Hotspot Mapping for product disassembly; a circular product assessment method

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Abstract

Designing products for the Circular Economy requires closing and slowing of loops by means of repair, remanufacturing, refurbishment, parts reuse and/or recycling. Ease of product disassembly facilitates these processes to be more cost-effective, resulting in a better circular strategy fit. In this paper we present the Hotspot Mapping method. The objective of this method is to help designers in (re)designing their products for ease of disassembly, by assessing which parts in the product architecture are most critical for ease of disassembly. Critical parts are parts with a high failure rate or maintenance need and/or with a high economic and environmental value, that should be easily accessible with low effort to enable cost-effective recovery processes. A product's ease of disassembly is determined by factors that help or hinder the disconnection of critical parts from the rest of the product. The Hotspot Mapping method is a spreadsheet-based tool that indicates ease-of-disassembly by flagging five 'hotspot' indicators: (i) time needed to disconnect parts, (ii) difficulty of access, (iii) priority parts, (iv) environmental impact and (v) economy valuable parts. The Hotspot Mapping method adds to recent repairability assessment methods proposed in standards such as EN45554:2020, by also taking into account other aspects than failure-rate and functionality, such as economic and environmental value of the parts and materials. This paper describes the Hotspot Mapping method and applies the method to a household blender.

1 Introduction

In the 1990's a number of methods was developed to assess the ease of disassembly of products. In those days, these methods were already considered as important for environmental reasons – in particular for product recycling [1]–[3]. The disassembly process was visualized in reverse fishbone diagrams or disassembly trees [4], [5]. Recently this work has come under renewed scrutiny, and there has been considerable activity to modernize and build upon these 'design for disassembly' methods [6], [7], reinforced by the European Green Deal and the commitment of the European Commission to promote a circular economy [8]. Ease of disassembly is not only necessary for successful recycling, but also for repair, refurbishment, remanufacturing and parts harvesting for reuse.

The recent EN45554:2020 [9] standard focuses on a "general method for the assessment of the ability to repair, reuse and upgrade energy related products". In this standard the identification and ranking of so-called "priority parts" is the first step in assessing a product on its repair, reuse and upgrade. The standard determines that a priority part is a part with "(i) the likelihood of the need to replace or upgrade the part; (ii) the suitability of the part for reuse; (iii) the functionality of the part". Besides this new standard another standard in the series of Material Efficiency standards [10] is the EN45555:2019 [11] which promotes recovering materials for recycling purposes and focuses on the recyclability and recoverability rate and the efficiency of recycling and recovery processes. However, both the EN45554 and EN45555 do not consider the environmental benefits of avoiding the production of equivalent amounts of primary materials and energy carriers, nor the impacts associated with the end-of-life treatment processes [12]. This is the reason we developed the Hotspot Mapping method, which allows a designer to focus on the recovery of 'priority parts', as well as those parts with a high economic and environmental value ('valuable parts').

To keep products in use for longer and to facilitate their reuse, a product's design should facilitate different circular recovery strategies. For each of these strategies (i.e. repair, refurbishment, recycling), it is vital that the product is easy to disassemble. This enables cost effective operations and makes products fit for all circular strategies. In the Hotspot Mapping method, we focus on 'critical parts', which consist of (i) priority parts, based on their functionality, and failure/maintenance rate, and (ii) the valuable parts, based on their embodied economic value and the embodied environmental impact. Hotspot Mapping is a method to pinpoint these critical parts, locate them in a product's architecture and to assess them on the ease of disassembly. Within the method all parts in a product are assessed and prioritized on these aspects in order to make them easy to reach while disassembling. The Hotspot Mapping method is a spreadsheet-based tool that indicates ease of disassembly by flagging five 'hotspot' indicators: (i) time needed to disconnect parts; (ii) difficulty of access (for instance the amount of force needed to disconnect a part); (iii) the part's failure rate and/or maintenance need; (iv) the part's economic value; and (v) the part's embodied environmental impact.

The first two indicators, time needed to disconnect parts and difficulty of access, are important factors for product repair and maintenance, but also for parts-harvesting for reuse. These indicators are also of value for the end of life recycling process, but considering that small household appliances (such as the blender in this paper) are generally not dismantled, but shredded as a whole [13] we think this indicator cannot be used for this purpose. Automated dismantling processes however are increasingly common for dismantling complex products that contain precious metals, such as for smartphones [14]. For these processes determining the ease of disassembly of critical parts might helpful.

Together with a visualization of the teardown sequence, the so-called disassembly map [6], it is now possible to locate the critical parts in the product architecture and assess them on the ease of part-disassembly. The Hotspot Mapping method is presented in the next section, followed by a product case study, where we applied the Hotspot Mapping method to a Solis household blender. We will discuss the learnings from the product case study and finalize with a conclusion.

2 Hotspot Mapping Method

Ease of disassembly depends on product-related aspects, such as the type of tools used and their availability, and on context-related aspects, such as the availability of a repair manual. The Hotspot Mapping method focuses only on the product-related aspects. It assesses the product architecture by locating critical parts and the ease of reaching these.

2.1 Recording teardown activities

In order to locate the critical parts, a product is dismantled to its core. Each step in the dismantling process is logged sequentially in a spreadsheet, which was based on the Disassembly Evaluation Chart from Kroll [15]. A screenshot of the spreadsheet can be found in Figure . Each row represents one step in the dismantling process. The operator logs the necessary data to determine the five hotspot indicators: general properties, activity properties, difficulty of access, functional sensitivity and material properties. These data entries are described below.

Property 1. *General properties* include the part or subassembly's name, whether it's a single part or subassembly that is removed, and from which part or subassembly it is taken. When a part entry is assigned as being a subassembly it can and should be dismantled further in the disassembly map.

Property 2. The *Activity properties* consist of the activity (e.g. unscrewing), tools involved and their size, and the time needed to for the activity described. The time is the actual time involved while disassembling, because proxy times for pre-defined activities [16]–[18] are still too unreliable at the time of writing [12]. The tools used during the disassembling procedure are classified according to the EN45554 standard, where hand or basic tools are defined as class A tools and proprietary tools as class D, see table 1.

Category Description	**Class**
Feasible with the use of no tool, or a tool or set of tools that is supplied with the product or spare part, or basic (common) tools	A
Feasible with product group specific tools	B
Feasible with other commercially available tools	C
Feasible with proprietary tools	D
Not feasible with any existing tool	E

Table 1: Classification of tools as defined in the EN45554:2020 standard [9], [19].

Property 3. The *Difficulty of Access* can be described by three properties: (i) the level of force needed in the process, (ii) the accessibility of the fastener and (iii) the positioning of the tool needed for the specific process.

- The amount of force has been defined on three levels based on the Maynard Operation Sequence Technique (MOST) work measurement system [16] as described in [6]. The operator can choose between three levels of force intensity: light (less than 5N), moderate (5 to 20N) and heavy resistance (exceeding 20N);
- The accessibility of the fastener is measured in three levels: clear access (where the fastener is visible for the operator), recessed access (where the fastener is accessible but not visible), and obstructed access (where the fastener is covered by another part or item like a sticker);
- The positioning of the tool is again divided in three levels which define the degree of precision required to position a tool or hand: no-to-low precision (when no tool is needed for successful finishing the particular step), moderate precision (when a tool is

needed but positioning is not precise), and high precision (when a tool is needed which is positioned with high precision).

Property 4. In the *Functional sensitivity* column, the operator enters data concerning the level of maintenance needed and the risk of failure during use. When available the operator can make use of the manufacturer’s failure-rate and repair data. For certain product categories (for instance vacuum cleaners) this data is available in literature [20], in studies by the European Commission [21], and in consumer association statistics [22]. When no data is available the operator should rely on experience and common sense.

Property 5. In the *Material properties* column, the operator enters data about the part’s material composition and its weight. When the operator has access to the Bill of Materials (BoM) of the assessed product it can make use of this data, otherwise the material has to be determined by using existing material-determination tables in literature. In the spreadsheet-tool the operator can choose from a range of material groups (like thermoset, metals, etc.), electronic components (like batteries, PCBs, etc.), or choose the option of mixed materials (with a main material contribution). In Hotspot Mapping, electronic parts like PCBs and batteries are not fully dismantled and should be logged as a part. The weight is measured with the help of a weighing scale and is entered in grams. To avoid duplicate contributions to the hotspot indicators the material properties data is entered only once per part.

2.2 Hotspot identification

Once the product is disassembled and the table is completed the spreadsheet flags hotspot areas, based on five hotspot indicators.

The first indicator, *Time*, shows the steps which take the most time, where the 80th percentile is flagged as yellow and the 90th as red.

The second indicator shows the difficulty of the *Activity* involved in disassembly, is calculated by summing the penalty points for the required tool(s) needed P_{class}, the force involved P_F, the accessibility P_{Acc} and the difficulty for positioning the tool(s) P_{Pos}.

$$Activity = P_{class} + P_F + P_{Acc} + P_{Pos}$$

Penalties for the used tools P_{class}, are classified according to the to the EN45554 standard, where class A tools are not penalized (0 points) while class B to E tools are penalized with a penalty of 1 to 4 points. The other three penalties range from 0 to 2 penalty points, where 0 points is given to a no-to-low level of impact (level 0), 1 to moderate impact (level 1) and 2 to high impact (level 2). For instance, for the force penalty, zero points are given for forces less than 5N (no-to-low, level 0), 1 point for forces in between 5N to 20N (moderate resistance, level 1) and 2 points when activity involves forces above 20N (heavy resistance, level 2). The activity indicator is flagged yellow when it equals or exceeds 4 penalty points, and red when it equals or exceeds 6 penalty points.

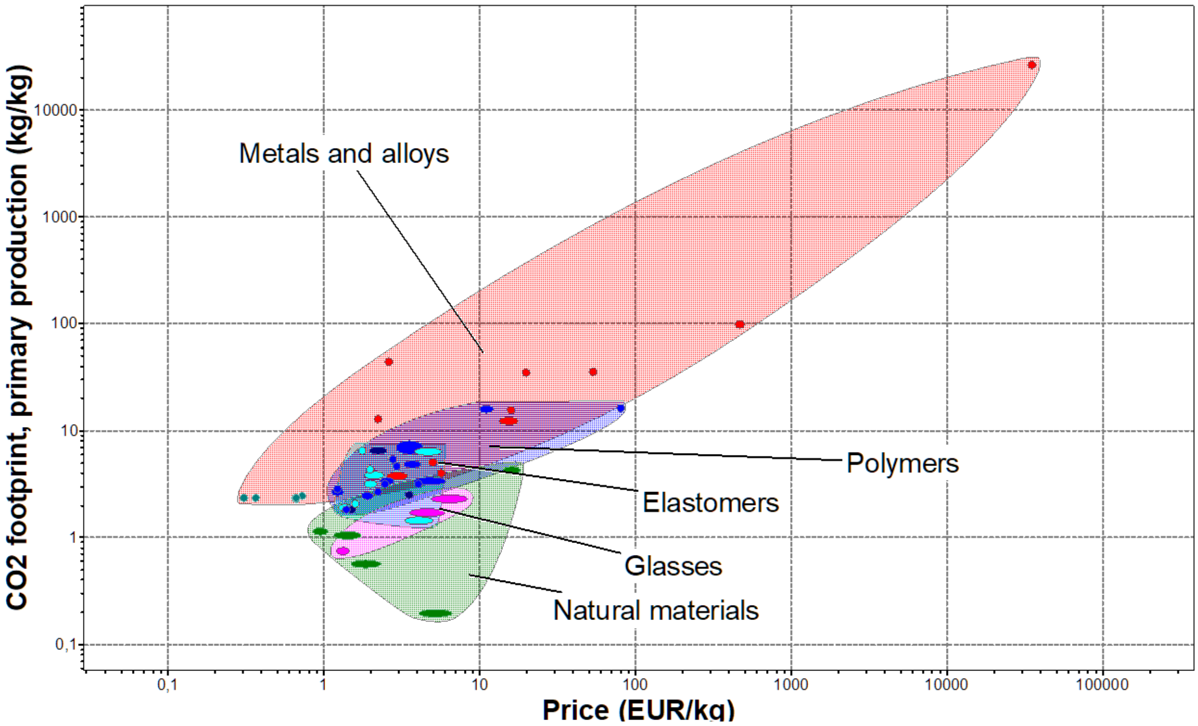


Figure 1: Different material groups’ economic value versus embodied environmental impact [23].

The third indicator shows the *Priority of the Part*. Priority parts, as defined by EN45554 are parts which have a high functionality and involve high maintenance. These parts require priority when improving ease of access and depth in the product architecture. Parts which are flagged yellow or red are the priority parts. This indicator is the result of summing penalty points from the level of Maintenance P_{Main} and the level of Functionality P_{Funct} for the part involved in this particular step.

$$Priority\ Part = P_{Main} + P_{Funct}$$

Just like the penalty points in the second indicator, three levels are defined, where no-to-low impact (level 0) is not penalized, and moderate (level 1) and high impact (level 2) are penalized with respectively 1 and 2 points. The activity indicator is flagged yellow when it equals or exceeds 3 penalty points, and red when it equals 4 penalty points.

The fourth and fifth indicator are based on the embodied *Environmental impact* and the embodied *Economic value* of the part in question. The most valuable parts are important for effective recycling strategies but also for parts reuse purposes for instance in refurbishment or remanufacturing. The embodied environmental impact and the economic value of each part is calculated using the averaged CO_2 footprint and averaged material price based on the Cambridge Engineering Selector (CES) Edupack level 1 database [23]. Figure 1 shows the range of impact for several materials and material groups. Both the *Environmental* and *Economic Indicators* are flagged when the part has the highest embodied impact or value, where the 80th percentile is flagged as yellow and the 90th as red.

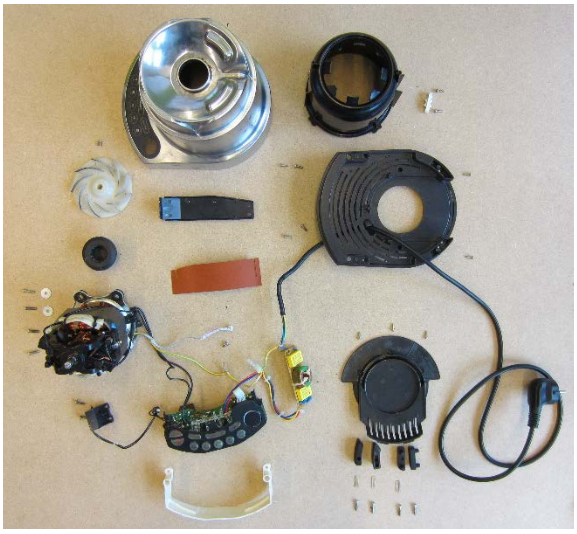


Figure 2: a "knolled" layout of the bottom motor-assembly of the Solis household blender.

Critical parts and associated disassembly activities can now easily be identified by the coloured flags in the indicators, the. Together with a visualization of the teardown sequence, the so-called Disassembly Map [6], [7], it is now easy to locate them in the product architecture. The disassembly map gives a visual impression of the disassembly depth of each critical part, and the use of specifically designed icons and colour codes makes it easy to assess how time-consuming and difficult it is to reach these parts. With this knowledge a designer can rearrange the parts in the product architecture where critical parts are easier to disassemble.

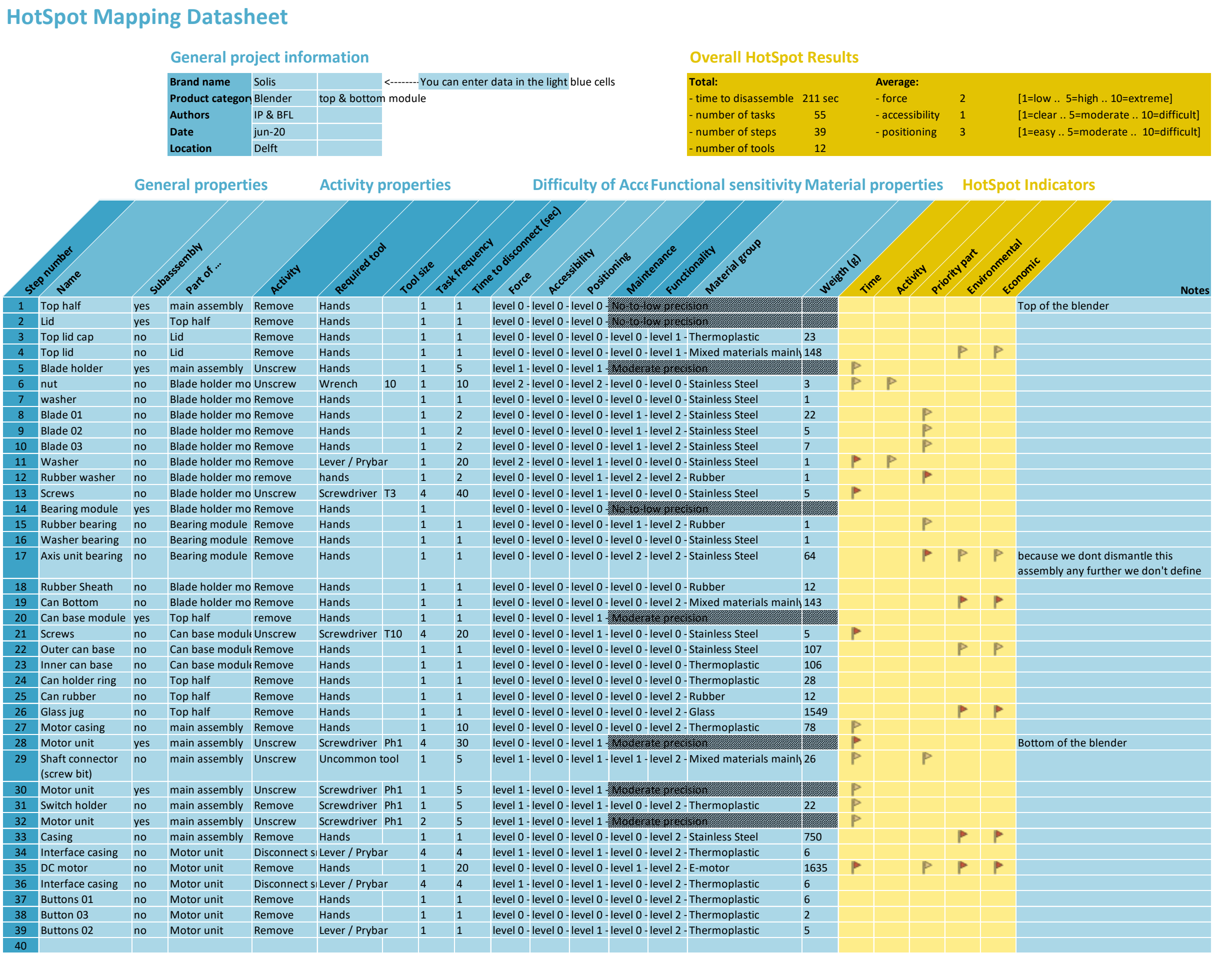
3 Blender case study

To illustrate the tool and its functionality for assessing a product's architecture on circular recovery strategies the Solis 837 household blender was disassembled and evaluated [24]. Figure 2 shows the "knolled" image of the bottom base module and figure 3 shows the complete product.

The blender was disassembled and evaluated using the Hotspot Mapping method. The product consists of two major subassemblies, the top-half can-assembly (including the cutting knife set, the transmission and the glass jug), and the bottom-base motor assembly (including all the electronics and the motor). The product is a sturdy blender containing a large number of parts and materials, including metals, plastics, rubber and glass, but also a large number of electronics such as PCB's, a display and a high-power electromotor. The disassembly process consisted of non-destructive activities and was stopped at the point where irreversible fasteners like solder was involved, and de-soldering or cutting was needed to disconnect the parts.

Figure 4 shows the Hotspot Map of the blender. 55 disassembly operations, or tasks, were needed to disassemble 39 parts, and in 12 of the disassembly steps, 6 different **tools** were needed. All parts were relatively **easy** to disconnect: no red flags are shown in the **activity** indicator column, only two yellow flags:

Figure 3: the Solis 837 household blender. Left the Bottom Base module and right the Top Half.



HotSpot Mapping Datasheet

General project information

Brand name	Solis	
Product category	Blender	top & bottom module
Authors	IP & BFL	
Date	jun-20	
Location	Delft	

<--------You can enter data in the light blue cells

Overall HotSpot Results

Total:		**Average:**		
- time to disassemble	211 sec	- force	2	[1=low .. 5=high .. 10=extreme]
- number of tasks	55	- accessibility	1	[1=clear .. 5=moderate .. 10=difficult]
- number of steps	39	- positioning	3	[1=easy .. 5=moderate .. 10=difficult]
- number of tools	12			

General properties | Activity properties | Difficulty of Acce | Functional sensitivity | Material properties | HotSpot Indicators

Step number	Name	Subasssembly	Part of ...	Activity	Required tool	Tool size	Task frequency	Time to disconnect (sec)	Force	Accessibility	Positioning	Maintenance	Functionality	Material group	Weigth (g)	Time	Activity	Priority part	Environmental	Economic	Notes
1	Top half	yes	main assembly	Remove	Hands		1	1	level 0 -	level 0 -	level 0 - No-to-low precision										Top of the blender
2	Lid	yes	Top half	Remove	Hands		1	1	level 0 -	level 0 -	level 0 - No-to-low precision										
3	Top lid cap	no	Lid	Remove	Hands		1	1	level 0 -	level 0 -	level 0 -	level 0 -	level 1 -	Thermoplastic	23						
4	Top lid	no	Lid	Remove	Hands		1	1	level 0 -	level 0 -	level 0 -	level 0 -	level 1 -	Mixed materials mainly	148				⚐	⚐	
5	Blade holder	yes	main assembly	Unscrew	Hands		1	5	level 1 -	level 0 -	level 1 - Moderate precision					⚐					
6	nut	no	Blade holder mo	Unscrew	Wrench	10	1	10	level 2 -	level 0 -	level 2 -	level 0 -	level 0 -	Stainless Steel	3	⚐	⚐				
7	washer	no	Blade holder mo	Remove	Hands		1	1	level 0 -	level 0 -	level 0 -	level 0 -	level 0 -	Stainless Steel	1						
8	Blade 01	no	Blade holder mo	Remove	Hands		1	2	level 0 -	level 0 -	level 0 -	level 1 -	level 2 -	Stainless Steel	22			⚐			
9	Blade 02	no	Blade holder mo	Remove	Hands		1	2	level 0 -	level 0 -	level 0 -	level 1 -	level 2 -	Stainless Steel	5			⚐			
10	Blade 03	no	Blade holder mo	Remove	Hands		1	2	level 0 -	level 0 -	level 0 -	level 1 -	level 2 -	Stainless Steel	7			⚐			
11	Washer	no	Blade holder mo	Remove	Lever / Prybar		1	20	level 2 -	level 0 -	level 1 -	level 0 -	level 0 -	Stainless Steel	1	🚩	⚐				
12	Rubber washer	no	Blade holder mo	remove	hands		1	2	level 0 -	level 0 -	level 1 -	level 2 -	level 2 -	Rubber	1			🚩			
13	Screws	no	Blade holder mo	Unscrew	Screwdriver	T3	4	40	level 0 -	level 0 -	level 1 -	level 0 -	level 0 -	Stainless Steel	5	🚩					
14	Bearing module	yes	Blade holder mo	Remove	Hands		1		level 0 -	level 0 -	level 0 - No-to-low precision										
15	Rubber bearing	no	Bearing module	Remove	Hands		1	1	level 0 -	level 0 -	level 0 -	level 1 -	level 2 -	Rubber	1			⚐			
16	Washer bearing	no	Bearing module	Remove	Hands		1	1	level 0 -	level 0 -	level 0 -	level 0 -	level 0 -	Stainless Steel	1						
17	Axis unit bearing	no	Bearing module	Remove	Hands		1	1	level 0 -	level 0 -	level 0 -	level 2 -	level 2 -	Stainless Steel	64			🚩	⚐	⚐	because we dont dismantle this assembly any further we don't define
18	Rubber Sheath	no	Blade holder mo	Remove	Hands		1	1	level 0 -	level 0 -	level 0 -	level 0 -	level 0 -	Rubber	12						
19	Can Bottom	no	Blade holder mo	Remove	Hands		1	1	level 0 -	level 0 -	level 0 -	level 0 -	level 2 -	Mixed materials mainly	143				🚩	🚩	
20	Can base module	yes	Top half	remove	Hands		1	1	level 0 -	level 0 -	level 1 - Moderate precision										
21	Screws	no	Can base module	Unscrew	Screwdriver	T10	4	20	level 0 -	level 0 -	level 1 -	level 0 -	level 0 -	Stainless Steel	5	🚩					
22	Outer can base	no	Can base module	Remove	Hands		1	1	level 0 -	level 0 -	level 0 -	level 0 -	level 0 -	Stainless Steel	107				⚐	⚐	
23	Inner can base	no	Can base module	Remove	Hands		1	1	level 0 -	level 0 -	level 0 -	level 0 -	level 0 -	Thermoplastic	106						
24	Can holder ring	no	Top half	Remove	Hands		1	1	level 0 -	level 0 -	level 0 -	level 0 -	level 0 -	Thermoplastic	28						
25	Can rubber	no	Top half	Remove	Hands		1	1	level 0 -	level 0 -	level 0 -	level 0 -	level 2 -	Rubber	12						
26	Glass jug	no	Top half	Remove	Hands		1	1	level 0 -	level 0 -	level 0 -	level 0 -	level 2 -	Glass	1549				🚩	🚩	
27	Motor casing	no	main assembly	Remove	Hands		1	10	level 0 -	level 0 -	level 0 -	level 0 -	level 2 -	Thermoplastic	78	⚐					
28	Motor unit	yes	main assembly	Unscrew	Screwdriver	Ph1	4	30	level 0 -	level 0 -	level 1 - Moderate precision					🚩					Bottom of the blender
29	Shaft connector (screw bit)	no	main assembly	Unscrew	Uncommon tool		1	5	level 1 -	level 0 -	level 1 -	level 1 -	level 2 -	Mixed materials mainly	26	⚐		⚐			
30	Motor unit	yes	main assembly	Unscrew	Screwdriver	Ph1	1	5	level 1 -	level 0 -	level 1 - Moderate precision					⚐					
31	Switch holder	no	main assembly	Remove	Screwdriver	Ph1	1	5	level 1 -	level 0 -	level 1 -	level 0 -	level 2 -	Thermoplastic	22	⚐					
32	Motor unit	yes	main assembly	Unscrew	Screwdriver	Ph1	2	5	level 1 -	level 0 -	level 1 - Moderate precision					⚐					
33	Casing	no	main assembly	Remove	Hands		1	1	level 0 -	level 0 -	level 0 -	level 0 -	level 2 -	Stainless Steel	750				🚩	🚩	
34	Interface casing	no	Motor unit	Disconnect s	Lever / Prybar		4	4	level 1 -	level 0 -	level 1 -	level 0 -	level 2 -	Thermoplastic	6						
35	DC motor	no	Motor unit	Remove	Hands		1	20	level 0 -	level 0 -	level 0 -	level 1 -	level 2 -	E-motor	1635	🚩		⚐	🚩	🚩	
36	Interface casing	no	Motor unit	Disconnect s	Lever / Prybar		4	4	level 1 -	level 0 -	level 1 -	level 0 -	level 2 -	Thermoplastic	6						
37	Buttons 01	no	Motor unit	Remove	Hands		1	1	level 0 -	level 0 -	level 0 -	level 0 -	level 2 -	Thermoplastic	6						
38	Button 03	no	Motor unit	Remove	Hands		1	1	level 0 -	level 0 -	level 0 -	level 0 -	level 2 -	Thermoplastic	2						
39	Buttons 02	no	Motor unit	Remove	Lever / Prybar		1	1	level 0 -	level 0 -	level 1 -	level 0 -	level 2 -	Thermoplastic	5						
40																					

Figure 4: the Hotspot Map of the Solis Blender.

- Step 6 required high force, as the blade holder module was tightly screwed with a nut and bolt. Unscrewing them also required a high precision placing of the tools.
- Step 11 needed high-force prying, because a washer was tightly clipped around the bolt, and it took considerable time before it slid from bold.

Figure 5: the axis bearing module with the worn down rubber sheath keeping it in place and protecting the bearing.

In step 12 and 17 two **priority parts** were addressed, the rubber sheath keeping the axis bearing module in place and the axis bearing module itself, see figure 5. Both parts are crucial for the functionality of the product, where the rubber sheath deteriorates over time because of its close contact with acid liquids dripping from the glass jug through the bearing module to the bottom motor subassembly. When the rubber sheath is deteriorated, the liquids from the jug drip slowly in the bearing, wherein the bearing is going to run rough and finally jams. Replacement of the rubber sheath should be easy to extend the life of this product.

The **time** required for disassembling was critical for more parts. Some parts required multiple tasks before they could be removed. For instance, to reach the bearing module, four screws had to be unscrewed (step 13) before the bearing module could be removed (step 14).

Based on the 5 indicators, the DC electromotor came out as the main critical part (step 35). It is red-flagged on the time-to-remove indicator, and both the environmental and economic indicator. Because this part is required for the primary function but only needs low maintenance the part is flagged yellow on the priority

Figure 6: the three second-critical parts derived from the hotspot map: glass jug (left), the can bottom (top right) and the metal blender casing (bottom right).

part indicator. Obviously, this part is the most important part and should be easily accessible in the product architecture.

Other critical parts, with each two red flags under the **environmental** and **economic** indicators are (i) the can bottom (step 19), (ii) the glass jug (step 26) and (iii) the metal bottom-casing (step 33), see figure 6. All three of them contain valuable materials with a large embodied environmental impact (metals and glass) and all have a high mass. These parts are very well reachable within the current product architecture, and thus easy to disassemble for refurbishment or recycling purposes.

The indicator system also shows other parts with a moderate impact (with one red flag or multiple yellow flags), which are not discussed further here.

4 Discussion & Conclusion

In this paper, we have proposed a method to identify hotspots for ease-of-disassembly in a product architecture. The systematic approach of evaluating the disassembly of a product can be used by designers to assess the suitability of a product design on circular aspects. The Hotspot Mapping method combines the disassembly of a product with the logging of all steps needed to reach the most critical parts in the product architecture. This results in five indicators: time needed to disconnect parts, difficulty of access, priority parts, environmental impact and economy valuable parts, which show the criticality of the part or the activity involved. The Hotspot Mapping method is unique because it also includes the economic and environmental value of parts, which distinguishes this method from existing repairability assessment methods. In this way, it gives designers a focus for redesign towards the Circular Economy and allows designers to learn from earlier iterations and from assessments of others.

Based on the assessment of the Blender case we identified a priority part we did not anticipate before the analysis, the rubber sheath containing the axis bearing unit. This part wears down during use, and should be easy to replace when a longer product life is wanted. Furthermore, based on the environmental and economic indicators, the bigger metal and glass components and the bigger electronic parts (the DC motor) contribute the most to the product's value. These parts do not tend to fail that often and could easily be harvested for refurbishment or remanufacturing processes.

While logging all activities in the Hotspot map, it became apparent that time varies depending on the operator, and a standardized proxy-time per activity is preferred over measured time. Currently, there are several researches investigating proxy times [12], [17], [25] but this has not matured sufficiently to be implemented in this tool yet.

The more qualitative assessment criteria referring to the Accessibility and the Functional Sensitivity columns, are not strictly defined yet, and their assessment depends on the category the product belongs to. For instance, there is a difference in force needed to dismantle a dishwasher compared to the dismantling of a smartphone. Also, knowledge on failure rate and maintenance is not always readily available to the user of the Hotspot Mapping. To further improve the tool, it could incorporate scoring criteria as used in the FMEA method, which is commonly used to predict the chances of failure of the parts in products.

A final point for discussion is that the embodied environmental impact indicator and the economic value indicator are both based on averaged data for material-only aspects, leaving out the influence of the production process. Generally speaking, the impact of materials exceeds that of the production impact and thus this approach could be a good and simple route to follow. The simplicity of the database limits its use for mass-produced consumer products embodying only commonly used materials. When the product contains special or technical materials a more detailed environmental impact and economic value analysis should be executed. Consequently, this tool is very applicable for mass-produced consumer products using common materials and to a lesser extend to products using specialty materials.

5 Literature

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