Design for Safe Repair in a Circular Economy

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List of abbreviations

AsMer:	The Assessment Matrix for Easy of Repair
DIY:	Do-It-Yourself
FMEA:	Failure Mode and Effect Analysis
JRC:	Joint Research Center
OEM:	Original Equipment Manufacturer
ONR192102:	Reference number for the Austrian Standard entitled “Durability Mark For Electric And Electronic Appliances Designed For Easy Repair (White And Brown Goods)”.
PCB:	Printed Circuit Board
prEN 45554:	Reference number for the European Standard entitled “General methods for the assessment of the ability to repair, reuse and upgrade energy-related products”
RAPEX:	Rapid Information Exchange System (This is the alert system used in the EU for non-food products which pose a risk to consumers or professional users.)
RSS:	Repair Scoring System (developed by the JRC)
UI:	User Interface

1 Introduction

Product lifetime extension is a key strategy in a circular economy, where the value of products, materials and resources is maintained in the economy for as long as possible, and the generation of waste minimized (European Commission, 2020). As such, there is a need to design durable products that can be repaired, should one or several components fail while the product as a whole could still be useful. This is illustrated by the recent introduction of policies to increase product repair, such as reparability labels (Right to Repair, 2020), reparability requirements (Constant, 2020) and reduced taxes on repair services (Dalhammar et al., 2020).

Previous research has investigated how the reparability of products can be assessed (e.g., Austrian Standards, 2014; Bracquene et al., 2019; Cordella et al., 2019; De Fazio et al., n.d.; Flipsen et al., 2020, 2019, 2016). Such reparability assessments can be used by designers to identify design improvements and by managers or policy makers to monitor progress. The different assessment approaches have slightly different scope and focus. For example, the repair scoring system developed by the EU Joint Research Center (Cordella et al., 2019) aims to "*develop a general approach for the assessment of the ability to repair/upgrade energy related products*" while the Disassembly Map (De Fazio et al., n.d.) was developed as a method to facilitate for designers to visualize the reparability of a product by indicating target components and the disassembly steps that are needed to reach them.

The EU has recently put into force new requirements for the reparability of 10 categories of products sold within the European Union. The regulations apply to, e.g., washing machines, refrigerators, televisions, and dishwashers and demand that manufacturers ensure the availability of spare parts for a long period of time (7-10 years), that repair and maintenance information is available, and that parts can be replaced with commonly available tools (European Commission, 2019).

The new requirements focus primarily on enabling repair by professional repairers and only to a limited extent on "do-it-yourself" (DIY) repairs by consumers. This choice of scope could potentially limit the effect of the policy to increase the rate of repair for consumer products (as argued by, e.g., Right to Repair, 2021). According to a recent literature and policy review, independent repairers and DIYs are currently the most impeded stakeholders in the repair system (Svensson-Hoglund et al., 2021). The decision to focus on professional repairs can be seen as a way to reduce the Original Equipment Manufacturers' (OEM) concerns regarding safety risks and liability issues (Harrabin, 2019), i.e., that increased reparability could lead to safety risks as non-professional repairers would attempt to repair components for which they do not have sufficient knowledge. This is an example of a larger discussion about which *target groups* should or should not be enabled to carry out repairs on consumer products. In some cases, only professional repair companies who have been explicitly authorized by the OEM can get access to in-depth repair information. Voluntary-based repair organizations, so called "repair cafés", usually run by people with extensive repair experience and knowledge, are however not always granted access to such information.

Considering the potential tensions between safety and manufacturers' liability on the one hand, and consumers' "right to repair" on the other, surprisingly little research has been published in this direction. This report thus explicitly draws attention to this tension through a systematic investigation of safety risks related to repair of household products. The aim of this project is to elucidate possible risks related to the repair of five common electronic household product categories (coffee makers, blenders, CD players, washing machines, and vacuum cleaners) and propose design-related recommendations to simultaneously allow for high reparability and safety during and after repair. As a basic approach to assess reparability and relate it to safety, we use and further elaborate the Disassembly Map, as this tool is specifically set up to guide designers in improving product reparability.

Towards this aim, four research questions are posed:

RQ1: What are the safety risks related to repair of the products – including risks during repair and after repair?

RQ2: How can these risks be assessed?

RQ3: How can design contribute to the reduction or elimination of safety risks during and after repair of the products?

RQ4: What modifications are needed to the Disassembly Map (De Fazio et al., n.d.) to document safety aspects during and after repair?

The remainder of this report is structured as follows. First, Section 2 presents background information about design for repair in general, and design for safe repair in particular. Section 2 also defines the scope of this study in relation to previous work. Section 3 details the approach that was used for data collection and analysis, including the development of a risk assessment framework (RQ2). Section 4 presents the adaptations made to the Disassembly Map (RQ4) in order to document safety aspects. Section 5 provides an overview of common failures for the five product categories, as well as known safety risks that could be relevant for repair of the products (RQ1). Section 6 presents safety risks and design recommendations (RQ1, RQ3) derived from dis- and reassembly activities carried out within this project (documented in detail in the Appendix). Section 7 provides a critical discussion of the project results and suggestions for additional improvements to the Disassembly Map (RQ4). Finally, Section 8 states the main conclusions of the project and proposes directions for future research.

2 Background and Scope

2.1 Design for reparability

Design has a key role to play in increasing the repair rate of consumer products. Design can reduce barriers to repair, e.g., by reducing the time needed and the cost associated with repairs. However, design can also limit the reparability of products and the 'Right to Repair' movement often accuses manufacturers of intentionally designing products that are difficult to repair, see e.g., (IFIXIT, 2019).

Design-for-repair strategies should support the repair process as depicted in Figure 1: product identification, fault diagnosis, disassembly, repair, reassembly, restoring/resetting, or testing (Cordella et al., 2019; Cuthbert et al., 2016). Examples of design strategies that can support repair are (1) non-destructive and easy disassembly that can be done with commonly available tools, (2) avoiding glued or soldered connections, (3) standardization of connections and parts, (4) ensuring interoperability/backwards compatibility between product models, and (5) easy access to parts with short lifespans (Flipsen et al., 2016; Pozo Arcos et al., 2020; RREUSE, 2013).

Finally, design can also be used to increase the durability of products, potentially reducing the need to repair. However, this is not in focus in this report.

Figure 1: Steps in the repair process

2.2 The Disassembly Map

The Disassembly Map is a recently developed tool that aims to support design for repair by enabling visual mapping of the disassembly of a product. The map clearly shows different routes towards target components, i.e. components with a high potential failure rate (important for repair), a high embodied environmental impact (important for recycling) and/or high economic value (relevant for components harvesting) (De Fazio et al., n.d.). This way, designers can assess how different design solutions influence the ease of disassembly.

The Disassembly Map for a blender is shown as an example in Figure 2. The map consists of *components* and *action blocks*. Components (or sub-assemblies containing multiple components) are represented using numbers indicated in light-blue circles; these are positioned in a logical order meant to describe the disassembly sequence. Action blocks of different color and shape are used to indicate different types of disassembly operations required for the removal of each part. Components positioned at the bottom of the Disassembly Map are deeply embedded in the product and are usually difficult to access.

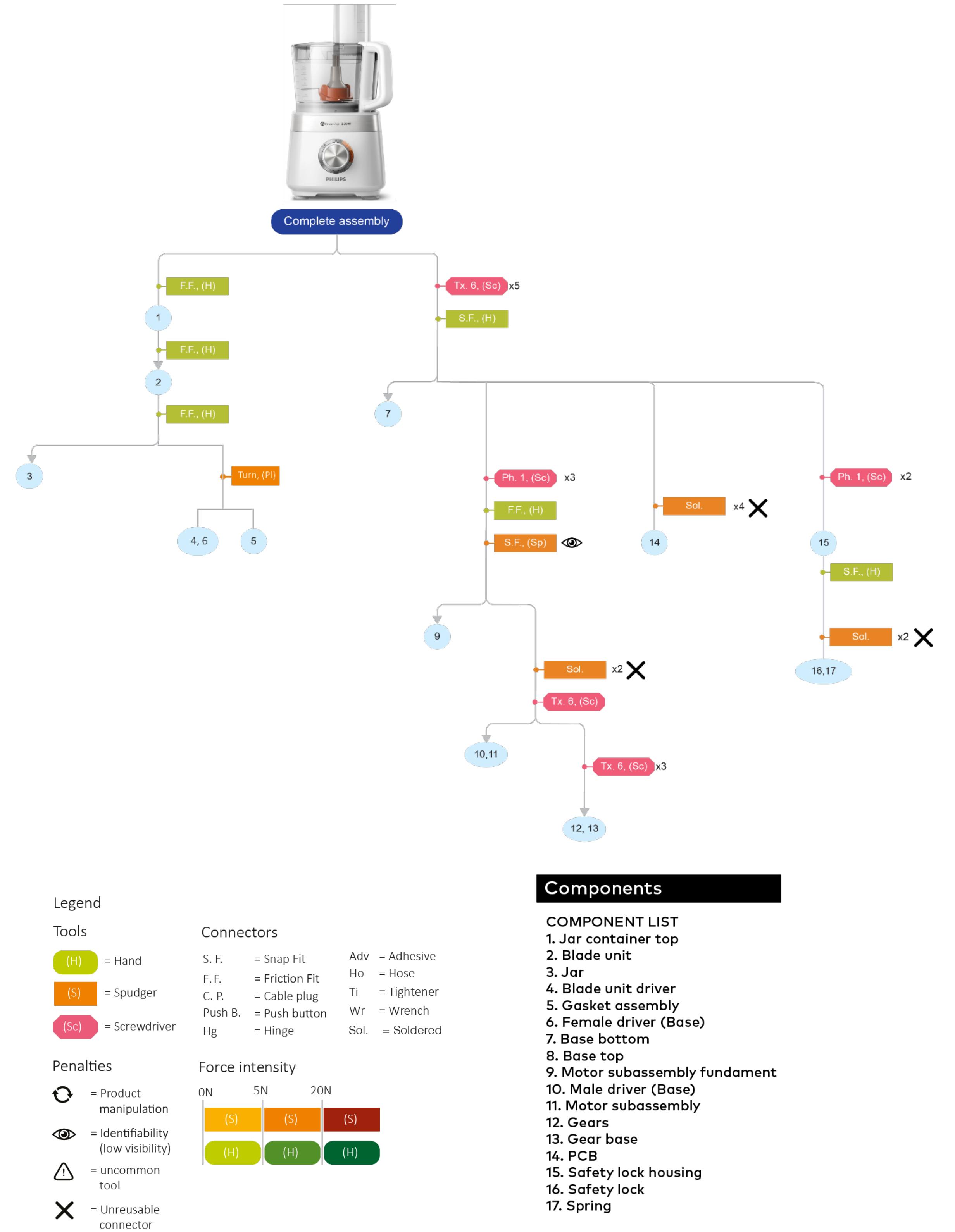

Figure 2: Example of a Disassembly map for the Philips Powerchop blender.

2.3 Design for safe repair

Specific literature about how products can be designed for safe repair is scarce. The preliminary study conducted on this topic within the TU Delft Design for Sustainability research group in 2019 (Bolanos Arriola et al., 2019) suggested the use of failsafe design solutions, i.e. "*design that ensures consumer safety at any moment of a repair procedure, composed of diagnosis, disassembly, repair, reassembly and testing. Additionally, a fail-proof design should avoid any improper reassembly of the product, preventing post-repair risks*". For example, they suggested that the product could be designed for automatic interruption of the main power supply upon removal of the casing around high-voltage electric components. Next to failsafe design, they also discussed information provision to the repairer, which could reduce risks during repair. However, they also found that many repairers do not take the time to read the instructions carefully.

Another publication discussing design for safe repair is Coulibaly et al., (2008). They discuss three types of strategies to reduce safety risks: (1) information provision about risks, (2) risk reduction by design, i.e., that changes are made to the design of the product so that a risk is eliminated or reduced, and (3) operational-level safeguarding, i.e., that barriers are added between the dangerous zone and the user/repairer, potentially leading to reduced accessibility and visibility and thereby lower reparability.

The choice of a suitable strategy is also dependent on the level of expertise that the designers can expect from a repairer, ranging from non-experienced to professional (Bolanos Arriola et al., 2019).

2.4 Safety considerations in existing reparability scoring systems

Among the currently available reparability scoring systems, there are only a few criteria that take safety into account. Dangal (2021) analysed the following six scoring systems with regards to their safety considerations:

- prEN 45554 (CENELEC, 2020)
- The repair scoring system (RSS) developed by the EU Joint Research Center (JRC) (Cordella et al., 2019)
- The Assessment Matrix for ease of Repair (AsMer) (Bracquené et al., 2018)
- ONR 192102 (Austrian Standards, 2014)
- The French Environment and Energy Management Agency system (ADEME RDC ENVIRONNEMENT, 2018)
- The iFixit's reparability scorecard (Flipsen et al., 2019).

Dangal (2021) found that the iFixit score has the most detailed safety considerations as it includes criteria about (1) how batteries are connected and whether they are protected by a hard casing or not, and (2) whether sharp or hot tools are required for the repair. The JRC RSS and the ONR 192102 standard give higher scores if the manufacturer provides instructions about safety issues related to repair. prEN 45554 and the JRC RSS include safety more indirectly by adjusting the score based on the kind of working environment (any condition, workshop, production environment) and expertise level that is needed for a safe repair process. None of the scoring systems include potential safety risks for the user when using a repaired product.

2.5 Other literature about safety in repair

Apart from the literature presented in Section 2.3 and 2.4, publications that include keywords related to safety and repair mainly touch upon the toxicity of materials used in products and how those can affect human health. For example, Ongondo et al., (2011) discuss health and safety issues related to informal repair, reuse, and recycling of electronic waste in, for example, China, India, and Nigeria. Examples of such safety issues are the use of acid baths to separate materials and the burning of unwanted parts in open fires, releasing toxic substances. Other papers discuss that a more circular economy requires that materials flows are kept free from toxic substances. Currently, waste streams still contain plastics from old products which did not follow the same toxicity regulations as today (Leslie et al., 2016). While surely important in the larger context of a safe circular economy, these findings are not directly applicable in this study since the repair processes that we are studying here do not lead to toxic materials being released. The only exception might be fumes released during soldering, but we assume that someone who chooses to use a soldering iron knows how to use it in a safe way.

There is also some literature available on how to ensure product safety and manage liability as 3D printing of products and spare parts becomes more mainstream. Researchers point out the potential for 3D printing to improve the availability of spare parts, but also the legal challenges related to third-party spare part production (Ballardini et al., 2018). A report by the British Department of Business, Energy and Industrial Strategy (BEIS, 2020) discusses safety issues and legal aspects of 3D printed spare parts by unauthorized manufacturers. They found that if the parts are printed by serious actors with approved processes and materials to meet specifications, the 3D printed spare parts should not increase the safety risks of the repair. However, they also highlighted that unauthorized 3D printed spare parts can be difficult to distinguish, and might suffer from low material quality or from reliability issues. As such, there seems to be a need for more extensive standards and qualification schemes in the area of 3D printed spare parts to ensure quality and safety. In this project, safety issues related to the quality of third party or self-fabricated spare parts is not in focus. However, we note that this can become an important aspect of safety in repair.

2.6 Scope of this study

Based on this background, we can conclude that a range of parameters are relevant to ensure safe product repair: risk reduction by ("failsafe") design solutions, operational-level safeguarding, repair experience, a safe working environment, tools and working procedures, high-quality information provision, and quality assurance of spare parts. In this project, the focus is placed on deriving product design recommendations that can improve safety during and after repair.

To do this, focus is put on developing a structured way of documenting risks related to repair. In the preliminary study conducted on this topic within the TU Delft Design for Sustainability research group in 2019 (Bolanos Arriola et al., 2019), some modifications were made to the Disassembly Map to visualize repair-related risks. However, that preliminary study did not include a quantitative assessment of risks. In this project, we build on the preliminary study by further detailing how risks can be visualized in the Disassembly Map (Section 4) and by developing a risk assessment framework through which the risks can be assessed (Section 3.1).

3 Approach

To elucidate possible risks and propose design-related recommendations for safe repair, the following steps were taken:

1. Development of a framework that can be used to document and assess safety risks during and after repair.
2. A review of common failures and safety risks related to the five product categories.
3. A search in the iFixit database of forum entries from the website www.ifixit.com, an online community gathering 1.2 million users to discuss and advise each other on product repair. We specifically searched for entries mentioning safety aspects of repair.
4. Dis- and reassembly of 14 products from the five product categories, documenting disassembly and reassembly steps well as possible risks during and after repair.
5. Discussions with three representatives from a professional repair company and one experienced volunteer from a repair café to evaluate the findings from step 4.

3.1 Development of the risk assessment framework

In order to systematically analyze the safety risks related to product repair, a risk assessment framework was developed, see Figure 3. The aim was to be able to assess the two types of risks that are relevant for this project: risk during repair and risks during use of an improperly repaired product (post-repair risks). For risks during repair, a repair action relates directly to an effect on the repairer's safety, see Figure 4. For post-repair risks, a repair action instead relates to some kind of product failure or malfunction, that in turn can have an effect on the user's safety, see Figure 5. In both cases, we wanted to identify design features that influence the risk, and suggest design solutions that could reduce or eliminate the risk.

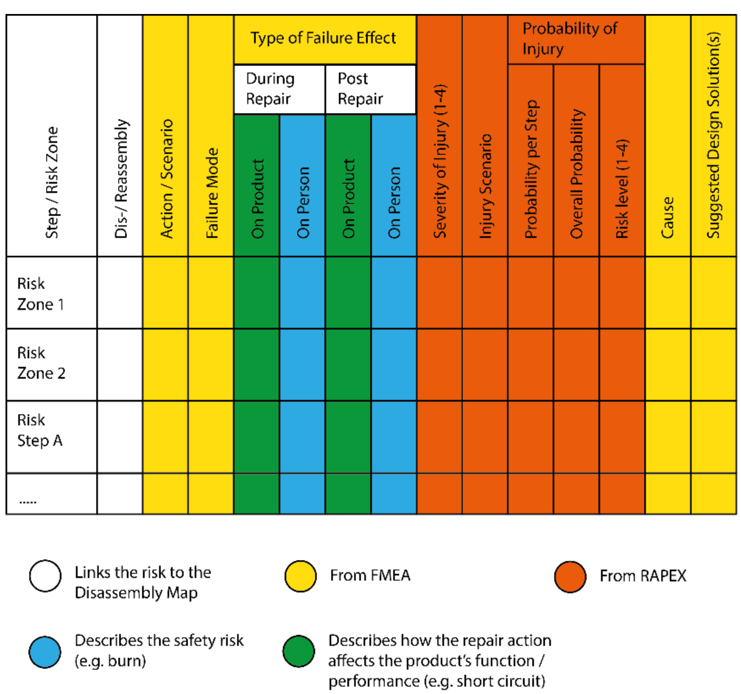

Figure 3: Risk assessment framework used in this project to investigate the risks related to repair.

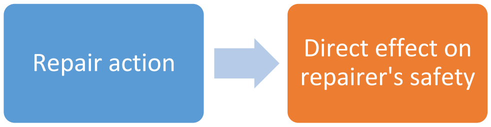

Figure 4: Link between a repair action and its effect for the first risk type: "Risks during repair".

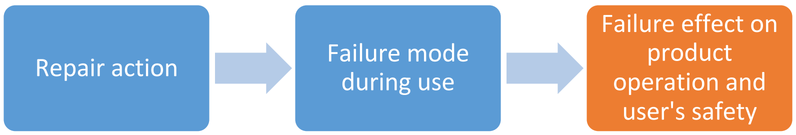

Figure 5: Link between an improperly performed repair action and its effect for the second risk type: "Post-repair risks".

The framework builds on two commonly applied frameworks: Failure Mode and Effect Analysis (FMEA) and the European Rapid Exchange of Information System (RAPEX).

FMEA can be defined as "a procedure for the analysis of a system to identify the potential failure modes, their causes and effects on the system performance" (Loznen et al., 2017). A failure mode is defined as "the manner in which a failure is observed to occur and its impact on the product's performance" while the failure cause is "the factor that is the basic reason for failure".

For risks *during* repair, there is no failure mode taking place in the product. However, we can still identify possible causes for why the repair action is associated with risk and derive design solutions that could help reduce the risk. For *post-repair risks*, we identify failure modes resulting from improperly performed repair actions, and the effect on both the product operation and the repairer/user's safety. We identify possible causes for why the repair action resulted in a failure and, again, propose design solutions to reduce the risk.

The effect of a failure mode is the "*result of a failure mode on the function of the product or process*". (Loznen et al., 2017). Effects of failure modes can be of different kinds, for example risk of injury to the user or product performance degradation. The FMEA suggests that effects of failure modes are detailed and, if possible, quantified. As such, a numerical ranking/quantification of the effect should be established (Loznen et al., 2017).

So called Risk Priority Numbers (RPN) are often used in FMEA to quantify failure effects. RPN includes quantitative estimations for the severity and occurrence (probability) of the effect as well as the likelihood that the failure mode is detected before it can have an effect. However, in this project, we saw a need to use a safety-specific risk assessment method. We therefore use the RAPEX guidelines (European Commission, 2018) used in the European Rapid Exchange of Information System for unsafe consumer products and consumer protection (RAPEX). The RAPEX guidelines lay out a structure for product risk assessment including a systematic way of assessing the probability of an injury through so called *injury scenarios*, and by defining *injury types* and *severity levels* for each injury type. Finally, it provides a look-up table for determining the risk level based on severity and probability, see Figure 6. Figure 3 shows which parts of our framework are taken directly from FMEA and RAPEX, and which parts have been added.

Finally, while our framework specifies that the probability of the risks should be estimated when possible, we did not have enough data in this project to reliably estimate the probability of the different steps in the injury scenarios. We thus use severity as an indication of the total risk for the products that we analyses (Section 3.4). This limitation is further discussed in Section 7.1.

Risk level from the combination of the severity of injury and probability

Probability of damage during foreseeable lifetime of the product		Severity of injury			
		1	2	3	4
High	>50 %	H	S	S	S
	> 1/10	M	S	S	S
	> 1/100	M	S	S	S
	> 1/1 000	L	H	S	S
	> 1/10 000	L	M	H	S
	> 1/100 000	L	L	M	H
	> 1/1 000 000	L	L	L	M
Low	< 1/1 000 000	L	L	L	L

S — Serious Risk
H — High risk
M — Medium risk
L — Low risk

Figure 6: Look-up table in the RAPEX guidelines to determine the risk level based on severity of injury and its probability.

3.2 Review of common failures and safety risks for the five product types

We reviewed available publications about common failures and safety risks related to the products in scope. Academic publications were identified that describe common failures of washing machines and vacuum cleaners (Cordella et al., 2019; Tecchio et al., 2019). A report from Dutch repair cafés also provided input on commonly repaired products and parts (Postma et al., 2020).

With regards to safety, we searched for risks directly related to repair, or risks during use that might be influenced by a repair action. We looked for injury databases and reports where the injuries could be associated with the use of a product. The European injury database (EU-IDB) was considered but not used because of restricted access and as it was unclear whether the database could provide injury data on the level of product type. A report from the US Consumer Product Safety Commission from 2004 (Carlson and Rutherford, 2004) provided input on safety issues for washing machines and vacuum cleaners, as observed in data about injuries among patients in hospitals in the United States in 2002. A report from the Swedish Electrical Safety Board provides statistics about electricity-related accidents in Swedish homes involving consumer products (Elsäkerhetsverket, 2019).

Finally, we also looked at the safety warnings and advice stated in a number of relevant user manuals as provided by manufacturers of the product types (note that we did not perform a systematic review across manufacturers or models), as well as repair manuals from the DIY community (iFixit and Dutch Repair Cafés). The findings from this step are presented in Section 5

3.3 iFixit data search

With permission from iFixit, we gained access to an offline copy of the forum entries made on www.ifixit.com during 2018. Using an SQL query, entries were selected that mentioned one of the five product categories, as well as one of the following safety-related terms: ‘Safe’, ‘Danger’, ‘Hazard’, ‘Fire’, ‘Explo’, ‘Overheat’, ‘Electric shock’. This resulted in 164 entries (including both questions and answers). The results were categorized according to type of product, relevance the topic of safety in repair (not relevant/advice about how to perform safe repairs/actual risk), injury type, severity of injury and moment of risk (during repair/after repair). Out of the 164 entries, 2 threads described an actual risk that took place after repair of a product and 12 entries mentioned possible risks in their repair advice. The findings from this step are presented in Section 5.

3.4 Dis- and reassembly of products

Five product types were selected for analysis: washing machines, blenders, portable CD players/radios, vacuum cleaners, and coffee makers. The selection was based on the aim to include different types of possible risks: electric risk (wired/battery), hot liquids, and rotating mechanical parts. Table 1 presents the 14 products from the five product types which we disassembled and then reassembled again in order to document the repair steps needed as well as potential safety risks during or after repair. The dis- and reassembly processes were video-recorded. The findings from this step are presented in Section 6.

Table 1: Products that were disassembled and reassembled in this project.

Coffee maker (N=3)	**Blender/mixer** (N=3)	**CD player/radio** (N=3)	**Washing machine** (N=2)	**Vacuum cleaner** (N=3)
Classic Gaggia (espresso machine)	Philips PowerChop	Philips Soundmachine AZ127	Miele W1	Philips FC8372
Philips Aroma Swirl HD756X (drip coffee maker)	Philips ProBlend4 (HR2100)	MTlogic CD-1587	Nordland WVL 2016 EL	Samsung SC07M3130V1
Philips Senseo Switch HD7892 (pods or drip coffee)	Bosch Haushalt MS6CM6120 (handheld stick mixer)	Philips AZ700T		Samsung SC8835

We used the Disassembly Map method (De Fazio et al., n.d.) to note all the steps needed for dis- and reassembly as well as the related risks. A few modifications had to be made to the Disassembly Map to map the risks. These modifications are described in Section 4.

Each risk was evaluated using the framework presented in Section 3.1, based on which we formulated design recommendations that could reduce the risk related to each risk zone/step. The full documentation from the dis- and reassembly processes (a Disassembly Map and a filled risk assessment framework for each product) can be found in the Appendix.

We decided to not include risks related to exchanging components on printed circuit boards (PCBs), as these can be considered as advanced repair actions. As such, we assume that a repairer who attempts to replace components on PCBs is able to choose the correct replacement part and knows how to solder safely. We do, however, include risks related to exchanging and resoldering wires connecting components that are not placed on PCBs.

3.5 Discussions with experts

We held two discussions with experts about repair of household appliances: three representatives from a professional repair company, and one experienced volunteer from a Dutch repair café. In these meetings, we asked their view on risks related to repair of the product types. We also used these meeting to verify the risks that we had noted during the dis- and reassembly processes described in Section 3.4.

4 Modifications to Disassembly Map

As the name suggests, the Disassembly Map was initially developed to document disassembly steps required to reach target components. In this project, we modified the Disassembly Map so that it also could be used to document risks related to both dis- and reassembly steps.

The following modifications were already made in the preliminary study conducted on this topic within the TU Delft Design for Sustainability research group in 2019 (Bolanos Arriola et al., 2019):

- Definition and visualization of ‘risk zones’;
- Differentiation between risk during repair and post-repair risks (related to reassembly);
- Categorization of risks according to four risk types: mechanical, electrical, thermal and chemical.

In this project, we expanded on this by adding the following modifications:

- A more detailed specification of how to determine a risk zone boundary;
- Introduction and visualization of ‘risk steps’ indicating risks during disassembly, reassembly or post-repair;
- A visual notation to highlight design features that support safety in design.

In Section 4.1-4.5, we explain these six additions to the Disassembly Map.

4.1 Risk zones as defined in the preliminary project

Bolanos Arriola et al. (2019) defined a risk zone as “*an interval of disassembly sequences which presents safety risks for the user carrying out the repair, independently from his/her degree of expertise*”. They also introduced the concepts of a risk zone’s ‘entry point’ and ‘exit point’, see Figure 7. The entry point is defined as “*the component or disassembly operation that, if removed or carried out, exposes the user to a* *certain safety risk*" and the exit point is "*the component or disassembly operation that, if removed or carried out, eliminates all the previous risk the user was exposed to*".

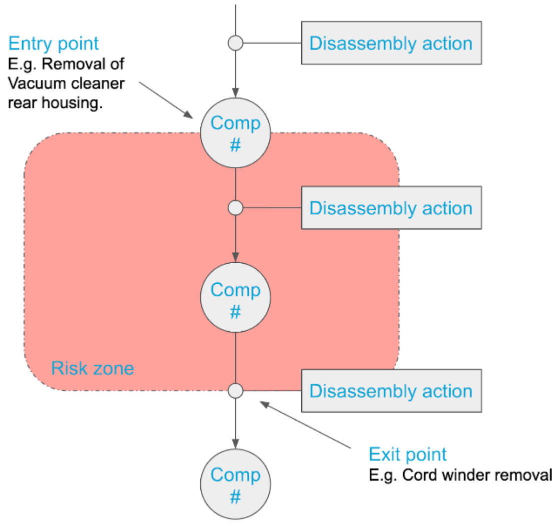

Figure 7: Conceptualization of a risk zone as presented by (Bolanos Arriola et al., 2019).

4.2 Differentiation between risk during repair and post-repair risks

Bolanos Arriola et al., (2019) also introduced 'post-repair risk zone' as "*zones that can be encountered when the design of a certain part or connection cannot ensure a proper and safe reassembly*". These risk zones relate to risks that present themselves after repair, distinguishing them from other risk zones in which the repairer is exposed to risk during the repair activity itself. Bolanos Arriola et al. (2019) used the following example to explain the concept of a post-repair risk zone: if water hoses in a coffee maker are not reassembled correctly, this can result in water leakage inside the product after repair. In turn, this could potentially lead to a short circuit and, in the worst case, a fire. They also noted that post-repair risk zones do not have clear entry or exit points.

4.3 Risk types

Bolanos Arriola et al. (2019) defined the following risk types, which we also use in this project:

1. *Mechanical Risks* are considered to be present when a component or disassembly/assembly action can cause any sort of physical injury to the repairer/user (e.g., cuts or bruising) or mechanical damage to the surrounding environment of the product.
2. *Electrical risks*, the risk of electric shock during the repair procedure as well as possible short circuits and consequences for the surrounding environment (e.g., fire caused by a bad repair).
3. *Thermal risks,* the risk of a component or disassembly/assembly action to cause burns to the repairer/user or fires/damage to the surroundings of the product.
4. *Chemical risks*, the risk of contact (e.g., through skin or inhaling) between the repairer/user and hazardous substances caused by a component and/or disassembly/assembly action.

4.4 Determining the risk zone boundary

While performing dis- and reassembly actions on products during this project, we saw a need to more clearly specify how to determine the boundary of a risk zone, as compared to what was presented in (Bolanos Arriola et al., 2019). The original definition of an exit point implicitly assumed that one single exit point existed for all risk zones. However, we observed that some risks zones do not have one single exit point because they include parallel disassembly paths following the same entry point. Instead, these risk zones have *multiple* disassembly operations which, if all carried out, would eliminate the risk. If the repairer follows one of the paths in the risk zone and carries out one of the necessary risk elimination operations, exposure to risks from the other paths is still possible. Instead of using the concept of an exit point we thus choose to refer to 'necessary risk elimination operations', i.e. *operations that, if all carried out, eliminate the risk that a repairer was previously exposed to*. Based on this insight, we specify that if the risk zone has more than one necessary risk elimination operation, then the lower risk-zone boundary should be set to the end of all parallel disassembly paths in the zone. In Figure 8, we visualize a risk zone with two necessary risk elimination operations, for which the risk-zone boundary has been determined as stated above. Figure 8 also shows how we label risk zones as Z1, Z2, ... ZN.

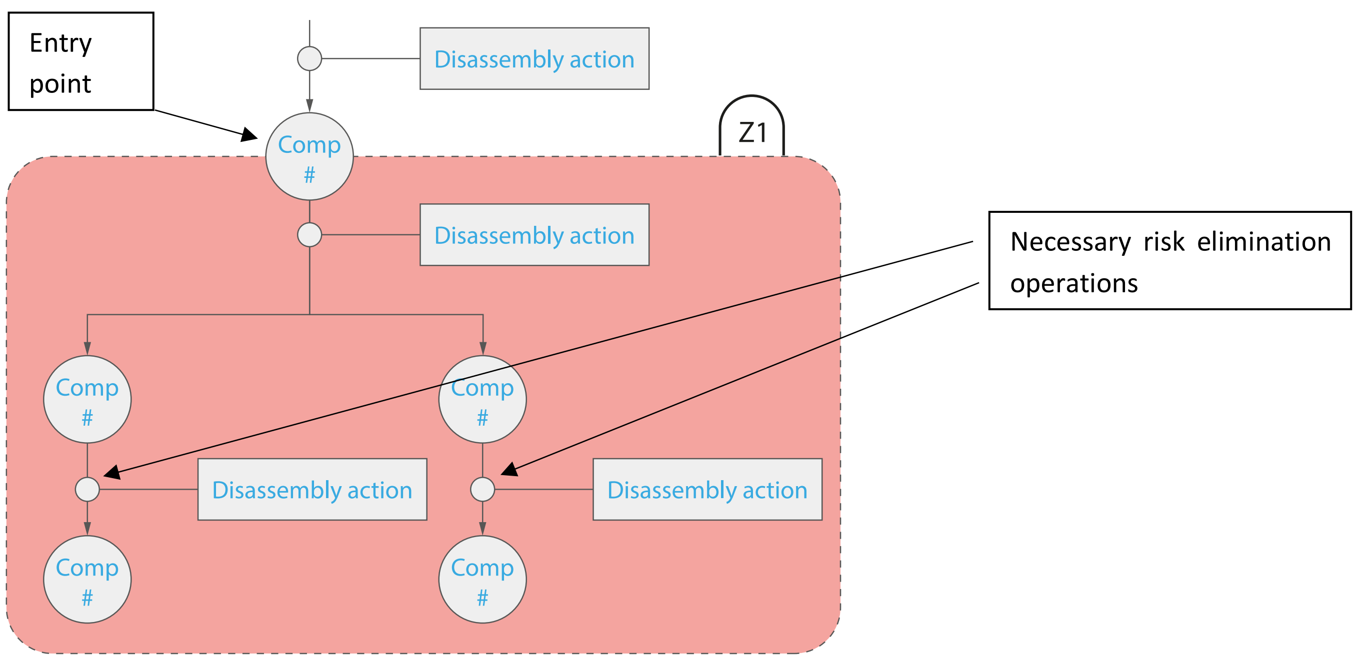

Figure 8: Visualization of how to determine the lower risk zone boundary if the risk zone (pink area) has more than one necessary risk elimination operation.

4.5 Risk steps

We decided not to use the ‘post-repair risk zones’ presented by Bolanos Arriola et al. (2019), as we saw that a post-repair risk was usually linked to a mistake made in a specific reassembly step. Instead of post-repair risk zones, we thus added the concept of a *risk steps.* Risk steps are distinct steps (rather than zones) that take place during disassembly or reassembly and that can lead to safety risks either during or after repair. We number risk steps as ‘A,B,C…’ (Figure 9). In our risk assessment framework, we describe risks related to each risk step. The same risk step can have multiple associated risks, i.e. during disassembly, during reassembly or post repair.

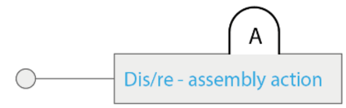

Figure 9: Risk step notation (A, B, C..)

4.6 Design features supporting safe repair

In order to not only visualize risk steps and risk zones but also visually highlight current design features with positive impact on safety in repair, we also decided to add a notation for such design features, in green (Figure 10).

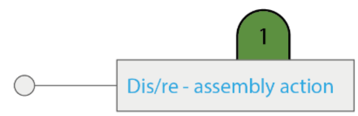

Figure 10: Notation of safe design examples (1,2,3 …)

5 Common failures and known safety risks per product type

Here, we lay out (1) the target components for each product type and (2) known safety risks in the use of the products that could be relevant also in the context of repair, and (3) repair-related risks identified from entries on the iFixit forum (if any). As mentioned in Section 2, target components are components with a high potential failure rate (important for repair), a high embodied environmental impact (important for recycling) and/or high economic value (relevant for components harvesting) (De Fazio et al., n.d.). Here, as the core aim is to improve safety during repair, we especially focus on components of the first category, i.e. components with high failure rates. In Section 6, when assessing risk related to repair, we focus on these target components and the dis-/reassembly steps needed to fix/replace them.

5.1 Washing machines

5.1.1 Common failures

Tecchio et al. (2019) used data from a professional repairer to identify the most common failures in washing machines. The most common faults that they report are issues in the electronics, followed by shock absorbers and bearings, doors, carbon brushes, and pumps.

5.1.2 Safety risks

Carlson and Rutherford (2004) identify the following injuries related to washing machines: body part hit by a falling washing machine led lid (top-fed), body part caught in the washing machine, electric shock from the washing machine, and burns from handling the washing machine. However, there is no information about how common these injuries are or how the accident happened. The Swedish National Electrical Safety Board (Elsäkerhetsverket, 2019) report that among the fires in Swedish homes caused by electrical products between the years 2005 and 2015, a washing machine was the most common cause (about 20% of the fires). However, the data does not give an indication of what failure mode or component in the machine caused the fire.

A Miele user manual mentions safety risks (electric shock) due to bad installation, e.g. if the machines is not correctly earthed (Miele, n.d.). Moreover, they explicitly state that only authorized Miele service technicians can repair the machine within the warranty agreement. They also specify that water hoses should not be reused, but only new ones should be used, and warn about flooding if the machine is not properly installed.

The iFixit data about safety aspects of repair of washing machines mentions mechanical risk from the spinning drum when the top panel has been removed (during repair), risks of water leakage (post repair) due to incorrect adjustments of electronic components and/or valves, risk of fire, and risk of electric shock during repair when working with electricity close to water. There is also a warning about risk of electric shock when troubleshooting the pump, and for thermal and chemical risks when soldering (advanced repair on PCBA level), advising the repairer to use safety glasses and wash their hands after touching the lead wire used for soldering. One forum thread discusses problems with the safety switch in the lid (top-fed machines). Some users mention the option of bypassing this switch, which would reduce the safety of the machine during use (post repair).

5.2 Blenders/stick mixers

5.2.1 Common failures

We did not find data about common failures in blenders. From our own experience, we judge that the following components are important for the functioning of a blender, and could therefore be seen as target components: motor (incl. brushes), blade unit, PCB(s), safety lock, gasket/seal, bearing, and gears (if any).

5.2.2 Safety risks

User manuals from manufacturers indicate the following risks: risk of water entering the motor unit causing a short circuit, risk of electric shock if the cord is damaged and/or replaced by a non-authorized person, the risk of cutting yourself on the blade, the risk of hot liquids ejecting from the blender because of sudden steaming, and the risk of electric shock if opening or disassembling the product without first unplugging it (Bosch, n.d.; Philips, n.d.).

An iFixit repair guide indicates that the repairer should test that the blender is properly sealed after repair, so that there is not a risk of water getting in contact with electrical components. The same guide points out that the bolt holding the blades should not be tightened too much since this can lead to friction around the rotating parts causing the rubber gasket to overheat or burn. Another iFixit repair guide mentions the risk of disabling the safety lock mechanism if screws are interchanged when reassembling.

The iFixit data about safety aspects of repair of blenders mentions a risk of overheating and fire if the gasket/seal at the bottom of the jar is worn or missing, or if the bearing is worn out. One person mentions that for blenders with gears, the gears can go bad causing the motor to jam and overheat. Others also mention the risk of overloading the motor more generally.

5.3 CD players/radios

5.3.1 Common failures

The Repair Monitor from Dutch repair cafés mentions three commons issues for radios: antenna is loose or not working, fault in PCB/electronics, and buttons are broken/not responding. From our own experience, we judge that the following components are important for the functioning of a CD player/radio, and could therefore be seen as target components: laser assembly, speakers, PCB(s), antenna, battery (in the case of a battery-powered product).

5.3.2 Safety risks

Media devices are often rechargeable, and battery charging can cause safety risks. The Swedish National Electrical Safety Board (Elsäkerhetsverket, 2019) reports that fire due to battery chargers have seen a fivefold increase between 2005 and 2015.

For CD players, some manufacturers warn for looking into the laser (Philips, n.d.). Some also warn about the risk of bodily injuries from battery leakage caused by e.g. installing batteries incorrectly or mixing batteries (old/new, carbon/alkaline), or letting batteries stay for too long in a product that is not used (Philips, n.d.). They also say that batteries should not be exposed to excessive heat and warn about the risk of batteries exploding if the wrong type is used. The user manuals also explicitly mention that you should never remove the product's outer casing but refer all servicing to qualified service personnel (MT Logic, n.d.; Philips, n.d.).

The iFixit data includes notes about being safety-aware when troubleshooting a circuit board, referring to the risk of high voltages as well as hot components. For safety reasons, an inexperienced forum user is advised to take his radio to a professional repairer rather than attempting a repair himself.

5.4 Vacuum cleaners

5.4.1 Common failures

Cordella et al. (2019) report target components and their relevance for repair in vacuum cleaners as seen in Table 2. We have added a note (in *italic*) to parts that are not present in the type of vacuum cleaners studied in this report.

Table 2: Target components for vacuum cleaners as reported by Cordella et al. (2019)

Part	**Relevance for repair**
Motor	Provision of main functionality. Very relevant in terms of failure rates.
Motor brushes	Provision of main functionality. Very relevant in terms of failure rates.
Filters	Common failure that the filter is blocked (however it is considered a maintenance action to replace it rather than a repair). Blocked filter could lead to damage to motor.
Hose	Provision of main functionality. Very relevant in terms of failure rates.
Battery	Only relevant for battery-powered vacuum cleaners (not covered in this report)
Power cable	Provision of main functionality. Very relevant in terms of failure rates.
Drive belt	Only relevant for upright vacuum cleaners (not covered in this report)

Wheels	Provision of main functionality. Relevant in terms of failure rates.
Switches/electronic board	Provision of main functionality. Relevant in terms of failure rates.
Battery charger/charging station	Only relevant for battery-powered vacuum cleaners (not covered in this report)
Brushes/Nozzles	Provision of main functionality for upright vacuum cleaners. Relevant in terms of failure rates for all.

5.4.2 Safety risks

Carlson and Rutherford (2004) identify the following injuries for vacuum cleaners: electric shock from the vacuum cleaner, body part (including hair) caught by suction, or burns from handling the vacuum cleaner. However, there is no information about how common these injuries are or how the accident happened. User manuals from OEMs warn for vacuuming up liquids, flammable substances, or hot ashes. They also warn for using the vacuum cleaners if the power cord is damaged and states that only service centres authorised by the manufacturer should do repairs (Philips, n.d.; Samsung, n.d.).

We did not find any quotes about safety risks related to vacuum cleaner repairs in the iFixit data.

5.5 Coffee makers

5.5.1 Common failures

Common failures in coffee makers are: problems with the magnet in the water-level sensor, pump failure, heating element failure, and calcification (Postma et al., 2020). From our own experience, we judge that the following components are also relevant for the functioning of coffee makers and could therefore be seen as target components: thermostats, thermal fuses, and PCBs (if any).

5.5.2 Safety risks

User manuals from manufacturers warn for water leaking into the product if it is immersed in water, which could cause a short circuit (Philips, n.d.). They also warn about using the coffee maker if the power cord is damaged and say that only service centres authorised by the manufacturer should do repairs. The Senseo Switch manual (Philips, n.d.) indicates that the product should be used in an earthed wall socket. The Gaggia manual (Gaggia, n.d.) also says that the user must be careful when using hot steam. The Dutch Repair Cafés have published a repair manual specifically for Philips Senseo coffee machines (Brattinga et al., 2020) in which they highlight some potential safety issues. They warn about the direct risk of electric shock from the 230V in the machine, the risk of getting burned by hot water, and the risk of replacing the suppression capacitor with a capacitor of the wrong type (which in the worst case could lead to a short circuit). They also mention that some older types of machines do not have an extra safety thermostat (in addition to the thermostat regulating the temperature of the coffee) to limit the maximum temperature in the boiler and as such reducing the risk of fire. They thus say that if you replace the boiler, you should always choose one with a safety thermostat. Finally, they mention that the safety thermostat does not prevent the heating element to break down in the case that the machine is left on without water in the boiler. It is unclear whether they consider this a safety risk or only a risk of product breakdown. In some Senseo models, there is also a water-level sensor which can be an additional mechanism preventing the water tank and boiler from running dry.

The iFixit data about safety aspects of repair of coffee makers mentions risk of fire (post repair) if the thermal fuse is removed and the brewing unit is left on for too long. An iFixit repair guide mentions the risk of water leakage in the machine if hoses are not reassembled properly with tighteners. It also advices the repairer to check the direction of water flow in a valve before reassembling it. One iFixit repair manual also points out risks when soldering (advanced repair on PCB level), advising the repairer to be careful with the hot soldering iron and to perform the repair in a well-ventilated area to avoid breathing in soldering fumes.

6 Observations from dis- and reassembly processes

In this section, we summarize the findings from the dis- and reassembly of the 14 products as described in Section 3.4. The full documentation of the dis- and reassembly processes, including disassembly maps and the filled-out risk assessment framework can be found in the Appendix.

Below, we present (1) risks during dis- and reassembly, (2) post-repair risks, (3) how the identified risks relate to the data from the desktop research presented in Section 5, (4) design features that influence the risk, and (5) design recommendations for each product type (Sections 6.1.1 – 6.1.5). In Section 6.2, we synthesize the findings into a few general recommendations across the product categories.

This section also builds on insights gained from interviews with repair experts. These insights were used to verify assumptions made in the risk assessment of disassembly and reassembly actions.

6.1 Risk Assessment and Design Features per product type

6.1.1 Washing machines

During dis- and reassembly of washing machine, we observed the following risks: risk of electric shock from direct contact with high-voltage parts (heating element, main PCB, motor, pump), risk of burns from touching hot parts (motor) or from spilling hot water when opening hoses, risk of cuts if the repairer uses a knife to take off plastic screw caps, risk of bruising when taking off the drive belt (high tension), and risk of bruising when taking off the door seal (high force required).

Post-repair risks that could be anticipated based on potential mistakes during reassembly are: risk of electric shock and fire due to incorrect reconnection of cable plugs (especially if this leads to bad earthing) and risk of electric shock and fire due to water leakage inside the machine caused by improper reassembly of door seal or water hoses. We also identified the post-repair risk of the machine moving in an uncontrolled way if the shock absorbers are not mounted correctly (the bolt not properly tightened).

These identified risks are similar to what was found in Section 5, with two exceptions. Firstly, while Section 5 mentioned the risk of touching the spinning drum during repair, this risk was not present for the products that we investigated since a safety switch in the door lock ensured that the motor cannot run if the door is opened or disassembled. Secondly, while Section 5 mentioned that the repairer might intentionally choose to reduce the post-repair safety of the product by bypassing the safety lock, we consider this largely out of scope of this project. We acknowledge, however, that the reason for bypassing the safety lock might be minimized by making the safety look easy to reassemble correctly with just a single cable plug (as was the case for both the machines that we disassembled).

The design features that we found to be impacting safety of repair (positively or negatively) in washing machines are presented in Table 3 along with design recommendations and the benefit that that recommendations could bring.

Table 3: Design recommendations for washing machines, based on observed design features negatively (red) or positively (green) impacting safe repair.

Observed design feature	**Design recommendation**	**Rationale**
The front panel has to be taken off before the door seal, door lock, and door can be disassembled (Nordland and Miele).	Make it possible to replace the door seal, door lock, and door without having to take off the front panel of the machine	Reduces the need for the user to enter the electric risk zone behind the front panel.
The pumps are placed far from motor, heating element, and main PCB (Miele).	Place the pump(s) far from the other high-voltage components	Pump(s) can be tested/repaired/replaced without the risk of touching other high-voltage components.
There is a plastic casing around the main PCB (Miele)	Cover high voltage PCB with plastic casing.	The risk of electric shock from touching live parts is eliminated except if the repairer actively takes off the casing itself.
There are no warning signs inside the machines (Nordland, Miele).	Use warning sign on dangerous components (i.e., hot or high voltage).	The repairer is aware about the fact that he/she is approaching a dangerous repair step.
It is difficult to reach the shock absorbers without touching the motor. (Nordland, Miele).	Design the machine in such a way that it is possible to reach the shock absorbers without touching the motor, which may be hot and has uninsulated high-voltage cable plugs.	The repairers arm does not have to be close to the dangerous component.
The repairer often has to plug the machine back in to troubleshoot heating element and motor (insight from expert discussions).	Add status indication or other troubleshooting support to heating element and motor, so that it is clear whether they are working or not.	Reducing the need to troubleshoot live parts.
The user interface (UI) PCB is far from high-voltage components. (Miele) The UI PCB is close to high-voltage components. (Nordland)	Make sure that the UI PCB (low voltage) is far away from any high-voltage components.	UI PCB can be tested/repaired/replaced without the risk of touching high-voltage components.
All cables are color coded. (Miele, Nordland) There is no indication to show the correct connection	Indicate cable plugs and their correct connection points (using, e.g., numbers or colors).	Reduces the risk of incorrect reconnection of cables.

	points for cables. (Miele, Nordland)		
Uninsulated cable plugs are used to connect motor and heating element. (Miele, Nordland)		Do not use uninsulated cable plugs for high voltages.	The repairer cannot touch the metal tip of the cable by accident, and the metal tip cannot touch the outer washing machine casing if the cable is left disconnected inside the machine by accident.
The machine has a metal casing. (Miele, Nordland)		Do not use electrically conducting casing material.	The casing cannot become conductive and as such the risk related to bad earthing is reduced.
The same connection shape and size is used for earth and line/neutral. (Miele, Nordland)		Make the shape of the earth connectors different from line/neutral.	Impossible to connect other cables where the earth should be connected.
Reusable tighteners are used for water hoses. (Miele, Nordland)	There is no feedback to the repairer whether the hose connection is reassembled properly. (Miele, Nordland)	Make hoses easy to reassemble correctly, e.g., by using reusable tighteners, hoses with sealing caps, or hoses with a click-connection.	Makes it easy for a repairer to ensure water-tight reassembly of hoses, thereby avoiding the risk of potentially dangerous water leakage.
The door seal tightener has to be closed with a screw that is difficult to reach. (Miele, Nordland)		Make the door seal easy to assembly correctly, e.g., by making the tightening screw easier to reach or by using an alternative solution for closing the tightener.	Make it easy for a repairer to ensure water-tight reassembly of the door seal, thereby avoiding the risk of potentially dangerous water leakage.
The shock absorbers are difficult to reach and tighten.		Make the shock absorber bolts easy to reach and indicate the recommended torque.	Reduces the risk of the shock absorbers coming loose (which could result in the washing machine moving in an uncontrolled way).

6.1.2 Blenders/Stick mixers

The main risk *during* dis- or reassembly of blenders was identified as the risk of electric shock from direct contact with high-voltage parts.

As for post-repair, there could be a risk of heat build-up and fire if the gaskets on both sides of the screw connection for the blade are not put back in place during reassembly. We also noted that since the PCB and the safety lock are both soldered (Philips Problend, Philips PowerChop), there could be a risk that the repairer solders things back in the wrong way. If the repairer then by mistake (or intentionally) bypasses the thermal fuse or the safety lock, this would add risk of fire and bruising/cuts, respectively. For these risks to appear, the user needs to have a soldering iron and be confident enough to unsolder electronic parts.

These identified risks are similar to what was found in Section 5, with two exceptions. Firstly, the risk presented on iFixit of heat build-up due to overtightening the bolt holding the blades was not present in the products that we analyzed. This had been solved by limiting the depth of the screw threading. Secondly, the risk presented in the iFixit data that for some models, interchanging screws during disassembly can cause the safety lock to stop working, was not the case in the models that we analyzed.

It should be noted here that the handheld stick mixer (Bosch Haushalt MS6CM6120) could not be disassembled to reach the target components. The reason for this was that the housing was designed to be watertight by using so called two component (2k) injection molding, leaving no openings for disassembly, except for taking off the control button. As such, the product has low reparability and we could not investigate the safety related to repair.

The design features that we found to be impacting safety of repair of blenders are presented in Table 4 along with design recommendations and the benefit that that recommendations could bring.

Table 4: Design recommendations for blenders, based on observed design features negatively (red) or positively (green) impacting safe repair.

Observed design feature	**Design recommendation**	**Rationale**
No warning signs inside the machine (Philips Problend, Philips Powerchop).	Use warning sign on dangerous components (i.e., hot or high voltage).	The repairer is aware about the fact that he/she is approaching a dangerous repair step.
All electric components and wires are soldered (Philips Problend, Philips Powerchop).	Replace soldered connections with insulated cable plugs.	The repairer cannot touch live parts by accident.
	… and encase the PCB (if any)	
	… and indicate cable plugs and their correct connection points (using, e.g., numbers or colors).	Reduces the risk of incorrect reconnection of the cables.
It is easy to lose the gaskets or forget to put it back. (Philips Problend, Philips Powerchop).	Design a solution that only allows the repairer to screw back the blade if he/she has first put in the gasket(s) correctly (or eliminate the need for a gasket).	Reduces the risk of leaving the gasket, which could create heat built-up.
It is possible to open the base unit casing while the jar/jar lid is still on, i.e., without breaking up	Extend the function of the safety lock to the opening of the base unit casing.	Reduce the risk of touching live components after opening the base unit casing.

the electric circuit (Philips Problend, Philips Powerchop).		
The threading on the screw connection for the blade does not allow for overtightening the screw. (Philips Problend, Philips Powerchop).	Limit the threading on the screw connection for the blade.	It becomes impossible to overtighten the screw, and as such the risk for friction-induced heat buildup and fire is reduced.

6.1.3 CD players/radios

The main risk *during* dis- or reassembly of CD players was identified as the risk of electric shock from direct contact with the power transformer. However, the current design is rather safe since the transformer is encased and situated directly where the power cord enters the product.

The most important *post-repair risks* that we identified are: risk of fire due to incorrect reconnection of cable plugs. The probability of this was deemed higher for the CD players than the other products, since the PCBs are big and have many cables connected to them, but without clear indication about which cable goes where. For the MT Logic CD-1587, we also noted that the soldered connections could easily break when removing the PCB, and that some cable plugs required a lot of force to be removed, which resulted in wires coming loose of the cable insulation piece.

These identified risks are similar to what was found Section 5, with two exceptions: risks related to the laser beam, and risk related to incorrect replacement or charging of batteries. In the products that we analyzed, there is basically no risk of looking into to the laser during repair since the power supply needs to be cut to take the back cover off, and the repairer needs to take the back cover off to reach the laser assembly. This design feature is thus positive for safe repair. The products were also designed in a way that the repairer could not reconnect the laser assembly in a dangerous way. The safety switch that prevents the laser to be on when the CD lid is open can only be plugged in one way and if it is not connected, the laser cannot be switched on at all. Again, this design feature can be considered positive for safe repair. While we do consider the risk of the laser in our risk assessment, it should be mentioned that all three CD players state that they are “Class 1 laser product” which most likely means that they use Class 1 lasers, which are considered safe for the eye (Laser Safety Facts, n.d.).

As for the risk related to incorrect replacement or charging of batteries, there is a risk that the user replaces the battery with an incompatible type, which could cause fire or even explosion. However, this risk is not strictly repair related and all three CD players had a clear indication about which battery type to use, which we noted as an example of good design. The players that we disassembled are not rechargeable. If chargers or charging stations are used, these might have their own repair-related risks, but this is outside the scope of this report.

The design features that we found to be impacting safety of repair in CD players are presented in Table 5 along with design recommendations and the benefit that that recommendations could bring.

Table 5: Design recommendations for CD players, based on observed design features negatively (red) or positively (green) impacting safe repair.

Observed design feature	**Design recommendation**	**Rationale**
Power transformer placed on the back cover where the cable plug enters the product (MT Logic CD-1587, Philips AZ700T, Philips CD Soundmachine AZ127)	Transform the incoming voltage to 12V as early as possible and attach the power transformer on the cover that the user has to take off to reach the other components.	The repairer will automatically break the circuit when taking the back plate off, and will free from electric risk when working on the rest of the product.
Power transformer is encased in plastic. (MT Logic CD-1587, Philips AZ700T, Philips CD Soundmachine AZ127)	Encase the power transformer in an insulating material.	Eliminates the electric risk in all cases but if the repairer opens the casing.
No warning sign on the power transformer specifically, however there are warnings on the outside of the product (MT Logic CD-1587, Philips AZ700T, Philips CD Soundmachine AZ127)	Put a warning sign on the power transformer.	The repairer is aware about the fact that he/she is approaching a dangerous repair step.
The safety switch can only be assembled in one way and if it is not properly assembled, the product will not start. (MT Logic CD-1587, Philips AZ700T, Philips CD Soundmachine AZ127)	Make it easy to reassemble the safety switch for the laser in the proper way, e.g. by using only one cable plug.	No risk of disabling the safety switch.
It is clearly stated which batteries to use (Philips AZ700T, Philips CD Soundmachine AZ127).	Clearly indicate on the product which batteries to use (and in the case of rechargeable products, which charger to use).	Reduces the risk of battery-related faults/accidents.
Large PCB with many cables and without a clear indication about how to connect them. (MT Logic CD-1587, Philips Soundmachine AZ127, Philips AZ700T)	Indicate cable plugs and their correct connection points (using, e.g., numbers or colors).	Reduces the risk of incorrect reconnection of the cables.
Due to the high force required to disconnect insulated cable plugs, the repairer risks pulling out wires from the plastic cable insulation piece (MT Logic CD-1587).	Make cable plug snap fits easier to pull out.	Reduces the risk of having loose metal ends left in the product, which could lead to short circuit.
Some soldered cables came loose during repair (MT Logic CD-1587).	Do not use soldered wires.	Reduces the risk of leaving loose wire ends in the product or soldering wires back incorrectly, which could lead to short circuits.

Laser assembly placed deep into the product, making it as good as impossible to reach it without breaking up the electric circuit (MT Logic CD-1587, Philips Soundmachine AZ127).	Place the laser assembly deep into the product.	Reduces the risk that the repairer is exposed to the laser beam.

6.1.4 Vacuum cleaners

The main risk *during* dis- or reassembly of vacuum cleaners was identified as risk of electric shock from direct contact with high-voltage parts (PCB, motor). In the Samsung SC07M3130V1 vacuum cleaner, this risk was reduced by the designing the PCB to have a minimal amount of exposed metal (see Figure 11) and by the fact that the PCB had to be disconnected before the following disassembly steps could take place (reducing the size of the risk zone). None of the products had a completely encased PCB.

A positive design feature present in the Samsung SC07M3130V1 was that the wheels were replaceable from outside, reducing the need to open the product casing and enter the risk zone. We also noted some disassembly steps where the repairer had to use a lot of force to open snap fits, with a risk of small cuts/bruises.

We did not find any *post-repair* risks for vacuum cleaners. During reassembly, there are only two cables to reconnect, and the motor will run correctly even in the case that they are exchanged.

These identified risks are similar to what was found in Section 5.

The design features that we found to be impacting safety of repair in vacuum cleaners are presented in Table 6 along with design recommendations and the benefit that that recommendations could bring.

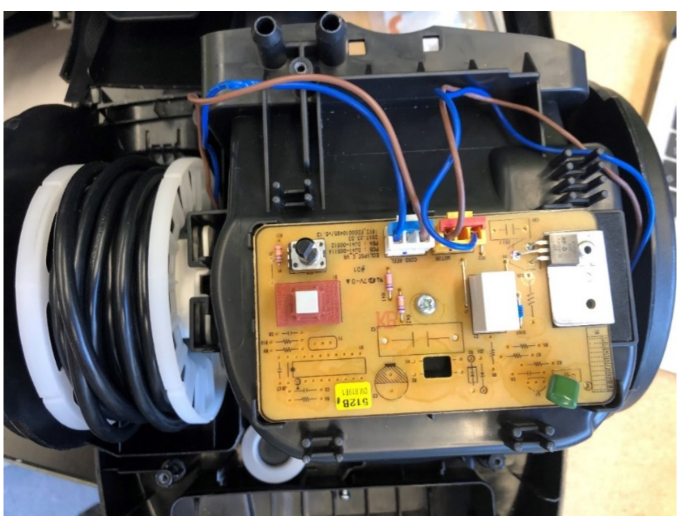

Figure 11: PCB on Samsung SC07M3130V1 in which metal endings cannot be touched, reducing the risk for getting electrified.

Table 6: Design recommendations for vacuum cleaners, based on observed design features negatively (red) or positively (green) impacting safe repair.

<table>
<tr><th colspan="2">Observed design feature</th><th>Design recommendation</th><th>Rationale</th></tr>
<tr><td colspan="2">Uninsulated cable plugs used (Philips FC8372/09).</td><td>Do not use uninsulated cable plugs.</td><td>The repairer cannot touch the metal tip of the cable by accident.</td></tr>
<tr><td colspan="2">PCB not encased (Philips FC8372/09, Samsung SC07M3130V1, Samsung SC8835).</td><td>Encase high voltage components.</td><td>Eliminates the electric risk of the components in all cases but if the repairer opens the casing.</td></tr>
<tr><td colspan="2">No warning signs inside product (Philips FC8372/09, Samsung SC07M3130V1, Samsung SC8835).</td><td>Use warning sign on PCB/motor subassembly.</td><td>The repairer is aware about the fact that he/she is approaching a dangerous repair step.</td></tr>
<tr><td>Possible to access the wheels from the side (Samsung SC8835)</td><td>Repairer has to open the outer casing to access the wheels (Philips FC8372/09, Samsung SC07M3130V1)</td><td>Make it possible to replace the wheels without entering the risk zone.</td><td>Eliminates the risk of touching live parts when replacing the wheels.</td></tr>
<tr><td colspan="2">High force snap fits (Philips FC8372/09, Samsung SC07M3130V1)</td><td>Design snap fit connection that require less force, or use other connection method, e.g., screws.</td><td>Reduces risk of cuts/bruising.</td></tr>
<tr><td colspan="2">PCB designed to minimize exposed metal (Samsung SC07M3130V1, Philips FC8372/09).</td><td>If PCB cannot be fully encased, design the PCB to minimize exposed metal.</td><td>Reduces the risk that the repairer touches live parts.</td></tr>
<tr><td colspan="2">The repairer has to take off the PCB to reach the next step in the disassembly (Samsung SC07M3130V1, Samsung SC8835).</td><td>Reduce the size of the electric risk zone by making it impossible to reach the following steps before disconnecting the PCB.</td><td>Reduces the risk that the repairer touches live parts.</td></tr>
</table>

6.1.5 Coffee makers

The main risks *during* dis- or reassembly of coffee makers were identified as: risk of electric shock from direct contact with high-voltage parts (main PCB, pump, boiler/heating element) and risk of burns from touching hot parts (boiler/heating element/steam tap) or spilling hot water when opening hoses.

The most important *post-repair* risks that we identified are: risk of electric shock and fire due to incorrect reconnection of cable plugs (especially if this leads to bad earthing), risk of electric shock and fire due to water leakage inside the machine caused by improper reassembly of water hoses.

Moreover, for the two machines with boilers (Philips Senseo Switch and Gaggia Classic) there is a risk that the user replaces the thermostat controlling the coffee temperature with the wrong replacement part which could mean that the water in the boiler starts boiling. This could lead to the user burning themselves on steam coming out of the machine. However, the maximum boiler temperature is controlled by an extra thermostat or fuse. We thus also noted the risk of a repairer bypassing the maximum temperature control intentionally, or unintentionally not putting it back in place correctly after replacing it (it should be in thermal contact with the boiler). However, for both products pressure build-up is still controlled by a mechanical valve. We thus also noted the risk of a repairer somehow disabling this valve, although this is highly unlikely.

These identified risks are similar to what was found in Section 5, with the exception of the risk of (1) short circuit/fire from replacing the suppression capacitor with another capacitor of the wrong type and (2) risks when soldering (heat, fumes). However, as mentioned in Section 3, risks related to advanced repairs on PCBs are considered out of scope for this report.

The design features that we found to be impacting safety of repair in coffee makers are presented in Table 7 along with design recommendations and the benefit that that recommendations could bring.

Table 7: Design recommendations for coffee makers, based on observed design features negatively (red) or positively (green) impacting safe repair.

Observed design feature		**Design recommendation**	**Rationale**
Plastic casing (Philips Senso Switch, Philips Aroma Swirl).	Metal casing (Gaggia).	Do not use electrically conducting casing material.	The casing cannot become conductive and as such the risk related to bad earthing is reduced.
No casing around the main PCB (Philips Senso Switch).		Cover high voltage PCB with plastic casing.	The risk of electric shock from touching live parts is eliminated except if the repairer actively takes off the casing itself.
Insulated cable plugs used for all electric connections except at the power inlet. (Gaggia)	Uninsulated cable plugs used in the products (Philips Senseo Switch, Philips Aroma Swirl)	Do not use uninsulated cable plugs for high voltages.	The repairer cannot touch the metal tip of the cable by accident, and the metal tip cannot cause short circuits or touch the outer casing if the cable is left disconnected inside the product by accident.
No warning signs inside products. (Philips Senso Switch, Philips Aroma Swirl, Gaggia)		Use warning sign on dangerous components (i.e., hot or high voltage).	The repairer is aware about the fact that he/she is approaching a dangerous repair step.
No clear indication about which cable should be connected where (Philips Senso Switch, Philips Aroma Swirl, Gaggia).		Indicate cable plugs and their correct connection points (using, e.g., numbers or colors).	Reduces the risk of incorrect reconnection of the cables.
The same connection shape and size is used for earth and line/neutral (Philips Senso		Make the earth connectors different from all the other, making it impossible to plug in	Impossible to connect other cables where the earth should be connected.

Switch, Philips Aroma Swirl, Gaggia).		other cables were the earth should be.	
The boiler has a mechanical valve limiting pressure build-up (Philips Senseo Switch, Gaggia).	Possible to put the valve back in the wrong direction (Senseo Switch).	Ensure that there is a mechanical valve limiting pressure build-up in the boiler, put a warning sign on the valve that it is a crucial safety component, and make it impossible to tamper with this function.	If the temperature regulation is not working properly the pressure in the boiler is still limited by the mechanical valve.
Hoses with sealing caps used (Gaggia)	Unreuseable zip-tie tighteners used. (Philips Senseo Switch, Philips Aroma Swirl)	Make hoses easy to reassemble correctly, e.g., by using reusable tighteners, hoses with sealing caps, or hoses with a click-connection.	Makes it easy for a repairer to ensure water-tight reassembly of hoses, thereby avoiding the risk of potentially dangerous water leakage.

6.2 Generic design recommendations across the product categories

The design recommendations for the product categories above have a number of aspects in common. These aspects are presented as a more generic set of design recommendation in Table 8.

Table 8: Generic design recommendations formulated based on the product-specific recommendations presented in Section 6.1

Design recommendation	**For example by..**
Aim for few and small risk zones.	• Encasing/insulating all high-voltage components and their connections. • Ensuring that the repairer has to break the electric circuit by performing a disassembly operation prior to reaching the high-voltage components. • Making often-failing components accessible from outside risk zones. • Placing target components at a large enough distance from the source(s) of danger, if the target components cannot be accessed from outside the risk zones. • Placing potentially dangerous components deep in the disassembly.
Reduce the need for manual troubleshooting and testing.	• Enabling the product to self-diagnose.
Make earthing fail-safe.	• Using differently shaped cable plugs for earth connections. • Avoiding insulated cable plugs or soldered connection that can come loose inside the product. • Avoiding electrically conducting materials for the product's casing.

Make correct reassembly of electrical wiring easy and intuitive.	• Numbering and coloring plugs and their connection points. • Avoiding soldered connections.
Make correct water-tight reassembly of water hoses easy and intuitive.	• Using reusable tighteners, hoses with sealing caps, or hoses with a click-connection.
Make it difficult to disable the products' built-in safety functions.	• Making it impossible to reassembly a valve in the wrong direction. • Making it impossible to reassembly safety locks and switches in an incorrect way.

7 Discussion

7.1 Completeness and reliability of risk assessment framework

The risk assessment framework presented in Section 3.1 proved useful in structuring the results and providing a harmonized documentation of risks per product. However, with regards to RQ1 and RQ2 (“*What are the safety risk related to repair of the products – including risks during repair and after repair?”* and “*How can these risks be assessed?”)* some limitations should be mentioned that will need further attention in future research on this topic.

Firstly, as mentioned in Section 3.1, we were not able to reliably estimate the probability of the different injury scenarios that we defined per risk step and risk zone for each product. It might also be necessary to calculate the probability for non-experienced and experienced repairers separately. To do this accurately, the actions of different types of repairers would likely need to be studied statistically. However, this would be challenging considering the wide range of designs even within one product category. The RAPEX guidelines acknowledge that probabilities of product-related injuries are difficult to determine and recommend the assessor to focus on a achieving a more accurate estimation for a few scenarios leading to the highest risk rather than describing too many scenarios. More openly available data about accidents and injuries related to the use/maintenance/repair of different types products would be useful in reaching reasonable estimations for the probability of the injury scenarios leading to the highest risk.

Secondly, the severity of risks is also not trivial to determine. The most common repair-related risks that we found were electrical risks related to handling high-voltage electronic components (200-400V). Incorrect handling of some high-voltage components could give rise to severe injury and even death, especially if incorrect reassembly leads to a short-circuit and a fire. Here, we chose to classify direct exposure to high-voltage component as RAPEX risk level 2 while incorrect reassembly that could possibly lead to fire was classified as RAPEX risk level 4. This is a rough first estimate of quantifying electrical risks related to repair. Future work should focus on making this more precise and unambiguous.

Apart from achieving a reliable quantification of risks through which products can be compared with regards to safety in repair, it is also important to discuss what level of risk is acceptable. A certain level of risk is unavoidable, and already present in many consumer products, from lighting fixtures to power tools, and it would thus be useful to be able to quantify repair risks on a similar scale as risks during normal use.

Finally, while the framework presented in this report supports systematic mapping and evaluation of risks related to repair, it does not guarantee that all possible risks are identified. Especially post-repair risks might be missed or underestimated.

7.2 Usefulness of the Disassembly Map to evaluate safety risks in repair

With regards to RQ4 ("What modifications are needed to the Disassembly Map to document safety aspects during and after repair?"), the disassembly map proved useful in mapping risks to the product architecture.

As mentioned in Section 4, we added specific notations for risk zones and risk steps. The risk zones indicate disassembly steps during which the repairer is exposed to some risk. Large risk zones are thus not desirable and as a general design recommendations, manufacturers should aim to take components out of the risk zone. The Disassembly Map with risk zones included supports this by giving a visual overview of the number and size of risk zones.

Nevertheless, the application of the Disassembly Map in this project sparked ideas about further development. Three specific points for improvement were identified. These are stated below, accompanied by suggestions to further improve the Disassembly Map methodology regarding safety of repair.

7.2.1 Parallel disassembly paths

Because of parallel disassembly paths and following the detailed definition of risk zones as presented in Section 4.4, the risk zones tend to become very large as they cover risks presented in their own disassembly path as well as risks presented in parallel paths. It would be helpful for the designer to also see the *necessary risk elimination operations*, i.e. the operations that, if all carried out, eliminate the risk that repairer was previously exposed to.

Solution opportunity

The risk zone might be divided into two parts, separated by the line of *necessary risk elimination operations*, see Figure 12. This way, the visualization distinguishes between the area where the repairer is always exposed to risk (filled orange area), and the area that becomes free from risk if all necessary risk elimination operations have been carried out (striped orange area).

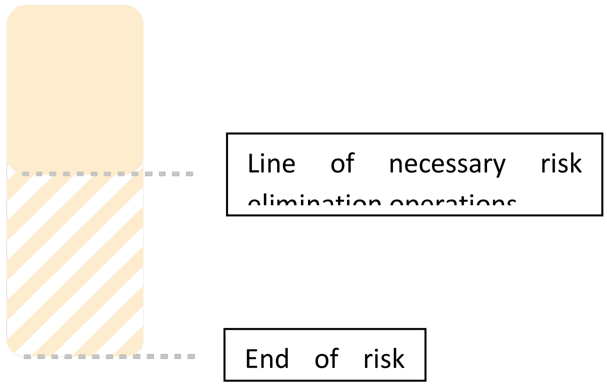

Figure 12: Suggested division of risk zones into two parts separated by the line of necessary risk elimination operations (i.e. the operations that, if all carried out, eliminate the risk that a repairer was previously exposed to).

7.2.2 Risk source visualization

Although the risk zone visualizes which steps and components lie within an area of risks, it does not visualize which components are the sources of danger. This would be interesting, because it would provide more detailed information about which components and/or connections could still be improved, in terms of safety, by the designer.

Solution opportunity

We suggest that components that are sources of danger are highlighted by an outer line, colored in the same color as the type of risk that is associated with the component, see Figure 13. One component can be a source of multiple types of risk, and would then have multiple outlines.

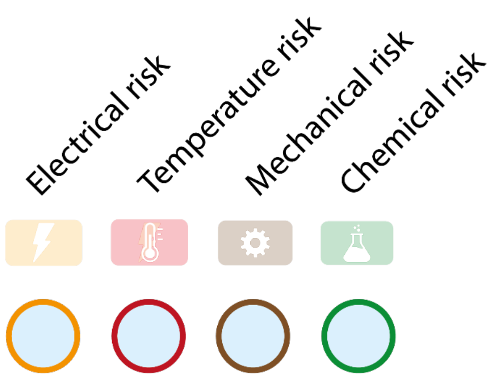

Figure 13: Suggested colored outline to highlight components that are sources of danger.

7.2.3 Uninsulated electric connections

For components that present electric risk, it would be useful to distinguish between those that have insulated electric connections, and those that do not. If the connections are insulated, the components are not dangerous to touch as long as the insulating cover is not taken off. Uninsulated connections, on the other hand, are dangerous to touch and might accidentally be touched while performing steps close to the component in question. Moreover, even if a component with uninsulated connections is disassembled from the rest of the product, the loose connections are still left in the product, meaning that the repairer can still get in contact with high voltage.

Solution opportunity

Components with insulated connections are distinguished from those with uninsulated connections by using a solid outline for insulated connections and a dashed outline for uninsulated connections, see Figure 14. PCBs form a special case here, as they both have connections to other components and connections on the board itself (usually soldered). For PCBs, we thus suggest that all electric connections need to be encased in insulating material for the component to be shown with a solid outline.

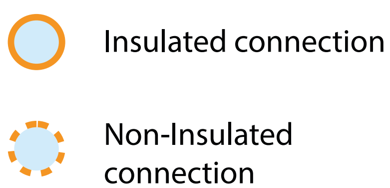

Figure 14: Visual representation of components with insulated or uninsulated electric connections.

7.2.4 Suggested modifications to the Disassembly Map

The modified version of the Disassembly Map is shown in Figure 15, next to the version used in the analysis performed in this project.

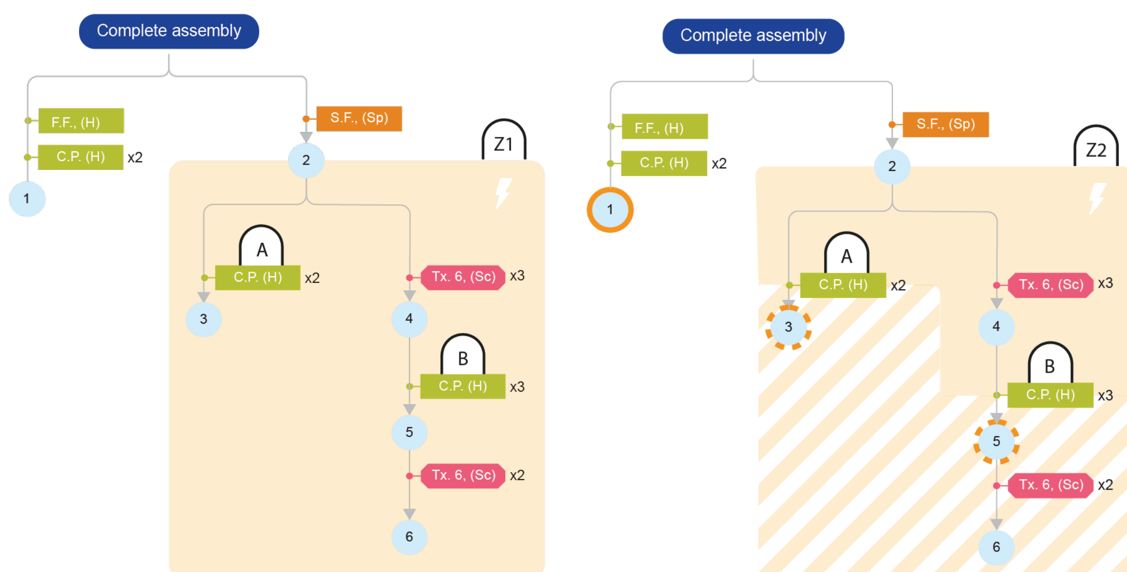

Figure 15: Suggested modifications to disassembly map (right) to improve the visualization of risk zones and components that are sources of danger. The notation used for the analysis in this project is shown to the left for comparison.

Using the Philips Powerchop blender as an example, Figure 16 illustrates how the suggested modifications to the disassembly map bring additional insights for designers. It is now instantly visible that components 10, 11, 14, 16, and 17 are possible sources of danger due to their uninsulated high voltage connections. Furthermore, it displays the line of necessary risk elimination operations for the risk zone (in this case, three unsoldering operations).

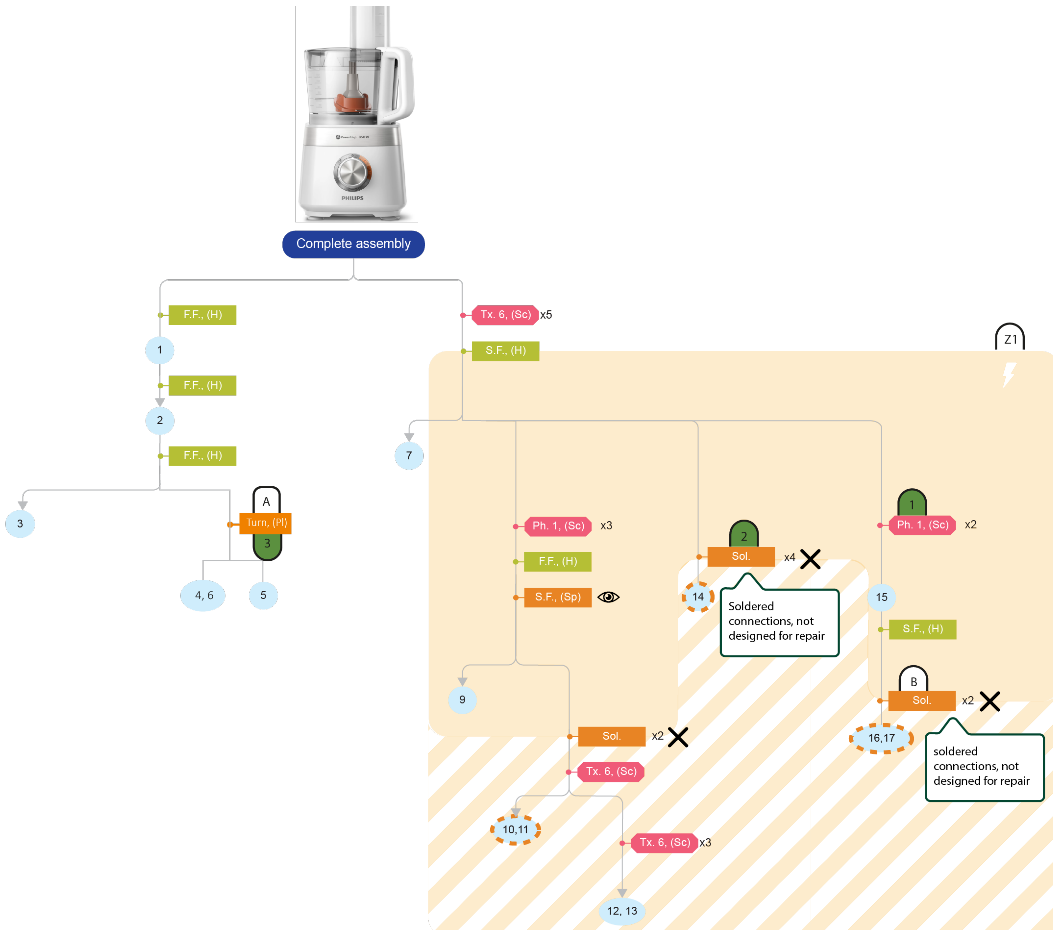

Figure 16: Using the modified disassembly map to show the risks present in the Philips Powerchop blender.

7.3 Implications for design for product reparability and safety

With regard to RQ3 (*How can design contribute to the reduction or elimination of safety risks during and after repair of the products?*) the results demonstrate that design plays an important role in enabling safe repair of household products. Based on our analysis of the five product types included in this report, many repair actions can be performed in an almost risk-free way, e.g. only involving low-severity risks such as bruising or small cuts on fingers. Moreover, many risks that are currently present could be significantly reduced or eliminated by relatively small design changes (see Section 6). The most severe risks that we found relate to incorrect reassembly of electric components and wires, which could lead to fires. As such, a focus on making these steps less prone to mistakes seems important. The risk of touching live parts during disassembly is often present but can in large be eliminated by insulating cable plugs and encasing printed circuit boards.

8 Conclusions and suggestions for future work

This project aimed to elucidate possible risks related to the repair of five common household electronic product categories and propose design-related recommendations to simultaneously allow for high reparability and safe repair. Furthermore, the aim was to further develop the Disassembly Map, a visual tool to facilitate design for repair, to also visualize safety risks related to repair, thereby supporting designers in making their products safer to repair.

Towards this aim, we developed a risk assessment framework and applied it in the analysis of the products. The framework builds on FMEA, which is a widely applied method for failure analysis of products, and RAPEX which is the commonly agreed framework for risk assessment of consumer products in the EU. Our framework supports documentation of risks through specifying risk type, injury type, the probability of injury through injury scenarios, the severity of injury, the cause of the risk, and design recommendations that could reduce or eliminate the risk. Using the framework, we documented risks associated with dis- and reassembly operations for 14 products. However, due to data limitations, we could not reliably establish the probability of the risks that we identified.

To provide improved guidance to designers about safety related to repair, we modified the Disassembly Map by (1) specifying how to determine risk zone boundaries, (2) introducing risk steps and (3) introducing a way to highlight good examples of safe repair in the current design. This modified Disassembly Map together with the risk assessment framework form a well-functioning methodology to assess safety related to product repair. The methodology enables designers to get an overview of the types of risks that are present, where in the product architecture the risks appear, whether the risks relate to disassembly or reassembly steps, and whether the effect of the risk takes place during repair or post repair.

By applying the methodology to different products from a number of household product categories, we derived design recommendations for safe design, both per product type and more generic. The results show that certain repair actions are already safe to perform, while others could be made safe through relatively small design changes. The most difficult risks to eliminate appear to be the risk of touching high voltage electronic parts, and the risk of wrongly reassembling high voltage components and cables. However, these risks can be significantly reduced by better insulating such parts, and by better indicating how cables should be reconnected. Another promising design solution is to improve the level of self-diagnosis in products in order to avoid extensive troubleshooting and testing of live high voltage parts.

Finally, our experience from using the methodology to assess the products led to additional suggestions for improvements to the Disassembly Map. These suggestions make it easier to visualize the components that form sources of risk, and give additional insights to designers about which improvements could be made.

Based on the insights derived from this project, we see several interesting paths for future research. Firstly, more work is needed to objectively define the probability of risks in repair. Specifically, more data is needed about common mistakes and injuries related to repair. Secondly, future research could explore the usefulness of the modified Disassembly Map as a design tool in practice, investigating to what extent it brings new insights to designers who want to make their products safer to repair.

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10 Appendix: Disassembly Maps, Risk Assessment, and Design Recommendations per product

Appendix

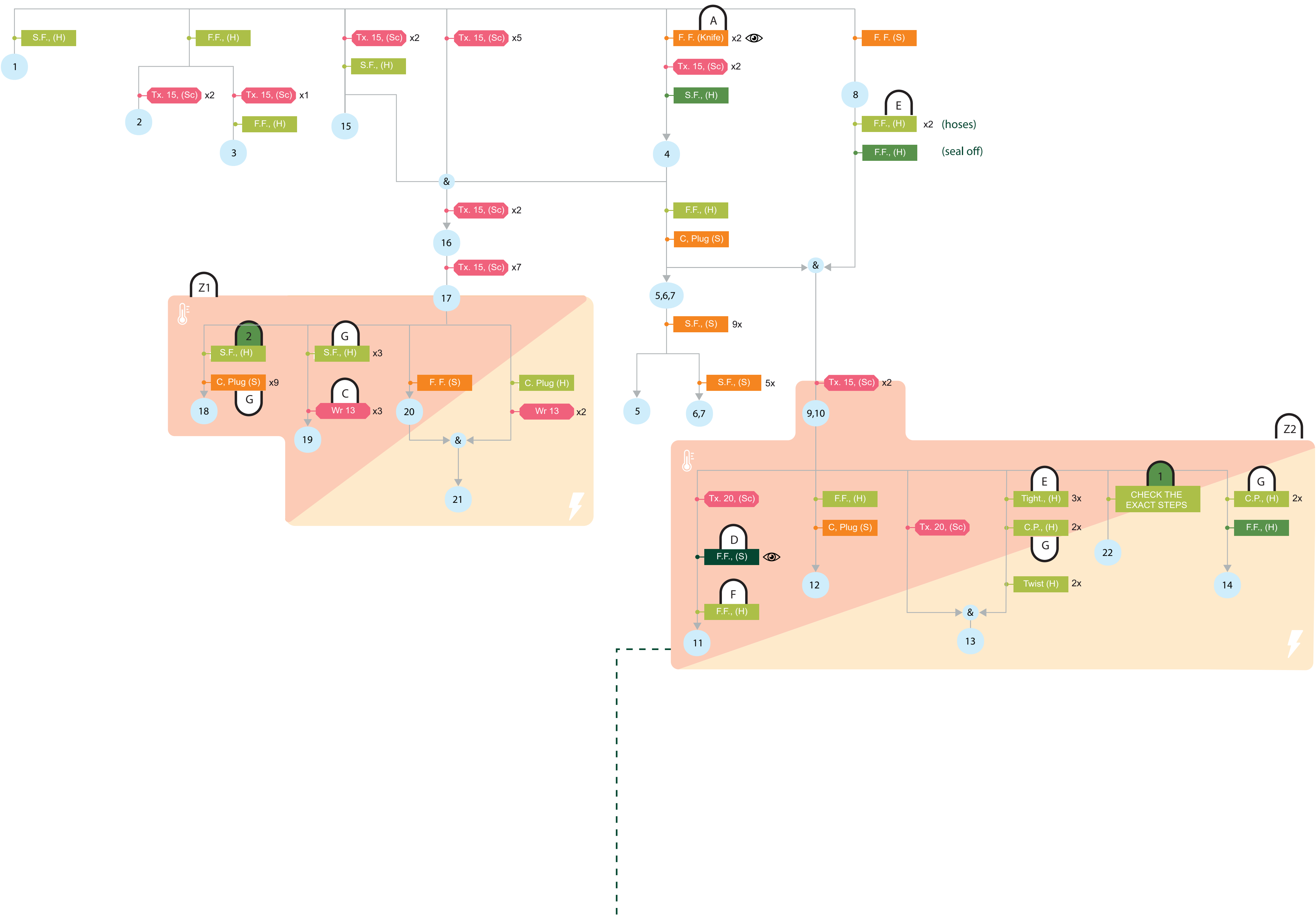
Disassembly Maps, Risk Assessment,
and Design Recommendations per product

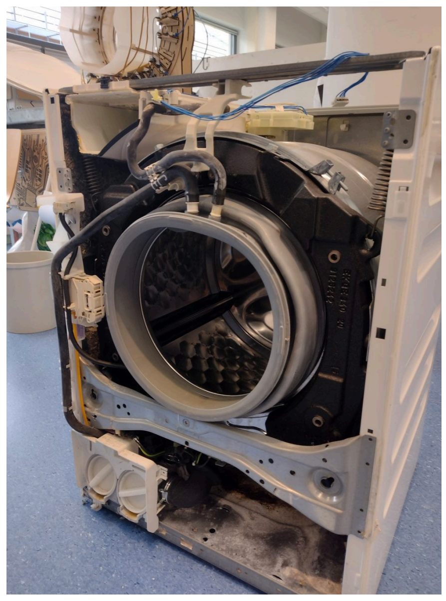
Product Type

Washing Machine

Product Name

Miele W1





Components

1. Soap drawer
2. Door lock (male)
3. Door lock (female)
4. Top panel
5. Front panel back plate
6. UI PCB
7. User interface panel
8. Outer metal seal ring
9. Front panel
10. Door
11. Door seal
12. Door lock
13. Drain hose
14. Heating element
15. Water hose attachment plate
16. Back top plate
17. Back lower plate
18. Main PCB (with casing)
19. Shock Absorbers
20. Drive belt
21. Motor
22. Pump

Legend

Tools

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

Connectors

S. F. = Snap Fit
F. F. = Friction Fit
C. P. = Cable plug
Push B. = Push button
Hg = Hinge
Adv = Adhesive
Ho = Hose
Ti = Tightener
Wr = Wrench
Sol. = Soldered

Safety risk zones

= Electrical risk
= Mechanical risk
= Thermal risk
= Chemical risk

Penalties

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

Force intensity

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

Product Type	Washing Machine	Product Name	Miele W1

Step / risk zone	Disassembly / reassembly	Action / scenario	Failure mode	Failure effect: During Repair – On product	Failure effect: During Repair – On person	Failure effect: After repair – On product	Failure effect: After repair – On	Severity of injury	Probability of injury: Injury scenario	Probability per step	Overall probability	Risk	Cause	Suggested design solution(s)
Z1& Z2	Disassembly	Risk of touching high voltage metal elements	-	-	Electrical - Electric shock	-	-	2	Leaving the plug in while disassembling Touching high voltage metal elements			2	Taking the panels off exposes the repairer to uncovered high-voltage components There are no clear indications that high voltage componentns in the zone can cause electrification The high volt connections have metal endings, which can make contact with the users body	Make it possible to replace the door seal, door lock and door without having to take off the front panel of the machine Use electric warning signs on high voltage components Do not use uninsulated cable plugs for high voltages
Z1 & Z2	Disassembly	Risk of burning body part on heat of motor or heating element	-	-	Thermal risk-burn	-	-	1	Repairing the washing machine shortly after use Touching the casing of the motor			1	Taking the panels off exposes the repairer to high temperature motor casing. Furthermore, to reach the shock absorbers you have to get really close to the motor, which increases the probability of burning the body. There are no clear indications that hot componentns in the zone can cause thermal risks	Place warning signs at components that can cause temperature related injuries Use thermal warning signs on high temperature components
A	Disassembly	Risk of cutting yourself using a sharp knife	-	-	Mechanical - Cut	-	-	1	While using a knife to open the two plastic closings on the side of the top panel, the user cuts him/herself			1	Designed in an aesthetically pleasing way, however not functional; difficult movement causing the risk of cutting yourself	Reposition the screw connection (for example, similar to thee Nordland - to the soap dispenser)
B	Disassembly	While taking off the belt, the high tension causes the belt to snap into the face of the user	-	-	Mecahnical - Bruise	-	-	1	The belt snaps in the face of the user			1	Low level of disassembly expertise can cause the user to incorrectly remove belt	Provide clear disassembly instructions
C	Re-assembly	Mechanical risks because of not properly tightened shock absorbers	Washing machine shaking abnormally	-	-	Seals disconnect (see; D, E)	Thermal - burn	4	Poorly tighten shock absorbers Washing machine shaking abnormally Seals disconnect, causing (D, E)			4	Unclear to repairer what torque is needed (Nm) to properly tighten shock absorbers	Indicate recommended bolt torque
C	Re-assembly	Mechanical risks because of not properly tightened shock absorbers	Washing machine shaking abnormally	-	-	Failure -	Mechanical	2	Poorly tighten shock absorbers Washing machine shaking abnormally Washing machine falls on user			2	Unclear to repairer what torque is needed (Nm) to properly tighten shock absorbers	Indicate recommended bolt torque
D	Re-assembly	If the tightener of the door seal is not tightened enough there can be leakage	Short circuit	-		Failure - fire	Thermal - burn	4	Door seal tightener is not tightened properly, causing water leakage Water causes an electric circuit Electric circuit causes fire			4	Tightener connection not fail-safe; can be considered 'reassembled' while not tightened properly Door seal tightener is very hard to reach, making it hard to properly reassemble the tightners	Use different connection type, like a clasp cloosure Position the door seal tightener on the top.
E	Re-assembly	If the tightener of the hose is not tightened enough there can be leakage	Short circuit	-	-	Failure - fire	Thermal - burn	4	Hose tightener is not tightened properly, causing water leakage Water causes an electric circuit Electric circuit causes fire			4	Tightener connection not fail-safe; can be considered 'reassembled' while not tightened properly	Use different connection type, like re-usable tighteners, sealing caps, or a click-connection
F	Disassembly	Riske of bruising / cutting the body due to high force door deal removal	-	-	-	-	Mechanical - bruise / cut	1	Bruising / cutting the body while removing door seal			1	High force required to remove door seal	Use different connection type, like a threaded fit (with the thread embedded in the rubber seal)
G	Re-assembly	Re-assembling the cables in the wrong order	Short circuit	-	-	Failure - Fire	Thermal - burn	4	Connecting the cables in such a way that causes a short circuit			4	There are many cables with the same connections and color The high volt connections have metal endings, which when can touch the outer washing machine casing if the cable is left disconnected inside the machine by accident	Design a differently shaped and coloured connection for ground and high voltage wires Do not use uninsulated cable plugs for high voltages Do not use an outer casing created from a conductive material

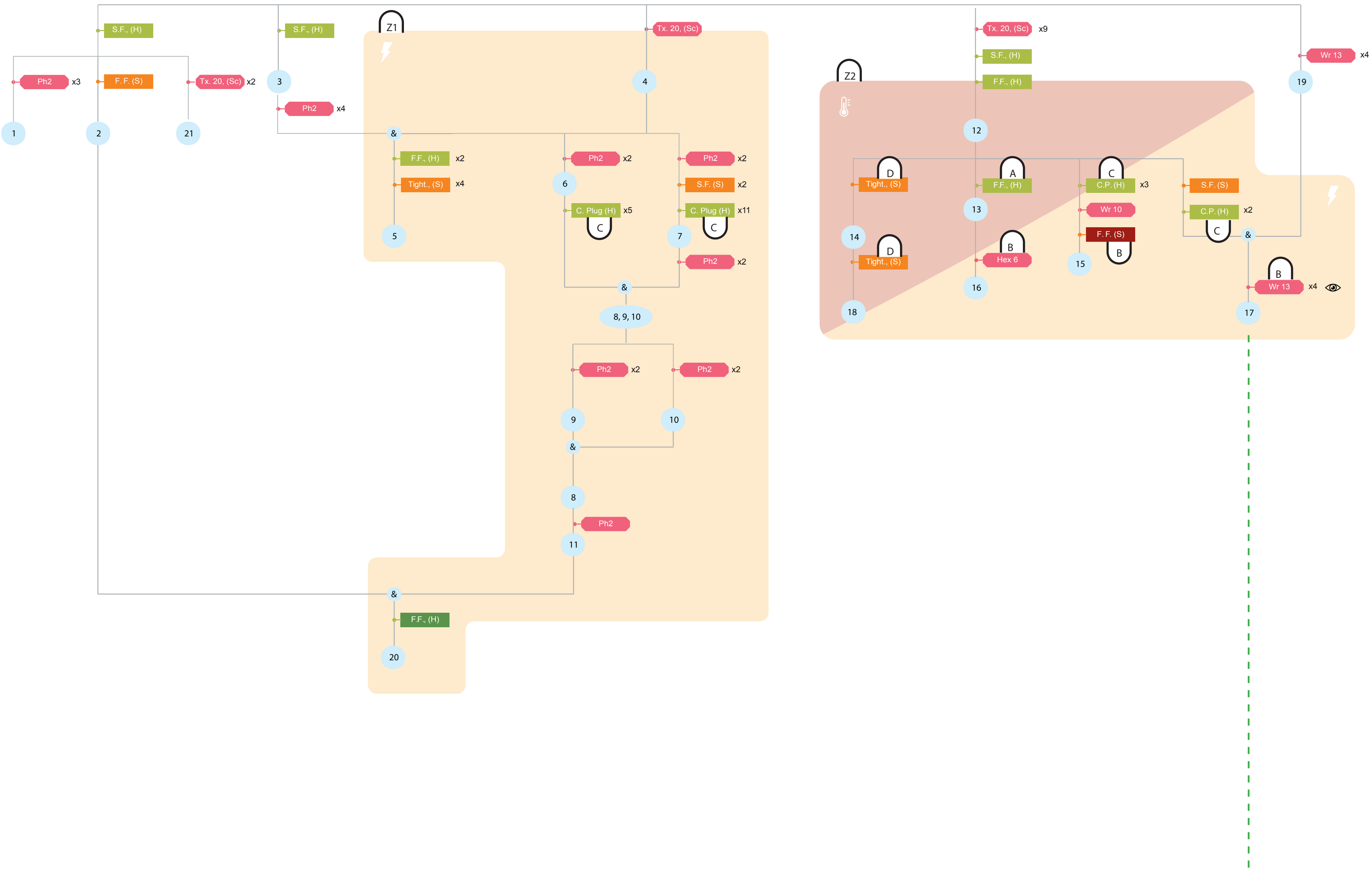
Examples of good design		
1	Disassembly	The pump is placed far away from any other high voltage components, lowering the risk of getting electrified while performing a repair on the pump
2	Disassembly	By placing a plastic cover around the high voltage PCB, the risk of getting electrified by the PCB, while performing a non PCB involved repair, is eliminated.

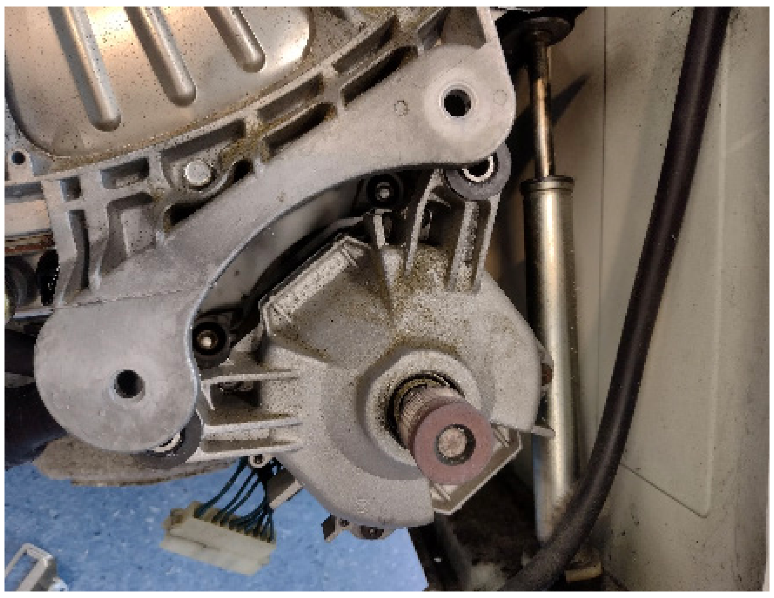
Product Type

Washing Machine

Product Name

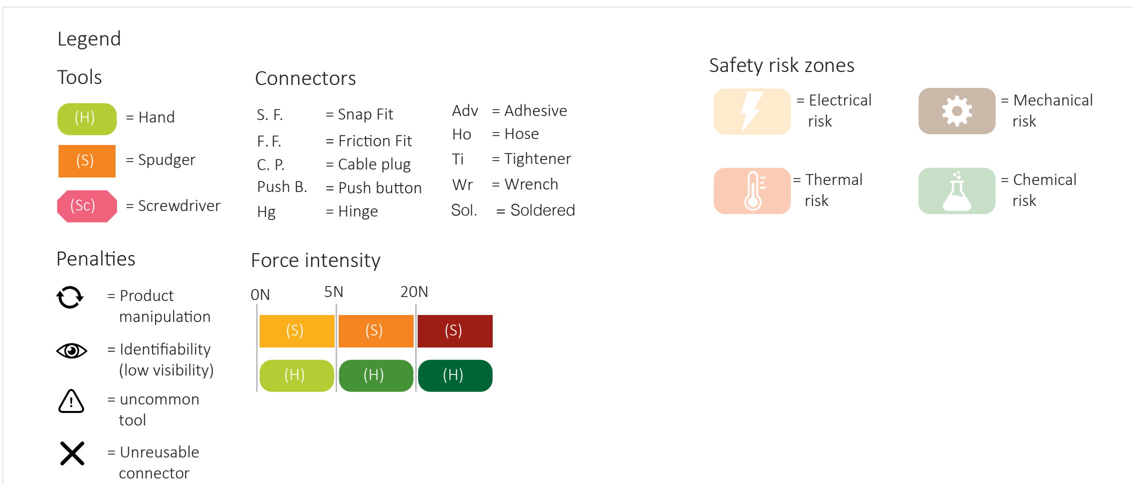
Nordland WVL 2016 EL





Components

1. The door
2. Door seal tension ring (front)
3. Soap drawer
4. Top plate
5. Soap dispenser
6. Casing UI PCBA
7. Main PCBA
8. Front panel top UI
9. UI PCBA 1
10. UI PCBA 2
11. Door seal tension ring (inside)
12. Back panel
13. Drive belt (motor)
14. Water inlet hose
15. Heating element
16. Pulley
17. Motor
18. Pump
19. Concrete weight
20. Rubber door seal
21. Door lock



Product Type	Washing Machine	Product Name	Nordland WVL 2016 EL

Step / risk zone	Disassembly / reassembly	Action / scenario	Failure mode	Failure effect: During Repair – On	Failure effect: During Repair – On person	Failure effect: After repair – On product	Failure effect: After repair – On person	Severity of injury	Probability of injury: Injury scenario	Probability of injury: Probability per step	Probability of injury: Overall probability	Risk	Cause	Suggested design solution(s)
Z1, Z2,	Disassembly	Risk of touching high voltage metal elements	-	-	Electrical - Electric shock	-	-	2	Leaving the plug in while disassembling Touching high voltage metal elements			2	- Taking the panels off exposes the repairer to uncovered high-voltage components - There are no clear indications that high voltage components in the zone can cause electrification - The high volt connections have metal endings, which can make contact with the users body	- Make it possible to replace the door seal, door lock and door without having to take off the front panel of the machine - Use electric warning signs on motor, heating element and pump. - Do not use uninsulated cable plugs for high voltage cables
Z3 & Z4	Disassembly	Risk of burning body part on heat of motor	-	-	Thermal risk-burn	-	-		Repairing the washing machine shortly after use Touching the casing of the motor			1	Taking the panels off exposes the repairer to high temperature motor casing	Cover motor casing with non-heat-conducting material
Z3 & Z4	Disassembly	Risk of touching high voltage metal elements	-	-	Electrical - Electric shock	-	-	2	Testing the heater or the motor, located in the high voltage test risk zone Touching high voltage metal elements			2	To test proper functioning of the heater / motor, the washing machine is turned during repair while possibly involving the user (by measuring current for example)	Add a status indication to heating element and motor, so that it is clear whether they are working or not, reducing the need to troubleshooting live parts
A	Disassembly	Risk of bruising / cutting the body due to high force used in removal belt	-	-	Mechanical - Bruise	-	-	1	While taking off the belt, the high tension causes the belt to snap into the face of the user			1	Low level of disassembly expertise can cause the user to incorrectly remove belt	Provide clear disassembly instructions
B	Disassembly	Risk of bruising / cutting the body due to high force used in heating element / motor	-	-	-	-	Mechanical - Bruise	1	Bruising the body due to high force needed to remove heating element			1	The connection of the heating component is tight, causing friction in removal	Using a screw connection, the same tightness can be achieved without such a high level of friction Instructions need to be provided about proper disassembly without using high force, by hitting the screw with a hammer
C	Re-assembly	Re-assembling the cables in the wrong order	Short circuit	-	-	Failure - Fire	Thermal - burn	4	Connecting the cables in such a way that causes a short circuit			4	There are many cables with the same connections and color The high volt connections have metal endings, which when can touch the outer washing machine casing if the cable is left disconnected inside the machine by accident	Design a differently shaped and colored connection for ground and high voltage wires Do not use uninsulated cable plugs for high voltages Do not use an outer casing created from a conductive material
D	Re-assembly	If the tightener of the hose is not tightened enough there can be leakage	Short circuit	-	-	Failure - fire	Thermal - burn	4	Hose tightener is not tightened properly, causing water leakage Water causes an electric circuit Electric circuit causes fire			4	Tightener connection not fail-safe; can be considered 'reassembled' while not tightened properly	Use different connection type, like re-usable tighteners, sealing caps, or a click-connection

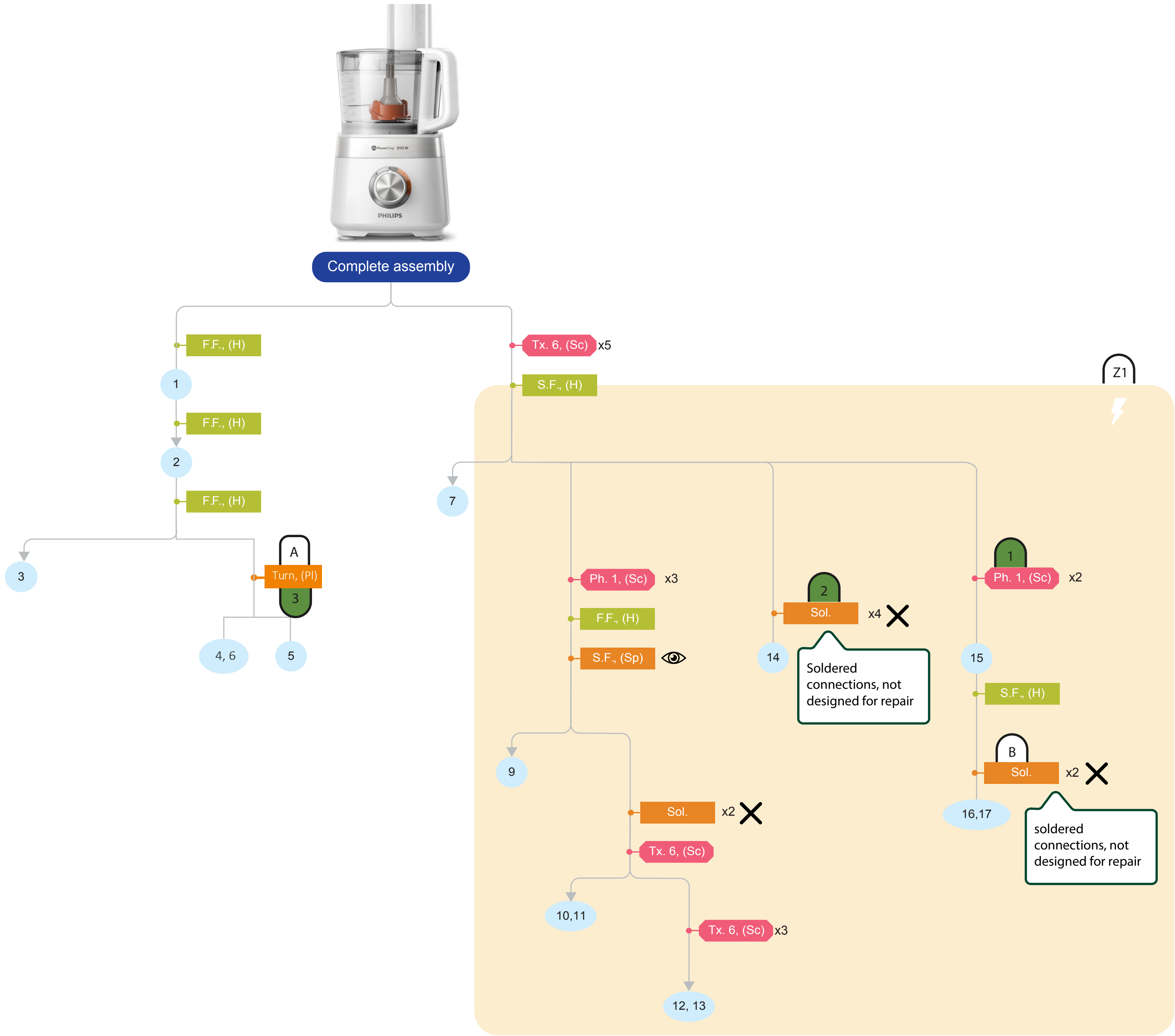
Examples of good design		
1	Disassembly	No sharp knife is needed to get the top panel off (like in the Miele), by hiding the screws for disconnection behind the soap drawer

Product Type

Blender

Product Name

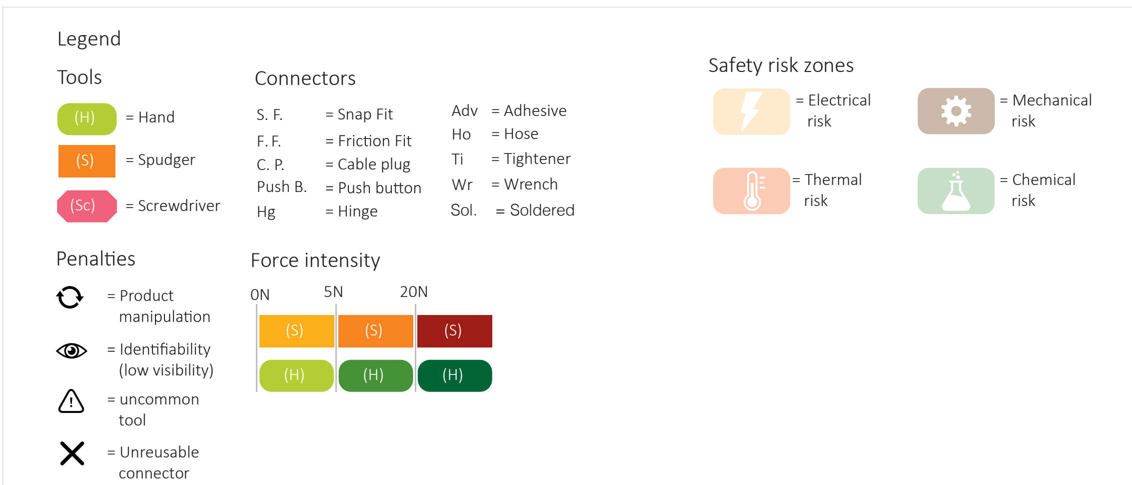
Philips Powerchop



Components

COMPONENT LIST

1. Jar container top
2. Blade unit
3. Jar
4. Blade unit driver
5. Gasket assembly
6. Female driver (Base)
7. Base bottom
8. Base top
9. Motor subassembly fundament
10. Male driver (Base)
11. Motor subassembly
12. Gears
13. Gear base
14. PCB
15. Safety lock housing
16. Safety lock
17. Spring



Product Type	Blender	**Product Name**	Philips Powerchop

Step / risk zone	Disassembly / reassembly	Action / scenario	Failure mode	Failure effect: During Repair – On product	Failure effect: During Repair – On person	Failure effect: After repair – On product	Failure effect: After repair – On person	Severity of injury	Probability of injury: Injury scenario	Probability of injury: Probability per step	Probability of injury: Overall probability	Risk	Cause	Suggested design solution(s)
Z1	Disassembly	Risk of touching high voltage metal elements	-	-	Electrical - Electric shock	-	-	2	Leaving the plug in while disassembling Leave the container on the product (and therefore the safety lock active) Touching high voltage metal elements			2	Taking the housing off exposes the repairer to uncovered high-voltage components	Insulate connections / encase PCB / extend the function of the safety lock to the opening of the base
A	Re-assembly	Risk of leaving out gasket	Excessive friction			Blender overheating	Temperature - burn	1	Touching the hot blender (as a result of the excessive friction)			1	The person forgets to put the gasket in, as the elements can be easily re-assembled without the gasket	It should be impossible to leave the gasket out in re-assembly / eliminate the need for a gasket
B	Reassembly	User solders wires in such a way the safety lock is bypassed	Product can function without the lid on	-	-	-	Mechanical - Cut	2	User repairs the safety lock while mixing up the wires, in such a way that bypasses the jar lid lock User puts hand in the jar while starting the motor			2	A soldered connection leaves the risk of incorrectly reconnecting the wires, creating the possibility to bypass the safety lock	Use colored cable plug connections

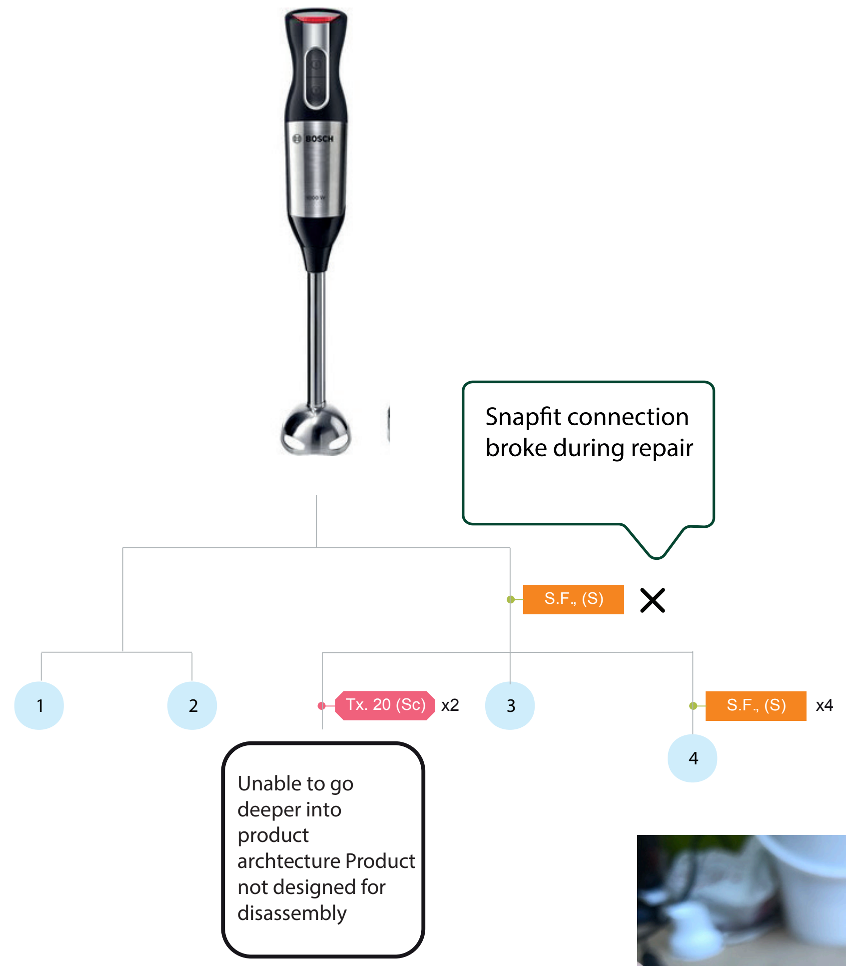
Examples of good design		
1	Reassembly	The safety lock is designed in such a way, there is only one possibility to reassemble the part within its environment. Because of this design, it is impossible to bypass the safety lock, triggered by closing the jar lid. Therefore, the chance of injury by the (sharp) blades is rejectable
2	Reassembly	Compared to the Philips ProBlend 4, there is not the risk of cutting the hand due to a soldered connection that changes the power button, because the safety lock is placed in the top lid. Placing the safety lock in the top lid eleminates the risk of being in contact with the blades, when the motor starts unintended.
3	Re-assembly	The threading on the screw connection for the blade does not allow for overtightening the screw

Product Type

Blender

Product Name

Bosch ErgoMixx



Legend

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

Connectors
- S. F. = Snap Fit
- F. F. = Friction Fit
- C. P. = Cable plug
- Push B. = Push button
- Hg = Hinge
- Adv = Adhesive
- Ho = Hose
- Ti = Tightener
- Wr = Wrench
- Sol. = Soldered

Safety risk zones
- = Electrical risk
- = Mechanical risk
- = Thermal risk
- = Chemical risk

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

Force intensity

0N 5N 20N

(S) (S) (S)

(H) (H) (H)

Components

1. Blade unit
2. Motor body
3. Speed controler
4. Power buttons

Product Type	Blender	Product Name	Bosch ErgoMixx

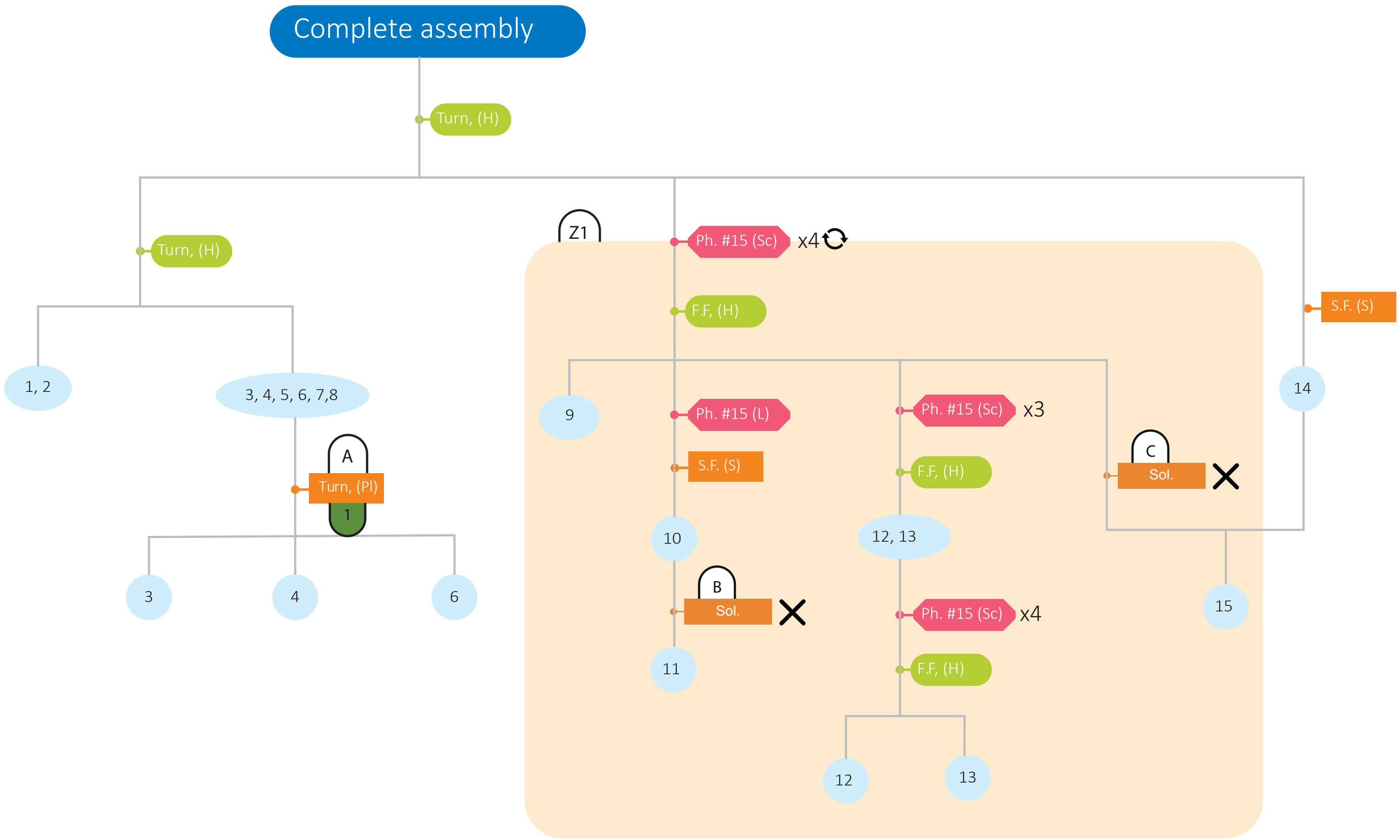
Step / risk zone	Disas-sembly / reas-sembly	Action / scenario	Failure mode	Failure effect				Se-verity of inju-ry	Probability of injury			Risk	Cause		
				During Repair		After repair			Injury scenario	Pro-babili-ty per step	Over-all probi-bility				
				On pro-duct	On person	On pro-duct	On person								

Product Type

Blender

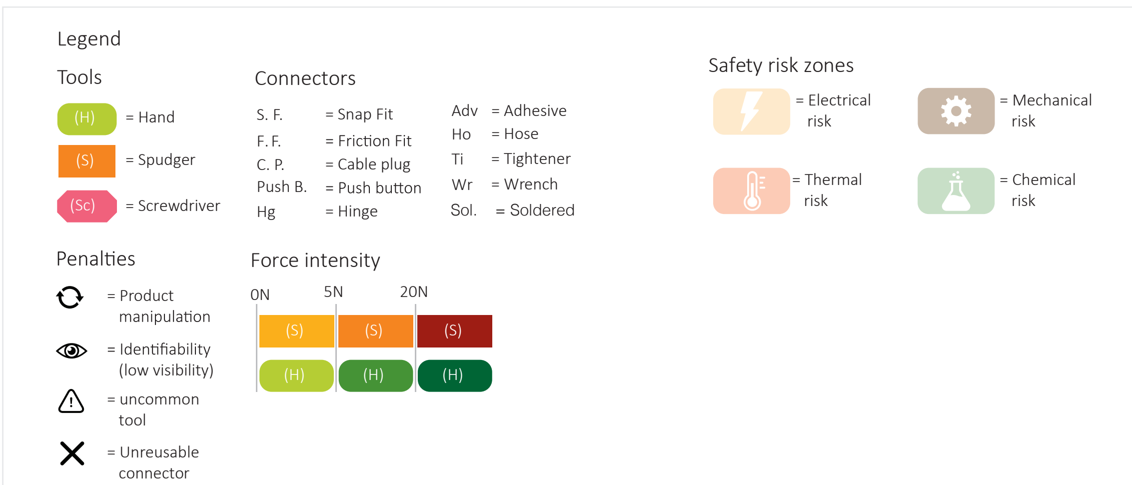
Product Name

Philips ProBlend 4 (HR2100)



Components

1. lid
2. jar
3. outer blade gasket
4. inner blade gasket
5. sealing ring for blender
6. 4 star blade unit
7. blade holder
8. male driver
9. lower housing bottom
10. safety switch
11. safety lock
12. motor subassembly fundament
13. motor subassembly
14. Control button (female, front)
15. Control regulator (male, inside housing, including fuse)



Product Type	Blender	Product Name	Philips ProBlend 4 (HR2100)

Step / risk zone	Disassembly / reassembly	Action / scenario	Failure mode	Failure effect: During Repair – On product	Failure effect: During Repair – On person	Failure effect: After repair – On product	Failure effect: After repair – On person	Severity of injury	Probability of injury: Injury scenario	Probability per step	Overall probability	Risk	Cause	Suggested design solution(s)
Z1	Disassembly	Risk of touching high voltage metal elements	-	-	Electrical - Electric shock	-	-	2	Leaving the plug in while disassembling			2	Taking the housing off exposes the repairer to uncovered high-voltage components	Insulate connections / extend the function of the safety lock to the opening of the base
									Leave the container on the product (and therefore the safety lock active)					
A									Touching high voltage metal elements					
B	Reassembly	User solders wires in such a way the control button is bypassed	-	-	-	Product starts without button being used	Mechanical - cut	3	Non-reusable connector is reconnected in such a way, that the product automatically starts if the power plug is connected without the need to use the power button			3	A soldered connection leaves the risk of incorrectly reconnecting the wires, creating the possibility to bypass the power button	Use colored cable plug connections
									Starting the machine with one hand in it					
C	Reassembly	User solders wires in such a way the safety lock is bypassed	The motor and jar-connection part are able to move without the jar being on	-	-	-	Mechanical - Bruising	1	User turning the machine on while the jar is taken off			1	A soldered connection leaves the risk of incorrectly reconnecting the wires, creating the possibility to bypass the safety lock	Use coloured cable plug connections
									User touching the 'jar connection part', getting bruised					

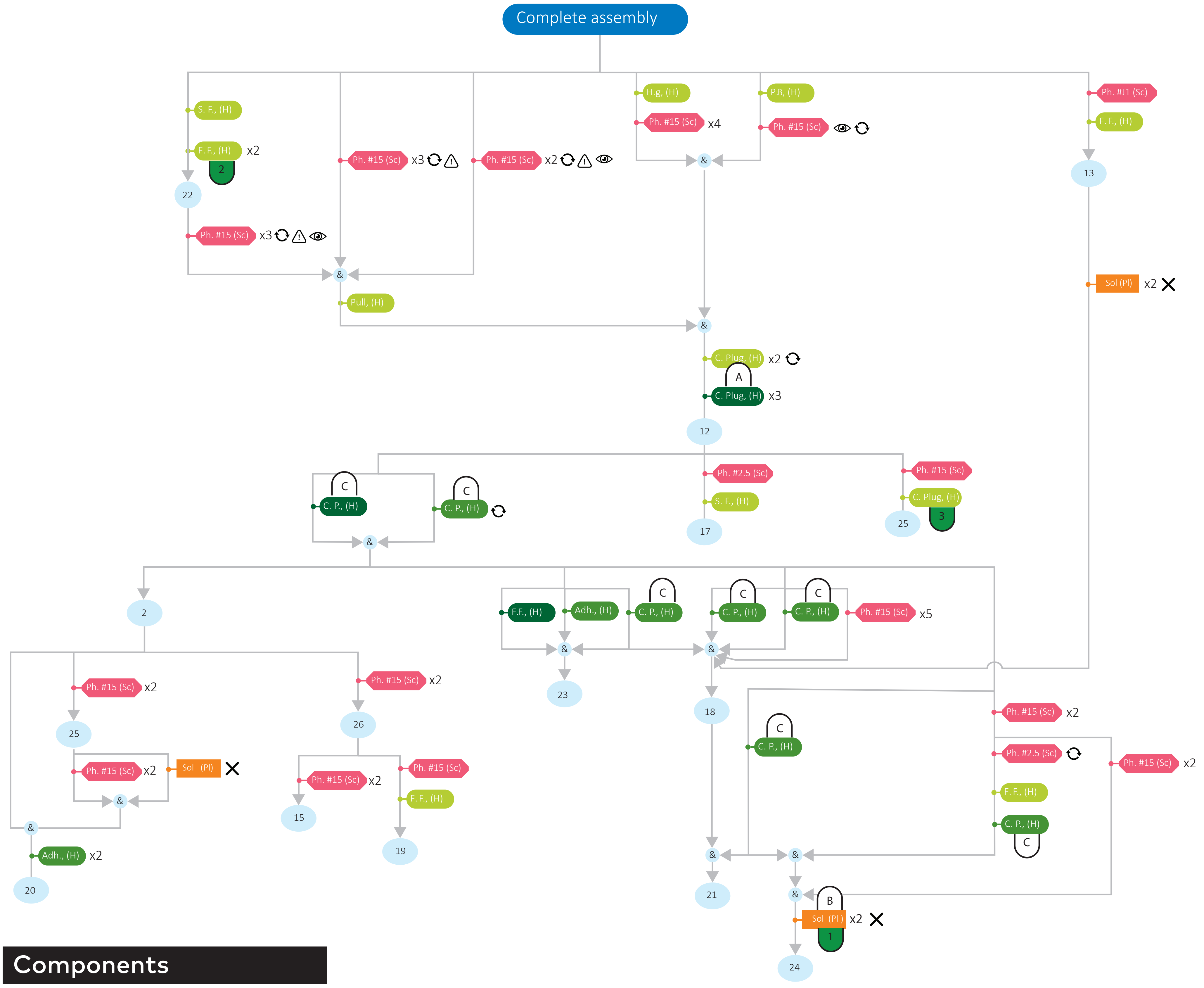
Examples of good design		
1	Re-assembly	The threading on the screw connection for the blade does not allow for overtightening the screw

Product Type

Media Player

Product Name

Philips AZ700T



Components

1. Back Panel
2. Front Panel
3. display
4. volume knob
5. usb input port
6. source selection
7. radio settings panel
8. switch ON/OFF
9. audio-IN jack
10. Headphone sockect
11. cd player lid
12. carrying handle
13. FM antenna
14. power cable output
15. battery lid
16. optical reader subassembly
17. audio input/output PCB
18. main PCB
19. display and command PCB
20. speakers (a&b)
21. speakers PCB
22. Batteries
23. NFC module
24. Power Transformer

Legend

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

Connectors
- S. F. = Snap Fit
- F. F. = Friction Fit
- C. P. = Cable plug
- Push B. = Push button
- Hg = Hinge
- Adv = Adhesive
- Ho = Hose
- Ti = Tightener
- Wr = Wrench
- Sol. = Soldered

Safety risk zones
- = Electrical risk
- = Mechanical risk
- = Thermal risk
- = Chemical risk

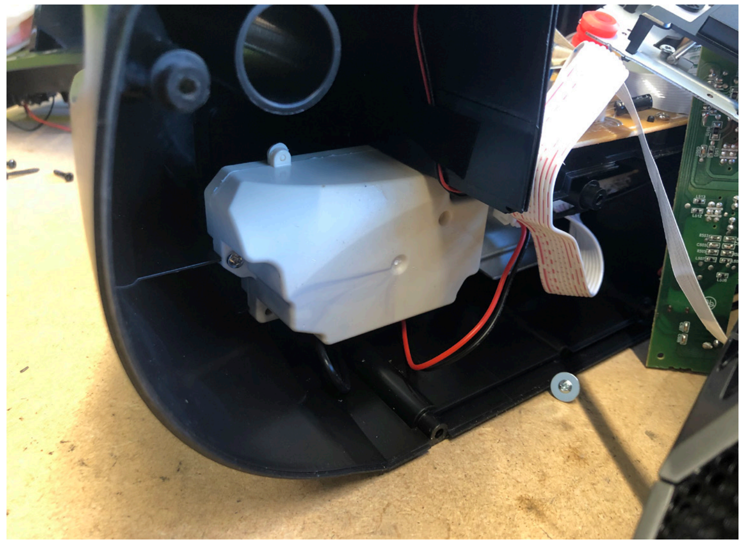
Penalties
- = Product manipulation
- = Identifiability (low visibility)
- = uncommon tool
- = Unreusable connector

Force intensity

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

Product Type	Media Player	Product Name	Philips AZ700T

Step / risk area	Disassembly / reassembly	Action / scenario	Failure mode	Failure effect: During Repair		Failure effect: After repair		Severity of injury	Probability of injury: Necessary scenario to enable injury		Overall probability	Risk	Cause	Suggested design solution
				On product	On person	On product	On person							
A	Disassembly	Risk of cutting yourself on the radio casing by applying a lot of force in the disassembly of the plugs	-	-	Cut, Bruise	-	-	1	Hitting the case while unplugging using a high force			1	The radio is designed in such a way that to the two main halves (back panel and front panel) have limited space between them	Use longer wires to enable a more accessible disassembly
B	Disassembly / reassembly	Risk of getting electrified by high voltage	-	-	Electric, shock	-	-	2	Leaving the plug in Touching the metal elements in which high voltage runs through			2		
C	Reassembly	Risk of swapping connectors at reassembly	Short circuit	-	-	Short circuit, overheating	Thermal, burn	4	Two cables swapped at reassembly, causing fire			4	Two cables were swapped because it is not obvious which one should go back where	The cables are already color coded, so changes in shape are a suggested solution / or numbering



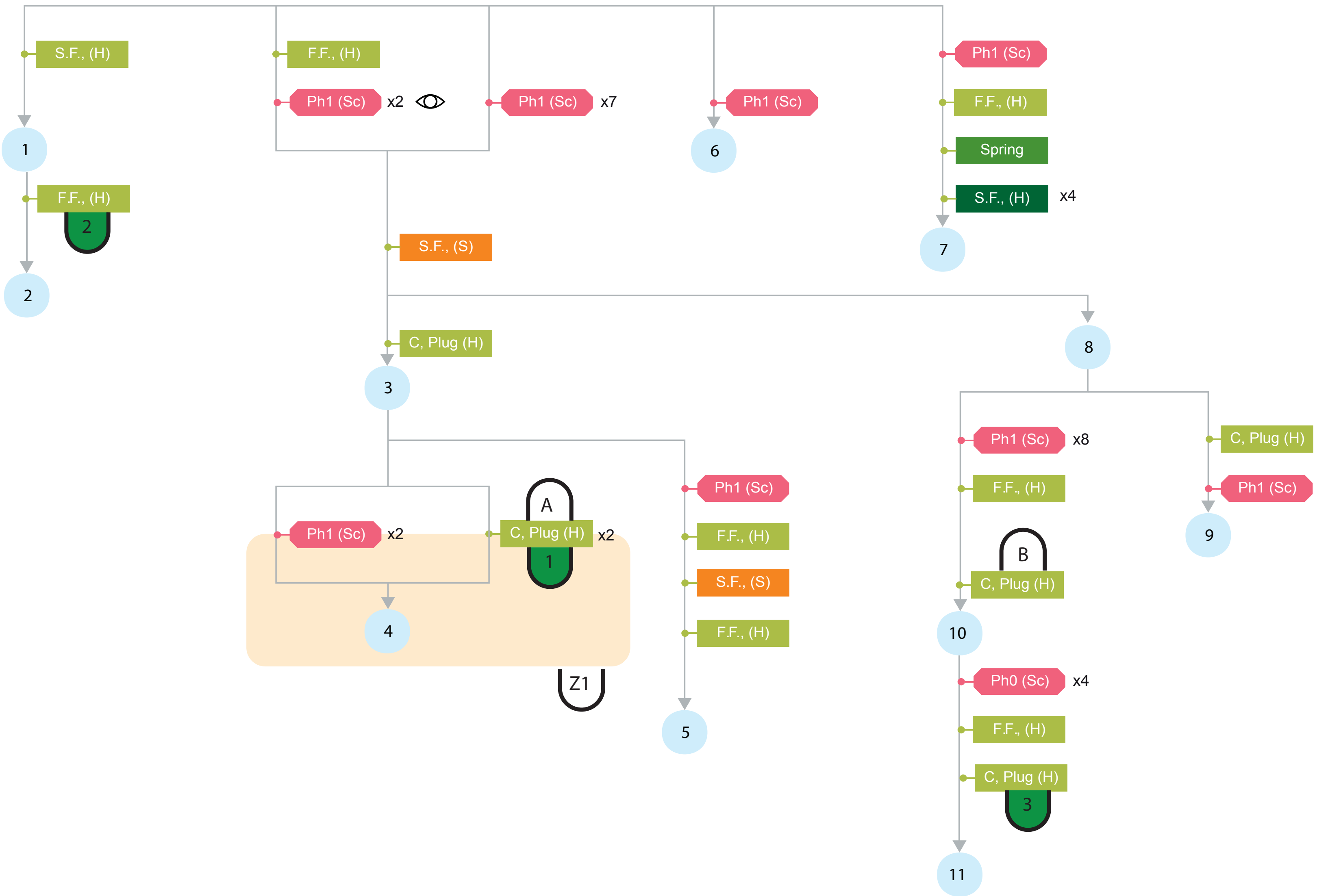
Examples of good design		
1	Disassembly	By placing the transformer appart from the PCBA's and other metal parts, at the very start of the circuit, the chance of getting electrified by 230 volts is eliminated.
1	Disassembly	Power transformer is encased in plastic, eliminating the electric risks in all cases (except for when the casing is opened).
2	Reassembly	It is clearly stated which batteries to use
3	Disassembly	CD reader placed deep in product architecture, which reduces the risk that the repairer is exposed to the laser beam.

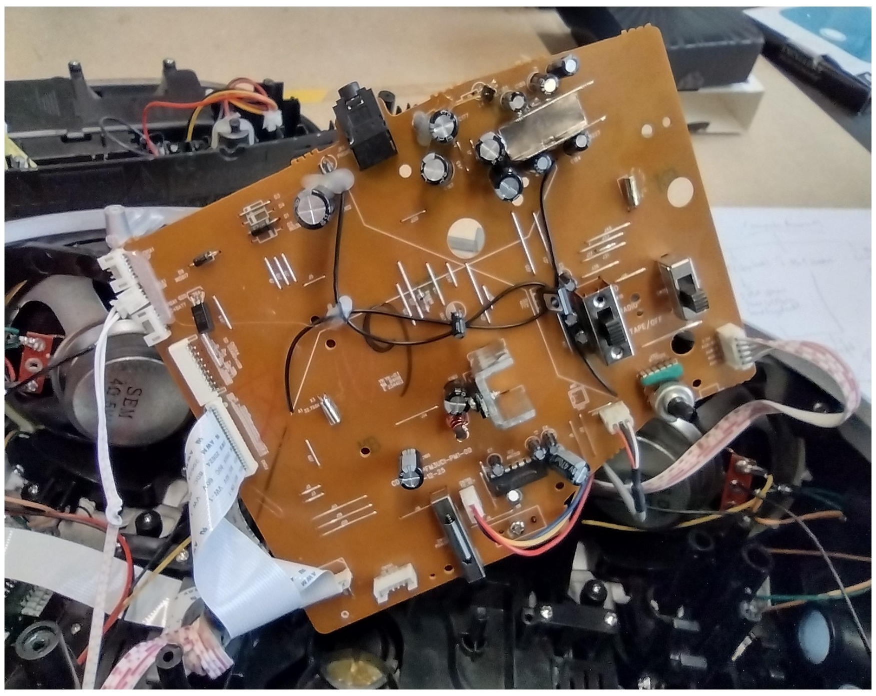
Product Type

Media Player

Product Name

MT Logic CD-1587





Components

1. Battery cover plate
2. Batteries
3. Bottom plate assembly
4. PCB voltage converter
5. Power cable
6. Antenna
7. CO lid
8. Main assembly
9. Headphone-jack-pcb
10. Main PCB
11. CD reader Assembly

Legend

Tools

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

Connectors

S. F. = Snap Fit
F. F. = Friction Fit
C. P. = Cable plug
Push B. = Push button
Hg = Hinge
Adv = Adhesive
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Ti = Tightener
Wr = Wrench
Sol. = Soldered

Safety risk zones

= Electrical risk
= Mechanical risk
= Thermal risk
= Chemical risk

Penalties

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

Force intensity

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

Product Type	Media Player	Product Name	MT Logic CD-1587

Step / risk area	Disas-sembly / reas-sembly	Action / scenario	Failure mode	Failure effect				Sever-ity of injury	Probability of injury			Risk	Cause	Suggested design solution
				During Repair		After repair			Necessary scenario to enable injury		Over-all proba-bility			
				On prod-uct	On person	On prod-uct	On person							
Z1	Disas-sembly	Exposure to PCB	-	-	Elec-trical shock low voltage	-	-	2	Power cable left in during the repair process			2	It is possible to open the product and get to the PCB without cutting the power	The current solution is already since the power inlet is on the back plate which makes it very natural to unplug before starting to do repair work on the main assembly. Also, on the main assembly voltage has already been transformed to 12V DC. However, on the back plate there is a risk that the cable is left in while touching the voltage converter PCB, which h as 230V on one side.
A	Reassem-bly	Loose connectors hanging next to PCB	Short circuit	-	-	Short circuit, over-heating	Ther-mal, burn	4	Repairer forgot to put one of the cables back that has exposed metal at the end of it OR a wire came loose from one of the uninsulated cable plugs or from a soldered connection so that metal is exposed OR a cable is reassembled in the wrong connection			4	Uninsulated conducting parts can come loose in the product / wrong connections can cause short circuit	Do not use uninsulated cable plugs / Use snap fits that require less force to prevent breaking the cables
B	Reassem-bly	Connectors swapped at reassembly	Short circuit	-	-	Short circuit, over-heating	Ther-mal, burn	4	Two cables swapped at reassembly, causing fire			4	Two cables were swapped because it is not obvious which one should go back where	Better color coding

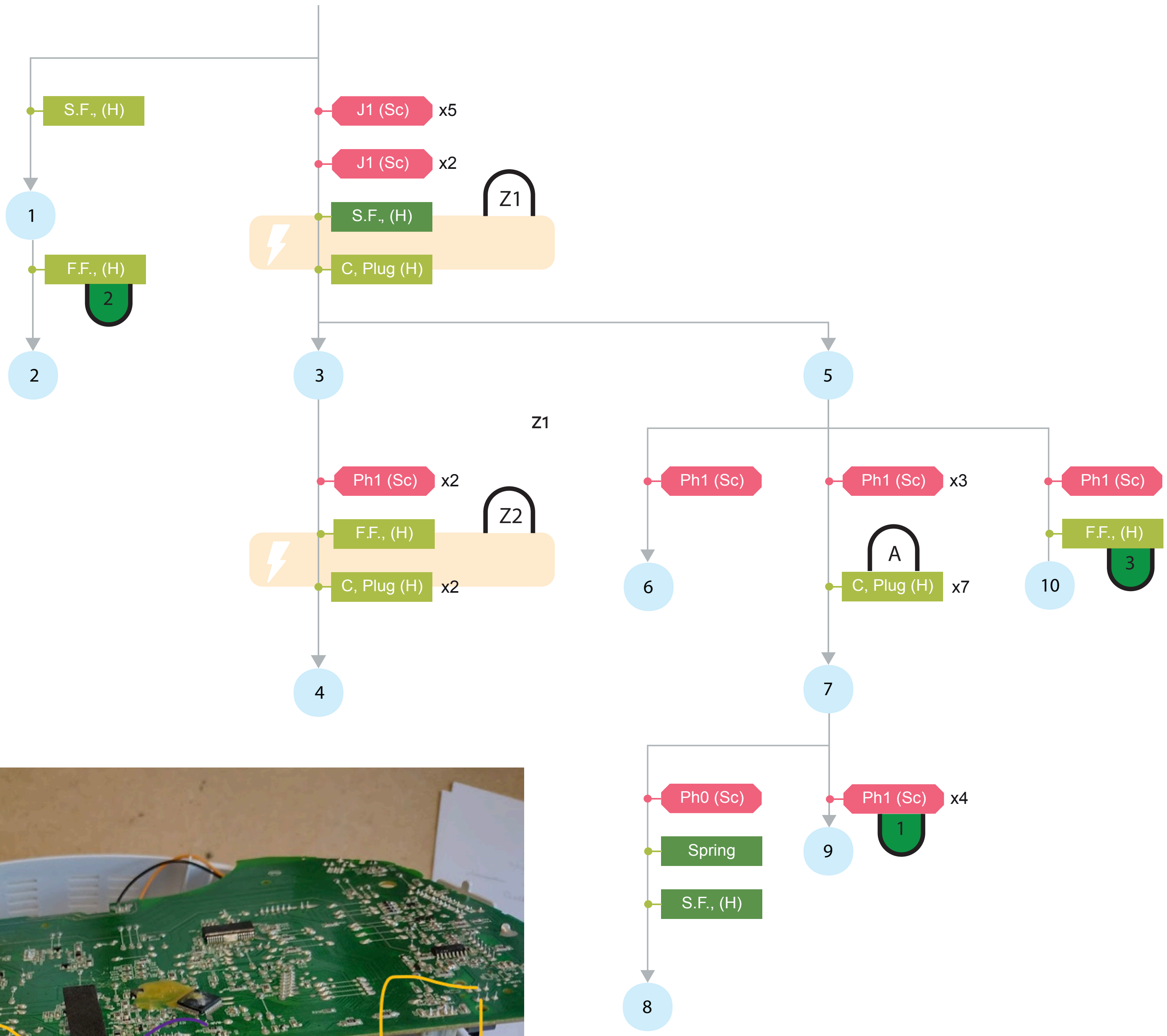
Examples of good design		
1	Disas-sembly	By placing the transformer appart from the PCBA's and other metal parts, at the very start of the circuit, the chance of getting electrified by 230 volts is eliminated.
1	Disas-sembly	Power transformer is encased in plastic, eliminating the electric risks in all cases (except for when the casing is opened).
2	Reas-sembly	It is clearly stated which batteries to use
3	Disas-sembly	CD reader placed deep in product archetiture, which reduces the risk that the repairer is exposed to the laser beam.

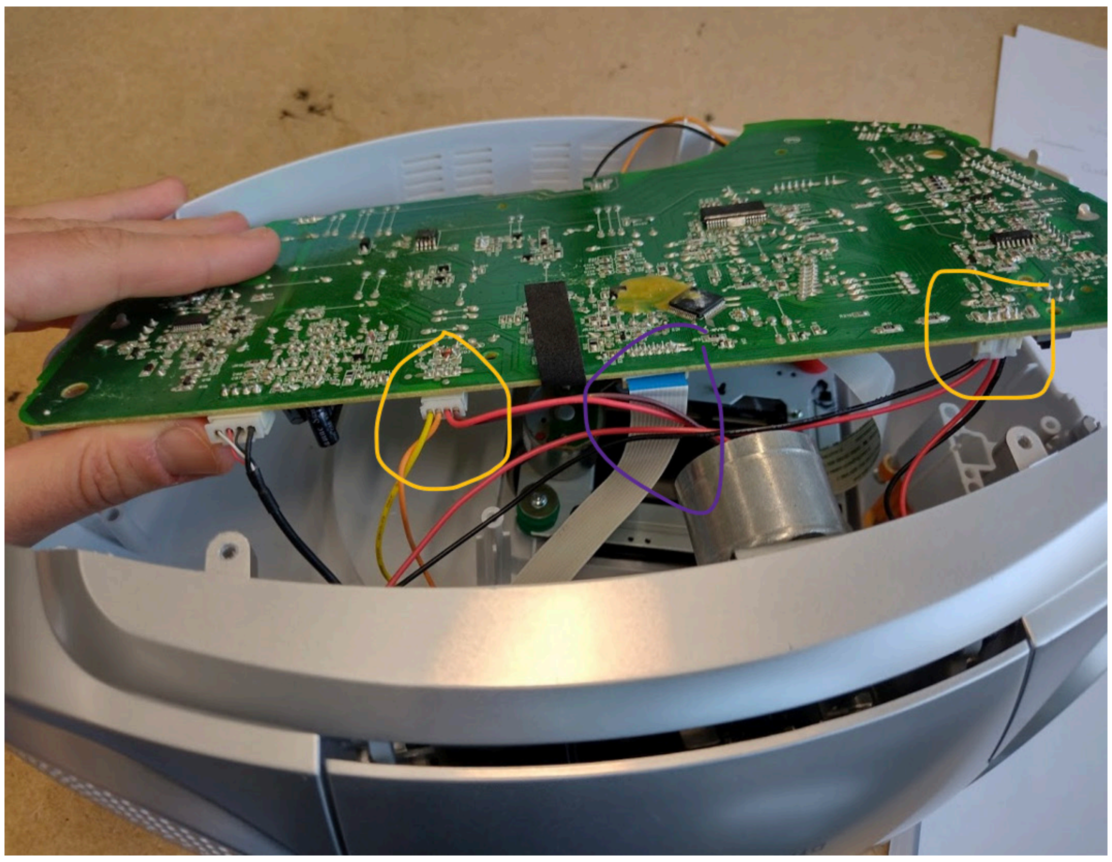
Product Type

Media Player

Product Name

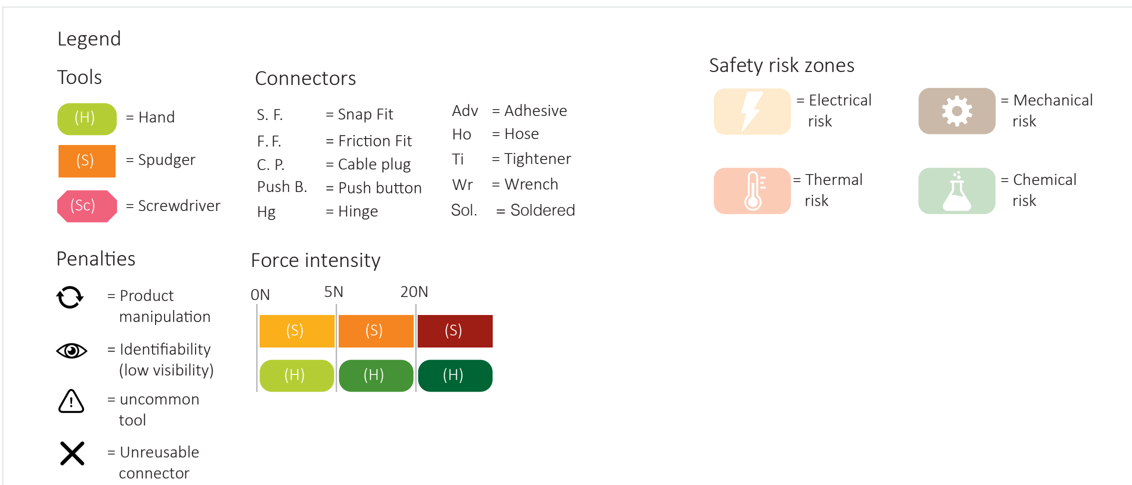
Philips CD Soundmachine (A7127)





Components

1. Battery cover plate
2. Batteries
3. Bottom plate assembly
4. Power transformer PCB
5. Main assembly
6. Antenna
7. Main PCB
8. CD lid
9. CD reader assembly
10 CD reader safety lock



Product Type	Media Player	Product Name	Philips CD Soundmachine (A7127)

Step / risk area	Disas-sembly / reas-sembly	Action / scenario	Failure mode	Failure effect				Sever-ity of injury	Probability of injury			Risk	Cause	Suggested design solution
				During Repair		After repair			Necessary scenario to enable injury		Over-all proba-bility			
				On prod-uct	On person	On prod-uct	On person							
Z1	Disas-sembly	Exposure to PCB	If power cable still in, the person could touch conducting parts	-	Elec-trical, shock	-	-	2	Power cable left in during the repair process			2	It is possible to open the PCB housing without cutting the power	Put an insulated cable plug on the outside of the housing and make the screws unreachable if you have not first unplugged the cable.
A	Reas-sembly	Short circuit	Incorrect reassembly of cable plugs (swap / forget) Also possible that one wire comes loose from the cable plugs (they are hard to get out so possible to pull too hard)	-	-	Short circuit, over-heating	Ther-mal, burn	2	Repairer forgot to put one of the cables back that has exposed metal at the end of it OR a wire came loose from one of the insulated cable plugs or from a soldered connection so that metal is exposed OR a cable is reassembled in the wrong connection			2	Uninsulated conducting parts can come loose in the product / wrong connections can cause short circuit	Do not use uninsulated cable plugs / Use snap fits that require less force to prevent breaking the cables

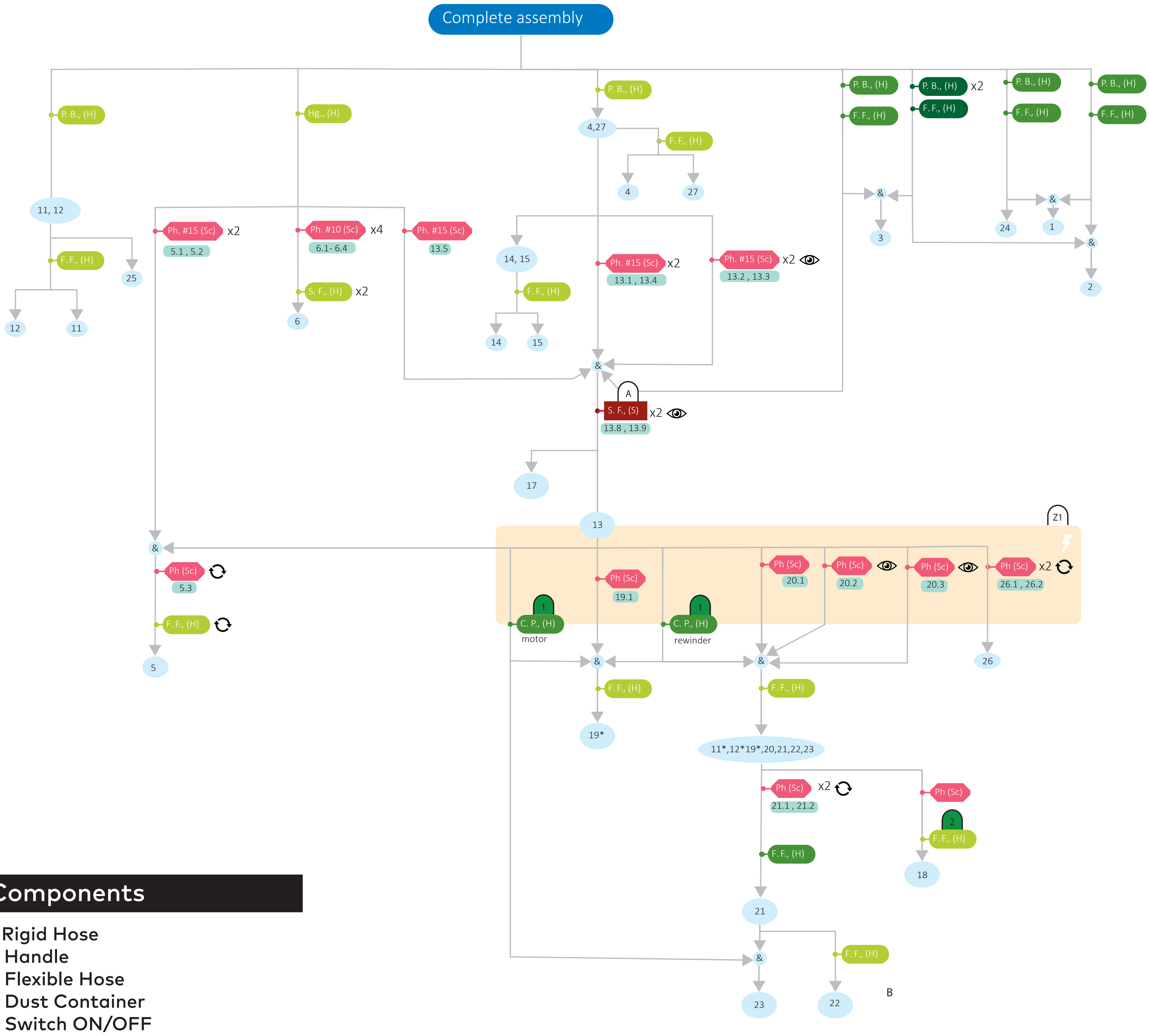
Examples of good design		
1	Disas-sembly	By placing the transformer appart from the PCBA's and other metal parts, at the very start of the circuit, the chance of getting electrified by 230 volts is eliminated.
1	Disas-sembly	Power transformer is encased in plastic, eliminating the electric risks in all cases (except for when the casing is opened).
2	Reas-sembly	It is clearly stated which batteries to use
3	Disas-sembly	CD reader placed deep in product archetictur, which reduces the risk that the repairer is exposed to the laser beam.

Product Type

Vacuum Cleaner

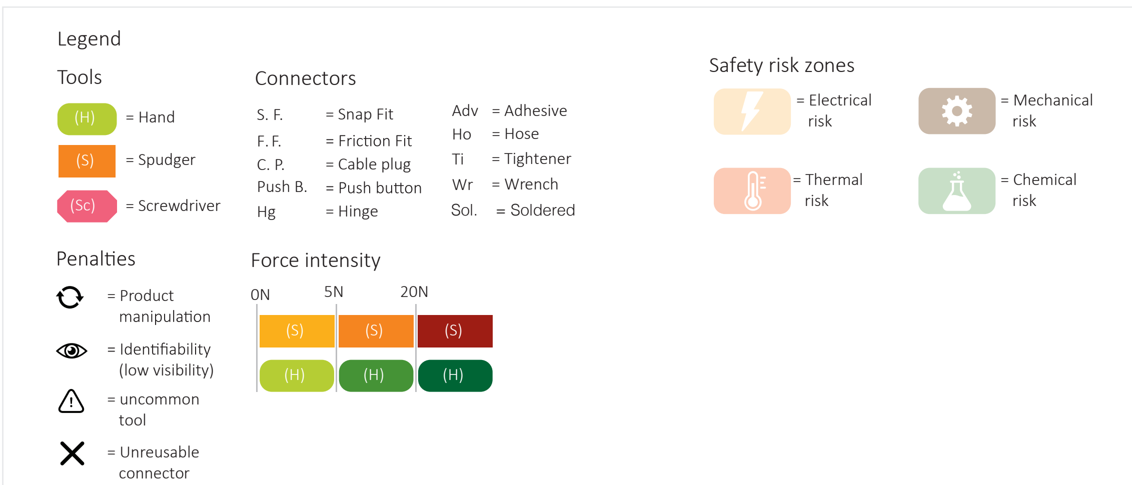
Product Name

Samsung SC07M3130V1



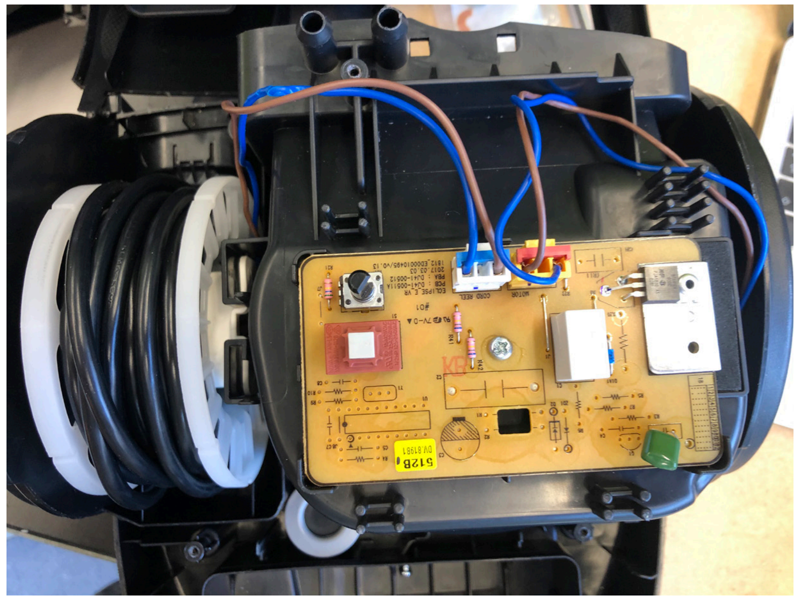
Components

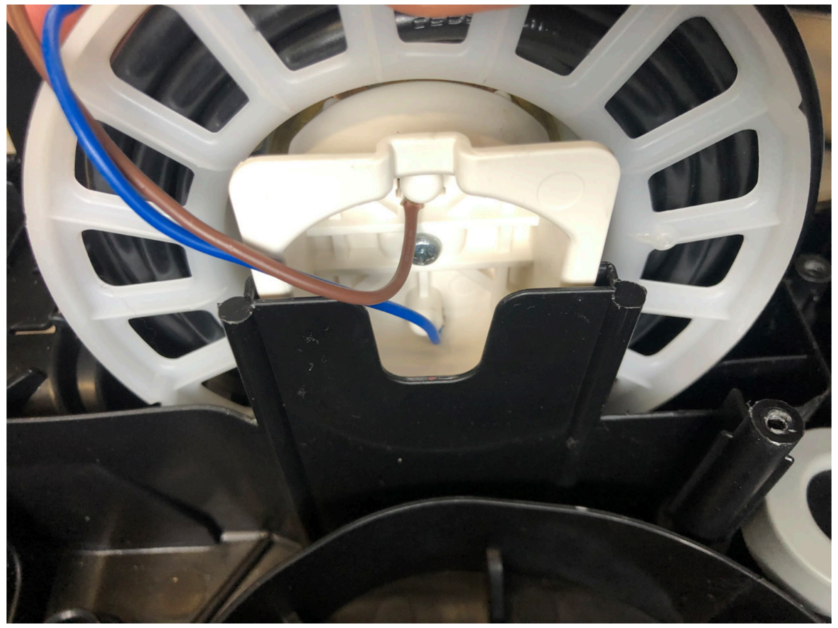
1 Rigid Hose
2 Handle
3 Flexible Hose
4 Dust Container
5 Switch ON/OFF
6 Carrying handle
7 Power Chord
8 Outflow Filter
9 Anti Tangle turbine
10 Wheel (x2)
11 Filter Cover
12 Exit Filter
13 Case cover
14 Sponge Filter housing
15 Sponge Filter
16 Main Body
17 Pressure valve
18 Power cord rewinder
19 PCB
20 Flow duct
21 Motor case
22 rubber gasket
23 Motor
24 Brush & other accesories
25 Sponge Exit
26 Rewinder Rail



Product Type	Vacuum Cleaner	Product Name	Samsung SC07M3130V1

Step / risk area	Disas-sembly / reas-sembly	Action / scenario	Failure mode	Failure effect				Sever-ity of injury	Probability of injury			Risk	Cause	Suggested design solution
				During Repair		After repair			Necessary scenario to enable injury		Over-all proba-bility			
				On prod-uct	On person	On prod-uct	On person							
A	Disas-sembly	Risk of cutting yourself due to high force removal case cover	-		Me-chanical - Cut			1	Cutting yourself during the disassembly			1	Unpredictable move when opening snap fit for which a lot of force is needed	Design a snap fit connection that uses less force to be opened, or use a different connection method (screws) to avoid the risk of cutting the body in the opening attempt.
Z1	Disas-sembly	Risk of getting electrified			Electric - Elec-tronic shock			2	Cable is plugged in Power button is pressed Body making contact with electrified component			2	There are electronic connections which are not completely covered in a non-conducting material	Cover the metal parts of the electric connection with a non-conducting material and exclude as many components from risk zone as possible. For example, move the wheels out of the risk zone (as been proven possible in the Samsung SC8835)





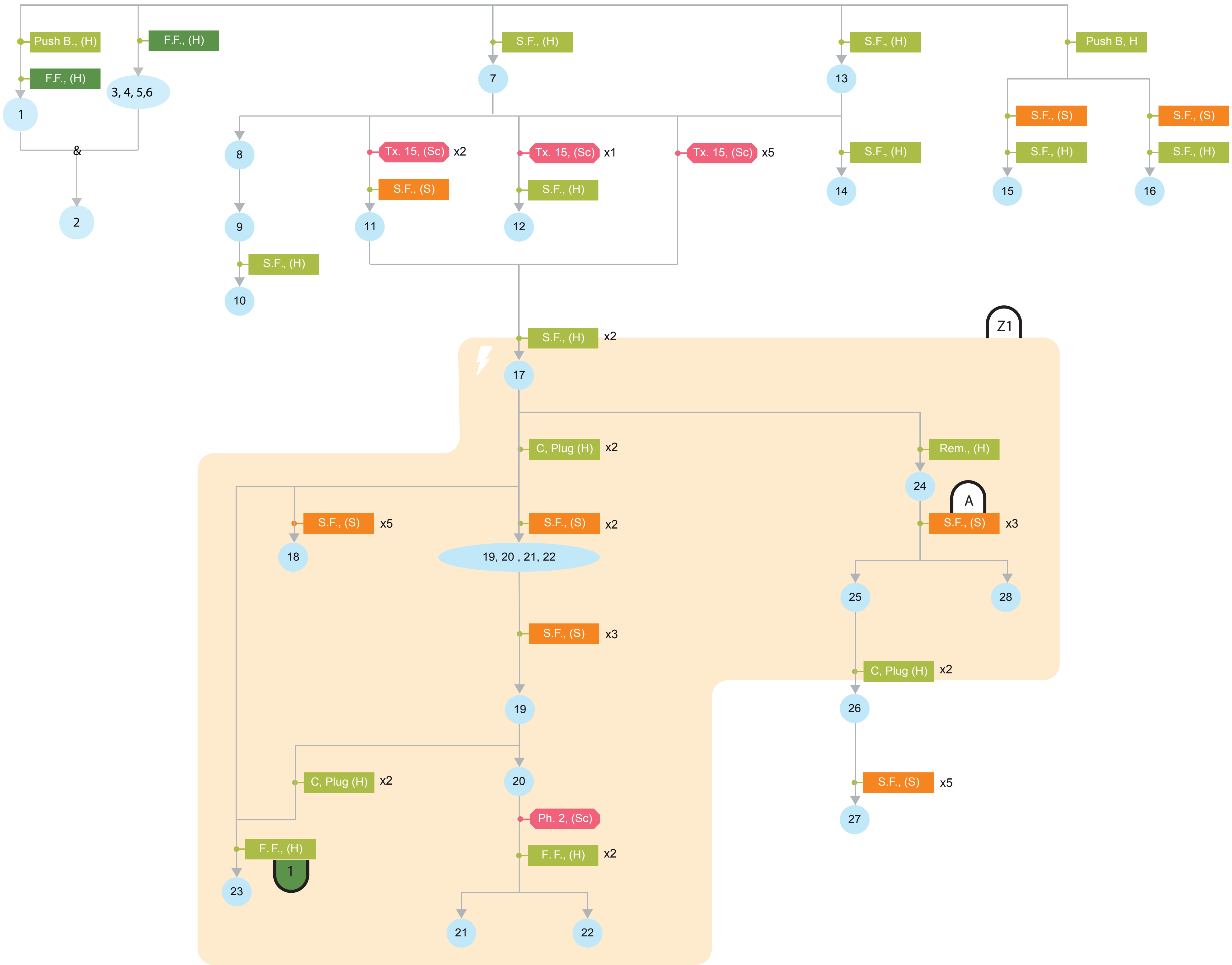
Examples of good design	
1	PCB designed to minimize exposed metal
1	Product archetictures requires the user to disconnect the pcb to get access to the filter cover, exit filter, PCB, motor case, rubber gasket and motor, therefore limiting the risk zone up the caple plugs (1).
2	Compared to the Philips FC8372, disconnecting the power cord rewinnder is safe, because of the insulated connection.

Product Type

Vacuum Cleaner

Product Name

Philips FC8372/09



Components

1-6. Hose components
7. Top Case
8. Bagholder
9. S-bag ultra long performance
10. Triple inlet filter
11. Dust chamber insert
12. Plastic divider
13. Exhaust grill
14. Exhaust filter
15. Cordwinder button
16. On off button
17. Dust chamber
18. Rear wheel left
19. Motor casing lid
20. Rubber Ring
21. Motor
22. Carbon brushes
23. PCB
24. Cord station
25. Cordwinder clip
26. Cordwinder
27. Rear wheel right
28. Rear wheel left

Legend

Tools

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

Connectors

S. F. = Snap Fit
F. F. = Friction Fit
C. P. = Cable plug
Push B. = Push button
Hg = Hinge
Adv = Adhesive
Ho = Hose
Ti = Tightener
Wr = Wrench
Sol. = Soldered

Safety risk zones

= Electrical risk
= Mechanical risk
= Thermal risk
= Chemical risk

Penalties

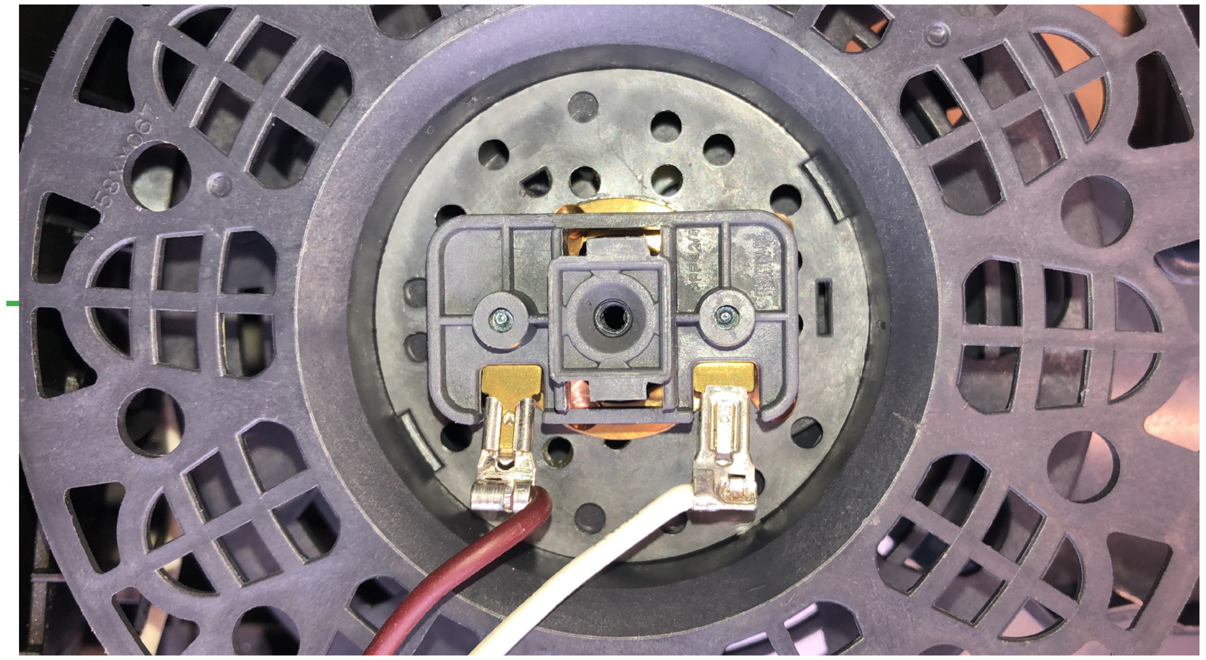
= Product manipulation
= Identifiability (low visibility)
= uncommon tool
= Unreusable connector

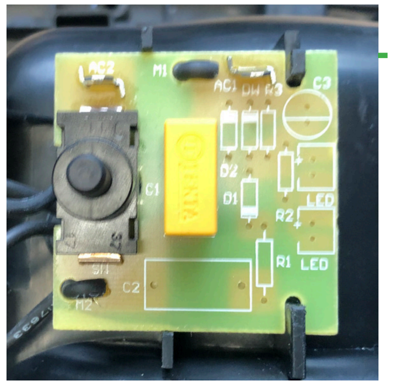
Force intensity

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

Product Type	Vacuum Cleaner	Product Name	Philips FC8372/09

Step / risk area	Disas-sembly / reas-sembly	Action / scenario	Failure mode	Failure effect: During Repair – On prod-uct	Failure effect: During Repair – On person	Failure effect: After repair – On prod-uct	Failure effect: After repair – On person	Sever-ity of injury	Probability of injury: Necessary scenario to enable injury	Probability of injury	Probability of injury: Over-all proba-bility	Risk	Cause	Suggested design solution
Z1	Disas-sembly	Risk of getting electrified	-	-	Electric - Elec-tronic shock	-	-	2	Cable is plugged in Power button is pressed Body making contact with electrified component			2	There are electronic connections which are not completely covered in a non-conducting material	Cover the metal parts of the electric connection with a non-conducting material and exclude as many components from risk zone as possible / Move the wheels out of the risk zone (like in the Samsung SC8835)
A	Disas-sembly / reas-sembly	Higher risk of touching electric connection, as your forced to put your hands close to the electronic connection to remove the cable cord component	-	-	Electric - Elec-tronic shock	-	-	2	Lifting out the cable cord Touching metal connection			2	The electronic connection is not completely covered in a non-conducting material + The electric connection is placed at the location where force is applied	Cover the metal parts of the electric connection with a non-conducting material
B	Disas-sembly	Bruising the body while removing the snap fits	-	-	Mechan-ical - Bruise	-	-	1	Bruising the body while removing the snap fits			1	The 3 snap-fits request a high force	Use snap-fits that require a lower force





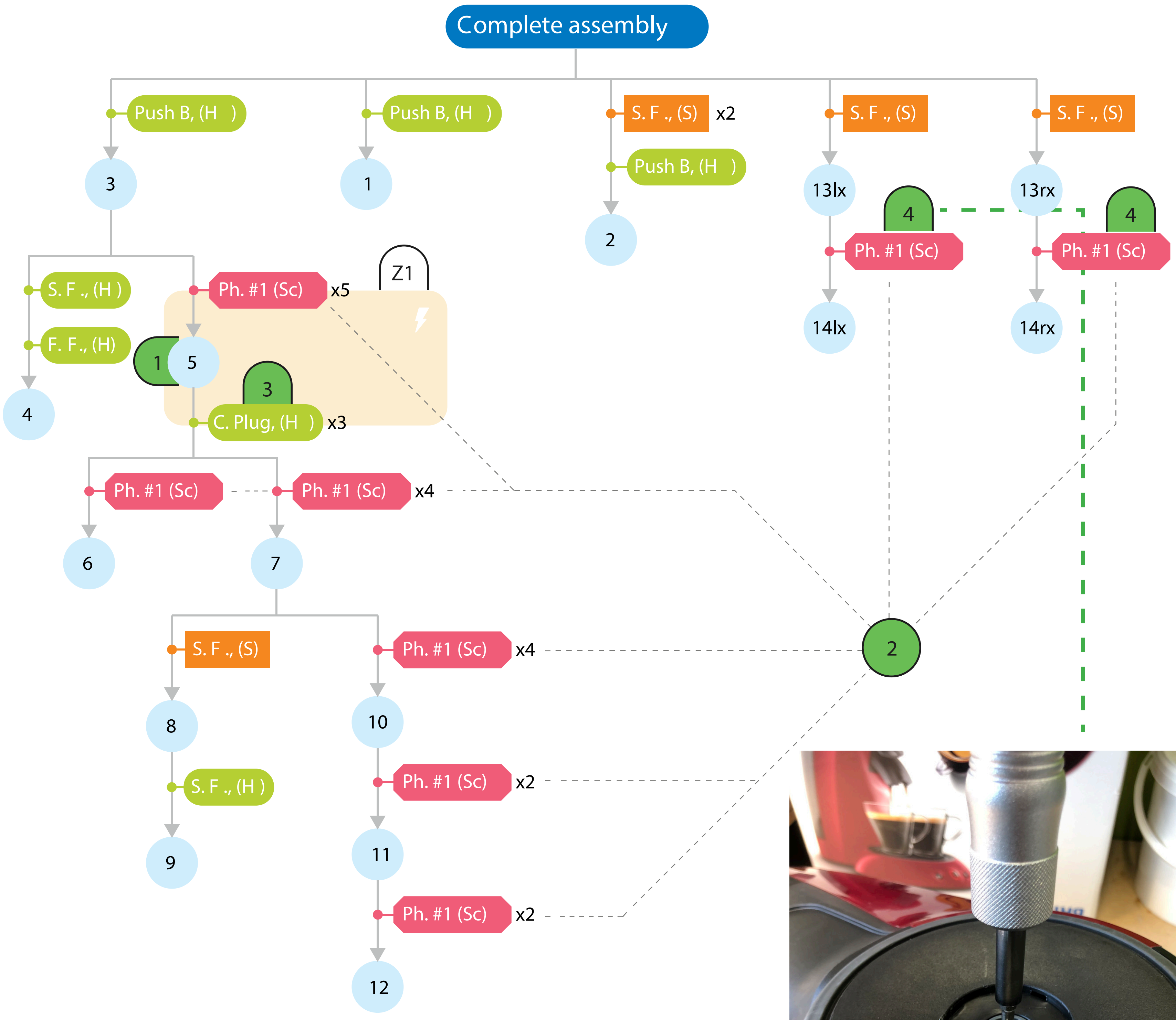
Examples of good design	
1	PCB designed to minimize exposed metal

Product Type

Vacuum Cleaner

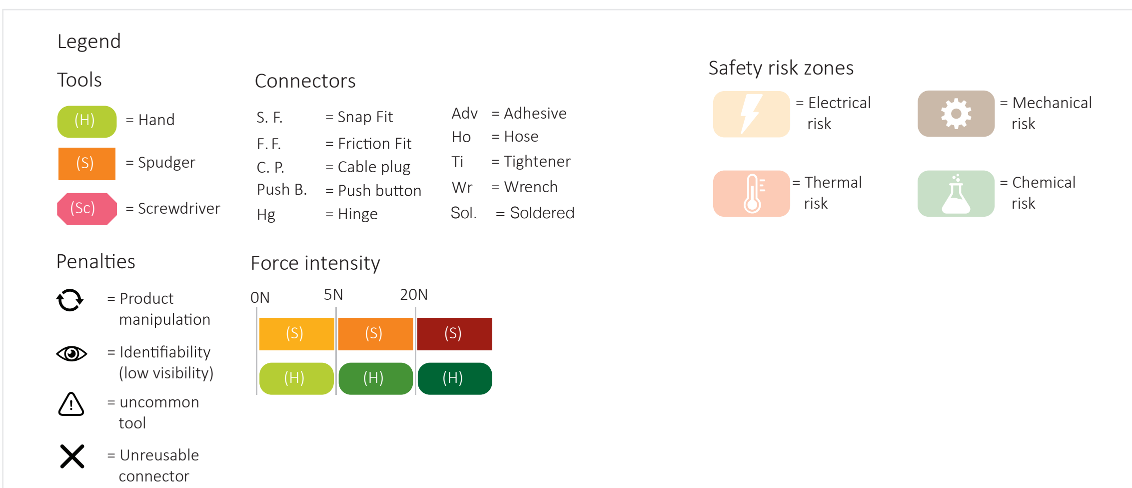
Product Name

Samsung SC8835



Components

1. Nozzle
2. Hose
3. Dust bucket
4. Inlet filter
5. Upper housing clump
6. PCBA and switches
7. Rear housing
8. Cord outlet
9. Cord-winder
10. Motor housing lid
11. Motor
12. Motor brushes
13.rx Wheel cover
13.lx Wheel screw cover
14.rx. Wheel rx
14.lx Wheel lx



Product Type	Vacuum Cleaner	Product Name	Samsung SC8835

Step / risk area	Disassembly / reassembly	Action / scenario	Failure mode	Failure effect: During Repair		Failure effect: After repair		Severity of injury	Probability of injury			Risk	Cause	Suggested design solution
				On product	On person	On product	On person		Necessary scenario to enable injury		Overall probability			
Z1	Disassembly / reassembly				Electric, shock			2	Cable is plugged in			2	After removing the upper housing clump, the user is exposed to electrical components in the PCB	Cover the PCB with a non-conducting cover.
									Power button is pressed					
									Body making contact with electrified component					

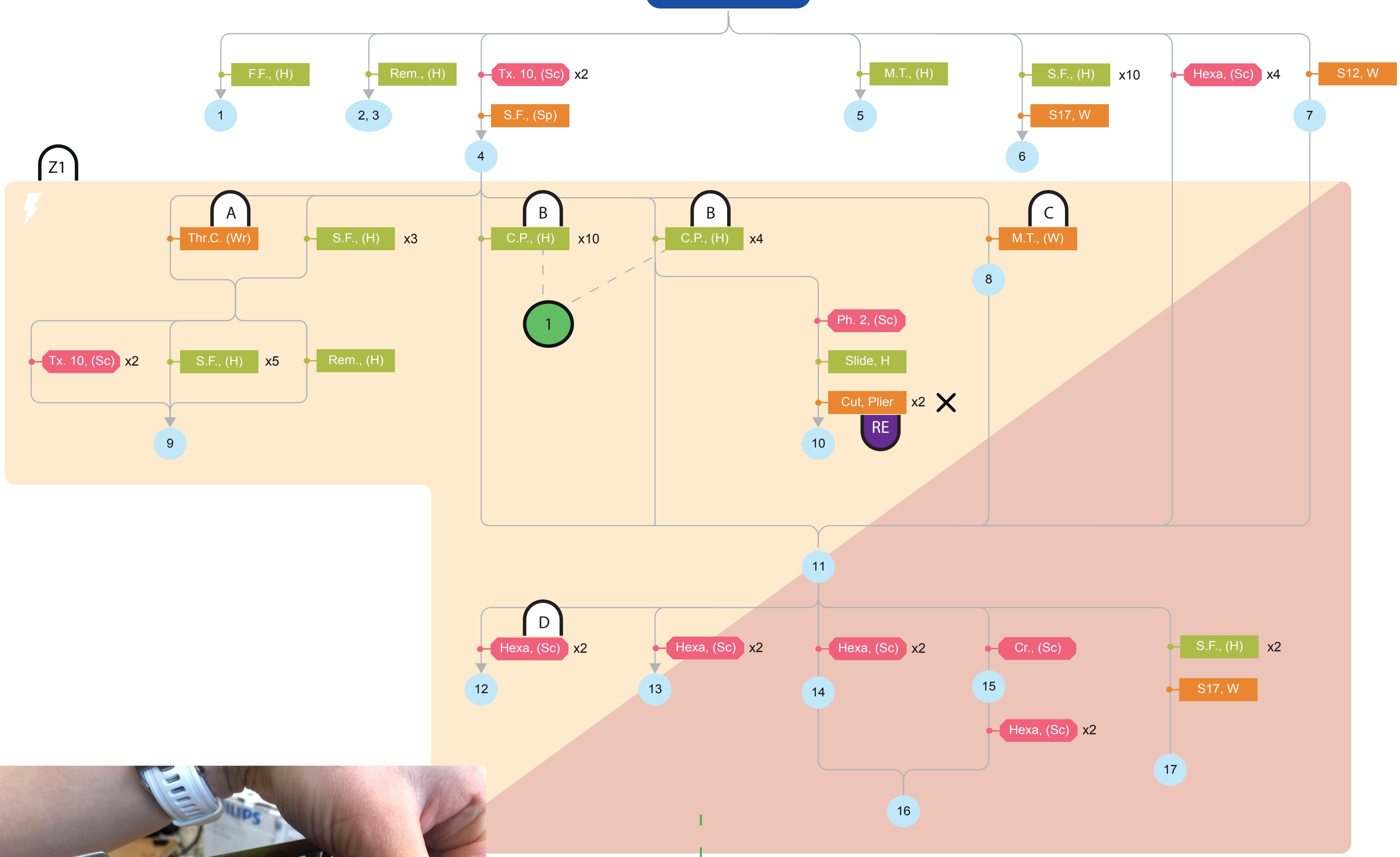
Examples of good design	
1	Indicator warns when the bag is full. Spring element stops the creation of a vacuum, preventing the motor from overheating
2	All screws used in the components designed by Samsung are the same type, and made of a durable metal. Even after multiple disassemblies, none of the screws got blind. Also the plastic didn't get deformed after these multiple dis-assemblies, so a screw-plastic connection does work in this case.
3	Plugs make the design easy and safe to repair. The possibility to get electrified is limited by the plug contact; no loose ends that might electrify the user
4	Screws on the side make the wheels directly accessible. This is a design feature not seen in the other examples of vacuum cleaners

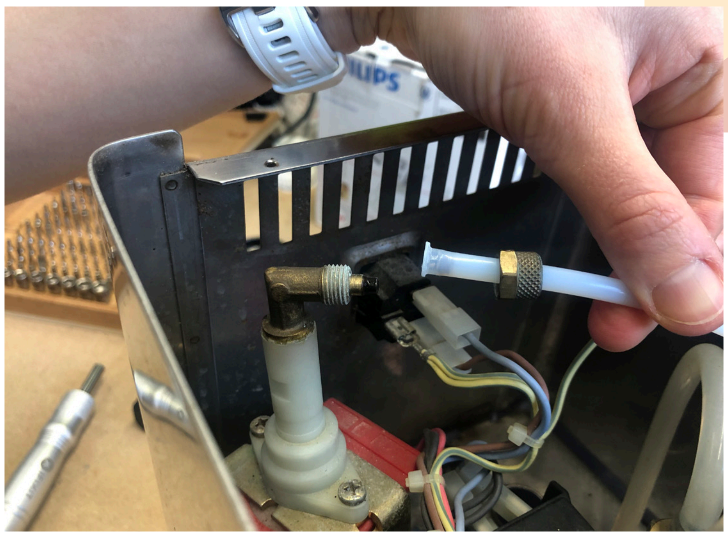
Product Type

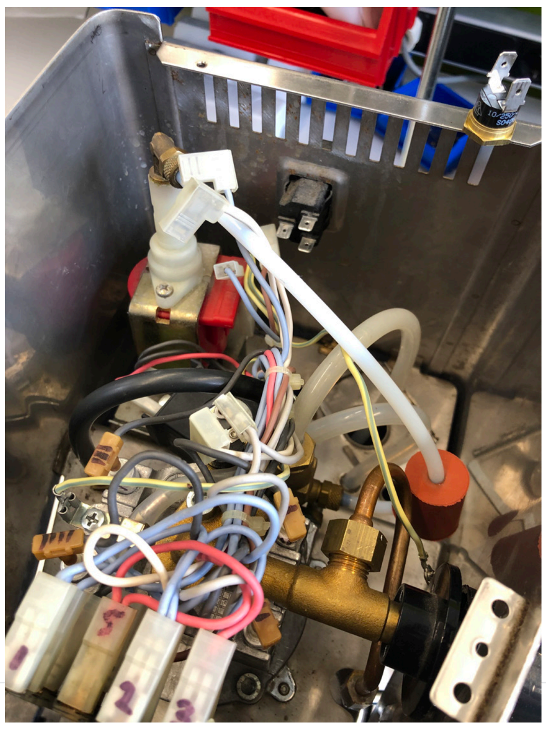
Coffee Maker

Product Name

Classic Gaggia







Components

1. Portafilter
2. Cup pedestral
3. Water holding plate
4. Top lid metal body
5. Mouthpiece milk foamer
6. Steam temperature switch
7. Pressure drainage pipe
8. Milk foamer
9. Water pump
10. Thermal fuse
11. Boiler assembly
12. Safety pressure valve assembly
13. Excess liquid electric valve
14. Top housing boiler
15. Filter
16. Bottom housing boiler
17. Coffee temperature switch

Legend

Tools

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

Connectors

S. F. = Snap Fit
F. F. = Friction Fit
C. P. = Cable plug
Push B. = Push button
Hg = Hinge
Adv = Adhesive
Ho = Hose
Ti = Tightener
Wr = Wrench
Sol. = Soldered

Safety risk zones

= Electrical risk
= Mechanical risk
= Thermal risk
= Chemical risk

Penalties

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

Force intensity

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

Product Type	Coffee Maker	Product Name	Classic Gaggia

Step / risk area	Disassembly / reassembly	Action / scenario	Failure mode	Failure effect: During Repair – On product	Failure effect: During Repair – On person	Failure effect: After repair – On product	Failure effect: After repair – On person	Severity of injury	Probability of injury: Necessary scenario to enable injury		Overall probability	Risk	Cause	Suggested design solution
B	Disassembly	Taking off the cable plugs, and during this action bruising / cutting the body on the metal outer casing			Bruising / Cutting			1	Hitting the metal outer casing with a relatively high force			1	Combination of sharp metal outer casing, and friction fits that require a lot of force, directed at the outer casing edge	Using friction fits that require little force + never direct force at components that have could possibly injure the user
A	Disassembly	Risking spoiling hot water on the body			Scald			2	Repair takes place very short after product was used Water spills on your body when opening the hose			2	Open hose that does not prevent water from coming out + no cover of electric components	Click connection for water hose that prevents water from coming out.
C	Disassembly	Taking off the milk foamer, and during this action bruising / cutting the body on the metal outer casing			Bruising / Cutting			1	Hitting the metal outer casing with a relatively high force			1	Combination of sharp metal outer casing, and a wrench connection that uses a lot of force, directed at the outer casing edge	
D	Reassembly	Disassembling the valve				Explosion (of the boiler)	Eye injury, cut, burn, scald	3	Taking the safety pressure valve apart during disassembly (which is not a priority part, and not needed to reach priority parts.) Not properly reassembling the safety pressure valve during re-assembly			3	It is not explicitly stated on this component that it is NOT meant to be removed by unprofessional repairers.	Make it impossible to create a situation where the component malfunctions / state clearly on the component not to remove it
Z1	Disassembly	Risk of getting electric shock from one of the metal components by revealed by removing the top lid					Electrical, shock		Leaving the plug in and opening the lid				The connecting plugs where the power cable goes in are exposed with no insulating material	Design the connection in such a way that the metal parts are not able to contact the human body of the user
Z1	Disassembly	Taking out the boiler when it is still hot	-		Extreme temperature - Scald			1	Repair takes place so shortly after product was used that the boiler is still dangerously hot Hands make contact with hot surface			1	The boiler is not insulated, and can therefore exchange heat	Warn the user about the temperature of the boiler

Examples of good design	
1	Plastic connection covers on all connectors prevent the metal in the connection from touching the metal casing of the coffeemaker, therefore eliminating the chance of getting electrified. Recommendation: if the outer body of a product contains conductive materials, make sure the electronics can never connect with these conductive materials to prevent the user from getting electrified

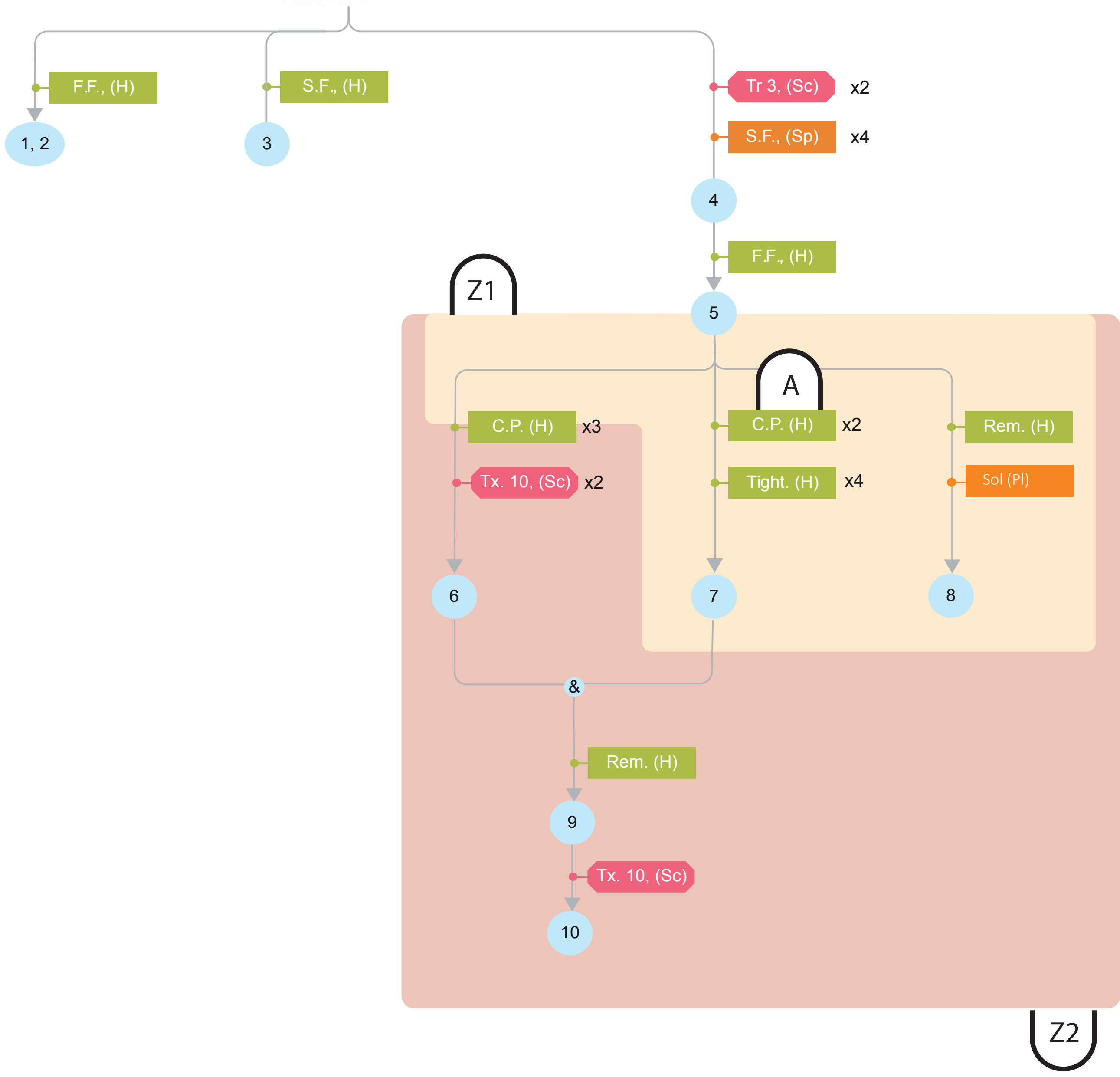
RE	Reassembly insight	As during disassembly a cut of the wiring takes place, re-assembly using the disassembly map is not an option here. The re-assembly takes the steps of inserting extra connectors or soldering the wires to each other

Product Type

Coffee Maker

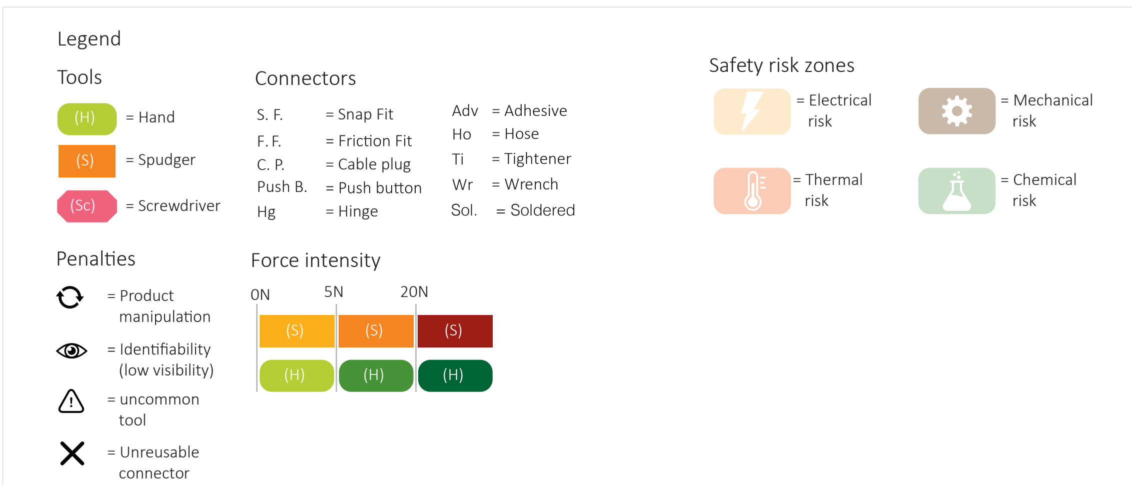
Product Name

Philips Aroma Swirl



Components

1. Coffee jar
2. Coffee jar lid
3. Filter holder
4. Main body, bottom lid
5. Main body
6. Button (on/off) assembly
7. Hoses
8. Fuse
9. Heating element
10. Heating plate



Product Type	Coffee Maker	Product Name	Philips Aroma Swirl

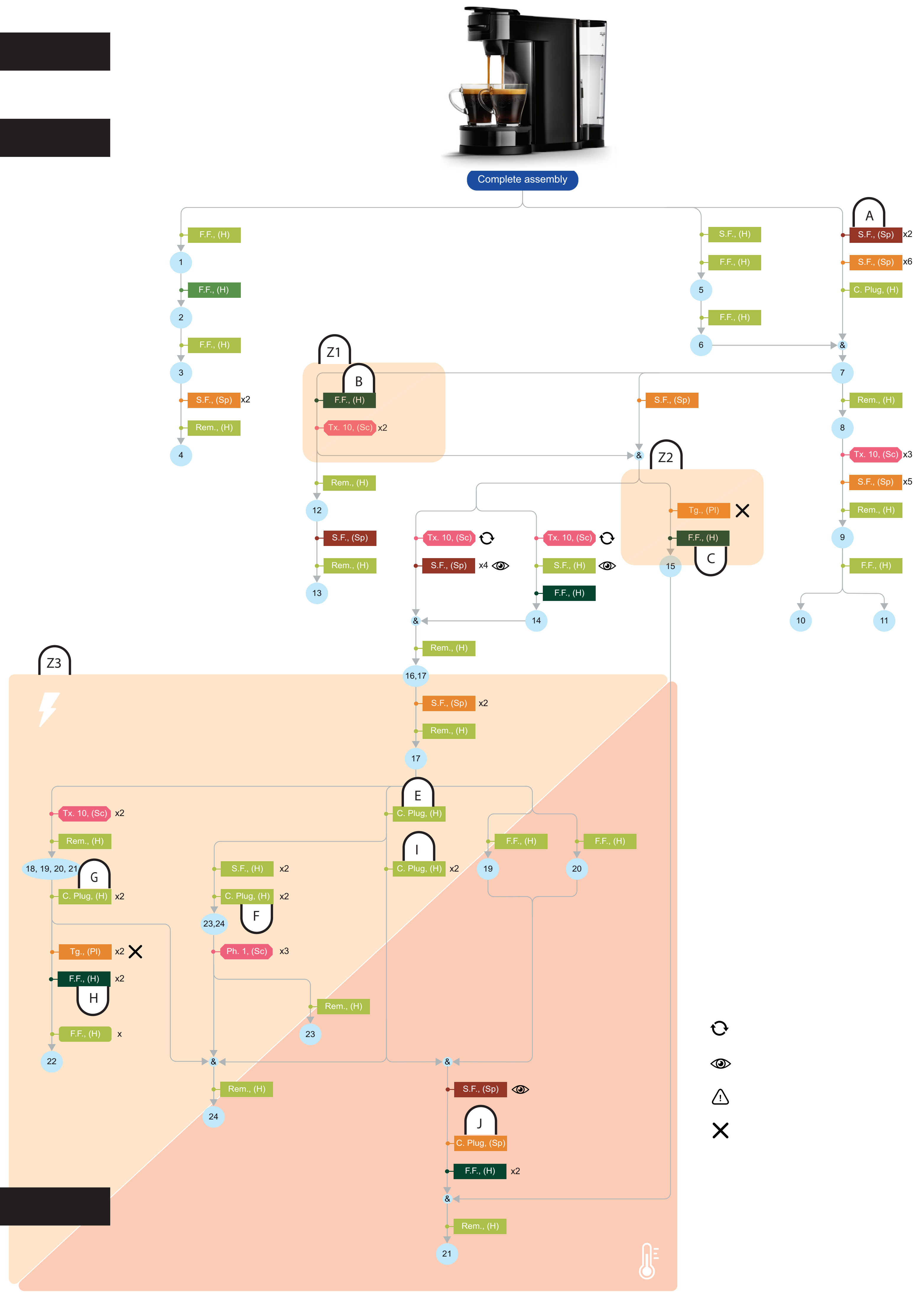
Step / risk area	Disassembly / reassembly	Action / scenario	Failure mode	Failure effect: During Repair – On product	Failure effect: During Repair – On person	Failure effect: After repair – On product	Failure effect: After repair – On person	Severity of injury	Probability of injury: Necessary scenario to enable injury	Probability of injury: Chance	Probability of injury: Overall probability	Risk	Cause	Suggested design solution
Z1	Disassembly	Risk of getting electrisc shock from one of the metal components by revealed by removing the bottom lid	n/a		Electrical - Electric shock			2	leaving the power button on leaving the plug in user not using an earthed socket touching conducting component			2	When the power button is left on and the plug left in, the user is exposed to many different metal elements, such as the heating element and heating plate.	Cover the metal parts of the electric connection with a non-conducting material and exlude as many components from risk zone as possible; in this case the heating element and the heating plate
Z2	Disassembly	Risk of getting burned by touching the heating element / heating plate				Extreme temperature - Scald		1	repair takes place so shortly after product was used that the boiler is still danergously hot hands make contact with hot surface			1	The boiler is not insulated, and can therefore exchange heat	Warn the user about the temperature of the boiler
A	Disassembly	Opening the hose when there is still (hot) water inside		-	Extreme temperature - Scald			1	repair takes place very shortly after product was used water spills on your body when opening the hose			1	open hose that does not prevent water from coming out + no cover of electric components	click connection for water hose that prevents water from coming out.
A	Re-assembly	The hose is not properly re-assembled, disconnecting after repair	leakage of water in product > Short circuit			Failure - Fire	Thermal - burn	4	Not putting the hose back tight enough Water leakage causes a short circuit Short circuit causes fire			4	no clicking or other indication saying when the hose is properly in + zipties cannot be put back in place	Make correct water-tight reassembly of water hoses easy and intuitive by, e.g., using reusable tighteners, hoses with sealing caps

Product Type

Coffee Maker

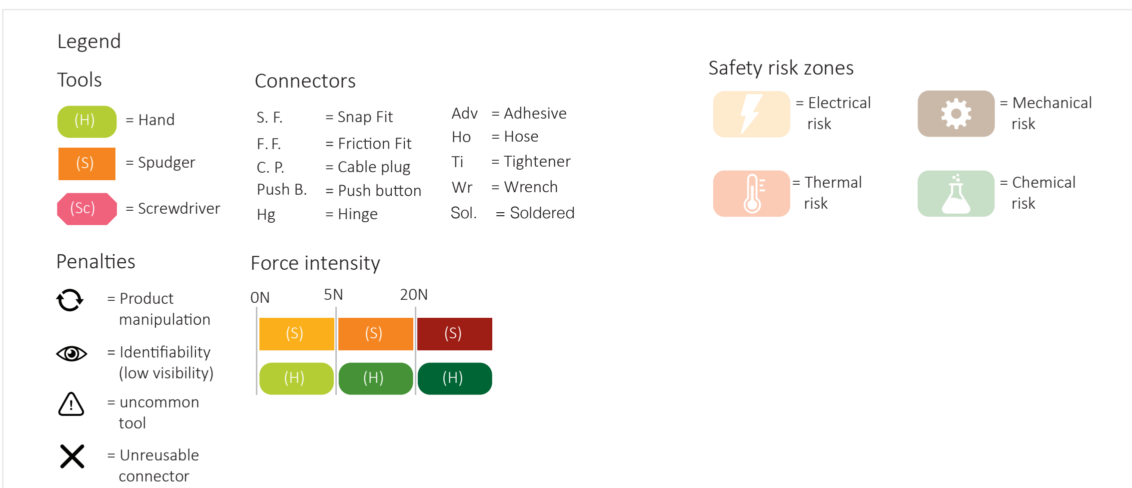
Product Name

Philips Senseo Switch



Components

1. Water container
2. Float spring
3. Float assy
4. Float magnet
5. Pad holder
6. Top collector
7. Top cover assy
8. UI plastic buttons
9. UI top housing
10. UI bottom housing
11. UI PCBA
12. Brew chamber assy
13. Brew chamber seal
14. Back plate assy
15. One way valve
16. Housing sensor
17. Housing
18. Inner frame
19. Boiler pin cover 1
20. Boiler pin cover 2
21. Boiler assy
22. Pump
23. Dissipator
24. Main PCBA



Product Type	Coffee Maker	Product Name	Philips Senseo Switch

Step / risk area	Disassembly / reassembly	Action / scenario	Failure mode	Failure effect: During Repair – On	Failure effect: During Repair – On person	Failure effect: After repair – On product	Failure effect: After repair – On person	Severity of injury	Probability of injury: Necessary scenario to enable injury		Overall probability	Risk	Cause	Suggested design solution
A	Disassembly	Opening top lid snap fits	n/a		Mechanical - Pinch			1				1	Low visibility, a lot of force needed	Click-and-open snap fits that are visible
Z3	Disassembly	Risk of getting electrified, by removing the main housing while the plug is still in	n/a		Electrical - Electric shock			2	Leaving the plug in Touching conducting component			2	There is always electricity going to the main board if the plug is in, i.e. no switch.	
E	Reassembly	Forgetting to reconnect the temperature sensor (white cable)				Either the coffee is cold, or no coffee at all		-	-			-		
Z1	Disassembly	Opening the hose when there is still (hot) water inside		-	Extreme temperature - Scald			1	Repair takes place very short after product was used Water spills on your body when opening the hose			1	Open hose that does not prevent water from coming out	Click connection for water hose that prevents water from coming out.
B	Disassembly	Opening the hose when there is still (hot) water inside	Short circuit		Electrical - Electric shock			2	Water spills on electric components You touch a part that was made conductive from the water			2	Open hose that does not prevent water from coming out + no cover of electric components	Click connection for water hose that prevents water from coming out.
Z2	Disassembly	Opening the hose when there is still (hot) water inside		-	Extreme temperature - Scald			1	Repair takes place very short after product was used Water spills on your body when opening the hose			1	Open hose that does not prevent water from coming out	Click connection for water hose that prevents water from coming out.
C	Disassembly	Opening the hose when there is still (hot) water inside	Short circuit		Electrical - Electric shock			2	Water spills on electric components You touch a part that was made conductive from the water			2	Open hose that does not prevent water from coming out + no cover of electric components	Click connection for water hose that prevents water from coming out.

				Failure effect					Probability of injury					
Step / risk area	Disassembly / reassembly	Action / scenario	Failure mode	During Repair		After repair		Severity of injury	Necessary scenario to enable injury			Risk	Cause	Suggested design solution
				On product	On person	On product	On person							
Z	Disassembly	Taking out the boiler when it is still hot	-		Extreme temperature - Scald			1	Repair takes place so shortly after product was used that the boiler is still dangerously hot Hands make contact with hot surface			1	The boiler is not insulated, and can therefore exchange heat	Warn the user about the temperature of the boiler
E, I, J, G, F	Reassembly	Swapping connectors in a way a short circuit is created	Short circuit			Failure - Fire	Thermal - burn	4	Connecting the cables in such a way that causes a short circuit			4	There are many cables with the same connections and color The high volt connections have metal endings, which when can touch the outer washing machine casing if the cable is left disconnected inside the machine by accident	Design a differently shaped and colored connection for ground and high voltage wires Do not use uninsulated cable plugs for high voltages Do not use an outer casing created from a conductive material
C, H, K, B	Reassembly	The hose is not properly reassembled, disconnecting after repair	Leakage of water in product > Short circuit			Failure - Fire	Thermal - burn	4	Not putting the hose back tight enough Water leakage causes a short circuit Short circuit causes fire			4	No clicking or other indication saying when the hose is properly in + zip-ties cannot be put back in place	Make correct water-tight reassembly of water hoses easy and intuitive by, e.g., using reusable tighteners, hoses with sealing caps
G	Reassembly	Forgetting to connect connectors / swapping connectors	Pump won't function			No ability to move water through the coffee machine			Forgetting to connect connectors / swapping connectors				No indication mentioning how the wires should be connected	Use colored connections / connections with indicators
C	Reassembly	The one-way-valve is reassembled in the wrong direction	High pressure - leakage - Short circuit			Failure - fire	Thermal - burn	4	Reassembling the one-way valve in the opposite direction			4	The valve will not let water through in the other direction, causing leakage (as leakage is more likely than the boiler exploding	Use different sized hoses to prevent reassembling in the wrong position