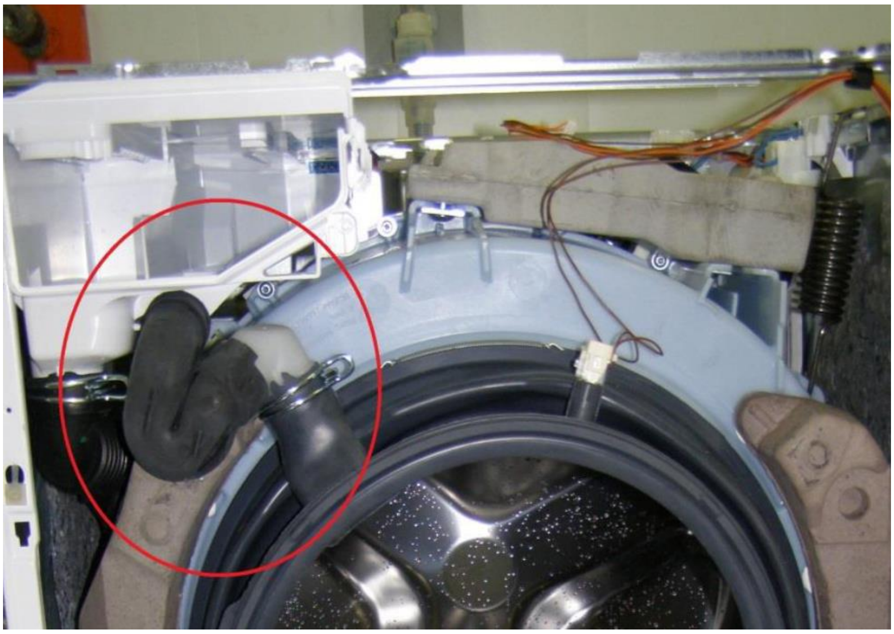

Figure 10: Large ben in detergent hose

Cable tolerances: A tight tolerances on cables could render the cable to break during when unplugging (Figure 11), this could mean the control board needs to be replaced as cable cannot be bought as separate part. A tolerance in the cable enough for it to be removed safely is recommended.

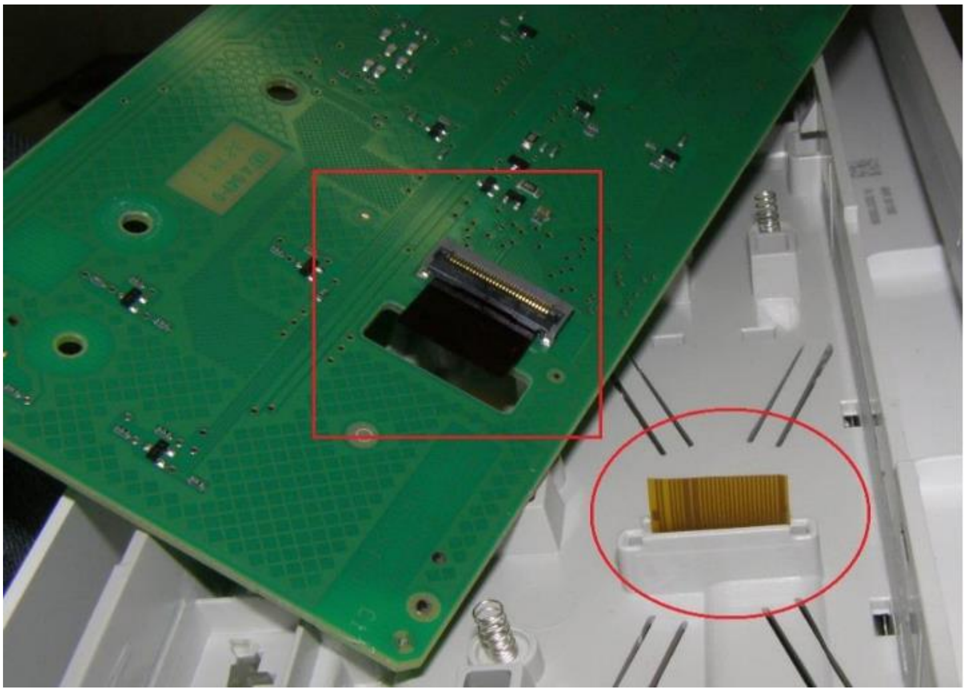

Figure 11: Damaged cable in control board

Cover panel design: Two designs were identified for cover panels; three part design with two side plastic rails encasing plywood board in the middle (Figure 16) and single panel design attached with glue or metal clips (Figure 17). The single part panel design is found to be easier to disassemble and reassemble.

Figure 12:Three part design of cover panel

Figure 13: Single part cover panel design

Protection in the suspension ring: Plastic protection (Figure 14) between suspension springs protects the spring from wear, in designs with suspension springs directly in contact with metal (or only protected by fatty layer (Figure 14**Fehler! Verweisquelle konnte nicht gefunden werden.**) could result in faster wear.

Figure 14: Suspension spring partially protected

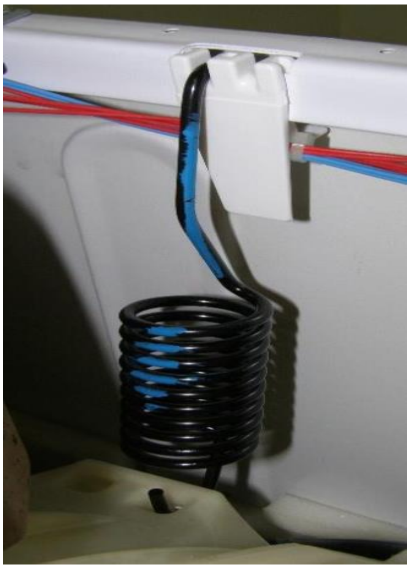

Figure 15: Suspension spring protected by plastic cover

Attachment of detergent drawer and input valve: In general detergent drawer is connected to input valve by separate hose (Figure 17) , however in some designs, hose and detergent drawer is constructed as a single plastic component (Figure 16**Fehler! Verweisquelle konnte nicht gefunden werden.**). This means if damage occurred in either the hose or the drawer, the entire unit needs to be replaced and thus increasing the spare part price and also decreasing the reliability of the unit as a whole. In addition, the spare part must be obtained from the washing machine manufacturer (in case of separable hose, the standard hose could be bought from several suppliers.

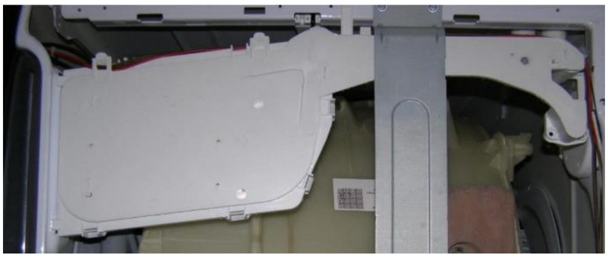

Figure 16: Detergent drawer and hose in a single

Figure 17: Separable detergent drawer and hose

Access to drain pump filter in the drum: Creating access to drain pump filter directly from the drum (Figure 18) reduces steps to change the filter, In addition, it is also possible to control heating in calcification from this design. However, the component is susceptible to damage during washing sessions.

Figure 18: Easy access to drain pump filter

Design features for vacuum cleaner as evident from RUSZ repair analysis

Some of the design features mentioned in Section 2.4 are here illustrated for practical cases.

Similar to washing machine R.U.S.Z have tested 40 vacuum cleaners against the ONR 192102. Design analysis was conducted on the results in order to extract design features that would assist or hamper reparability of vacuum cleaners. Design features already addressed and extracted from ONR 192102 criteria was not looked further in detail.

Sharp protrusions in components that requires disassembly: Sharp protrusions in components (Figure 19**Fehler! Verweisquelle konnte nicht gefunden werden.**) increases the risk to the service technician and therefore hampers the reparability process.

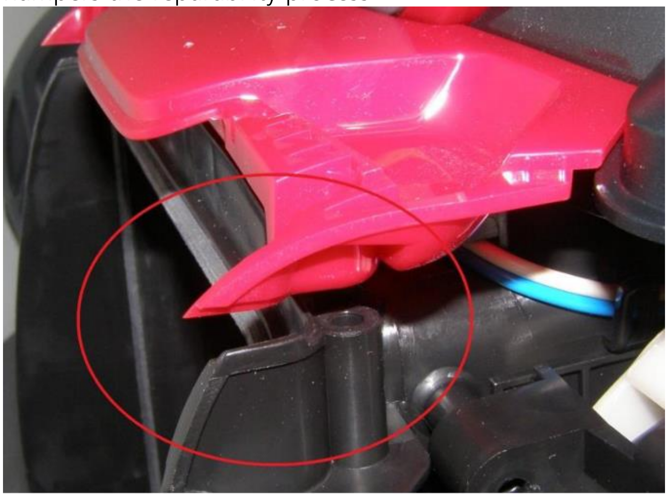

Figure 19: Sharp protrusions from top cover

Hidden screws required to be unscrewed for disassembly of outer cover: several vacuum cleaners had hidden screws either under buttons or wheels that needed to be removed before removal of the top cover (Figure 20), without a proper disassembly instructions it becomes increasingly difficult to locate the screws for disassembly.

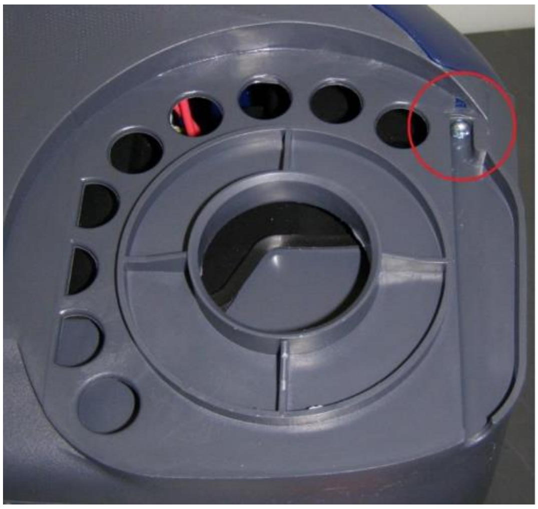

Figure 20: Hidden screw behind the wheel

8 Appendix 3: Inventory of design features extracted from different reparability scoring system.

List of design features extracted from different reparability scoring system. (green cells represents features related to product design, yellow cells: features regarding information availability (information available on), Blue cells: features related to manufacturers service). Note: There is no link in-between the rows

Identification	Failure Diagnostic	Disassembly & Reassembly	spare part replacement	Restoring to working condition	Longevity	Update	Use phase
Brand and unique model	Troubleshooting common failures	Exploded Diagrams	Address	procedure to reset default factory settings	Increased of lifespan for more than 10 years indicated by the manufacturer	Update method	Safety measures identified in accordance with Low voltage directive (2015/35/EU)
Barcode or QR code	Test method	List of connectors used	web shop information	toll free web based contact available for reconditioning	Electronics control protected against moisture, high temperature and dust	list of required tools and software For update	Safety measures identified in accordance with Machinery directive (2006,42,EC)
Identification Accessible after removal of only 2* connections	Error codes list	List of required tools	unique reference numbers of available spare parts	Regular training provided to technicians from all repair shops		How updates will affect the original system characteristics	Regular maintenance schedule
Identification Accessible without disconnecting components	Required repair actions	Description of recommended disassembly steps to remove priority parts	information to 3d print spare part is available when relevant	resetting to factory settings can be done without intervention of external/specialized device or software		Access to software and current updates	Maintenance plan

Product identification engraved or printed	Printed circuit board diagram	Wiring diagram	compatible spare parts available	resetting to factory settings can be done with freely accessible software		Standardised software updates	Specifics of transporting the appliance attached to the unit
Technical support for identification for at least 10 years	Fault detection software	support available for disassembly and reassembly for atleast 10 years after last production	backwardly compatible spare parts are widely available to replace priority parts (to			Software/firmware updates support offered for at-least X years after placing last unit on the market	Full compatibility with open source software is ensured
Toll-free or web based support available for product identification	Diagnostic Support available for at least 10 years after last production	Toll-free or web based contact available for disassembly and reassembly allowing customer to access, repair and repair failed part through assisted disassembly and reassembly	Recovery time for components or groups of components is same time as availability of spare parts			Update of a feature is achievable in the product without performing a product exchange	Medium of information
Clear warning sign on dangerous components	Toll-free or web based Diagnostic support available for failure diagnostic and repair	Availability to spare parts*	Priority parts can be replaced individually			ports, slots or connectors used for the update are accessible with (a)no tools, (b) common tools (c) tools available from manufacturers	Built-in secure data transfer and deletion functionality
	Appliance can still be activated when the cover is opened	Cost of spare parts	Standardised priority parts				Accessibility of Information*

	product is able start despite faulty components	Standardized fasteners used	Peripherals are standardized				warranty *
	Test mode available in software	Sufficient cable length for connecting groups of components					
	Accessible measuring points at edge of circuit board	Space large enough for hand soldering					
	Product is still functional despite the failure of peripheral functions	Parts in PCB can be de-soldered					
	Accessibility of diagnostic software*	Reusability/Removability of fasteners					
		Tools Required*					
		Disassembly time					
		Disassembly sequence					