Redesign of a coffee machine for repair safety

Master Thesis

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Foreword

Before introducing the project, I would like to thank everyone who has helped or supported me during my thesis and the last two years. First, I would like to thank my supervisors for giving me the opportunity to contribute to the topic of repair. Thank you, Ruud, for always pushing me to think beyond my comfort zone and for your critical and actionable feedback over the last five months. Your insights helped shape the project and ensured that I didn't lose track of the goal. Thank you, Julieta, for always being available to discuss the smallest of details and knocking sense into me when I was (often) stubborn. I could openly voice my concerns and ideas, knowing that I would not be judged.

I would like to thank my friends, who I could rely on for support. The last two years would not have been as much fun, and I definitely would not be the designer I am today if I hadn't had you all to learn from and grow with.

Finally, I would like to thank my mom and sister, who made it possible for me to make my dream of pursuing design a reality. Thank you for your patience and unwavering support and for having faith in me and my choices, even when I didn't.

ABSTRACT

The growing volume of electronic waste highlights the need for sustainable product life extension strategies, such as repair. While repair is a high-value circular economy strategy, safety concerns prevent consumers with minimal repair experience (non-professional repairers) from engaging in at-home repairs. Prior research has identified these risks in consumer electronics but has not yet developed or tested design interventions aimed at mitigating them. This thesis addresses that gap by exploring how design can make consumer products safer to repair for non-professional repairers, using a coffee machine as a case study. The coffee machine was chosen as it is a commonly repaired product having a range of safety hazards.

First, two coffee machines were disassembled and reassembled in a controlled setting. Risks observed were divided repair and post-repair risks. They were further segregated according to their type and assessed using RAPEX guidelines to determine their severity. These were documented using the modified disassembly map, allowing for a visual representation of risk zones and steps across the repair process. Based on this analysis, eight high-priority risks were identified. These were used to formulate a program of requirements for design interventions and to guide ideation. A series of creative sessions produced a broad set of ideas, which were clustered into solution spaces. Ideas were then qualitatively assessed, leading to the selection of one idea per risk for further development.

The selected ideas were incorporated into a prototype of a redesigned coffee machine and evaluated through functionality tests and user validation. The tests aimed to assess whether the ideas performed as intended and if they improved safety during repair. Results showed that certain interventions such as a power interlock switch, a program to empty residual water, and the use of colour-coded wires and hoses effectively reduced the likelihood of the identified risks. On the other hand, features like the thermal locking mechanism using a bimetal strip and the use of warning indicators on the product, showed potential but required further refinement to be more effective.

The applicability of these ideas to other coffee machines and consumer electronics was also discussed, highlighting how similar risks and product architectures make them suitable for adaptation. The final chapter reflects on the overall process, noting that beyond individual interventions, the structured design approach adopted in this thesis provides a transferable methodology for incorporating repair safety into future product development. In doing so, this thesis offers a starting point for designers aiming to support safer, user-led repair practices in a repair conscious product landscape.

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CHAPTER 01

INTRODUCTION

The first chapter provides context to the project, highlighting its relevance to the circular economy and the gaps in existing research that the project aims to explore. These gaps are used to define the study's goal, introduce the research questions that will be investigated, and the method employed to address them.

1.1 The relevance of repair safety

In 2022, an estimated 62 million metric tons of e-waste was generated globally. Only 22.3% of this was documented as formally collected and recycled (Cornelis et al., 2024). This plastic generation is a product of the linear 'take, make, use, waste' industrial system prevalent today (Ellen MacArthur Foundation, 2013). To solve this issue, the Circular Economy (CE) has been promoted in recent years, focusing on retaining value throughout the product's lifecycle by addressing inefficiencies in material and energy loops (Geissdoerfer et al., 2016). The CE system provides various avenues to retain resources within the value chain, including repair, refurbishment, and recycling, among others (Figure 1). However, policymakers and businesses have noted that some strategies have a higher potential for success in practice, for example, strategies like repair (Reike et al., 2017).

Repair is considered a high-value strategy because it sustains and extends the lifespan of products, thereby preventing resource depletion and diversion of material to landfills and incinerators (Interreg Europe, 2022). It is also one of the strategies that the consumers can actively engage in through various degrees. However, barriers exist that make it difficult for the consumer to explore this avenue. One such significant barrier is the safety risk associated with performing at-home repairs (Lefebvre, 2019).

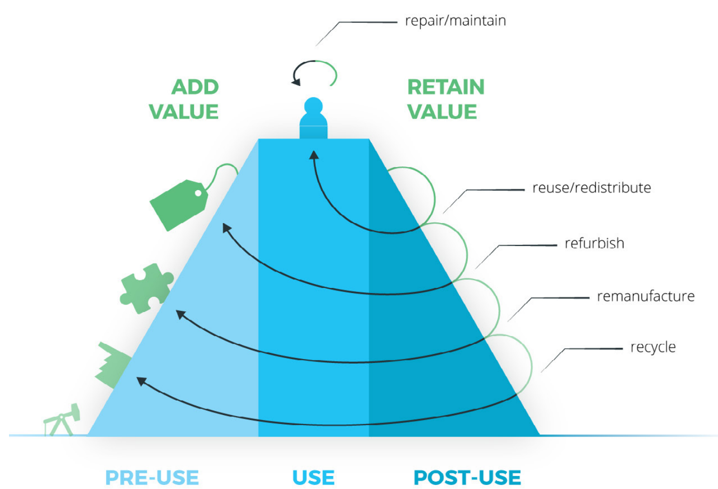


Figure 1: The Value Hill (Achterberg et al., 2016)

1.2 Existing research & gap

Despite awareness of this barrier, research on steps to mitigate it is scarce. Preliminary work in this regard was conducted by Bolanos Arriola et al. (2019) where they identified the safety risks associated with repairing coffee makers and vacuum cleaners, presented a method for product designers to visualise and identify these safety risks, and tested the extent to which information dissemination made self-repairs safer (during and post-repair). As part of their study, they extended the Disassembly Map (De Fazio, 2019) - a design tool that illustrates the disassembly process and helps visually represent product architecture - to create the Modified Disassembly Map (Figure 2). The Modified Disassembly Map utilises the disassembly map as a base to visually denote the risks associated with both the disassembly and reassembly steps. These risks were further defined based on their types,

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

They also categorised the risks based on when they are encountered - during repair due to disassembly actions or post-repair caused by repair procedures that are not completed correctly. For example, in the study they found that post-repair risks were associated with the reassembly of connectors, hoses, and housing elements. Here, the reliance on memory and the absence of necessary information presented an opportunity for mistakes that could lead to post-repair risks. Finally, they noted that the presence of a safety manual did not have an important positive effect on safe repair and proposed investigating alternative methods for delivering this information.

Another study in this field was conducted by Ingemarsdotter et al. (2021), which focused on further detailing the visualisation of risks, developing a risk assessment framework for repair risks, and providing design recommendations to address the identified risks. The study expanded on the modified disassembly map developed by Bolanos Arriola et al. (2019) by adding the following modifications (also shown in Figure 2),

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

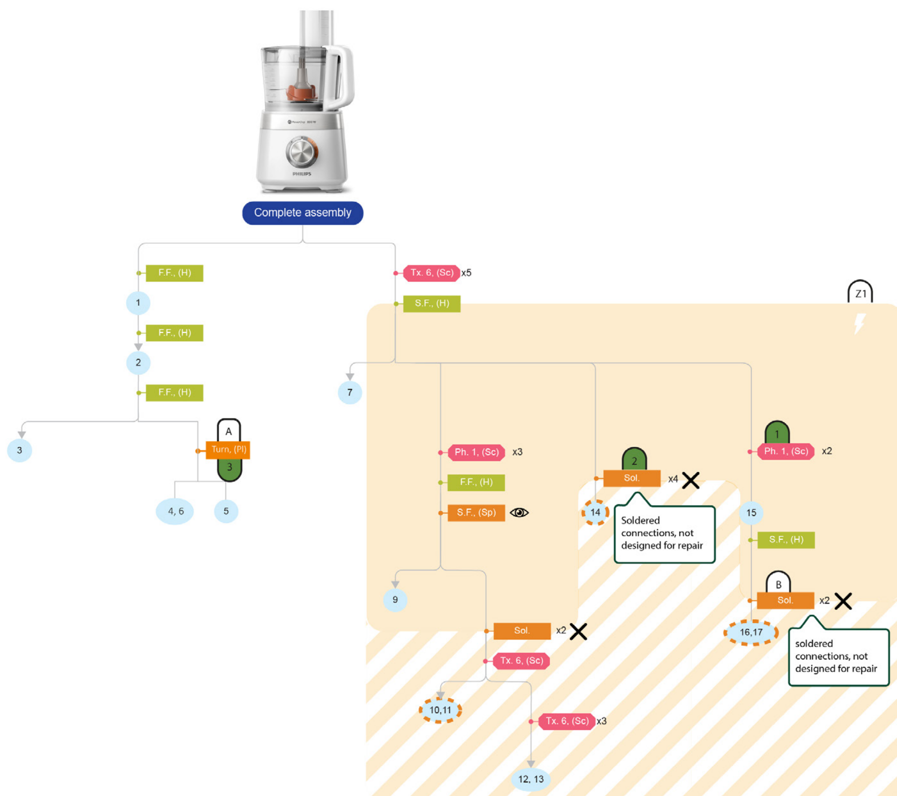


Figure 2: The modified disassembly map as developed by Bolanos Arriola et al. (2019) and expanded by Ingemarsdotter et al. (2021)

This expanded disassembly map was then used in the analysis of five common consumer products, where the researchers observed that a number of repair actions were already safe to perform. In contrast, others could be made safe with small design changes. A risk assessment framework was also developed to structure the observed risks and quantify them, facilitating comparison between products from a repair safety perspective. However, they were unable to reliably estimate the probability of the injury scenarios. Thus, the severity of the risks was used to determine the total risk for a particular hazard.

While the studies provided a structured approach to identifying the safety risks that are encountered during and post-repair of a consumer product and estimating their severity, the following gaps still exist to be explored,

- Embodiment design of safe-to-repair solutions for non-professional repairers applied to consumer electronics
- Evaluating the effectiveness of the solutions in reducing the risks observed

1.3 Project goal & scope

Considering the gaps in knowledge, this thesis aims to identify design-related safety issues for a consumer product taken as a case and redesign it to make it safe for non-professional repairers to perform at-home repairs.

With the goal defined, the following research questions were developed:
1. What design features make a product unsafe for repair?
2. Which design features mitigate potential safety risks?

For this thesis, the coffee machine was chosen as the product to be investigated, as it was the most frequently repaired product in the EU and the second most frequently repaired product in the world in 2024 (Figure 3). Coffee machines also pose multiple safety hazards due to the combination of electromechanical systems, a water system, and a heating element. This enables us to examine various types of safety risks (Bolanos Arriola et al., 2019).

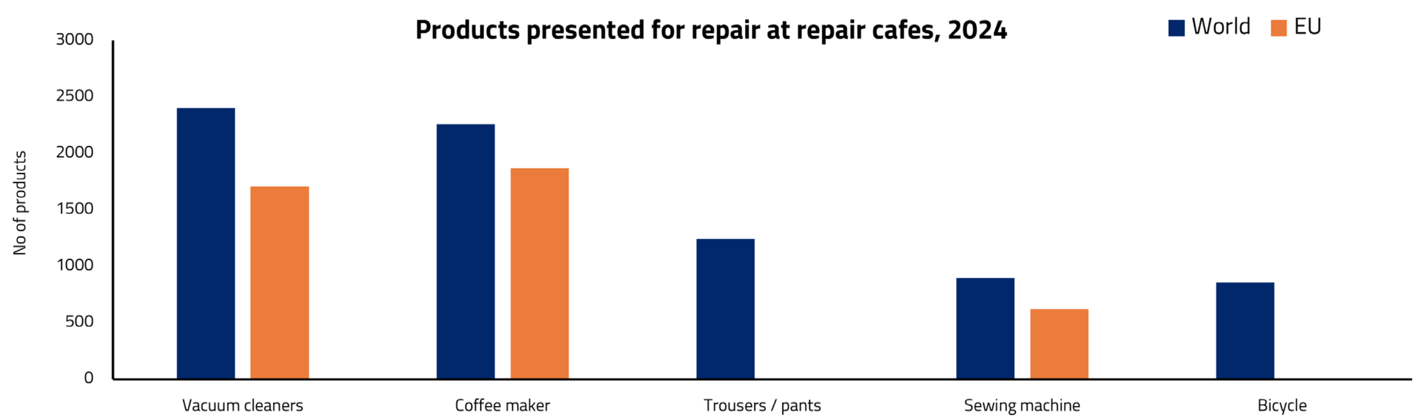
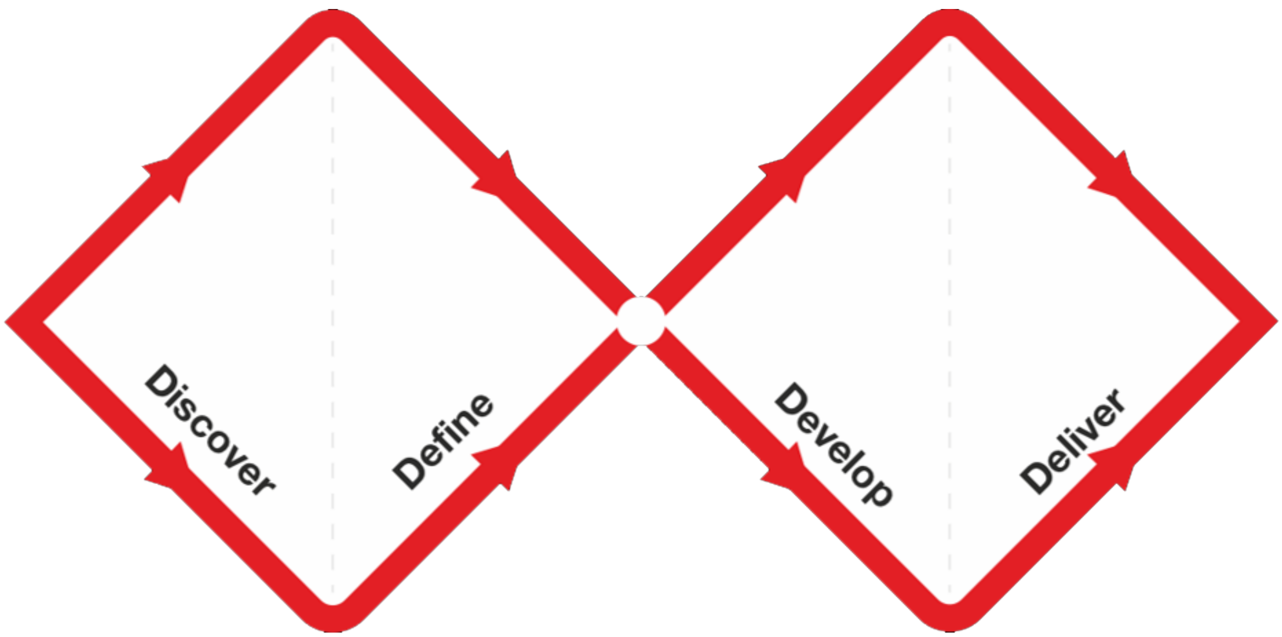


Figure 3: Repair Monitor data for products presented for repair, 2024 (Dashboard Repairmonitor, 2025)

Next, for the context of this investigation, a few terms are defined which are relevant to safe repair. First, non-professional repairers are defined based on Bolanos Arriola et al.'s (2019) study: "Those who do not have sufficient technical knowledge to complete a repair task without risks and who are not aware of possible post-repair consequences". Second, this study considers several types of risks as defined by Bolanos Arriola et al.'s (2019) study (see Section 1.2).

1.4 Project approach

To answer the research questions, a double diamond approach (Design Council UK, 2005) was employed (Figure 4). During the analysis phases, two coffee machines, the Magimix Citiz and Senseo Quadrante, were disassembled and reassembled. All the associated risks were identified for these activities and were prioritised based on their severity. A program of requirements was created based on this analysis, which was used later in ideation. Ideas were generated for each prioritised risk and grouped into solution spaces to arrive at concepts for a safe-to-repair coffee machine. Ideas were selected for each risk across these concepts, which were prototyped and tested. The purpose of the tests was to evaluate if the ideas performed as intended. Finally, the test results were discussed, elaborating on the success or failure of the ideas to perform as intended. Based on this, future opportunities for improvement and the applicability of the ideas in other consumer electronic products was discussed.



- Product teardown
- Modified disassembly map
- Risk assessment

- Design takeaways
- Design vision
- Program of requirements

- Ideation
- Morphological chart
- Concept generation & idea selection

- Embodiment design
- Prototyping
- Functional & user testing

Figure 4: Double diamond (Design Council UK, 2005) approach utilised for the project

Also shown is a mapping of the outlined approach to the research questions (Table 1), highlighting the expected result for each question,

Table 1: Research question vs Method

Research question	Method	Result
What existing design features make a product unsafe for repair?	Product teardown, Modified disassembly mapping, Risk assessment framework	Table linking design features to the risk it exposes the user to. Risks are evaluated using the RAPEX guidelines
Which design features mitigate potential safety risks?		

The next chapter is dedicated to the research questions, detailing the procedure employed to answer them and the subsequent result.

CHAPTER 02

ANALYSING COFFEE MACHINES FOR REPAIR SAFETY RISKS

In this chapter, the design features that contribute to unsafe and safe repair of the Magimix Citiz and Senseo Quadrante coffee machines are identified. The specific methods employed for this analysis and the subsequent results are presented. The chapter concludes with a discussion comparing the two coffee machines and identifying general design takeaways that will be applied in the ideation phase.

2.1 Method for risk identification

To help in the risk identification, the following procedure was followed,

1. Product architecture analysis
   The two coffee machines (Figure 5) were disassembled and reassembled using the same setup.

Figure 5: Coffee machine disassembled for the testing

The products were placed on a table with one to two cameras recording the process (Figure 6). In the case where two cameras were used, software was employed to simultaneously record both video streams and merge them into a single video file. One camera was always placed on one side of the product, and the other, when utilised, was placed above.

Figure 6: Setup to capture disassembly and reassembly steps

With the help of the recording, repair risks and post-repair risks observed during the product disassembly and reassembly were documented in Table 2. In the table, each risk was characterised based on their nature – mechanical, electrical, thermal or chemical. The risk was also linked to the design feature of the product responsible for it. Columns were added to the table to record the severity level and risk priority level of these risks. These were determined in the next step using the RAPEX guidelines.

Table 2: Format of the table used to capture design features leading to risks

No.	Risk zone/step	Observed design feature	Image	Why is it problematic	Risk type	Severity level	Rationale for Severity	Risk priority level (RAPEX)

The product also had design features implemented to mitigate risks. These were documented with the help of a second table (Table 3). The table noted the implemented design feature, its benefits from a repair safety perspective, and the risk it avoided.

Table 3: Format of the table used to capture design features that help mitigate risks

No. and Disassembly map code	Observed design feature	Image	Why is it a good design feature	Risk avoided

2. Severity of identified safety risks
   For each safety risk identified in Step 1, the severity level was defined by estimating the potential harm caused by the risk. This was done based on the RAPEX guidelines (Figure 7) and added to the

Severity of harm			
Severity level	**Injury**	**Harm (abstracted)**	**Risk priority level**
1	Injury or consequence that after basic treatment (first aid, normally not by a doctor) does not substantially hamper functioning or cause excessive pain; usually the consequences are completely reversible	Negative effect, usually completely reversible within the short term without specialist intervention.	Low
2	Injury or consequence for which a visit to A&E may be necessary, but in general, hospitalisation is not required. Functioning may be affected for a limited period, not more than about 6 months, and recovery is more or less complete	Negative effect, reversible within a certain period, specialist intervention is required.	Medium
3	Injury or consequence that normally requires hospitalisation and will affect functioning for more than 6 months or lead to a permanent loss of function	Significant negative effect only in the longer term, significant effort to reverse by specialist intervention, irreversible without this intervention and effort.	High
4	Injury or consequence that is, or could be, fatal, including brain death; consequences that affect reproduction or offspring; severe loss of limbs and/or function, leading to more than approximately 10 % of disability	Large negative effect15, irreversible in several aspects, whether or not acute.	Serious

Figure 7: RAPEX guideline for determining severity of harm

table described above. The severity level was used as a metric to prioritise the risks (Figure 7). This information was added to the last column of the table. It was used to shortlist the risks that had to be mitigated through design interventions.

3. Mapping repair risks on the disassembly map
   Using the table and the video recording, the modified disassembly map (as presented by Bolanos Arriola et al. (2019) and Ingemarsdotter et al. (2021)) was created to visualise the product architecture, risk zones, risk steps and design features that support safe repair. The risk zones, risk steps and design features supporting safe repair had an identification codes in the disassembly map, that was added to the table from Step 1 for reference.

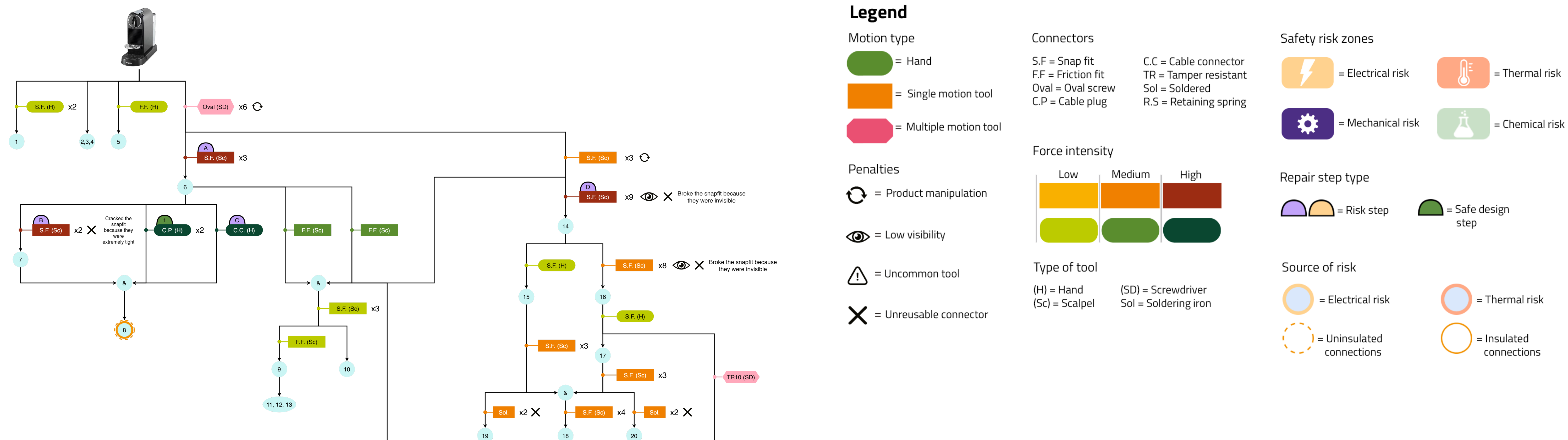
2.2 Results of risk identification

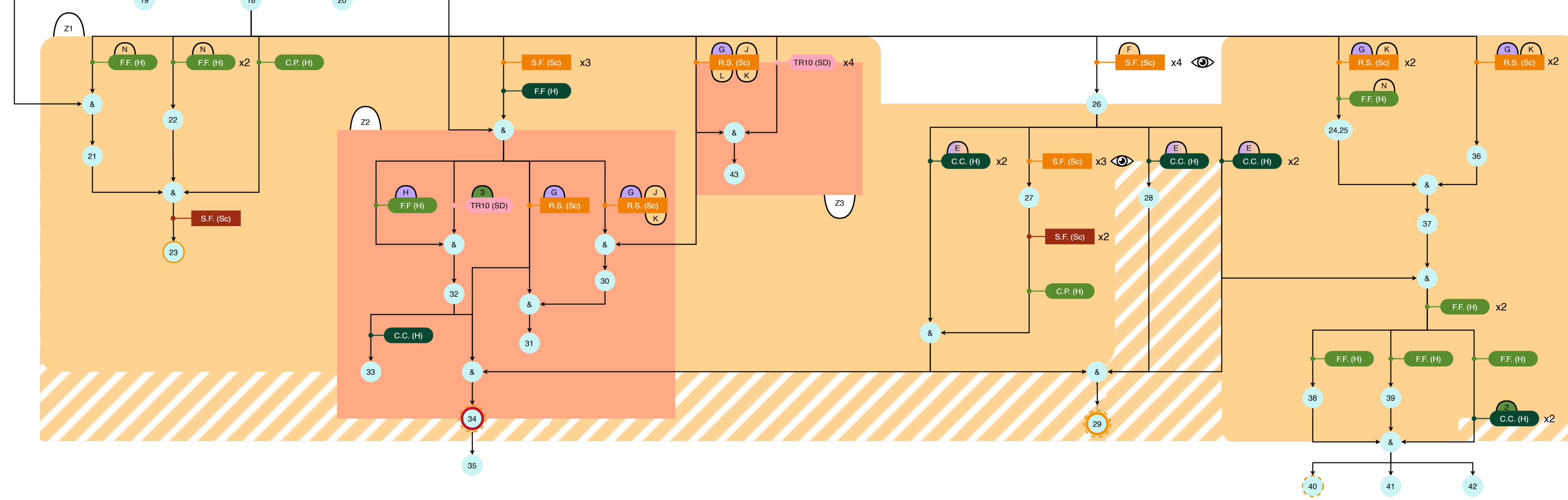
2.2.1 Magimix Citiz

Figure 8 illustrates the outcome of the product architecture analysis and risk assessment, presented in the form of a Modified Disassembly Map. The map highlights the identified safety risks, which are explained below,

1. One electrical risk zone is highlighted in yellow. The exposed uninsulated connectors inside the product cause this. The user is exposed to the risk once the “Top & back cover” is taken out.
2. Often, hidden snap fits broke during disassembly. This is important from a safety perspective because it could lead to the risk of creating gaps when the parts are reassembled. These gaps could expose the internal components to water, dust and other environmental contaminants, which could damage or, in some situations, cause electrical fires.
3. There are two thermal risk zones highlighted in orange – one for the boiler and the other for the brewing assembly. Since these two components are spatially separated, the repairer is twice as likely to be exposed to thermal risk.

In the following subsections, these risk zones and steps are further explained with the help of Table 4 and Table 5.





Components

1. Nozzle metallised cover
2. Coffee pod trash bin
3. Coffee cup holder
4. Excess liquid collector
5. Water tank
6. Power cable panel cover
7. Power cable holder
8. Power cable
9. Water tank gasket
10. Coffee machine base
11. Stainless steel ring
12. SS mesh
13. Plastic intake
14. Right casing
15. Coffee dispensing silicone button - R
16. Left casing
17. Coffee dispensing silicone button - L
18. Top & Back cover
19. Coffee dispensing button PCB - R
20. Coffee dispensing button PCB - L
21. Hose (Bluish white), Flowmeter - Water tank
22. Hose (Blue), Pump - Flowmeter
23. Flowmeter
24. Hose (White), Boiler inlet connector - Water tank
25. Boiler inlet connector
26. PCB connector cover
27. PCB cover
28. Blue power line wire
29. PCB
30. Pipe, Boiler outlet connector - Brewing assembly
31. Boiler outlet connector
32. Boiler top cover
33. Earthing metal strip
34. Boiler
35. Boiler bottom cover
36. Pump outlet connector
37. Pipe, Pump outlet connector - Boiler inlet connector
38. Vibration absorber - Pump outlet
39. Vibration absorber - Pump inlet
40. Pump
41. Vibration absorber - Pump back
42. Grey wire, Pump - PCB
43. Brew group assy

Figure 8: Modified disassembly map of the Magimix Citiz

Risks during repair - Magimix

Table 4 details the risks observed during the repair of the Magimix. A summary of these risks is presented below,

1. Multiple mechanical risks were observed due to hidden snap-fits, sharp metal connectors and the use of fasteners (JURA retaining springs) that require large forces to reassemble (Figure 9).

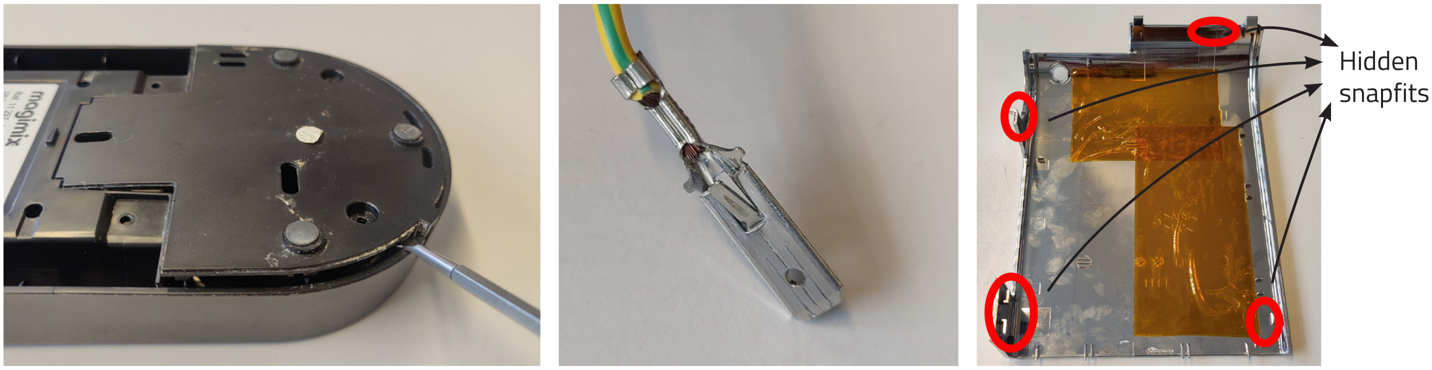


Figure 9: Mechanical risks due to hidden snap-fits and sharp metal connectors

2. Additionally, multiple metal connectors (Figure 10) were uninsulated, which have the potential to expose the user to severe electrical risk when accessing them or through accidental contact.

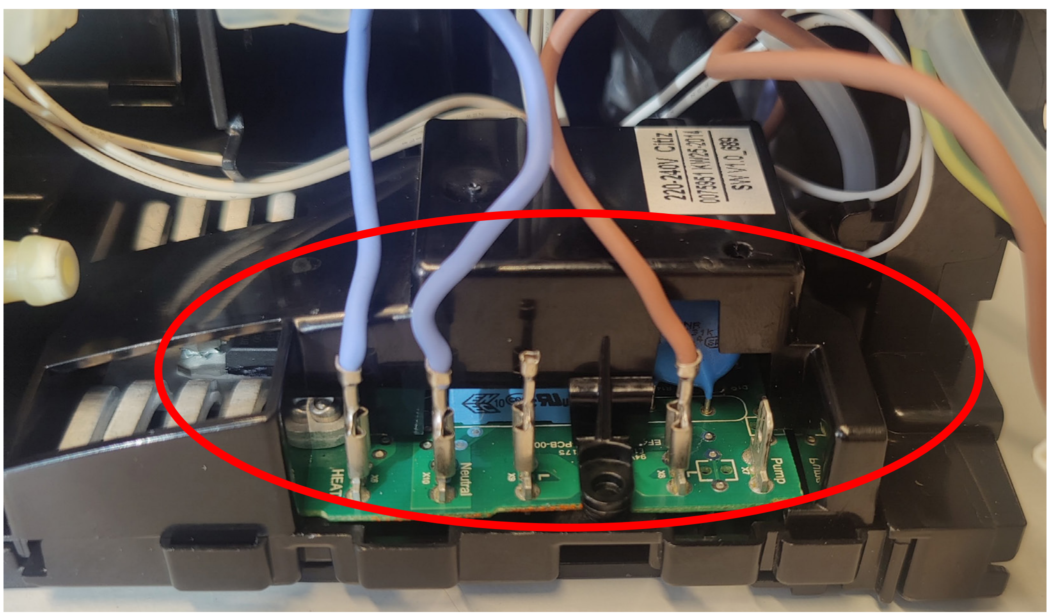
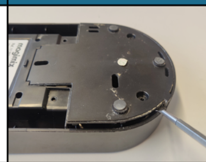
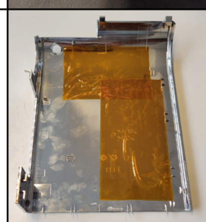
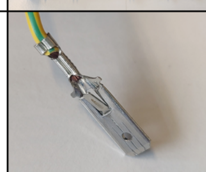
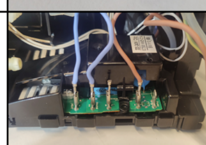
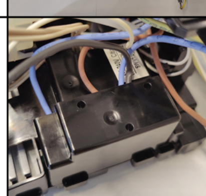
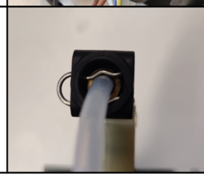


Figure 10: Uninsulated metal connectors

3. Two prominent thermal risks identified were burns caused by the release of residual hot water in the system during pipe disassembly and by touching the boiler while it is still hot.

Table 4: Risks observed during repair (Disassembly and reassembly)

No.	Risk zone/step	Observed design feature	Image	Why is it problematic	Risk type	Severity level	Rationale for Severity	Risk priority level (RAPEX)
1	A	Hidden snapfits in Power cable panel cover		User is inclined to insert their finger into a gap to make it easier to release other snapfits - Can cause pinching	Mechanical	1	In the worst case situation the user would require first aid	Low
2	B	Part with thick snapfit to hold power cable in place inside the base panel	 	The thick plastic of the part requires a large force and a multiple simultaneous-motion disassembly action to release it - Can lead to cuts	Mechanical	1	In the worst case situation the user would require first aid	Low
3	D	Multiple hidden snapfits for the Polycarbonate (PC) side panel		Multiple snapfits along the perimeter of the PC side panel make it difficult to release the snapfits one at a time, prompting users to instinctively use their fingers to keep any gaps free – Can cause pinching	Mechanical	1	In the worst case situation the user would require first aid	Low
4	C	Unprotected metal cable connectors		The connectors require force to take out or reattach. They have sharp projections that a user has to press against with their fingers – Can lead to cuts	Mechanical	1	In the worst case situation the user would require first aid	Low
5	E	Unprotected metal cable connectors		Potential to electrocute the user if the machine is still connected to the power supply and the user touches the metal connector	Electrical	4	User can receive an electric shock	Serious
6	Z1	Unprotected metal cable connectors – Earthing connector and 5 connections to the PCB		Metal connector can touch other metallic components/connectors inside the product and cause a short-circuit	Electrical	4	A short-circuit could lead to a fire	Serious
7	Z1	The PC side panels are accessible after the screws holding the base and the body of the coffee machine are removed		The internal components and PCB are accessible to a user before the power cable connections are taken out. Touching the unprotected cable connectors can lead to electrocution	Electrical	4	User can receive an electric shock	Serious
8	F	Cover over the 5 uninsulated PCB connectors may not fit snugly because it interferes with the connector wires		If the snapfit cover is not put in place correctly, it can leave the uninsulated PCB connectors exposed to the user the next time they open the product for repair. This can lead to electrocution.	Electrical	4	User can receive an electric shock	Serious
9	Z2	Residual water in the hose, pump or boiler can spill out when parts are disconnected		If the power connections have not been taken out, this water can cause short-circuits and sparking	Electrical	4	User can receive an electric shock	Serious
10	Z3	Residual water in the hose, pump or boiler can spill out when parts are disconnected		If the coffee machine is opened immediately after use, hot water can spill out – Can lead to burns	Thermal	2	Will require A&E care	Medium

11	Z3	Residual water in the brewing assembly is hot and exposed when accessed		If the coffee machine is opened immediately after use, contact with hot water in the brewing assembly can lead to burns	Thermal	2	Will require A&E care	Medium
12	Z2	Boiler can be accessed while it is still hot		If the coffee machine is opened immediately after use, the user can burn themselves by touching the boiler during its repair	Thermal	2	Will require A&E care	Medium
13	G	JURA standard retaining springs used for holding pipes and connections in place		The springs sometimes tend to widen, making it difficult to reattach. This either requires a lot of force or manipulation from the user – Can lead to cuts	Mechanical	1	Will require first aid in the worst case	Low

<u>Post-repair risks - Magimix</u>

1. All the risks identified were Electrical and were caused by incorrect wire connections and potential water leakage.
2. One of the reasons for potential water leakage is the inability to attach the hose to the brewing assembly because a specific assembly order is required. As shown in Figure 11, once the hose is attached to the brewing assembly, there is no space to insert the retaining spring. This is because it has to be inserted while the connection point is inside the brewing assembly, which makes it impossible.

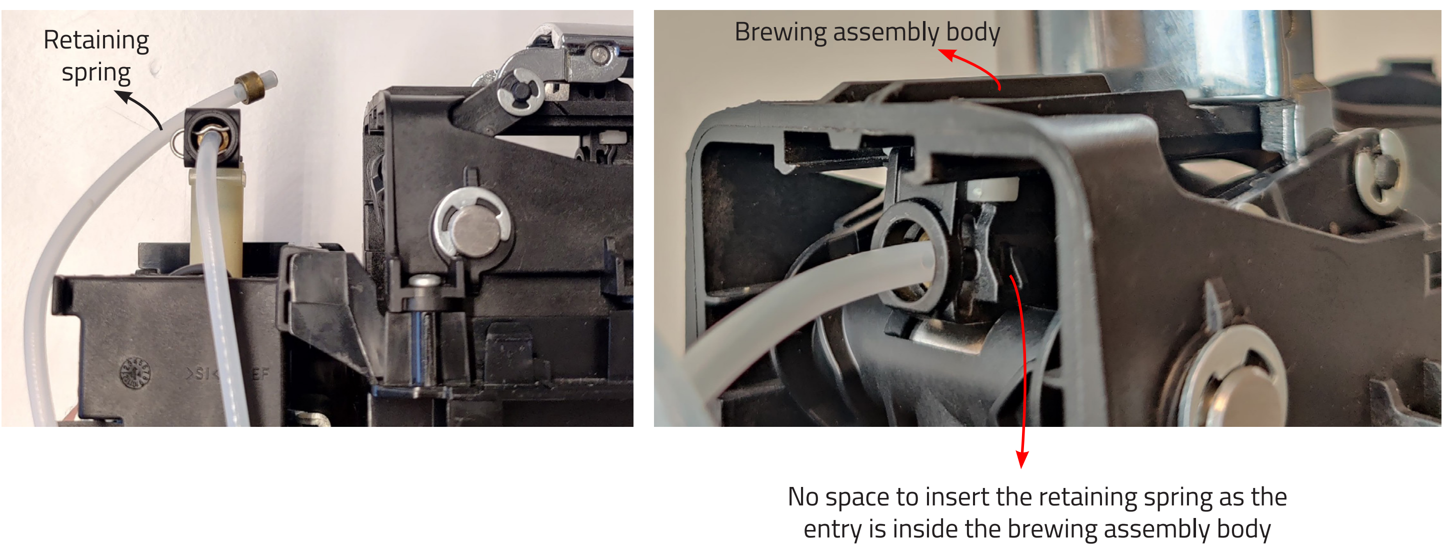
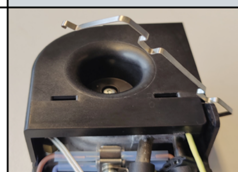
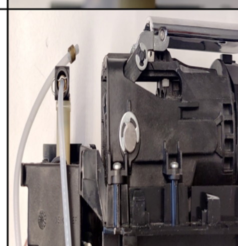
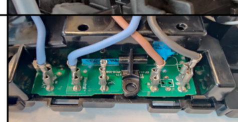


Figure 11: Brewing assembly must be disassembled to be able to add retaining spring due to lack of space

Table 5: Risks observed that would appear post repair

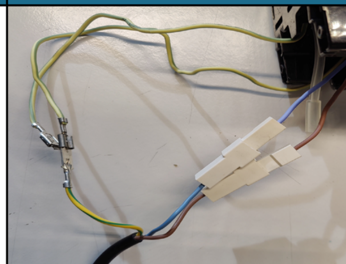
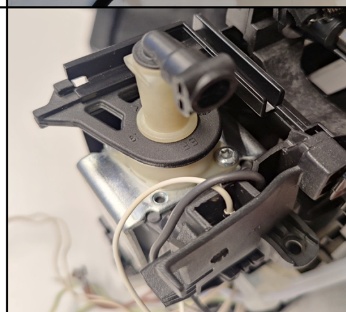
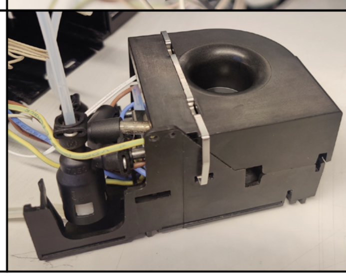
No.	Risk zone/step	Observed design feature	Image	Why is it problematic	Risk type	Severity level	Rationale for Severity	Risk priority level (RAPEX)
1	Z2 & Z3	Residual water in the hose, pump or boiler can spill out when parts are disconnected or product is moved		If the water is not sufficiently cleaned before connecting the power, it can cause short-circuits and fires	Electrical	4	Short-circuit can cause fire	Serious
2	H	No design cue on how the earthing metal strip is to be attached to the boiler casing		Incorrect placement of the earthing wire can lead to unwanted contact with other uninsulated connections inside the product which can cause short-circuits and fires	Electrical	4	Short-circuit can cause fire	Serious
3	G	JURA standard retaining springs used for holding pipes and connections in place		If the pins are not secured with sufficient tension, the pipes it holds in place could get loose leading to water leakage and subsequent short-circuit during use	Electrical	4	Short-circuit can cause fire	Serious
4	J	No design cue to inform the user which pipe has to be connected to the Brewing group		If the incorrect pipe is attached, the brewing group would malfunction as the pipe would be too short to allow the brewing group to travel back and forth. This can cause the pipe to get loose causing leakage and eventual short-circuit	Electrical	4	Short-circuit can cause fire	Serious
5	K	No design cue informing the user to check for the presence of an O-ring at the intersection between two connection points		Inserting a pipe without an O-ring into a connection point not having an O-ring can lead to loose connections that will cause water leakage and subsequent short-circuiting	Electrical	4	Short-circuit can cause fire	Serious
6	L	JURA standard retaining spring for brewing assembly cannot be put back once taken out w/o disassembling the brewing assembly		Incorrect order of assembly can lead to certain pipe connections being improperly secured – Water leakage and subsequent short-circuiting	Electrical	4	Short-circuit can cause fire	Serious
7	E	No design cue to indicate correct placement of wire connectors into the PCB		Incorrect connections can cause components to malfunction leading to power surges and sparking	Electrical	4	Short-circuit can cause fire	Serious
8	M	The hoses are not properly reassembled		Water leakage leading to short-circuiting and possibly fires	Electrical	4	Short-circuit can cause fire	Serious

Design features that prevent risk - Magimix

The product also contains design interventions to mitigate repair risks. These interventions are as follows,

1. Uninsulated connectors have been protected in two instances – on the Pump and the PCB.
2. For thermal protection, the additional cover for the boiler helps reduce the likelihood of the user intentionally or unintentionally burning themselves on the hot boiler.
3. The colour-coded power cable connections are another design cue added to reduce the likelihood of incorrect connections.

Table 6: Existing design features that mitigate risks

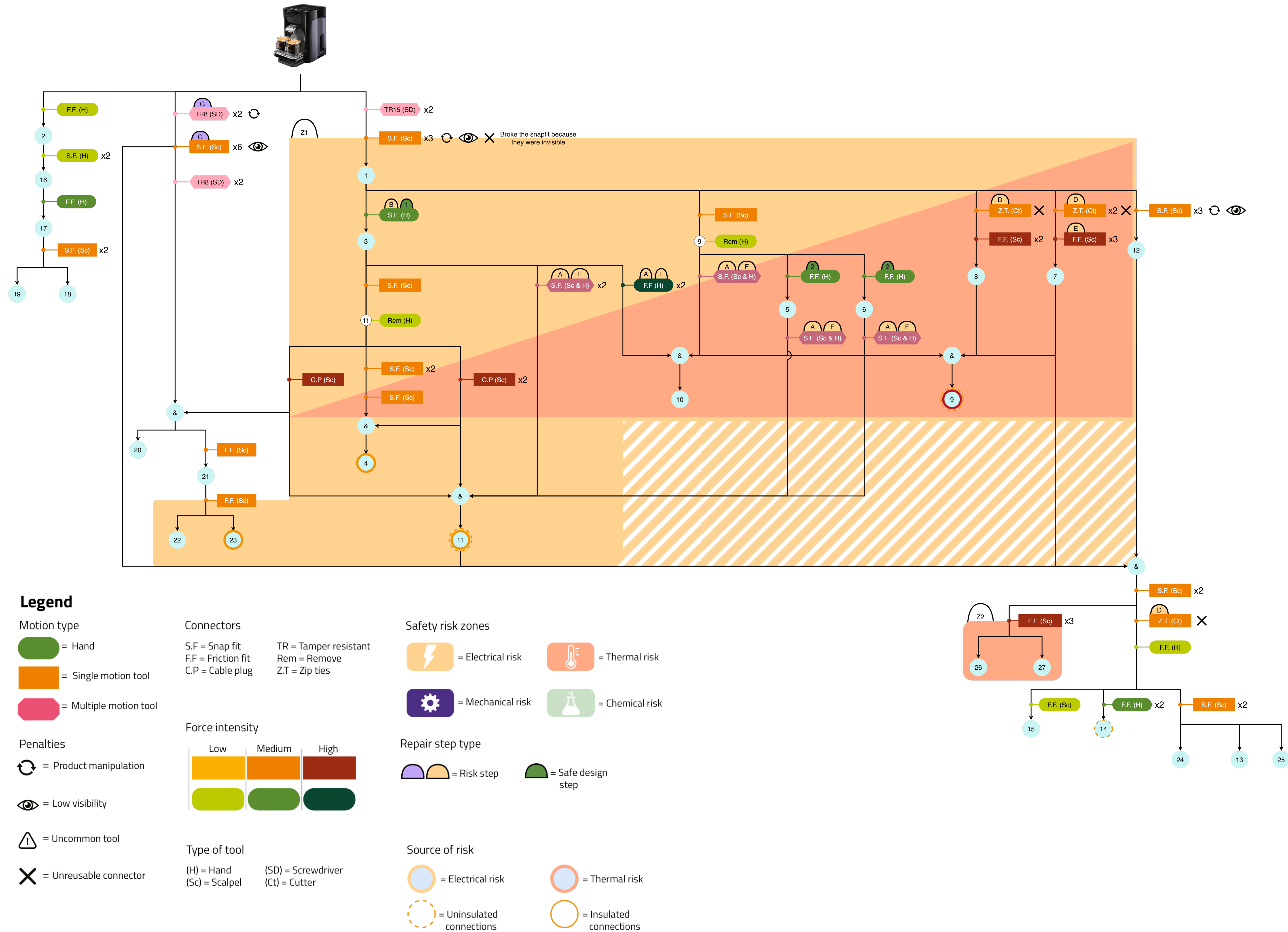
No. and Disassembly map code	Observed design feature	Image	Why is it a good design feature	Risk avoided
1	The live connections for the power cable have a insulation cover		Prevents the user from accidentally touching the metal connector underneath and getting electrocuted if the power cable is still connected to the socket	Electrical
2	Pump uninsulated covers hidden inside the vibration absorbers		When working with the internal architecture exposed, this design choice eliminates the possibility of the user accidentally touching an uninsulated metal connector	Electrical
3	The boiler is encased inside two protective casings		Acts as a layer of protection against potential thermal burns when handling or working around the boiler unit	Thermal

2.2.2 Senseo Quadrante

The outcome of the product architecture analysis and risk assessment, presented in the form of a modified disassembly map, is shown in Figure 12 below,

1. The electrical (yellow) and thermal risk zones (orange) are present during most of the disassembly process due to the uninsulated connectors underneath the PCB cover and the presence of the exposed and unprotected boiler.
2. Another thermal risk zone exists near the brew nozzle, but it is small due to the limited water present in this part of the product.

In the following subsections, these risk zones and steps are further explained with the help of Table 7 and Table 8.



Components

1. Left body panel
2. Water tank
3. Protection cover - PCB
4. PCB - Water level
5. Thermostat cover
6. Neutral connection cover
7. Hose, Boiler - 3 way valve
8. Hose, Pump - Boiler
9. Boiler
10. Power cable
11. PCB - Main
12. Right body panel
13. Water tank back support panel
14. Pump
15. Hose, Water tank - Pump
16. Water tank top cover
17. Float spring
18. Float magnet
19. Casing - Float magnet
20. Top cover assembly
21. Back cover, PCB - Buttons
22. Button assembly
23. PCB - Buttons
24. Water tank gasket
25. Water tank intake assy
26. Hose, 3 way valve - Brew nozzle
27. 3 way valve

Figure 12: Modified disassembly map of the Senseo Quadrante

Risks during repair - Senseo

1. Mechanical risks observed were due to the presence of multiple hidden snap fits that required the user to apply a large force, as well as ill-positioned screws leading to cuts (Figure 13).

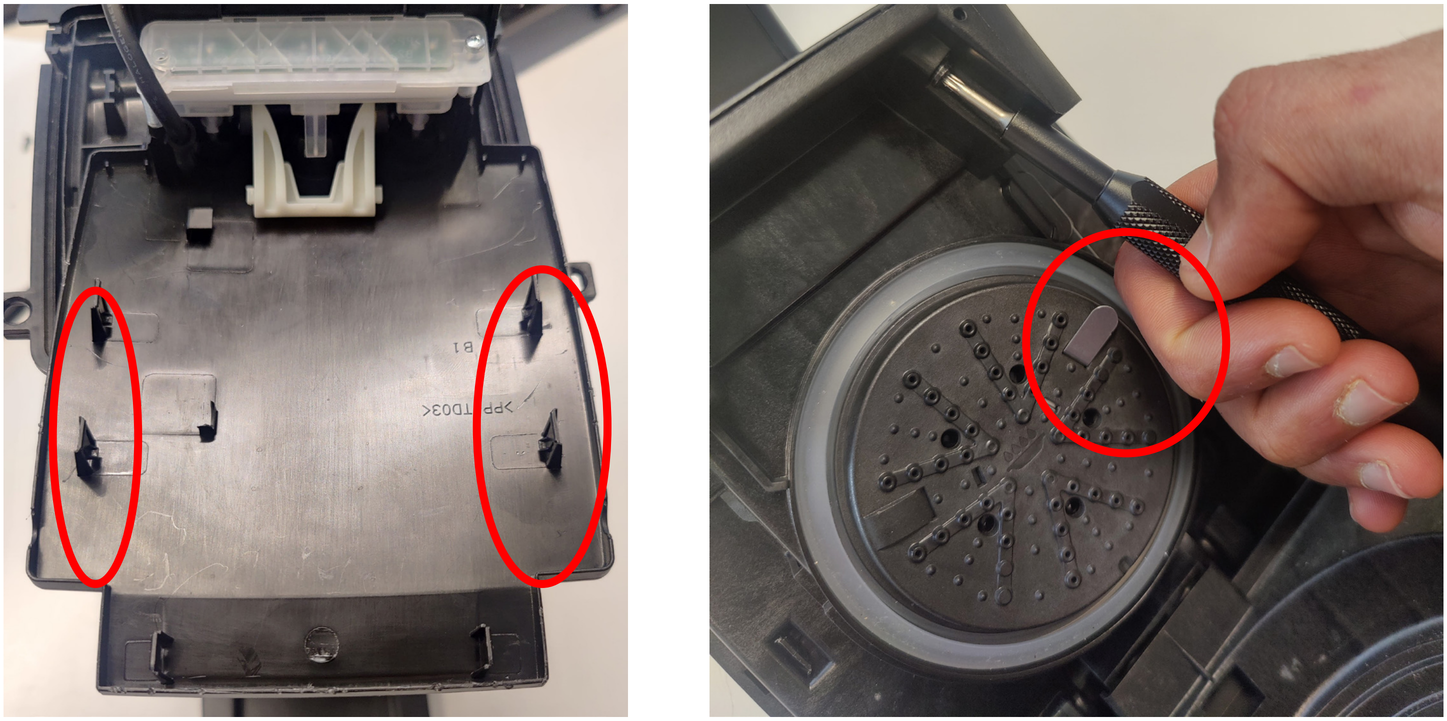


Figure 13: Hidden snap-fits and unintentional cuts during disassembly

2. The power cable connectors in the Senseo can be left connected while accessing components (Figure 14), which poses a severe electrical risk. No attempt has been made by design to direct the user to first disconnect the connections.
3. Additionally, multiple metal connectors were uninsulated (Figure 15), posing a severe electrical risk to the user through intentional or accidental contact.

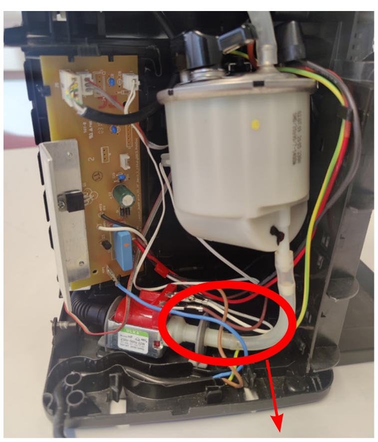


Figure 14: User can access internal components without disconnecting the power cable connectors

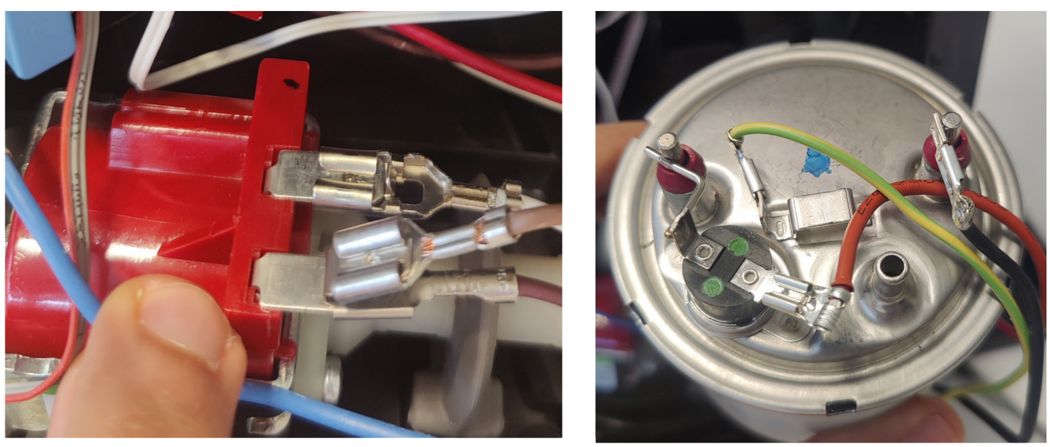


Figure 15: Uninsulated metal connectors

4. Two prominent thermal risks were burns caused by the release of residual hot water in the system during pipe disassembly and contact with the exposed hot boiler (Figure 16).
5. A thermal risk unique to the Senseo is the possibility of water from the boiler burning the user when disassembling the pipe connected to the boiler inlet. This is unique because the boiler is connected to the roof of the internal cavity; thus, water falls freely from its inlet.

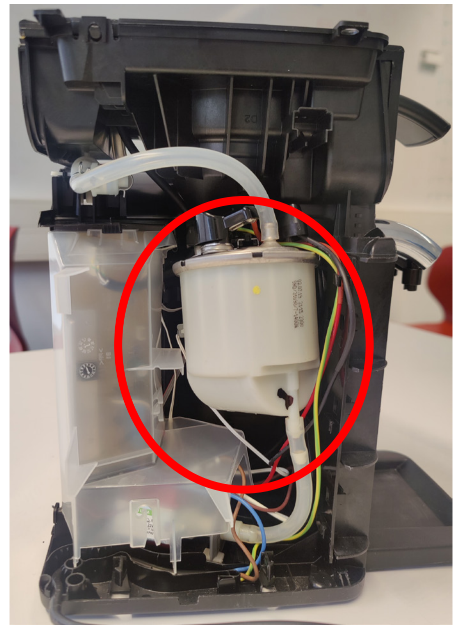
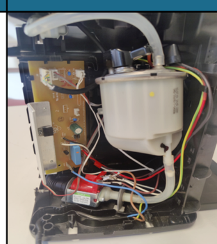
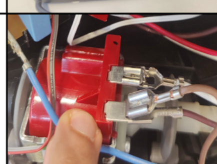
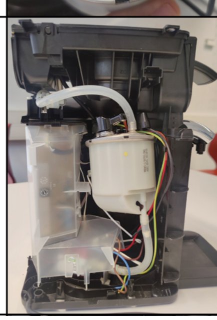
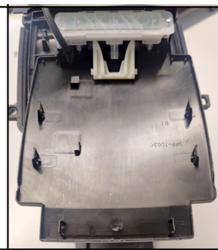


Figure 16: Exposed and unprotected boiler

Table 7: Risks observed during repair (Disassembly and reassembly)

No.	Risk zones/steps	Observed design feature	Image	Why is it problematic	Risk type	Severity level	Rationale for Severity	Risk priority level (RAPEX)
1	Z1	Power cable connections can be kept connected while accessing other components		If an uninsulated connection is accidentally touched by the user while performing repair, they can be electrocuted	Electrical	4	User will die due to the high voltage input supply	Serious
2	A	All wire connectors are uninsulated metal	 	Potential to electrocute the user if they accidentally touch it while performing repair	Electrical	4	User will die due to the high voltage input supply	Serious
3	Z1	Boiler is unprotected and exposed		If the boiler is still hot when the coffee machine is opened, the user could accidentally burn themselves when performing repair	Thermal	2	Will require A&E care	Medium
4				If the boiler is still hot when the coffee machine is opened, the user could burn themselves when replacing the boiler	Thermal	2	Will require A&E care	Medium

5	C	Top panel covering the buttons have multiple hidden snapfits		The hidden snapfits require a large force to release that could lead to cuts. Additionally, for the snapfits that have been released, a tools needs to be put in place to keep the snapfits free. If not done, it closes back and can pinch the user.	Mechanical	1	Requires first aid in the worst case	Low
6	Z1	Liquid can leak out when removing hoses		If the power cable has not been disconnected, leaking water can create a short circuit which is problematic. The water can also be hot if the coffee machine is opened shortly after use which can burn the user.	Electrical	4	Short-circuit will result in a fire	Serious
7	Z1	Liquid can leak out when removing hoses		If the machine is opened immediately after use or without it cooling down, the water can be hot which can burn the user.	Thermal	2	Will require A&E care	Medium
8	Z1	Water in the boiler spills out when taking out hoses		The boiler stores water in it which can be hot if accessed shortly after use. This can cause burns to the user	Thermal	2	Will require A&E care	Medium
9	Z2	Residual water in the brew group assembly is hot and exposed when accessed		If the coffee machine is opened immediately after use, contact with hot water in the brew group assembly can lead to burns	Thermal	2	Will require A&E care	Medium
10	G	Position of the Top cover screws causes interference between screwdriver and coffee pad piercer		When trying to put the scew, the coffee pad piercing tool causes cuts in the user's hands	Mechanical	1	Requires basic first aid	Low

<u>Post-repair risks - Senseo</u>

1. All the risks identified were Electrical and were caused by incorrect wire connections and potential water leakage.
2. Potential water leakage can be caused by improper hose fastening and the hose being attached in the incorrect orientation (Figure 17). The first cause can be attributed to the use of non-reusable connectors and the absence of clear design cues indicating the depth to which the hoses need to be inserted. The second cause can be attributed to the absence of design cues. Both these causes are unique to the Senseo owing to the choice of hose.

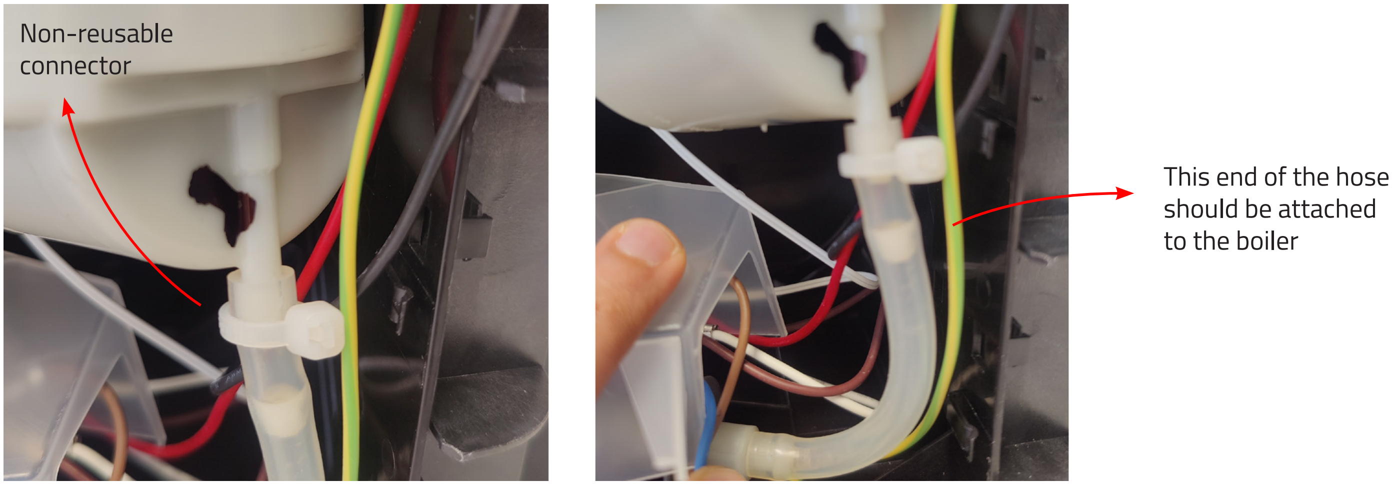
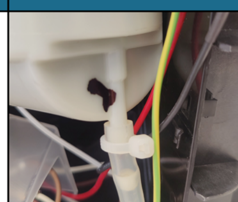
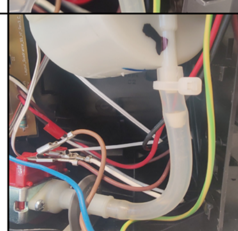
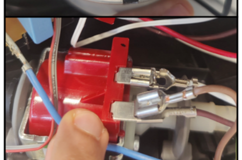
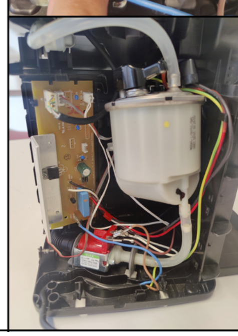


Figure 17: Use of non-reusable connectors and hose that has a specific orientation

Table 8: Risks observed that would appear during product use post repair

No.	Risk zones/steps	Observed design feature	Image	Why is it problematic	Risk type	Severity level	Rationale for Severity	Risk priority level (RAPEX)
1	D	Some hose connections were attached with zip-ties which cannot be reused		Loose hose connections during reassembly which can cause short-circuiting during use	Electrical	4	Short-circuit can cause fire	Serious
2	E	Pump – boiler hose has a specific attachment orientation – no design cue to explain this		Changing the orientation would create back-pressure into the pump that could cause pump failure or even hose connections to get loose and leak water	Electrical	4	Short-circuit can cause fire	Serious
3	F	No design cue explaining wire connector connections	  	Incorrect connection could cause short-circuit, malfunctions or fire in the worst case	Electrical	4	Short-circuit can cause fire	Serious

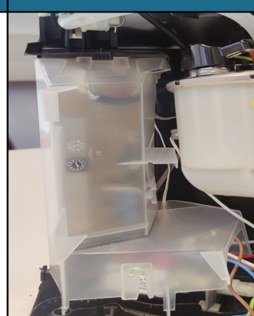
4	Z1	Residual water in the hose, pump or heater can spill out when parts are disconnected or product is moved		If the water is not sufficiently cleaned before connecting the power, it can cause short-circuits and fires	Electrical	4	Short-circuit can cause fire	Serious

<u>Design features that prevent risk - Senseo</u>

Like the Magimix, the Senseo also had design features implemented to mitigate risks. The examples of these implementations are given below,

1. The uninsulated connectors on the boiler have been protected with the help of individual plastic caps that can be easily taken out.
2. A plastic, translucent cover has been added to prevent accidental contact with the uninsulated connectors on the PCB and the Pump.
3. Instructions showing the correct orientation of a part that is likely to be assembled incorrectly have been added to the mating surface for the user's ease.

Table 9: Existing design features that mitigate risks

No. and Disassembly map code	Observed design feature	Image	Why is it a good design feature	Risk avoided
1	PCB and Pump connection points are protected with a plastic casing		Protects the user from accidentally touching uninsulated cable connectors	Electrical
2	Boiler connection points are covered with a protective casing		Protects the user from accidentally touching uninsulated cable connectors	Electrical
3	Indication of water tank intake assy orientation		Correct assembly of the intake assy ensure there is no water leakage during use that could lead to electrical fires	Electrical

2.3 Comparison of the Magimix and Senseo coffee machines

2.3.1 Differences between the Magimix and Senseo coffee machines

The coffee machines were two contrasting examples of nested and open product architecture, and their effect on risk exposure during repair was evident – the open architecture of the Senseo increased the likelihood of being exposed to risk. However, in contrast, this does make the Senseo easier to repair. Other notable differences were as follows,

1. The absence of a cue to first disconnect the power cable connections in the Senseo, compared to the Magimix, is a major difference and is a useful design decision to consider.
2. The use of minimal hidden snap-fits reflects the limited occurrence of mechanical risks in the Senseo compared to the Magimix.
3. The location and protection offered to the boiler are starkly different for the two coffee machines – deeply nested and covered on three sides for the Magimix and exposed and unprotected for the Senseo.
4. Some of the hoses of the Magimix coffee machine have O-rings at the ends that need to be in place to prevent water leakage. This creates an additional point to be cognizant of when replacing them. This complexity is lacking in the Senseo. However, the Senseo uses non-reusable connectors to secure the hoses, which poses a serious risk post-repair.

2.3.1 Similarities between the Magimix and Senseo coffee machines

Despite the difference in product architecture and some design choices, many risks are similar across the two machines. This is interesting, as it suggests the possibility of applying a design solution across brands to enhance the safety of repairs. Notable similarities in the context of repair risks are as follows,

1. All electrical risks observed during repair can be traced to a common root cause – the ability to access components without disconnecting the live power cable connections (Appendix B). Solving this issue would address all subsequent risks during repair.
2. All thermal risks observed during repair can also be traced to a common root cause – the ability to open the housing before the boiler and the water inside has cooled down (Appendix B).
3. Other similar electrical risks that the user is exposed to include electric shock due to uninsulated connectors and the absence of design cues to help ensure correct wire and hose connections
4. Additionally, there exists a risk of burns during testing (which occurs during product repair) for both coffee machines. This risk arises because the user is more likely to touch the boiler immediately after testing.
5. As seen in the disassembly map, both machines have two distinct thermal risk zones – one created by the boiler and the second created by the brewing assembly. The same source creates these risk zones – hot water generated as part of the product functionality. However, because the boiler and the brewing assembly are spatially separated, they have separate risk zones.
6. Whenever hidden snap-fits were used, they often broke over multiple disassembly cycles. As explained in Section 2.2.1, this poses a risk and should be considered during ideation.

2.4 Conclusion & Design Takeaways

The analysis of the Magimix and Senseo coffee machines helped map the design features that led to safety risks during repair and post-repair. These risks were then assessed using the RAPEX guidelines for severity.

The analysis also highlighted the use of design to address specific risks. This is the approach to risk mitigation that will be used to eliminate prioritised risks in subsequent chapters. For this project, all design features that led to a risk rated two or higher for severity level are prioritised for design interventions. This is because exposure to these risks requires the user to seek specialist intervention in the best-case scenario and hospitalisation in the worst-case scenario. The prioritised design feature and resulting risks were formulated into risk scenarios, which are mentioned below,

1. User receives an electric shock when accessing internal components during repair
2. User spills residual water to cause short-circuiting during repair
3. User burns themselves through intentional or unintentional contact with the boiler or water during repair
4. User receives an electric shock when performing testing
5. User makes the incorrect electrical connections during reassembly
6. Hoses are not attached securely
7. Incorrect hose is attached between two components
8. Hose is attached in the incorrect orientation

Based on these risks and the analysis presented in this chapter, the following design takeaways are derived,

<u>For performing safe repair</u>

1. Currently, repair activities involving access to internal components are possible while the product is still connected to power. This presents an electrical safety risk. The procedural relationship between power-related elements and areas that require access for repair must be considered during the design process.
2. Specific components may remain hot or contain hot liquids even after power is disconnected, creating a thermal hazard. Access to such components should account for their thermal state during the repair process.
3. Users may come into contact with exposed electrical terminals or wiring during the repair process. The likelihood and consequences of accidental contact should be minimized.
4. Disconnection of components in the presence of residual water inside them can create the risk of short circuits. The product should be designed to prevent water from remaining in components or connectors during repair.

<u>For safe post-repair use</u>

1. Incorrect wiring during reassembly can lead to functional failure or safety hazards. The risk of user error in electrical reconnections highlights the need for clarity and error prevention in connection design.
2. Improper hose attachment or orientation can lead to leaks or malfunctions. The reattachment process presents risks if hoses are not easily distinguishable or reversible.
3. Some hoses or components may be interchangeable in ways not intended by the original design. The potential for incorrect part connections during reassembly should be considered during the design phase.
4. Removable parts that are not securely or correctly reattached after repair may compromise product safety. The reassembly process should account for ease of correct alignment and secure fastening.

CHAPTER 03

DESIGN VISION

In this chapter a design vision is created to aid in the ideation process. A program of requirements and desires are also defined, that will be used later in the study to evaluate the concept.

3.1 Design vision

This project aims to make it safe for non-professional repairers to perform repairs on the coffee machine. Before proceeding with ideation based on the insights gained from the previous phase, this aim must be made more specific. To that end, a design vision was formulated to aid in ideation,

"To design a coffee machine that is safe by design. This means that non-professional repairers do not need to possess prior knowledge to perform safe repair because the design either mitigates the safety risks or guides them through a safe repair process."

3.2 Program of requirements & desires

To aid in the final selection of a concept in the next phase, a set of requirements and desires were established. These were determined by the findings from previous research and the design takeaways from the previous chapter.

<u>Product requirements</u>

1. The severity of prioritised risks is reduced to Low (or severity level 1) as defined by the RAPEX guidelines
2. Safety information, if any, should be offered by the product

<u>Electrical requirements</u>

1. The design should prevent the user from getting electrical shock during repair.
2. The design should aid the user in making the wire connections correctly.
3. There should be no short-circuiting caused by water leakage during product use or while disconnecting components during repair.

<u>Thermal requirements</u>

1. The user should be safeguarded from burns while physically interacting with a component where the burns are caused due to,
    a. The component being hot
    b. The component releasing liquid that is hot

<u>Mechanical requirements</u>

1. The user should be able to securely reattach any removable part in the coffee machine during reassembly.

<u>Desires</u>

1. Minimise cognitive load on the user during the repair process
2. The solution should be difficult to circumvent or ignore
3. The solution should be simple (impact on architecture/no of parts/mechanism)
4. The solution should be cost-effective

CHAPTER 04

IDEA SELECTION FOR SAFER REPAIR

In this chapter, ideas are generated to mitigate the risks prioritised from the previous analysis. The ideas are grouped into solution spaces to identify concepts that make the coffee machine safe for repair.
The ideas were then compared at a risk level, creating combinations across solution space for further development and prototyping.

4.1 Idea generation

To generate a large number of ideas, two creative sessions were organised – an individual brainwriting session followed by a group brainstorming session with three current and former students from the IPD program.

In the individual brainwriting session, each risk was presented as a How-To, and 5 minutes were devoted to writing down as many ideas as possible.

The group brainstorming session began with an introduction to the project, its goal, and the two coffee machines that were analysed in their disassembled state. The session was structured into eight rounds, where each round began with a risk scenario (Appendix C); for example, a user burns themselves on the hot boiler through intentional or unintentional contact. The coffee machines were used to explain how, why, and under what circumstances this risk scenario could occur. Following this, the participants had 3 minutes to come up with as many ideas as possible. These ideas were then discussed before moving on to the next risk scenario.

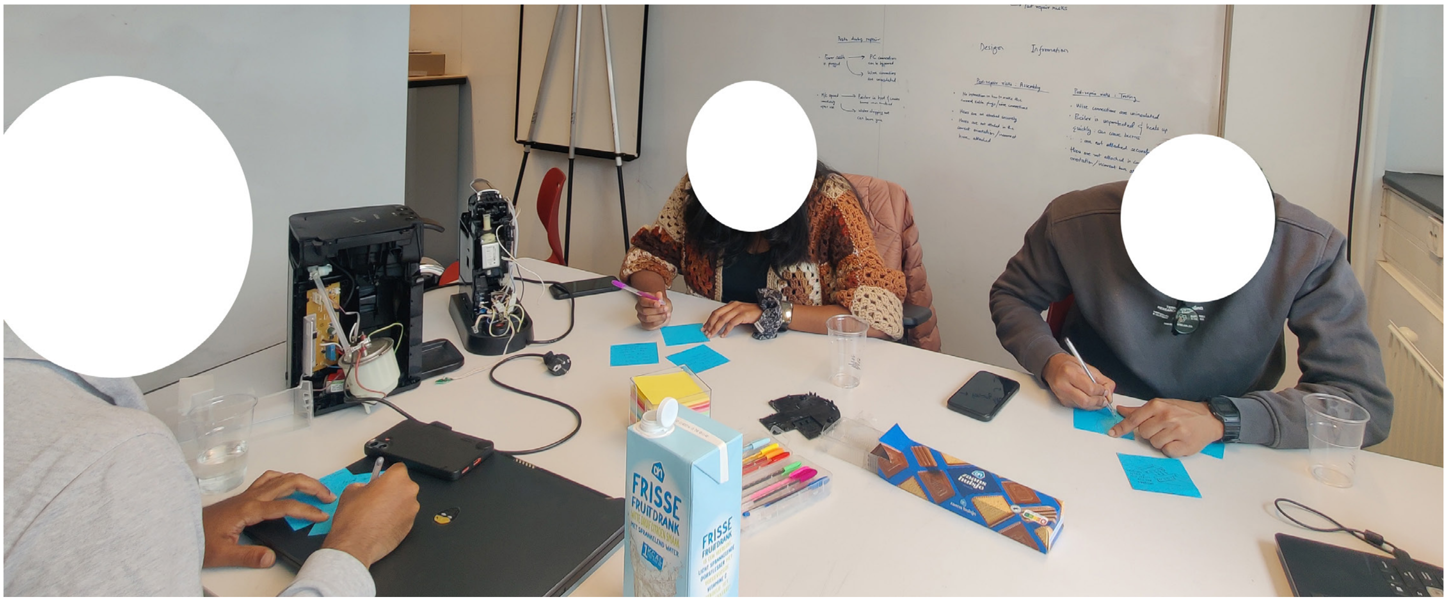


Figure 18: Brainstorming session conducted to generate ideas to mitigate each risk

4.2 Identifying promising ideas for repair safety

The ideas collected from the two sessions were then organised using their principle of operation as a differentiator (Appendix C). This helped identify three solution spaces that were present for all the risks. (Note: In Figure 19, two solution spaces are visible for Risk 4. This is because the second solution space also encompasses ideas for the third solution space and has been colour-coded accordingly.) These spaces focused on one of two things – addressing the risk or changing the user's interaction with the risk. This is further explained below with the help of an example,

- Design cues – Use design cues to draw attention to the risk or guide the user to perform a safe repair. In this solution space, the risk is present, but design is used to change the user's interaction with the risk in a way that avoids the risk.

  Example: If a product has a sharp edge near a fastener, a warning label placed close to the edge could alert the user to the potential hazard, encouraging them to proceed with caution.

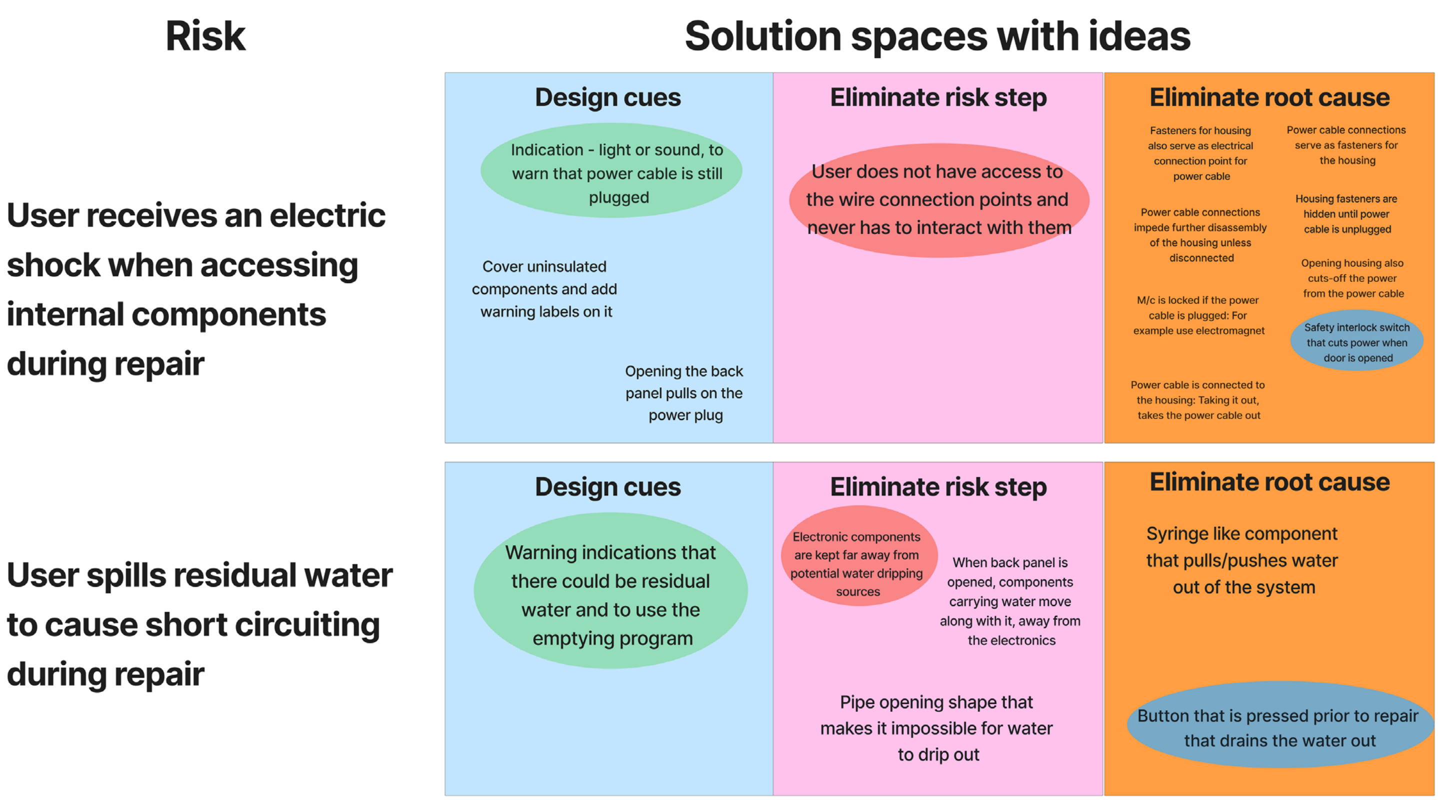
- Eliminate risk step – Prevent the user from being exposed to the risk by eliminating the interaction that exposes the user to the risk. In this solution space, the risk is present, and design is used to change the user's interaction such that they avoid the risk altogether.

  Example: Instead of placing a fastener close to a sharp edge, it could be relocated to a safer position. This way, the user can complete the task without coming near the sharp edge at all.

- Eliminate the root cause of the risk – The risk is mitigated before the user can expose themselves to it through any subsequent interactions. In this solution space, the risk is mitigated by design, so that any subsequent interactions are inherently safe.

  Example: The sharp edge itself is eliminated by rounding it off or covering it, making the area safe regardless of how or when the user interacts with it.

Next, for each solution space, exploratory sketches were made for every idea to visualise possible embodiments. The ideas were then qualitatively assessed at a solution space level using the Harris profile to select a single idea for each solution space. This was done to simplify the ideation process in the interest of time. The criteria for assessment were the Desires listed in the Program of Requirements. The details of the idea sketches and the evaluations can be found in Appendix D. The result was a single idea for a risk level for each solution space. This is presented below in Figure 19 and tabularised in Table 10.



User burns themselves through intentional or unintentional contact with the boiler or water during repair

Design cues
- Heat sensitive material that shows the text "I am hot, dont touch" based on its temperature
- Indication that machine is still hot and should not be opened
- Warning indications for boiler and brew group that they could be hot

Eliminate risk step
- Boiler is enclosed in an insulated material that the user never needs to opens

Eliminate root cause
- Housing is locked until the boiler does not cool down
- Only boiler and brewing group are locked out until boiler cools down
- Button that is pressed prior to repair that allows access only once the boiler is cool - naturally or by passing cold water through it

User receives an electric shock when performing testing

Design cues
- Light that blinks when the connectors are not covered

Eliminate risk step
- When power is live, these connections are hidden
- Power can only be live with the housing open if the PCB is enclosed
- Transparent body - no need to keep the housing open
- Power can only flow if the housing is closed
- Check repair effectiveness through a mobile app

User makes the incorrect electrical connections during reassembly

Design cues
- Write on the wire & the PCB
- Colour code the connections
- Feedback that the connections have been made correctly

Eliminate risk step
- Wire connections are never taken out when component is taken out

Eliminate root cause
- Use cable plugs with unique shape for each connection

Hoses are not attached securely

Design cues
- F.F with magnets that inform you of the correct depth of attachment
- Marking on the counterpart indicating how deep the F.F hose needs to be inserted
- Latch that turns colour when rotated and also squeezes the hose in place

Eliminate risk step
- Hoses are never disassembled unless they need to be replaced

Eliminate root cause
- Use snap-fit connections
- Thread based connection (like Classic Gaggia)
- F.F hose with an additional clip like the food clips
- Use something like the retaining springs in the Magimix to ensure tight connection

Incorrect hose is attached between two components

Design cues
- Hose cap and mating part have a unique shape
- Colour the hose cap and the corresponding part with the same colour
- Write the connection it is responsible for

Eliminate risk step
- Hoses are never disassembled unless they need to be replaced

Eliminate root cause
- Unique size threaded connection between two parts
- Hose length determines where it can exactly fit

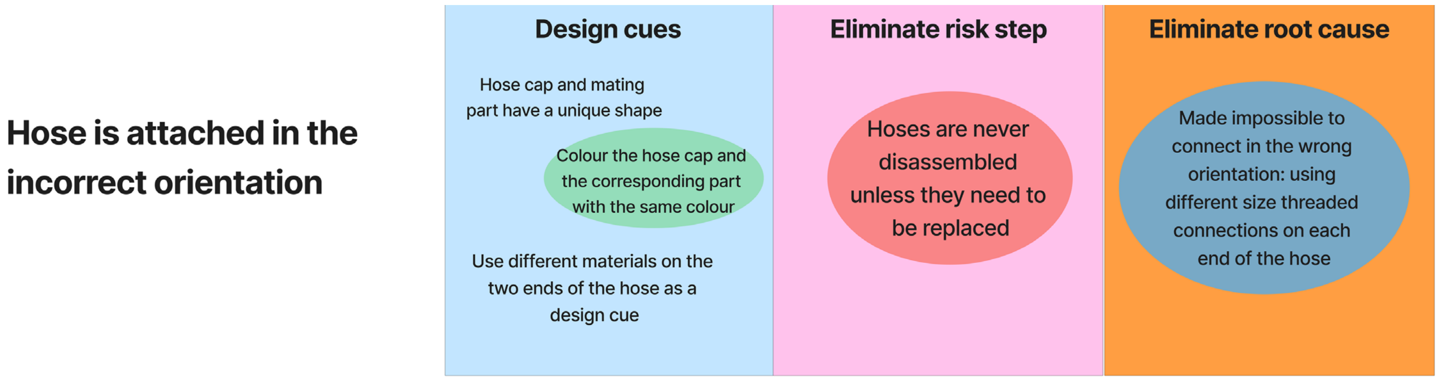


Figure 19: Result of the brainstorming and brainwriting session with the ideas selected for concept sketches highlighted

Table 10: Ideas selected for each direction

Risk	**Design cues**	**Eliminate risk step**	**Eliminate the root cause of the risk**
User receives an electric shock when accessing internal components during repair	Indication - light or sound, to warn that power cable is still plugged	User does not have access to the wire connection points and never has to interact with them	Safety interlock switch that cuts power when door is opened
User spills residual water to cause short circuiting during repair	Warning indications that there could be residual water and to use the emptying program	Electronic components are kept far away from potential water dripping sources	Button that is pressed prior to repair that drains the water out
User burns themselves through intentional or unintentional contact with the boiler or water during repair	Warning indications for boiler and brew group that they could be hot	Boiler is enclosed in an insulated material that the user never needs to opens	Housing is locked until the boiler does not cool down
User receives an electric shock when performing testing	Light that blinks when the connectors are not covered	Power can only be live with the housing open if the PCB is enclosed	Power can only flow if the housing is closed
User makes the incorrect electrical connections during reassembly	Colour code the connections	Wire connections are never taken out when component is taken out	Use cable plugs with unique shape for each connection
Hoses are not attached securely	Marking on the counterpart indicating how deep the F.F hose needs to be inserted	Hoses are never disassembled unless they need to be replaced	Thread based connection (like Classic Gaggia)
Incorrect hose is attached between two components	Colour the hose cap and the corresponding part with the same colour	Hoses are never disassembled unless they need to be replaced	Unique size threaded connection between two parts
Hose is attached in the incorrect orientation	Colour the hose cap and the corresponding part with the same colour	Hoses are never disassembled unless they need to be replaced	Made impossible to connect in the wrong orientation: using different size threaded connections on each end of the hose

In the next section, the ideas selected under every solution space are made more concrete. This is done to gain insights into their potential by sketching their implementation in a concept.

4.3 Refining selected ideas into safe for repair concepts

The purpose of this step in the design process is to use the ideas selected above as inspiration for conceptualisation. This is done by creating preliminary sketches of how all the ideas in a solution space could be implemented into a coffee machine concept. As explained earlier, the Magimix Citiz has been selected as the product to be redesigned. Thus, the shape and size of its components have been retained and accounted for in the design. The end goal of this exploration is to gain insights into how effectively the ideas mitigate risk, which will inform the selection of ideas across the solution spaces to prototype and test with users.

4.3.1 Concept 1 - Design cues

The concept utilises the existing design and architecture of the coffee machine and implements the design cues in it. When the user removes the water tank before starting the repair, they see a warning light hidden behind the tank (Figure 20) that indicates the power cable is still connected. They are also asked to run the "Emptying program" that is currently present in the Magimix machine (Magimix User Manuals, n.d.). This program flushes all the water from the system into the empty collection tray at the front of the machine. This also ensures that the expelled water does not burn the user.

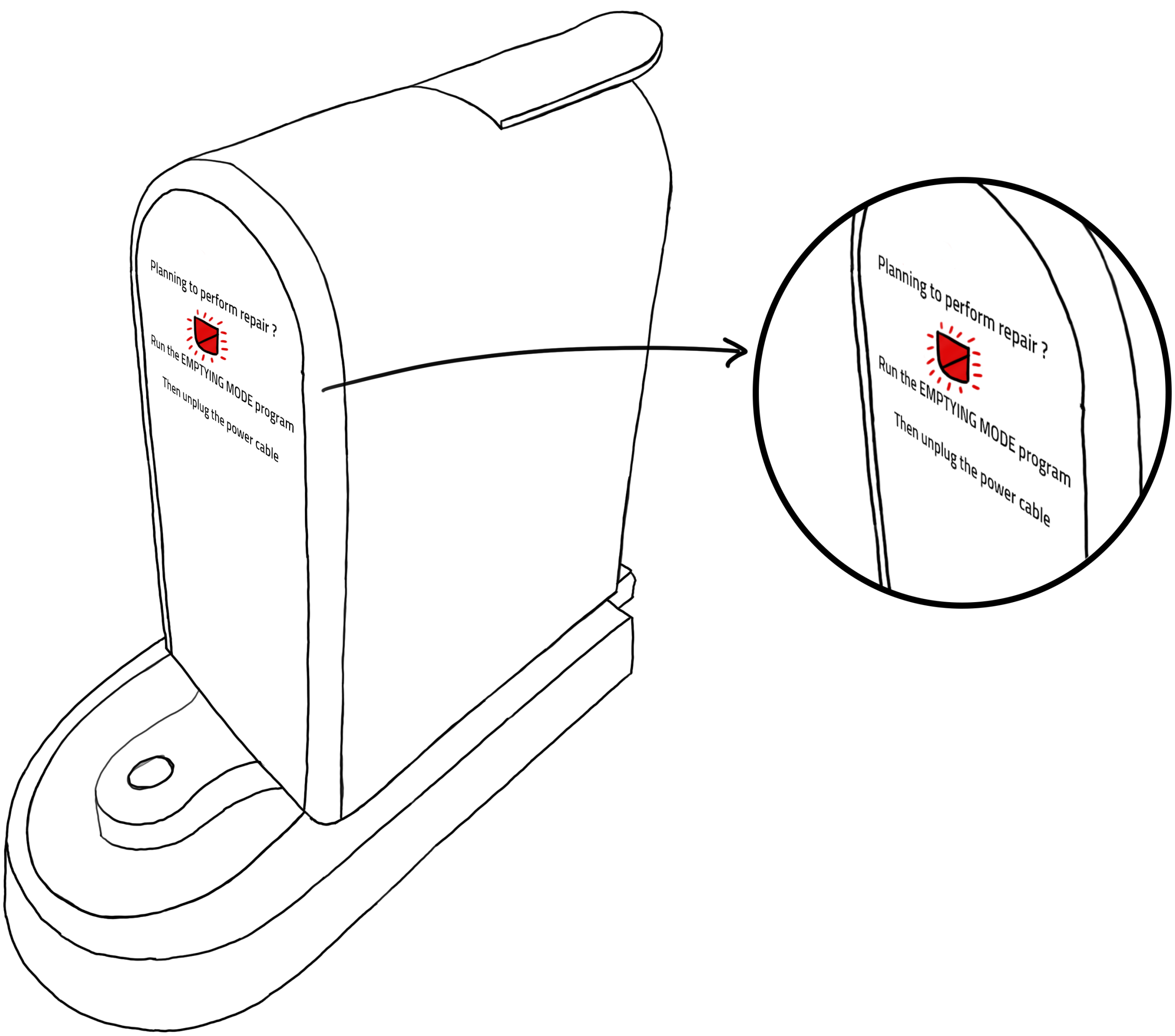


Figure 20: Warning light and text asking user to empty the machine of water and then unplug the connector, hidden behind the water tank

Once the user performs the above steps and opens the housing, they are presented with the view shown in Figure 21. Warning labels have been added to alert users to potential risks. For example, a label on the boiler cover informs the user that the boiler underneath may be hot and advises them to exercise caution when accessing it.

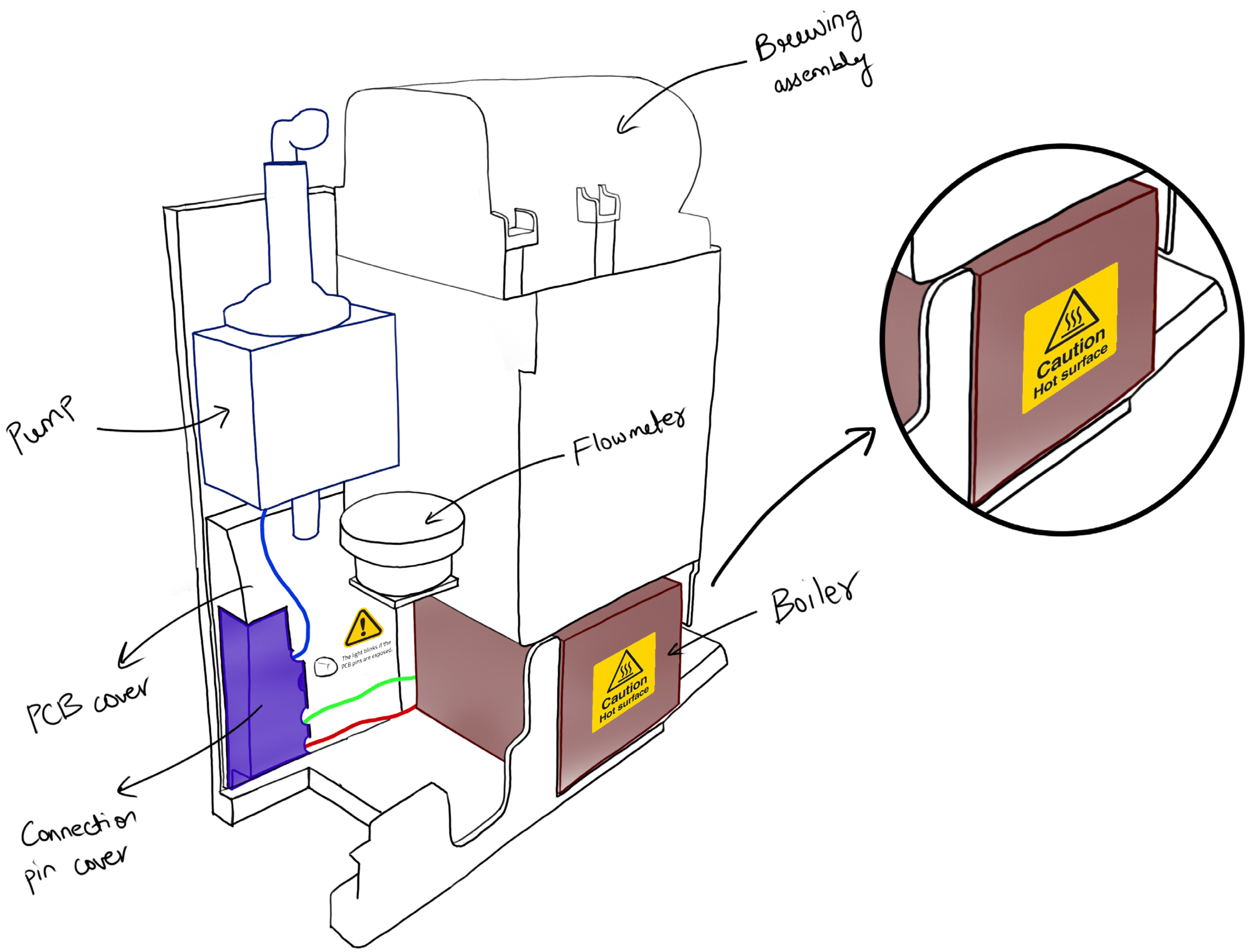


Figure 21: Warning label on the boiler cover indicating that the boiler underneath could be hot

Another warning label with a light is placed on the PCB cover (Figure 22). This is present to warn the user whenever the connection pin cover (in purple) has been removed while power is being supplied to the PCB. This is necessary because the connections are uninsulated.

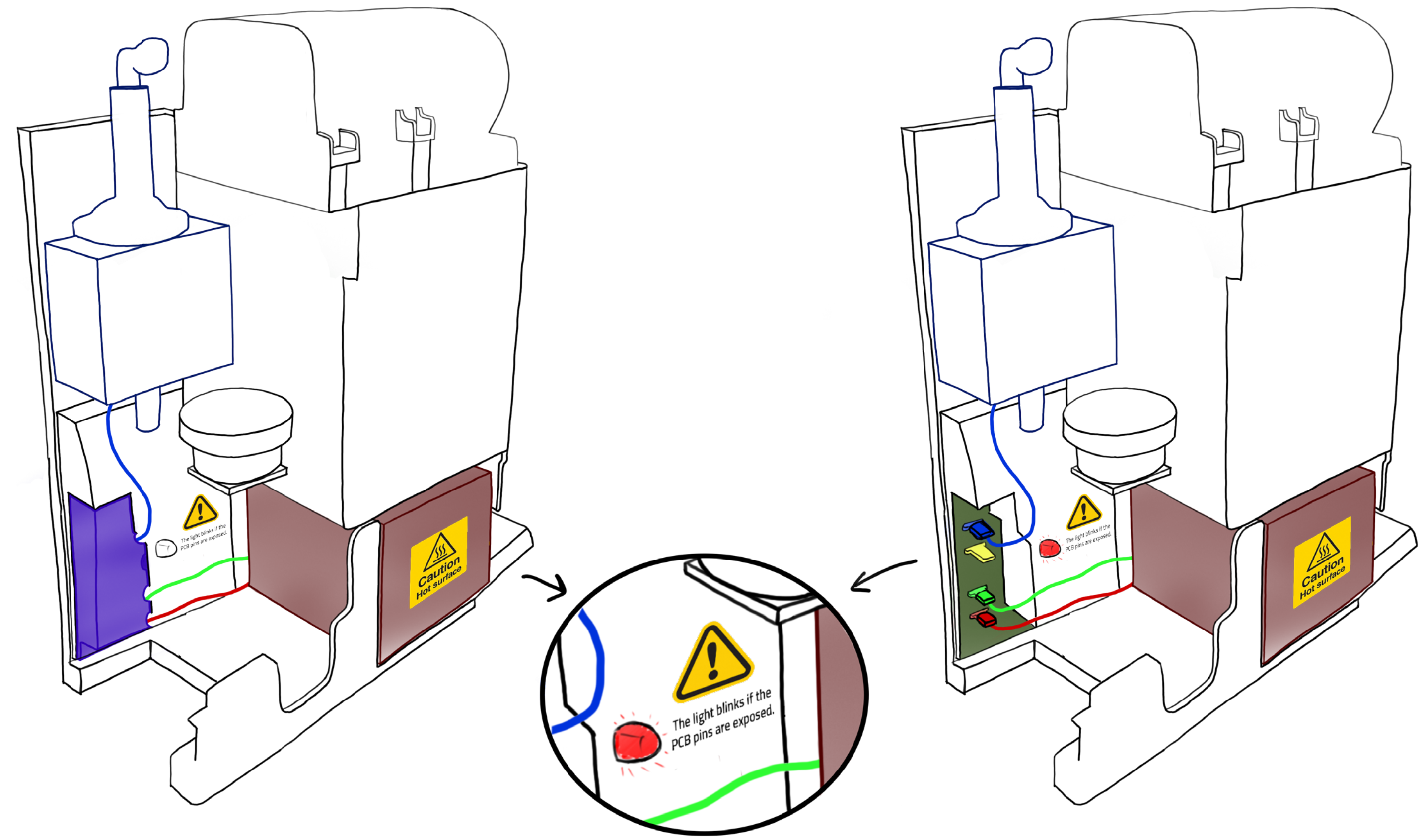


Figure 22: Warning label and light to warn of exposed uninsulated connection points on the PCB

Finally, colour has been used to help the user make the correct wire and hose connections (Figure 23). For the wires, the cable and the corresponding pin have been given the same colour. For the hoses, the hose cap and the part to which it mates have been given the same colour. This helps the user identify the correct hose and orientation of the attachment. To help secure the connection, the colour on the mating surface acts as an indicator of how deep the hose needs to be inserted.

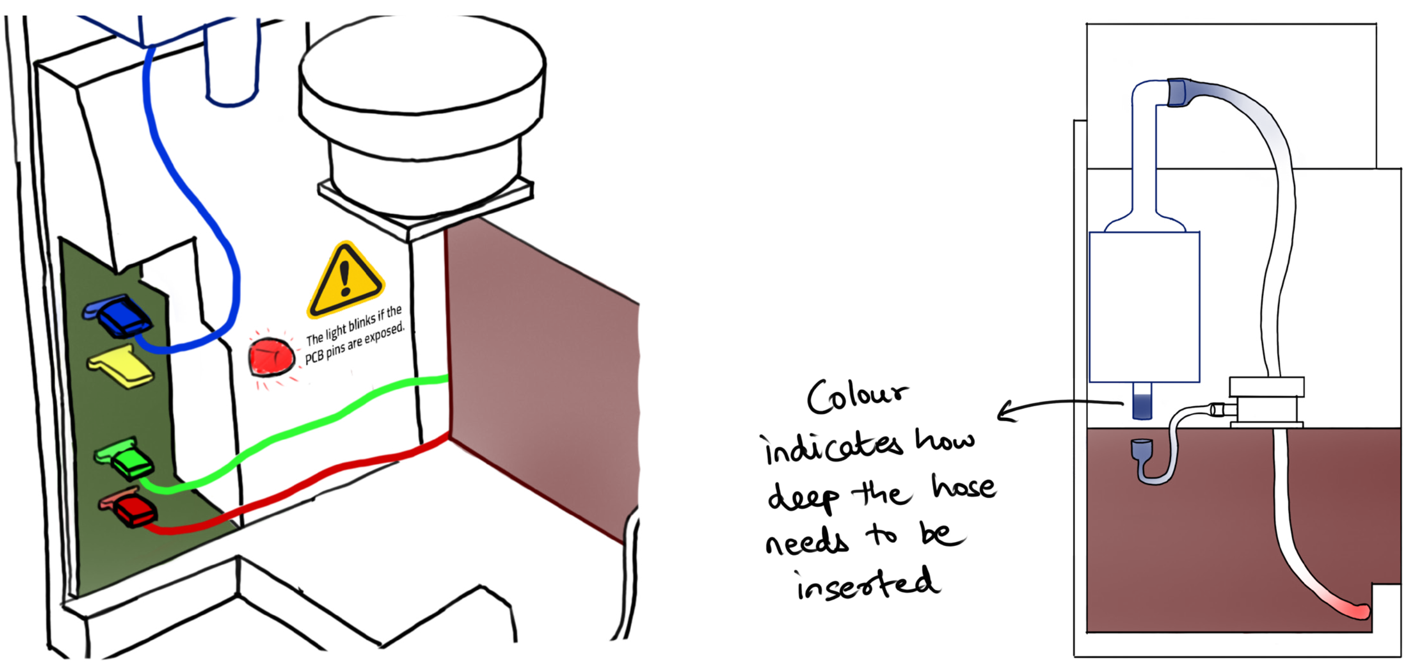


Figure 23: Use of colour coding in wire and hoses. In the hoses for example, blue is used to indicate pump connections whereas red is used for the boiler (side view machine)

4.3.2 Concept 2 - Eliminate risk step

Unlike the previous concept, which utilised the same product architecture as the original Magimix, this concept rearranges components as a consequence of implementing the ideas. One of the ideas involved isolating the PCB from components that transport water. To do this, the PCB is placed as shown in Figure 24. The PCB is placed behind a door that cuts off power when opened, utilising a magnetic reed switch. This prevents electric shocks from occurring due to uninsulated connections (Figure 24).

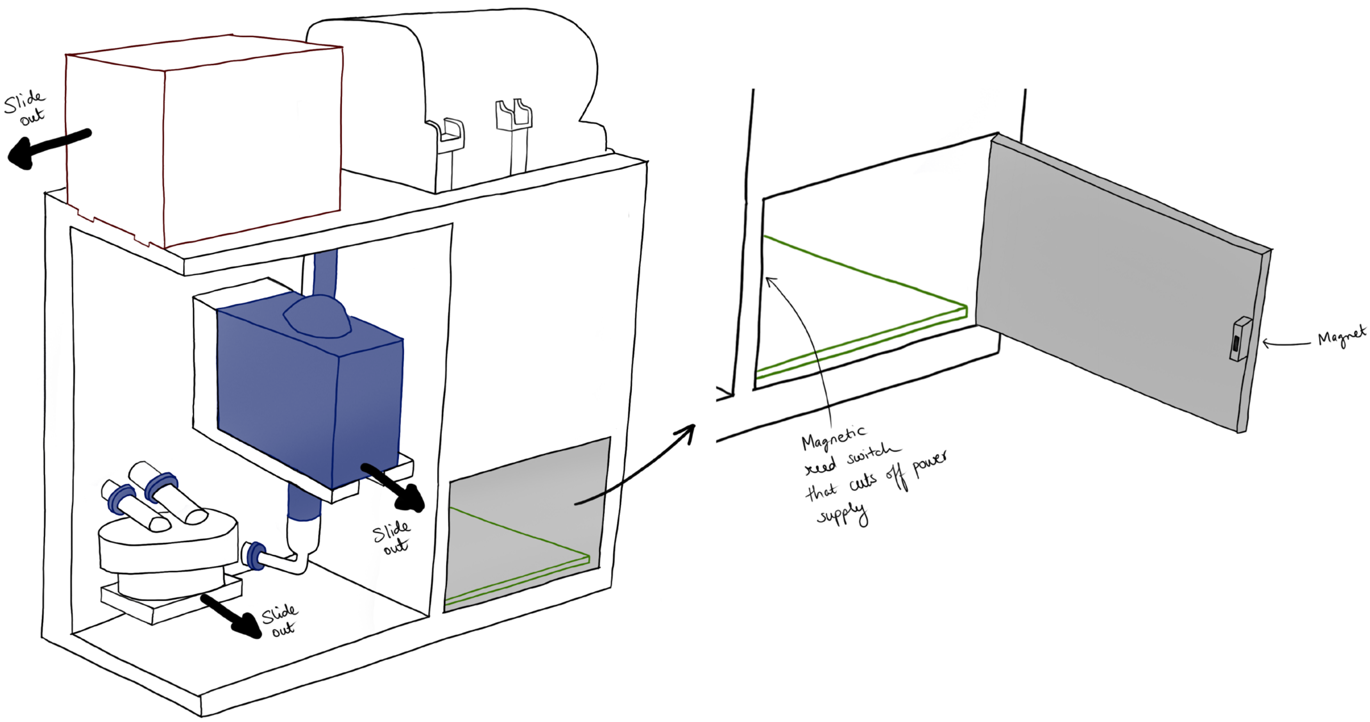
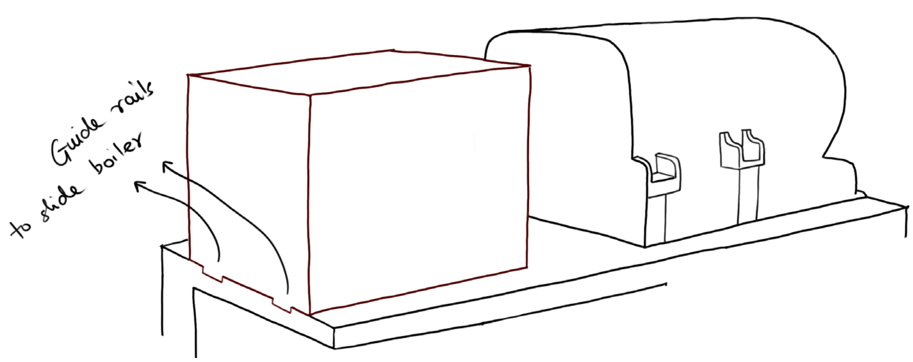


Figure 24: Internal view of the coffee machine. PCB placed behind cover with an interlock that cuts power when opened

Risks arising from incorrect wire and hose connections have been mitigated through the use of drawer connectors and push-to-connect hose couplings. This allows the user to disconnect and reconnect the component to disengage wire and hose connections (Figure 25). Drawer connectors are used in server room racks where each rack can be pulled out for inspection, and this action disconnects the connections. Pushing it back in place reconnects them. Since there is no need to interact with wire connection points, this also eliminates the risk of electrical shock.

Each component has a hose coupling and a hose that connects it to the hose coupling of another component. This hose is never removed unless it needs to be replaced. Shown below is how this would look for the boiler.



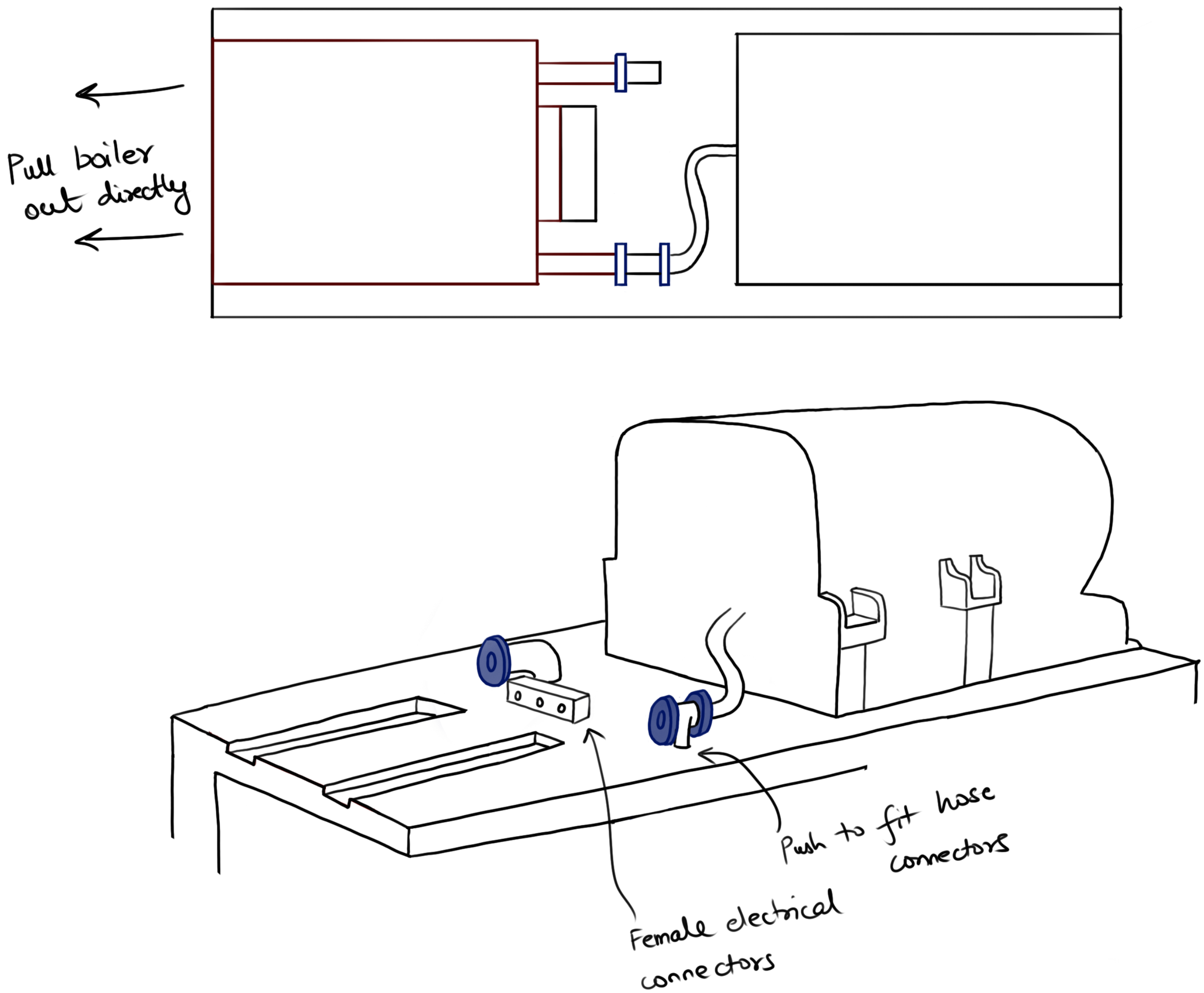


Figure 25: Use of drawer connectors and push-to-connect hose couplings for the boiler as an example (perspective and top view)

Finally, interaction with the hot boiler is eliminated by covering the boiler in an insulating cover that the user never opens (Figure 26). The entire unit is replaced as a whole during repair.

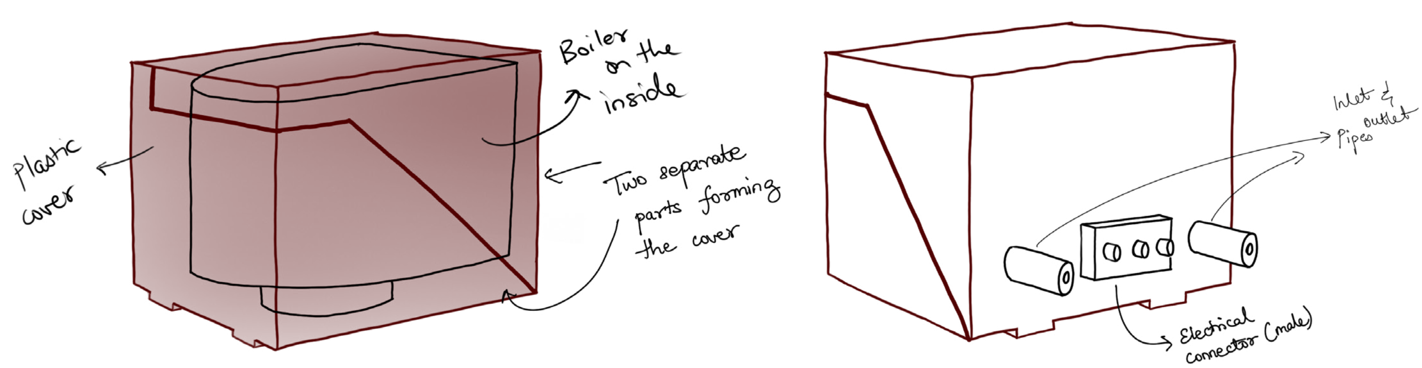


Figure 26: Boiler design to eliminate risk step

4.3.3 Concept 3 - Eliminate the root cause of the risk

Like the previous concept, the implementation of the safety ideas resulted in the shape of the machine and the position of the components being changed. When the user takes out the tank at the back of the machine for repair, they will see a button (Figure 27). This button initiates the “Emptying program,” which empties the system of water, a feature currently available in the Magimix (Magimix User Manuals, n.d.). After this, they can unscrew the housing and open it.

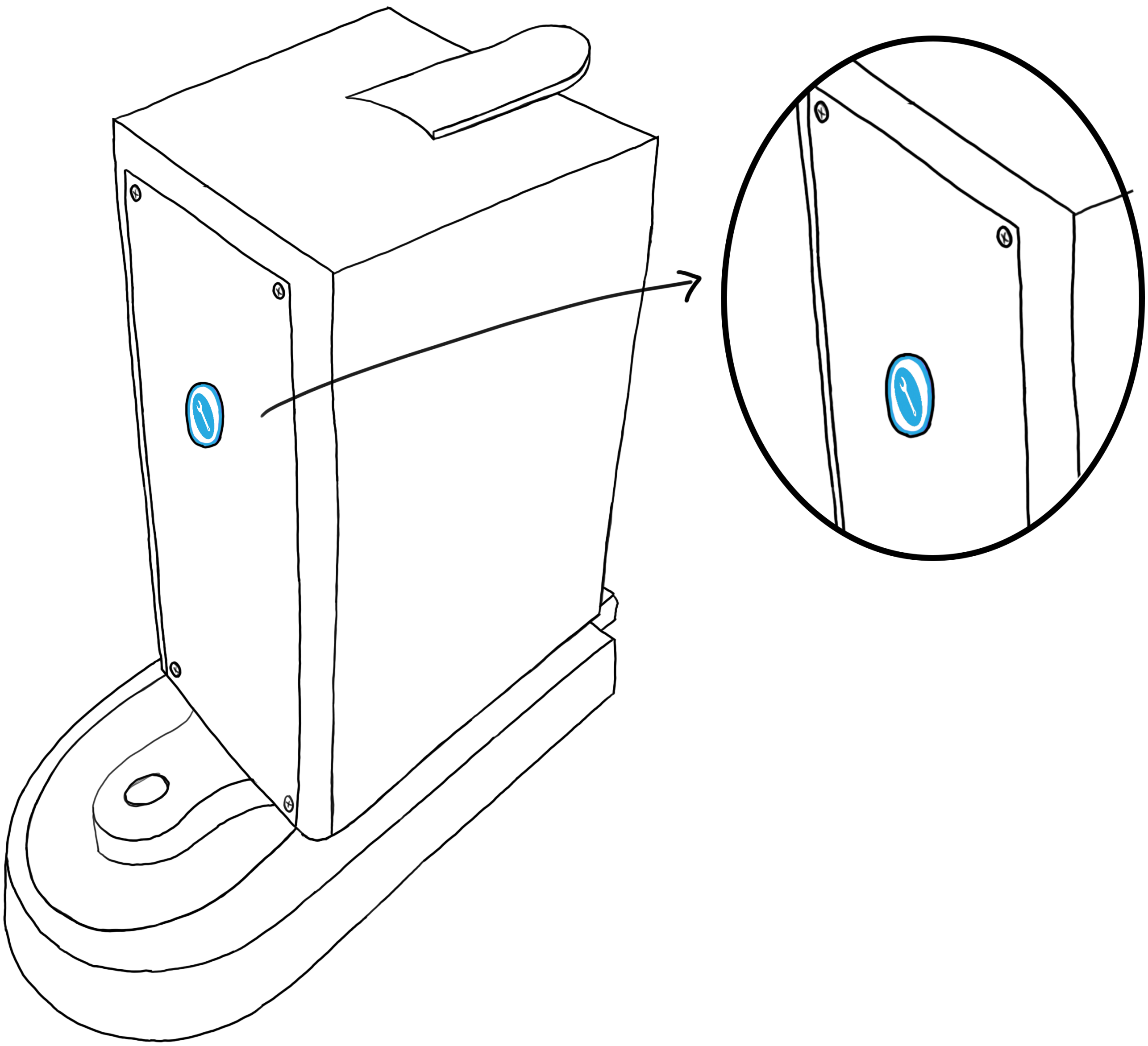


Figure 27: Button that the user presses prior to repair to empty the system of water, hidden behind the water tank

Show below in Figure 28 is the side view of the housing. A part of the housing slides underneath the coffee machine body and contains a magnet that activates a magnetic reed switch. The magnetic reed switch is connected to the power cable that passes underneath the housing and the water tank. Thus, when the housing is in place, the switch is active, and power flows to the PCB as shown.

The housing is also locked into place with the help of the boiler and a bimetallic disc. When the boiler is above a specific temperature, the centre of the bimetal disc expands upwards, pushing a pin that locks the housing in place, preventing it from being slid out.

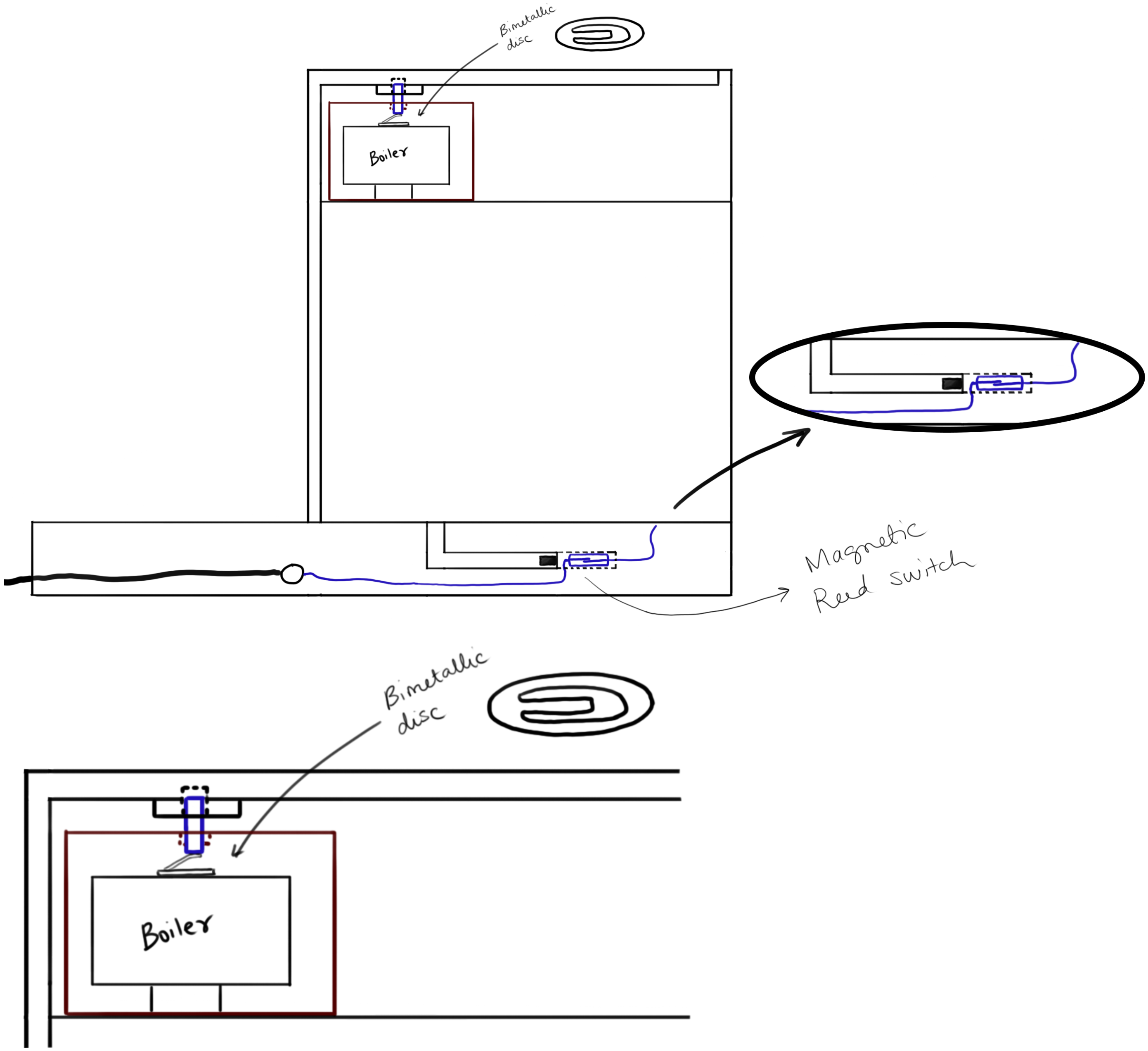


Figure 28: Housing locked in place due to boiler. Power flows due to reed switch being activated

When the boiler has cooled down, the housing can be slid out. The sliding action also moves the magnet away from the magnetic reed switch, thus cutting the power from the power cable to the PCB and thus to the system. This is shown in Figure 29.

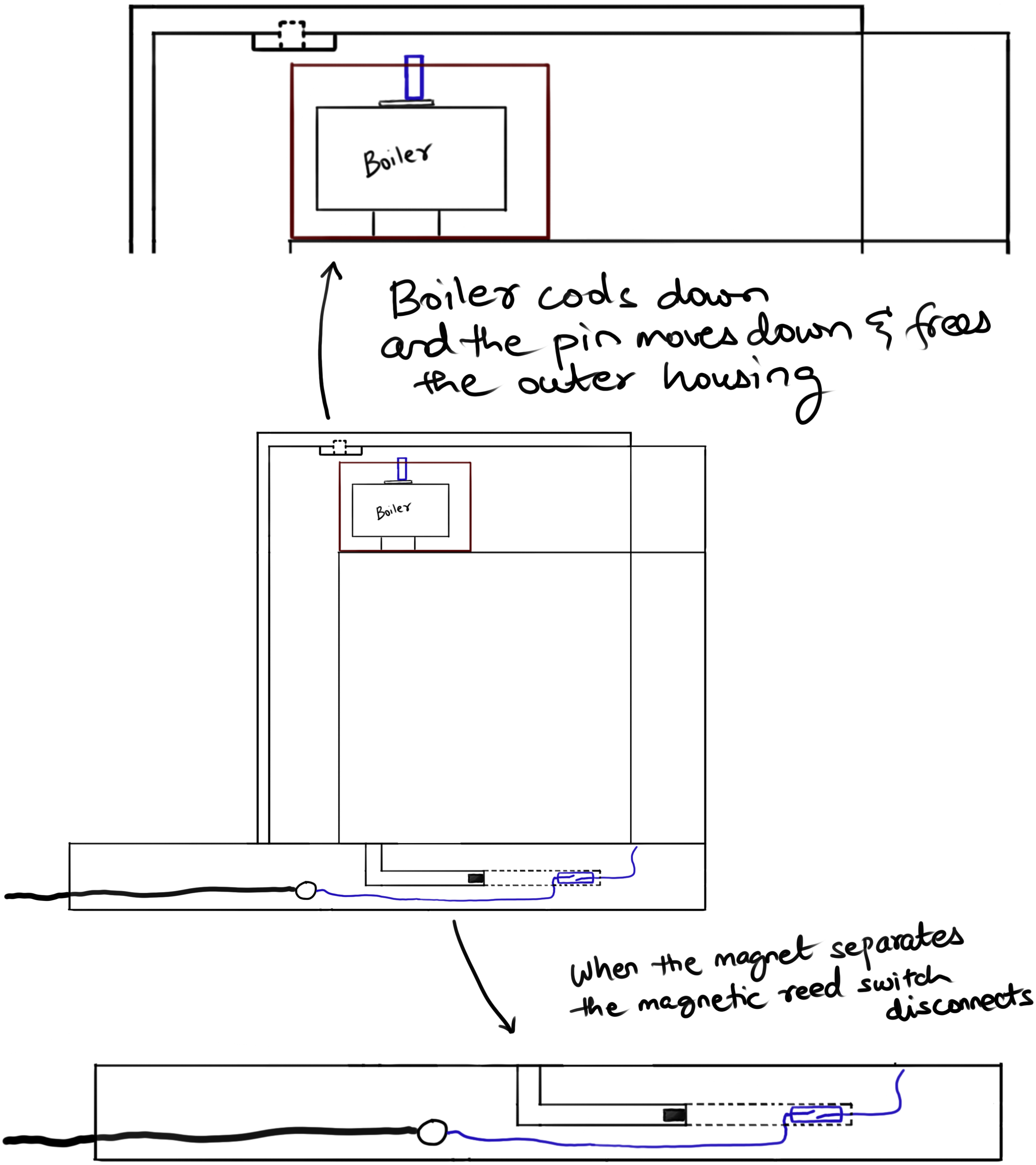


Figure 29: Housing can slide out once boiler has cooled down. Magnetic reed switch deactivates

Figure 30 shows the internal view of the coffee machine. The boiler has been placed on the top so that it can lock the housing when it is hot. Wire connectors have been designed with a unique shape to help users make connections correctly. Hoses have been connected using threaded end connectors. Each inlet/outlet has a unique size – a hose can only fit in one orientation between the correct two components.

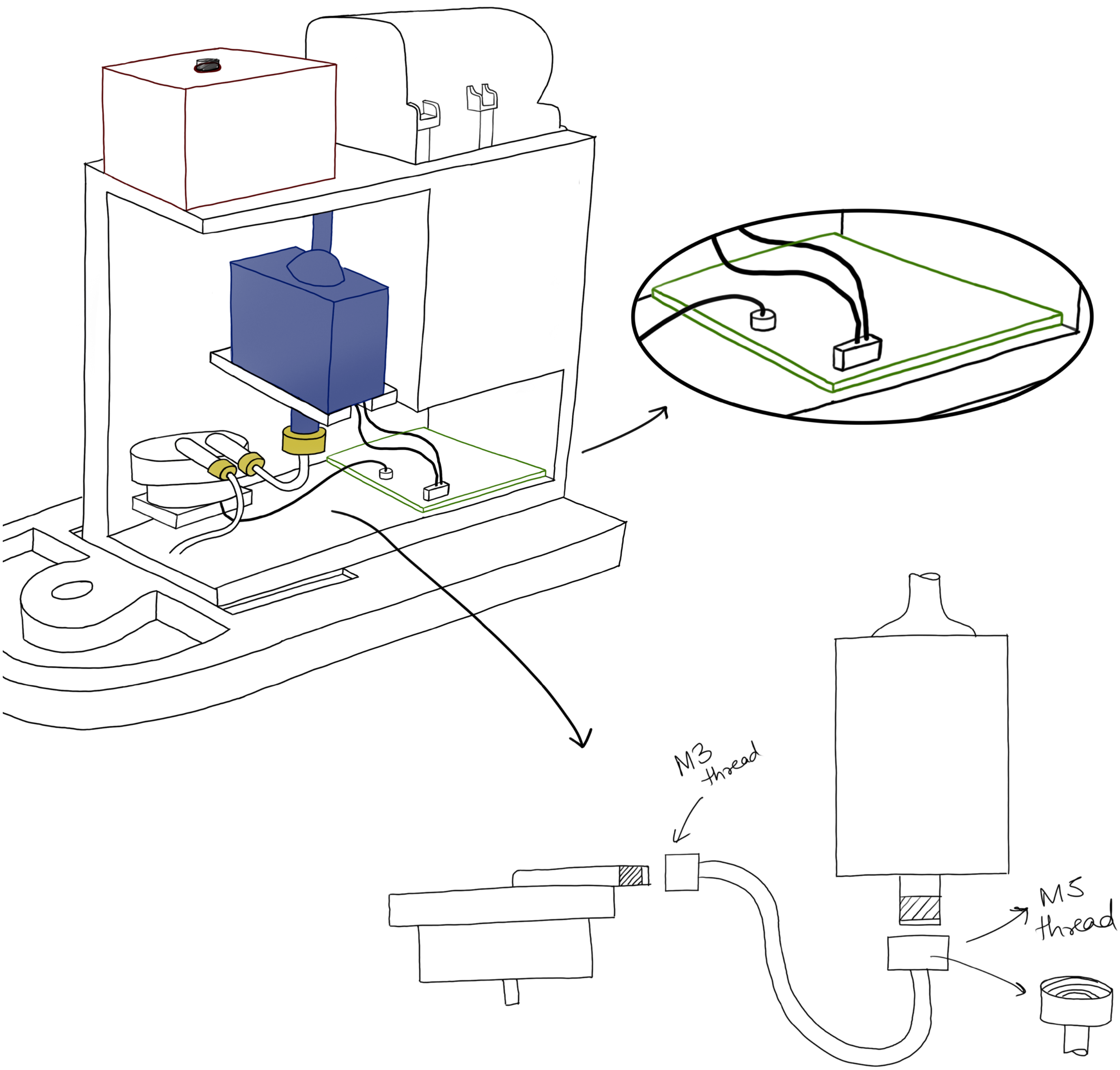


Figure 30: Wire connector shape and threaded hoses to prevent incorrect assembly

4.4 Insights from idea exploration

The previous section explored how the selected ideas could be combined into a coffee machine concept for the three solution spaces. In this section, these explorations were analysed to derive insights into how well the ideas might help eliminate risk. Ultimately, these insights will inform the selection of ideas to be further explored in the form of a prototype to evaluate their effectiveness through functional and user testing.

The concept exploration helped gain a rudimentary understanding of what the implementation of these ideas could look like in a coffee machine. It is important to note that there was still room to modify, optimise, or redesign these explorations and conduct in-depth analysis. However, in the interest of time, the embodiments explored in the concept sketches were qualitatively assessed to identify promising ideas.

<u>Solution space – Design cues</u>

The ideas were the simplest to implement. However, their ability to enforce risk elimination would depend on how effectively they can attract the user's attention. It is essential to note that attracting the user's attention does not guarantee risk elimination, as in most cases, the root cause of the risk remains present.

<u>Solution space – Eliminate risk step</u>

These ideas have the potential to address the risk because they alter the repair step from unsafe to safe. However, the risk may not have been eliminated, and a new risk zone or step may have been created. This will be explained through the example below,

The risk of electrocution was addressed by eliminating the interaction between the user and the electrical connection through the use of drawer connectors (Figure 31). This is achieved by preventing the user from manually disconnecting the wires from the component to the PCB. Instead, they pull the component out of its position, causing it to disconnect from the drawer connectors and lose power (Figure 31). However, this means that power may still be flowing to the system if the power cable has not been unplugged. Suppose the drawer connectors are the faulty component. In that case, interaction with the connector and its wires may still pose the risk of an electrical shock.

This possible shift in risk location, from the component to the drawer connector in the example, needs to be explored for each of the ideas. This presents a safety concern.

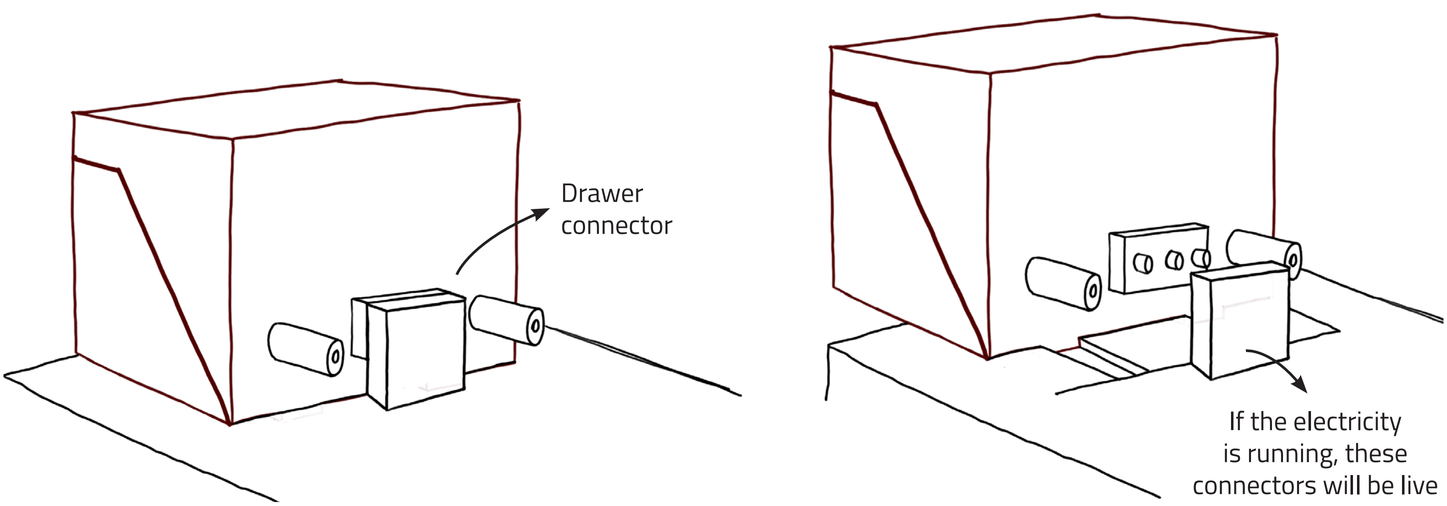


Figure 31: Possible new risk zone or risk step created by the implementation of the ideas from solution space 2

Solution space – Eliminate the root cause of the risk

The ideas were also effective at addressing the risk, as they targeted the source of the risk. However, it is possible that the black-box nature of the ideas meant that the user could often be left confused. For example, one of the ideas prevents the housing from being opened until the boiler has cooled down. Unless this information is provided to the user in some form, the user's inability to open the housing can cause confusion. It may also trigger unfavourable responses, such as mishandling the product.

With these insights in mind, the following ideas were selected for further development into a prototype that can be user-tested. An explanation of why these ideas were selected is presented after the table.

Table 11: Ideas selected from concept exploration

Risk	**Design cues**	**Eliminate risk step**	**Eliminate the root cause of the risk**
User receives an electric shock when accessing internal components during repair	Indication - light or sound, to warn that power cable is still plugged	User does not have access to the wire connection points and never has to interact with them	Safety interlock switch that cuts power when housing is opened
User spills residual water to cause short circuiting during repair		Electronic components are kept far away from potential water dripping sources	Button that is pressed prior to repair that drains the water out
User burns themselves through intentional or unintentional contact with the boiler or water during repair		Boiler is enclosed in an insulated material that the user never needs to opens	Housing is locked until the boiler does not cool down
User receives an electric shock when performing testing	Light that blinks when the connectors are not covered	Power can only be live with the housing open if the PCB is enclosed	Power can only flow if the housing is closed
User makes the incorrect electrical connections during reassembly	Colour code the connections	Wire connections are never taken out when component is taken out	Use cable plugs with unique shape for each connection
Hoses are not attached securely	Marking on the counterpart indicating how deep the F.F hose needs to be inserted	Hoses are never disassembled unless they need to be replaced	Thread based connection (like Classic Gaggia)
Incorrect hose is attached between two components	Colour the hose cap and the corresponding part with the same colour	Hoses are never disassembled unless they need to be replaced	Unique size threaded connection between two parts
Hose is attached in the incorrect orientation	Colour the hose cap and the corresponding part with the same colour	Hoses are never disassembled unless they need to be replaced	Made impossible to connect in the wrong orientation: using different size threaded connections on each end of the hose

As seen, a combination of ideas from "Design cues" and "Eliminate the root cause of the risk" solution spaces have been selected. "Eliminate the root cause of the risk" has been selected over the "Eliminate risk step" solution space because these ideas offer the opportunity to eliminate the risk as opposed to eliminating the unsafe interaction without addressing the risk.

Ideas from the "Design cues" solution space have been selected to either complement the ideas from

“Eliminate the root cause of the risk” or to test whether simple design interventions can aid in safe repair. They have been used to complement ideas where it felt important to explain to the users why their coffee machine is behaving the way it does. As explained earlier, if the user is not informed that their coffee machine will not open unless cooled down, there may be a tendency for the user to force open the machine, which can cause damage. The purpose of adding design cues in the form of visual instructions is to determine if they help provide transparency.

In the case of the fifth risk – User makes the incorrect electrical connections, and the eighth risk – Hose is attached in the incorrect orientation, design cues have been chosen to establish whether they can aid in correct assembly. These interventions are significantly cheaper compared to other available ideas for these risks, and it is thus worthwhile to validate their effectiveness through user testing.

CHAPTER 05

FIRST PROTOTYPE: IMPLEMENTING DESIGN FEATURES FOR REPAIR SAFETY

This chapter explains the design of the first prototype that was created for subsequent testing of the ideas selected in the previous chapter. The focus is primarily given to those design features that relate to the implementation of the ideas and their relation to the prevention of the identified risk.

5.1 Body of the prototype

The external view of the coffee machine is shown (Figure 32), where there are four distinct parts – the outer housing, the water tank, the inner housing and the base. In the image, it is seen that the inner housing of the coffee machine is attached to the base using two screws at the front. This was done to facilitate easier iteration of the design during prototyping and should instead be a single unit (clumped together).

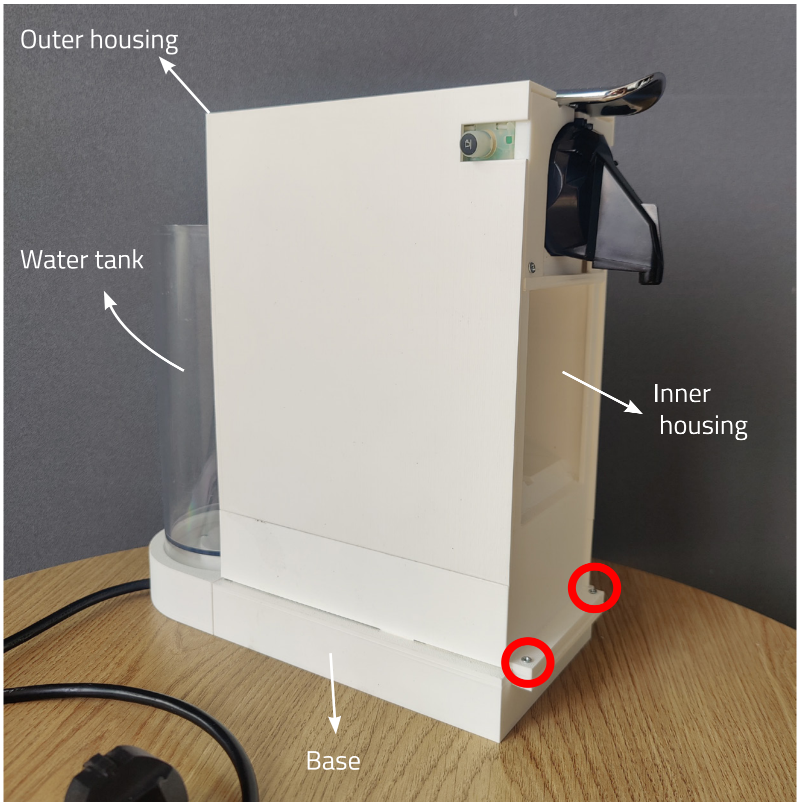


Figure 32: View of the prototype from the outside

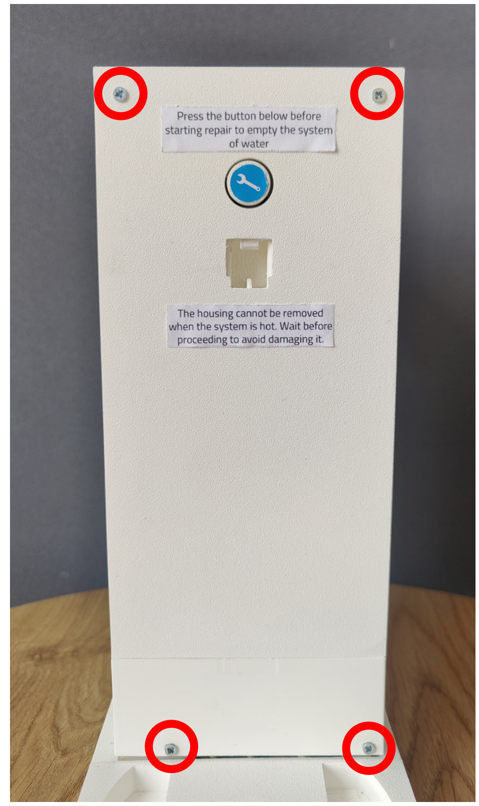


Figure 33: Back-view of the prototype

The internal components of the coffee machine can be accessed by removing the screws located at the back, which are hidden by the water tank (Figure 33). The water tank also hides instructions and a button. Pressing the button triggers the "emptying program," which flushes the water from the system. The instructions around the button explain the purpose of the button and inform the user that the housing is locked until the boiler cools down.

Once the four screws are removed, the outer housing is free and can be disassembled by sliding it away from the body of the coffee machine (Figure 34). At one point, while sliding the outer housing, the housing must be lifted because of a small projection that inserts itself into the base of the coffee machine. This projection (switch trigger for future reference) is used to press against the interlock switch. This completes the electrical connection, allowing power to flow to the PCB (Figure 35). Thus, if the housing is taken out, the connection is broken, and the power is cut. If a user accesses the internal components without taking the power cable out of the socket, they will not get an electric shock.

Figure 34: Outer housing slides out once the screws are removed

Figure 35: Switch trigger that presses against the PTM switch

Once the outer housing is removed, a long, thin plate (housing lock for future reference) can be seen inside (Figure 36). This is used to lock the housing when the boiler is hot. Its working will be explained later.

Figure 36: Housing lock used to restrict the outer housing when the boiler is hot

5.1.1 Base of the coffee machine

The base of the coffee machine holds the safety interlock switch for the power. A PTM switch was chosen (Appendix E) because it was quick and easy to use to design an interlock system—when the outer housing is fastened in place, it pushes a spring-loaded button to make the connection, and when the outer housing is taken out, it releases the button to break the connection between its terminals (Figure 37).

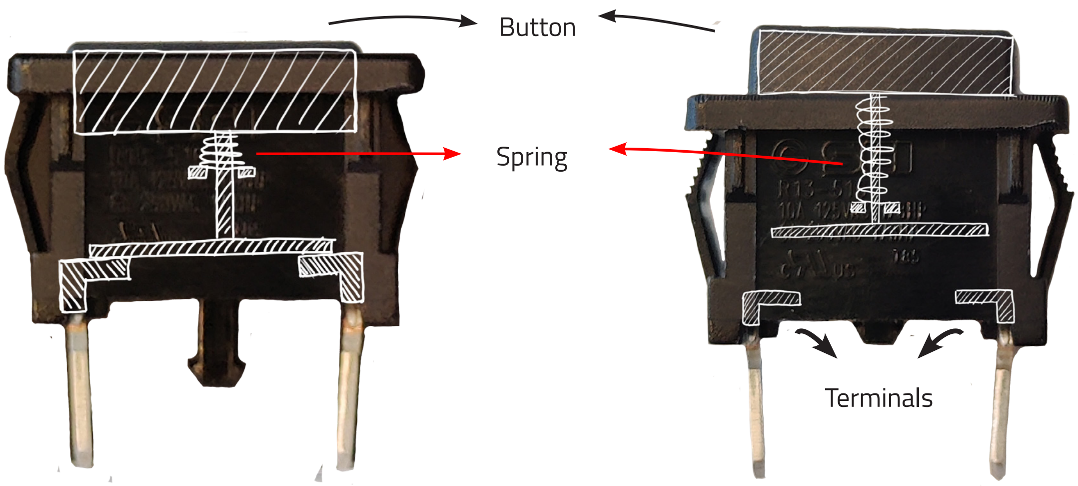


Figure 37: Working of a PTM switch: Push button to complete the circuit between the terminals, release to break the circuit

This switch can be accessed by removing four screws located at the bottom of the base and removing the back panel (Figure 38). A terminal of the PTM (push-to-make) switch is connected to the live connection of the power cable, and the other terminal is connected to a wire from the coffee machine. In the image, the switch has been glued in place because the enclosure designed for it broke during installation.

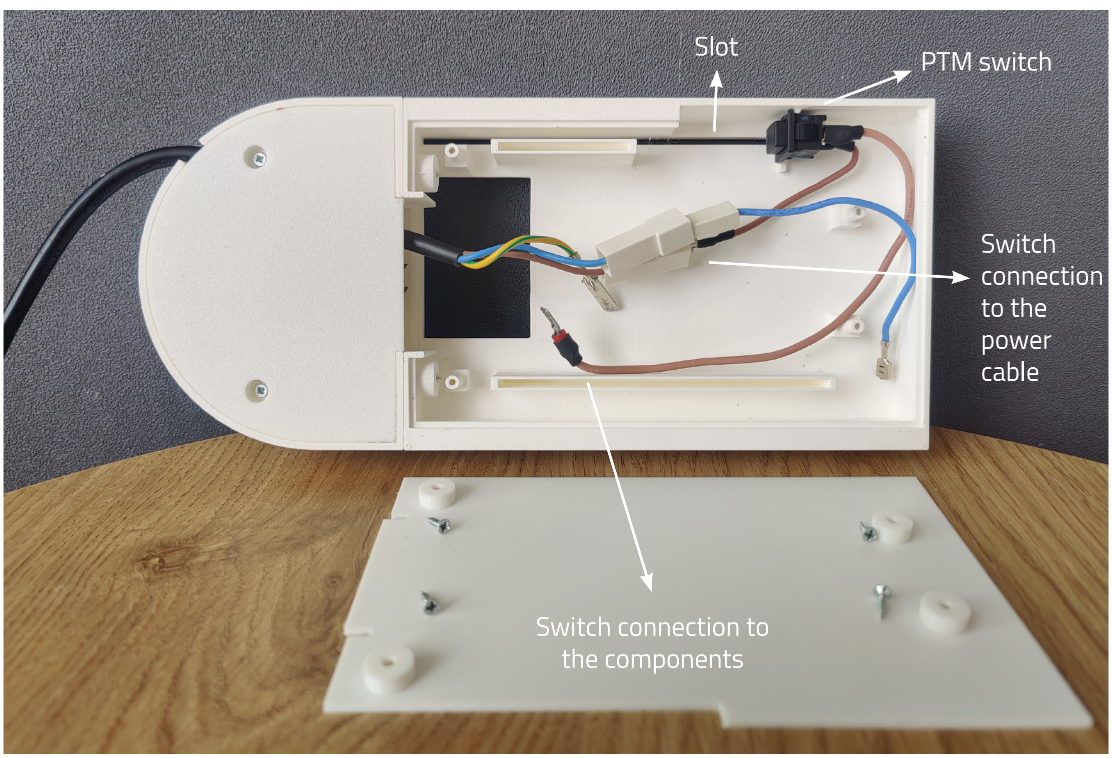


Figure 38: Internal view of the coffee machine base

In front of the PTM switch is a slot (Figure 38). This slot is present to allow the switch trigger (Figure 39) to insert itself into the base and press against the PTM switch when the outer housing is installed. This completes the circuit inside the PTM switch, allowing power to flow to the internal components.

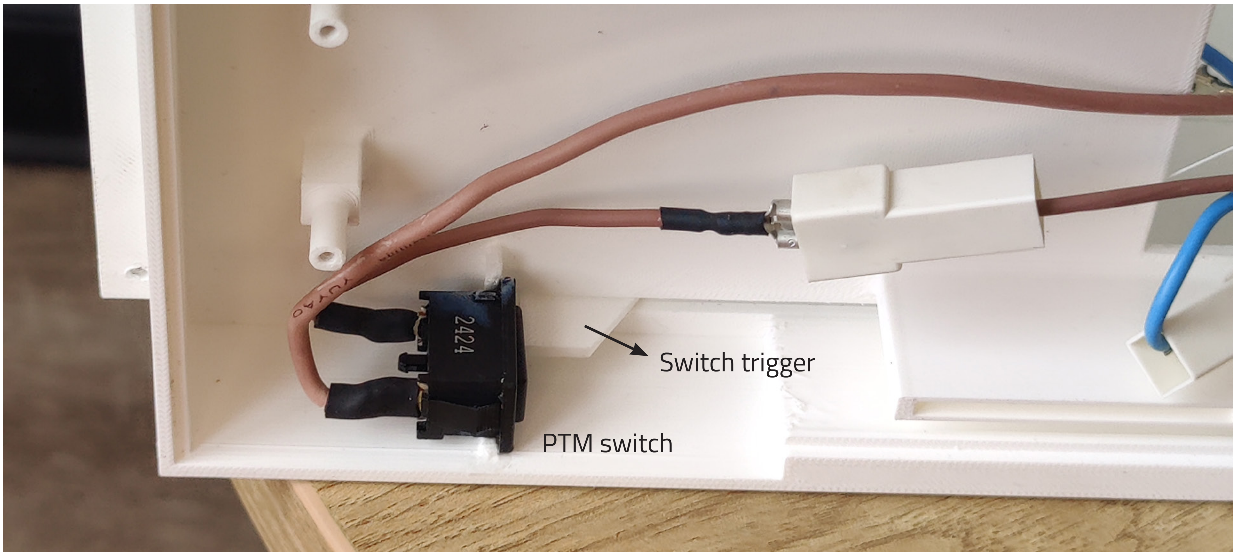


Figure 39: PTM switch button pressed by the switch trigger. This completed the circuit and allows power to flow to the coffee machine

5.2 Internal components

Once the outer housing is taken out, the internal components of the coffee machine are visible (Figure 40). The PCB, pump, and flowmeter are attached as in the Magimix, using a friction fit to slot them into place. The attachment of the brewing assembly cover and the boiler unit has been changed.

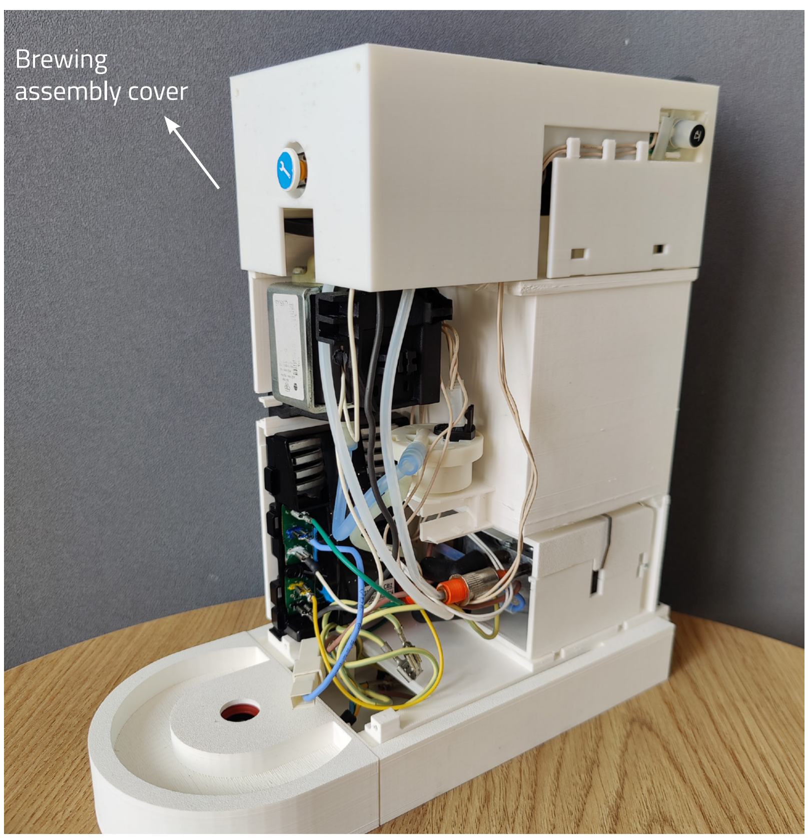


Figure 40: Internal view of the coffee machine

The brewing assembly cover can be removed using the two screws at the front (Figure 41), as opposed to the four snap-fits in the Magimix. This was done because, in the Magimix and the first iteration of the prototype, the snapfits broke with repeated use.

Figure 41: Use of screws to attach the brewing assembly cover (left) as opposed to the use of snapfits (right)

While the location of the boiler unit was not changed to improve space utilisation (Appendix E), the unit itself was redesigned to implement the solution to address risk 3 - User burns themselves through intentional or unintentional contact with the boiler or water during repair. The details are presented below.

5.2.1 Boiler unit

The redesigned boiler unit consists of the parts shown in Figure 42. The bottom cover anchors the boiler through the silicone ring in between. Three new components are shown: the HTR (heat transfer ring), the bimetal strip, and the pin. These work together to trigger the mechanism that locks the housing when the boiler is hot, thus preventing the user from burning themselves through intentional or unintentional contact.

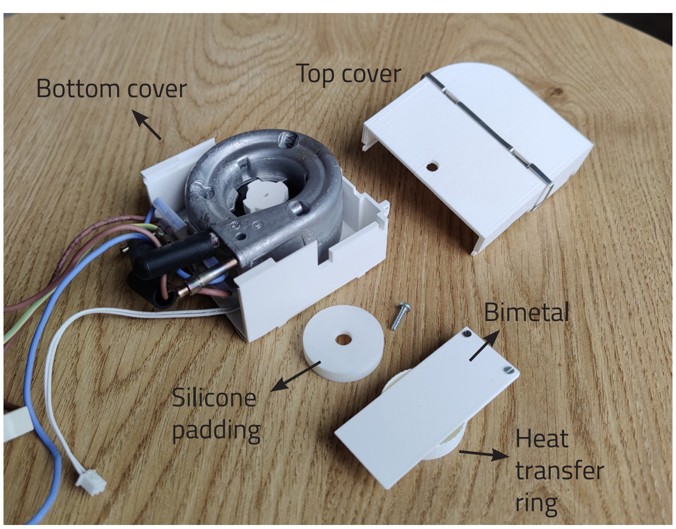


Figure 42: Components of the boiler unit

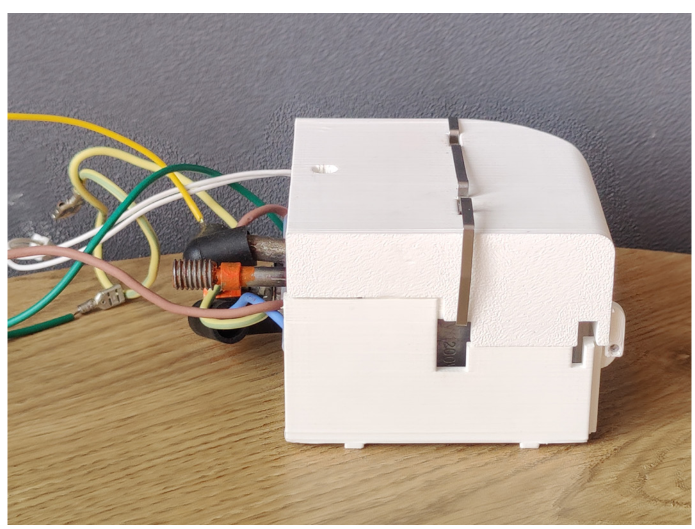


Figure 43: Boiler unit assembled

The selected idea to mitigate risk 3 involved locking the coffee machine housing when the boiler was hot. This meant that a method was required to detect the boiler temperature. Next, it had to lock the housing above a specific temperature and then release it once it fell below this threshold. For the prototype, a bimetal was selected as the method of temperature detection because,

1. Bimetals are commonly used in low-cost steam irons, electric kettles and toasters to actuate a mechanism when a threshold temperature is reached.
2. Are readily available to test

For actuation, the bimetal was used to push a pin vertically up as it deforms. This pin would then lock the housing when the boiler is hot and release the housing when the boiler cools down and the bimetal returns to its undeformed state.

Selection of the bimetal to actuate a pin involved choosing from the readily available options. Bimetals used in electric kettles and steam irons were tested by applying physical force or providing heat to determine their ability to provide the required amount of vertical displacement (Figure 44).

Figure 44: Testing the bimetals used in an electric kettle (left) and steam iron (right) to actuate a mechanism (details in Appendix E)

The bimetals needed to provide sufficient vertical displacement, as the goal was to use the pin to secure itself between two points of contact. Two points of contact were targeted because, as shown in Figure 45, in the case of two points of contact, the pin is supported on both ends and can withstand twice the load (Account, 2020) as opposed to being supported on one end only. In the case of the prototype, the two points of contact were the boiler top cover and the inner housing, while the pin passes through the housing lock of the outer housing.

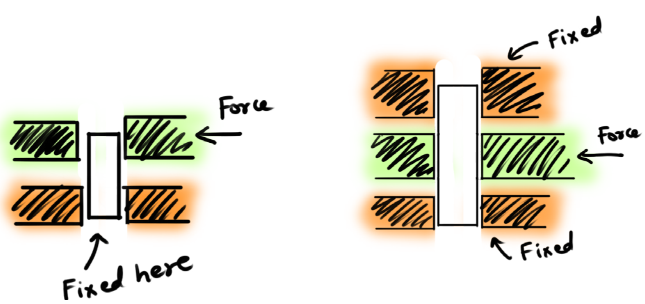


Figure 45: Single point of support (left) vs two points of support (right)

The top cover of the boiler is 2 mm thick, and we can assume that the pin inserts 2 mm into the inner housing. If the part of the housing being locked by the pin is also 2 mm in thickness, at least 8 mm (with clearances) of vertical movement is required from the bimetal (Figure 46).

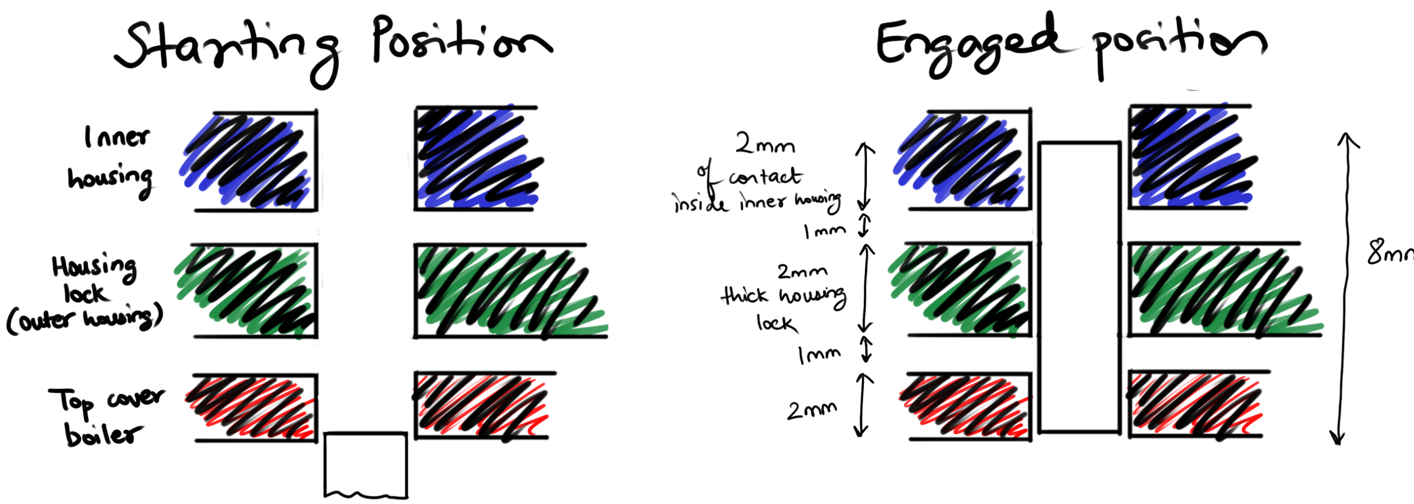


Figure 46: Minimum vertical movement required for the pin to create a secure lock

When tests were conducted with the two bimetals (Figure 44), it was concluded that the bimetals in their existing shape would not be sufficient. Thus, a bimetal design was proposed using Kanthal's Thermostatic Bimetal Handbook (Kanthal, 2008). The resulting bimetal dimensions are shown in Table 12. The bimetal was designed to provide 8 mm of deflection, exerting a 1 N force, and deform over a temperature range of 50°C (from 40 to 90°C). The choice was made based on the design that produced the lowest stress in the bimetal as it reduces failure from fatigue loading over repeated use.

Table 12: Calculation to determine dimensions of the bimetal strip

KANTHAL 230		
Travel	8	mm
Force	1	N
Temp difference	50	(40 - 90 C)
Length of strip	70	mm
Specific deflection	2.27 x $10^{(-6)}$	
Modulus of elasticity	135000	N/mm2

Proportion of temperature used for deflection	Thickness (mm)	Width (mm)	Stress (MPa)	Angle @ full deflection (deg)	Length reduction due to deflection (mm)
0.6	0.42	26.26	91.94	21.83	5.02
0.5	0.35	30.25	114.92	26.19	7.19
0.7	0.49	25.72	68.95	18.71	3.70
0.8	0.56	29.54	45.97	16.37	2.84

With the bimetal characteristics and shape defined, a method for attaching it and transferring heat from the boiler had to be determined. The HTR was designed to serve that purpose by maximising contact with the boiler body and transferring heat to the bimetal strip (Figure 47). The bimetal strip absorbs this heat and deforms. Since it is attached to the HTR on one end, the other end is free to move and rise.

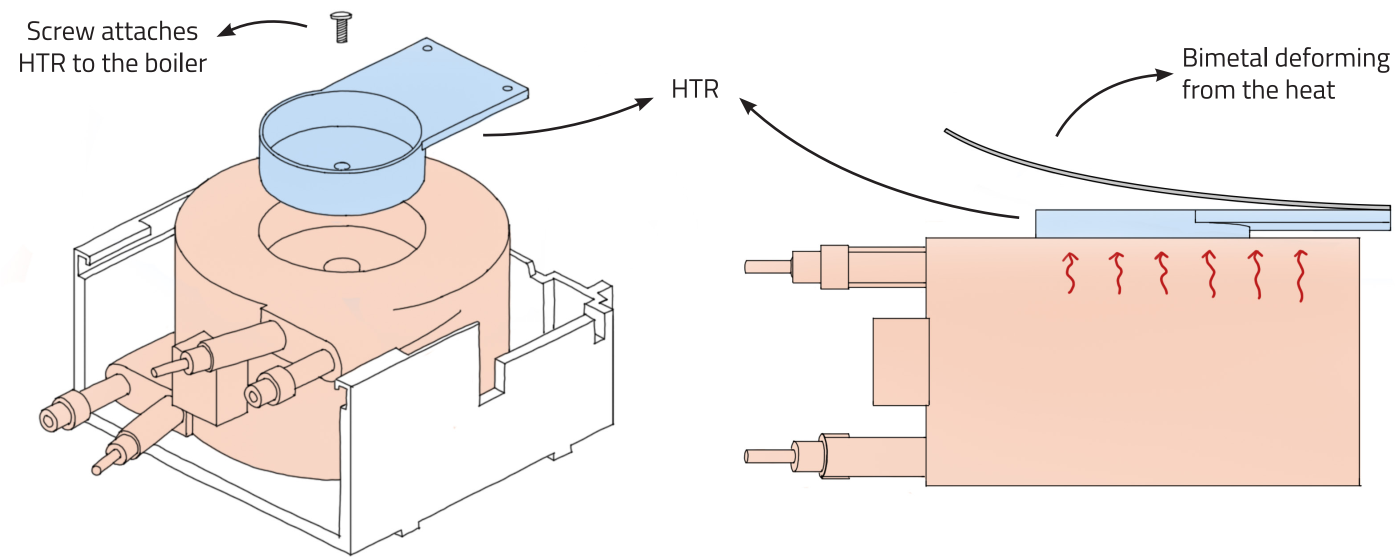


Figure 47: HTR connection to the boiler and its method of heat transfer to the bimetal

This, in turn, pushes the pin upwards through the boiler's top cover (Figure 48). The pin passes through the outer housing (through the housing lock) and into the inner housing, thus preventing the user from removing it (Figure 49). Once the boiler cools down, the bimetal returns to its original shape, and the outer housing is released.

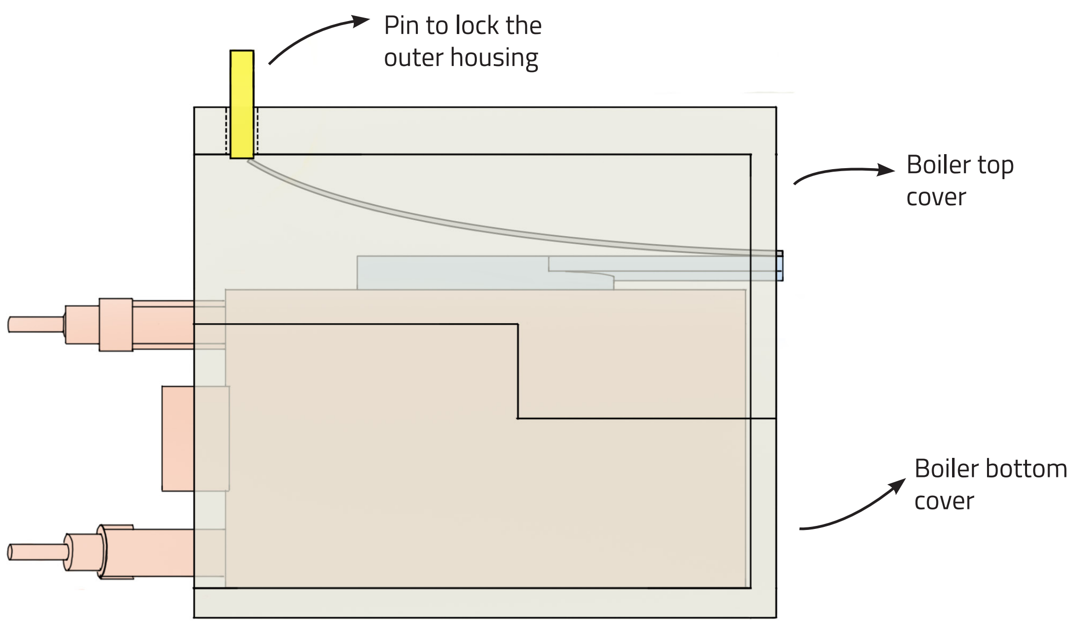


Figure 48: Bimetal pushing the pin through the boiler top cover, to insert into the inner housing.. This locks the outer housing in-place as the pin is now fixed in-place on two points

This mechanism is further explained on the next page using the prototype. Since the prototype used a bimetal designed on paper, a 3D-printed model has been attached to the boiler. Thus, it was not possible to deform it by applying heat, and the locking mechanism is explained through other alternatives.

Figure 49 shows a section view of the prototype. When the outer housing is installed, the housing lock lies between the top cover and the inner housing. Thus, when the boiler is hot, the pin moves through the housing lock, securing it in place. The bimetal has been designed to deform between 40 and 90 degrees, and thus, the outer housing is only free once the boiler falls below this temperature.

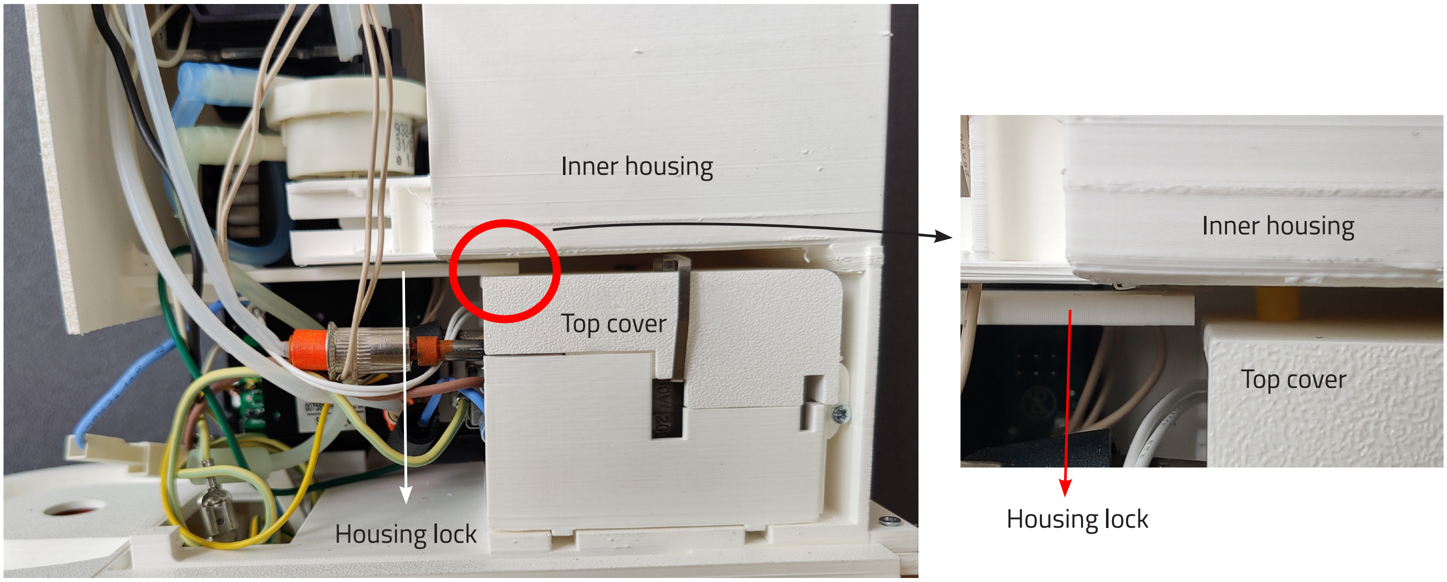


Figure 49: Section view of the prototype showing the housing lock sandwiched between the boiler top cover and the inner housing (left). To illustrate the pin's role, the outer housing has been pulled away to reveal the pin passing from the top cover to the inner housing. (right)

The top cover has also been redesigned to slide into place (Figure 50), as opposed to the Magimix design, where it is bolted into the bottom cover from the top (Figure 51). This is not possible in this design as the bimetal strip blocks access to the bottom cover.

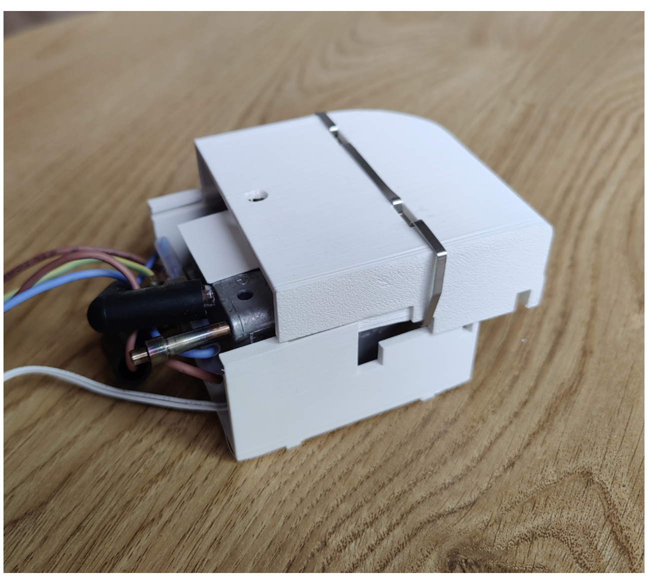


Figure 50: Top cover sliding on the bottom cover to fit into place

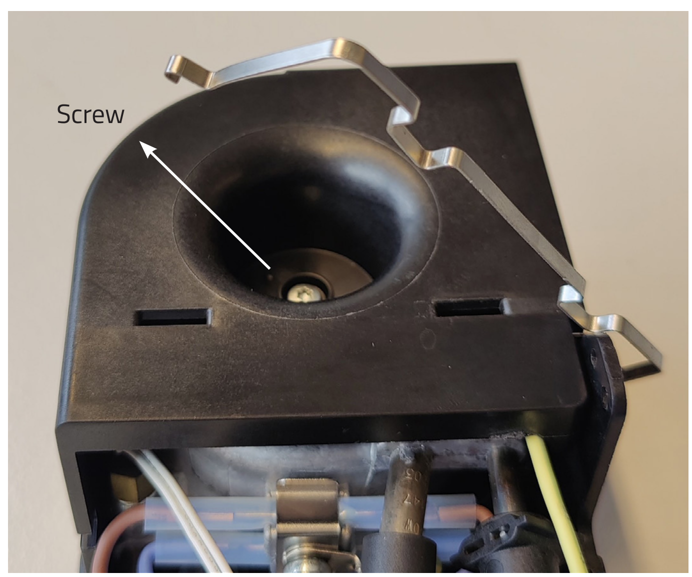


Figure 51: Boiler unit is attached to the inner housing using a screw. The screw passes through the top and bottom cover, clamping them together

The boiler unit has also been chosen to test the ideas for risks 6, 7, and 8, which aim to ensure secure and correct hose connections – using threaded connections and colour coding. This is because,

1. The hoses near the boiler inlet and outlet had limited space. Thus, if the ideas worked in this limited space, they would work for the other components as well.
2. The boiler has the most wire connections, so it makes sense to ask users to dismantle it. Asking them also to dismantle the hoses would complete the test.
3. The boiler was easier to retrofit for the user test compared to the other components.

Threads ensure a tight connection, whereas colour helps the user identify the correct hose to be attached between two components and the orientation in which they are to be attached.

Figure 52 shows the boiler inlet and outlet. The outlet has an M6 threaded end, whereas the boiler inlet uses M8. The hoses attaching to the inlet and outlet have also been appropriately modified (Figure 53). For the inlet, an M8 bushing has been installed, and for the outlet, an M6 plastic coupling. They have also been colour-coded orange to signify that they are to be connected to the boiler (which also has orange applied to connection points).

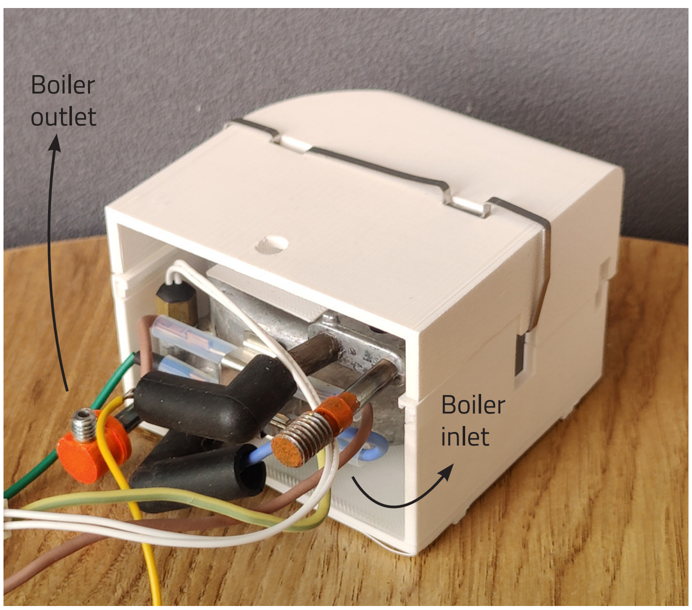


Figure 52: Boiler with the colour coded hose connection points. The connections points have threaded connections to ensure secure attachment of hoses

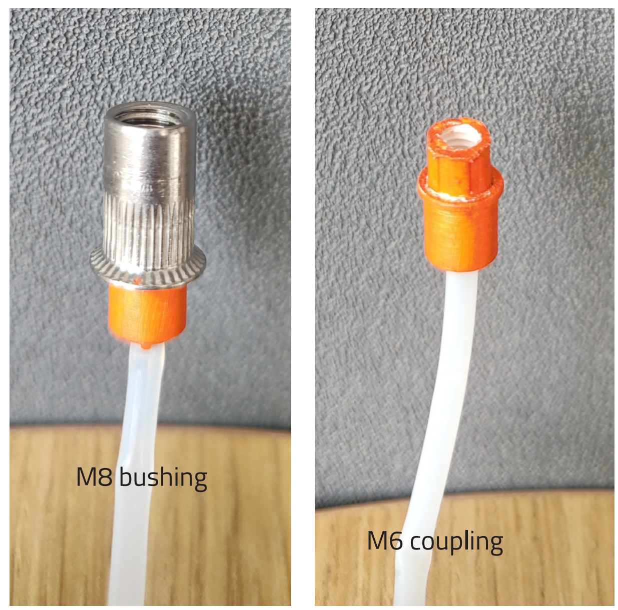


Figure 53: Hose for the boiler inlet (left) and boiler outlet (right) with the appropriate female-thread component

The hose to the boiler's inlet originates from the pump, whereas the hose to the boiler's outlet terminates at the brewing assembly. The connection points on these parts have also been modified to allow threaded connections and have been colour-coded to help the user understand which hose and which end of the hose connects to which component (Figure 54).

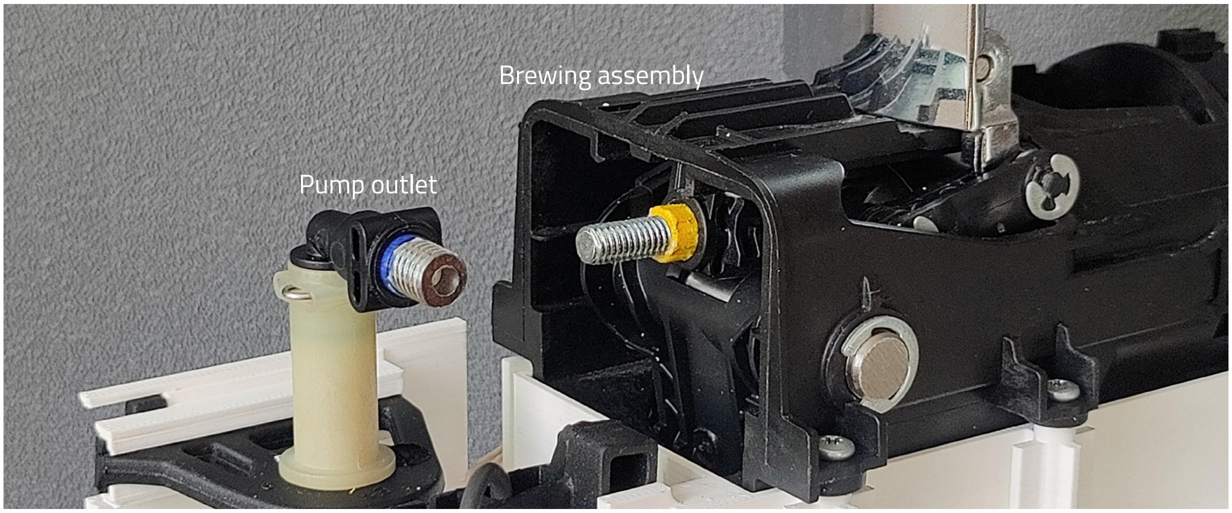


Figure 54: Pump outlet and brewing assembly inlet colour-coded and retrofitted with threads to match the appropriate hose

Finally, the ends of the hoses connecting to the pump and the brewing assembly have also been modified accordingly, as shown in Figure 55.

Figure 55: Hoses modified to connect to the components and appropriately colour coded to indicate the orientation of attachment

5.2.2 PCB

The PCB has not been modified, except that the connection pins and the corresponding wires have been colour-coded as shown in Figure 56. This has been done to validate the effectiveness of using colour to aid in making the correct wire connections during reassembly. For user testing, paint has been used to colour code.

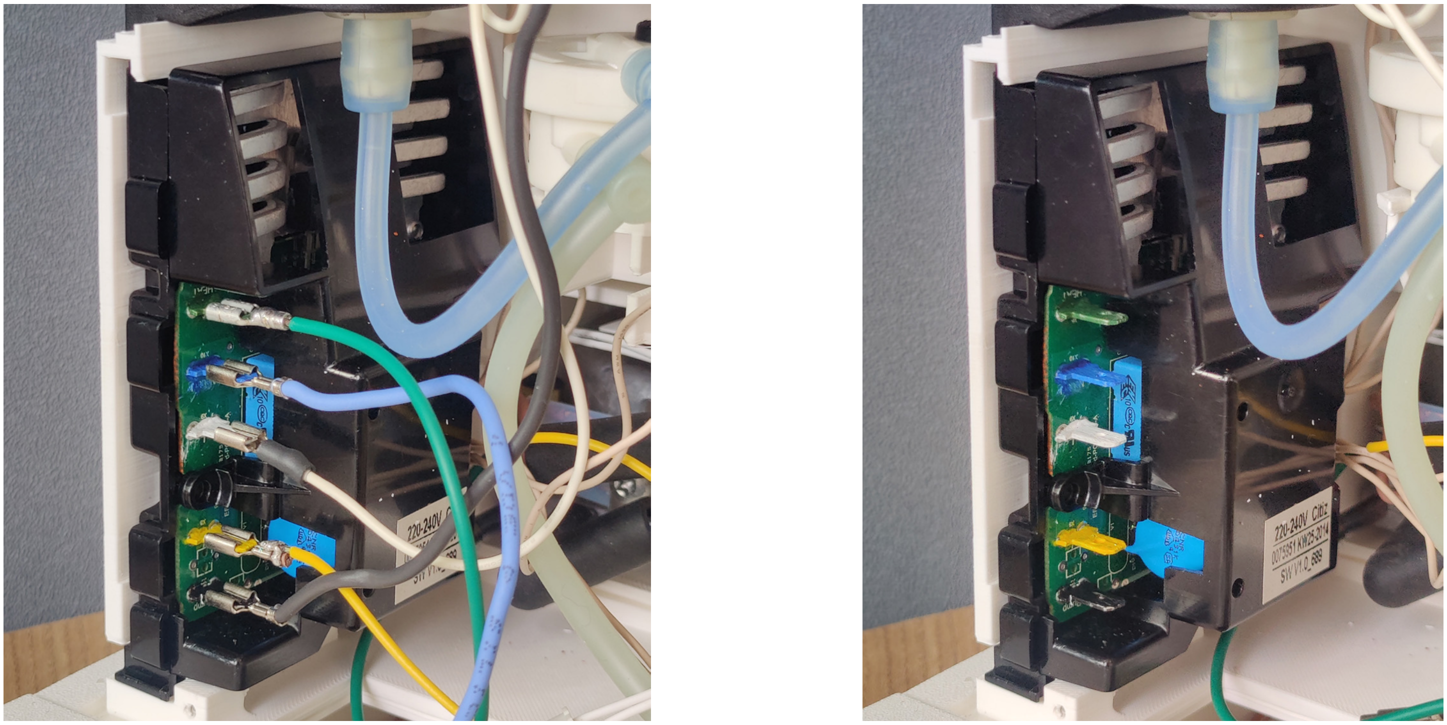


Figure 56: PCB with wires (left) and without wires (right) shows the use of colour to match the wires to the appropriate pins

CHAPTER 06

EVALUATION OF REPAIR SAFETY IDEAS AND THE PROTOTYPE

In this chapter, details of the prototype evaluation are provided. Two methods are employed: testing and the use of a modified disassembly map with risk assessment. Testing is divided into two types: a functionality test and a user validation test. Functionality tests were conducted to verify that specific ideas functioned as designed. The user test was conducted to evaluate the effectiveness of the ideas that relied on design cues. This was achieved by asking users to execute a specific repair task and observing their actions. The modified disassembly map was used to visualise the product architecture and risks in the prototype. Risks were identified from the user testing, and highlighted using the risk assessment table from Chapter 2. Gaps observed were used to generate insights for future iterations.

6.1 Testing objective

With the prototype built, the next step was to test the ideas incorporated into it. To that end, the following objective was set for the testing phase,

"Evaluate the ideas prototyped to improve repair safety to see if they perform as intended."

6.2 Approach to testing each idea

To test the effectiveness of the ideas, two different approaches were utilised - a functionality test and a user interaction test. The functionality tests were performed on those ideas that required technical evaluation to ensure they functioned as designed. For example - a safety switch was added to cut power off. However, does it still perform effectively when the outer housing is taken out? This implementation had to be tested. The user interaction test was conducted to evaluate ideas that relied on providing users with design cues to guide them in performing correct disassembly and reassembly steps.

To summarise, a table detailing the type of test performed to evaluate each idea is presented below,

Table 13: A summary of the idea and the test planned to evaluate it

Idea	Type of test	Test number	Test planned
Safety interlock switch that cuts power when housing is opened	Functional	1	Connect power cable to the mains and test output voltage using a multimeter before and after the housing is taken out
Using a bimetal to actuate a mechanism that locks the outer housing when the boiler is hot	Functional	2	Using a bimetal to actuate a pin in the vertical direction to verify that it can lock a component in place
		3	Maximum weight that a bimetal can lift while achieving the required vertical deflection
		4	Placing a prototype of the HTR on a hot plate to evaluate its heat transfer efficiency
Adding information to the back of the coffee machine to instruction the user to use the button (Idea 2) and warning them that the housing could be locked	User interaction test	5	Involve participants to perform mock replacement of the boiler
Colour coding wire connections to aid in reassembly			
Thread based connections to ensure hoses are securely attached			
Unique size threads for each hose to ensure the correct hose is attached between components			
Colour code the thread connections of the hose to ensure that the hose is attached in the correct orientation			
Button that empties the Magimix of water			Not being tested because this feature is present in the Magimix

The following sections cover each test, presenting the objective and results. Appendix F provides details of the setup and procedure.

6.3 Test #1 - Evaluating the safety switch to cut power

6.3.1 Objective

The objective of this test was to evaluate whether the power safety switch worked as intended - when the outer housing is connected, power flows from the switch's exit terminal, and when the outer housing is removed, the power is cut off.

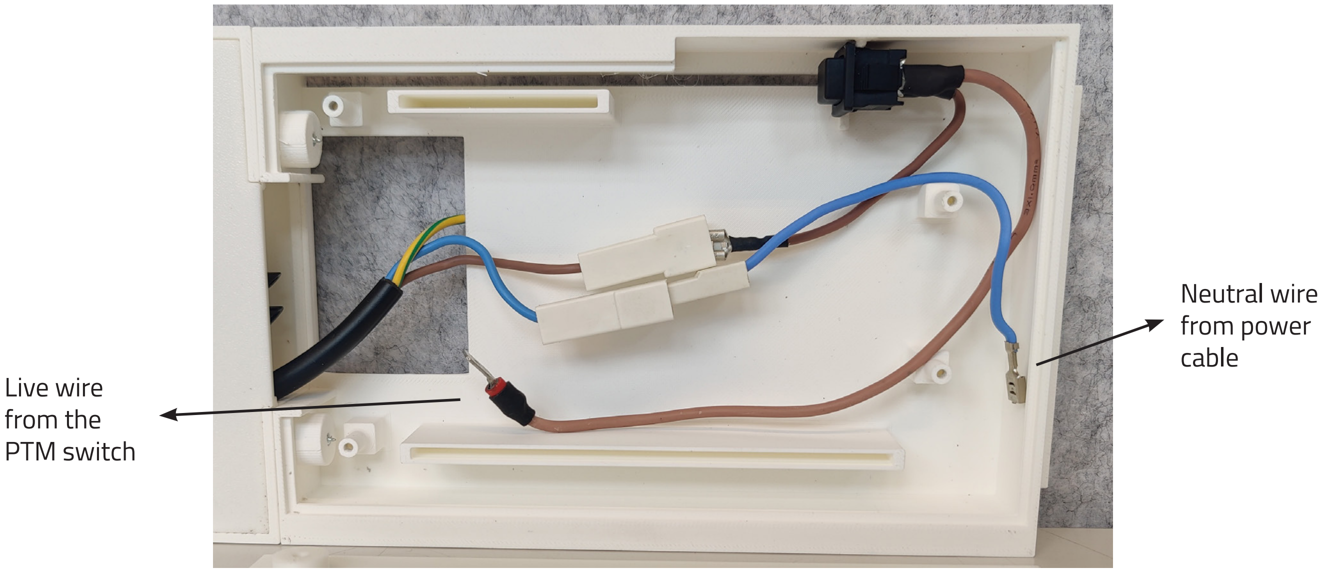


Figure 57: The live wire from the PTM switch and the neutral wire from the power cable

6.3.2 Results

Figure 58 illustrates the setup for performing the test. The neutral wire (Figure 57) has been clamped along with the neutral terminal of the multimeter (Figure 58) to allow one hand to be free. The live wire (Figure 57) is left to lie beside the prototype (Figure 58).

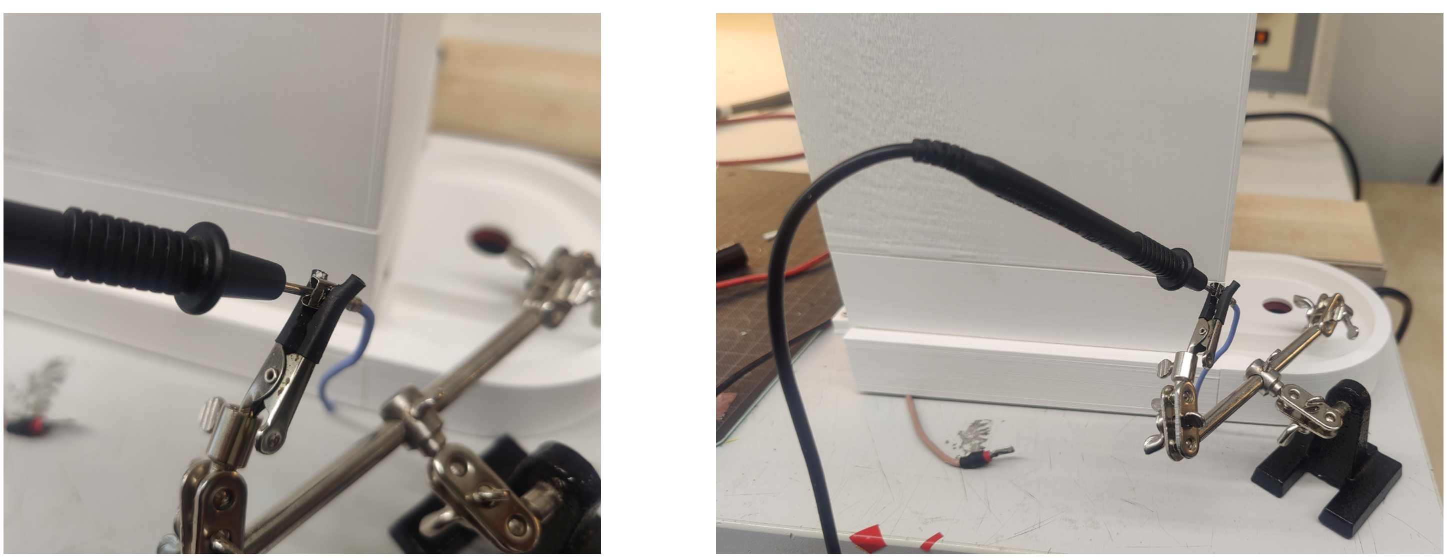


Figure 58: Setup to perform the test

Shown below are the voltage values registered with the outer housing installed (Figure 59). As seen, a voltage of ~ 225 V is registered by the multimeter.

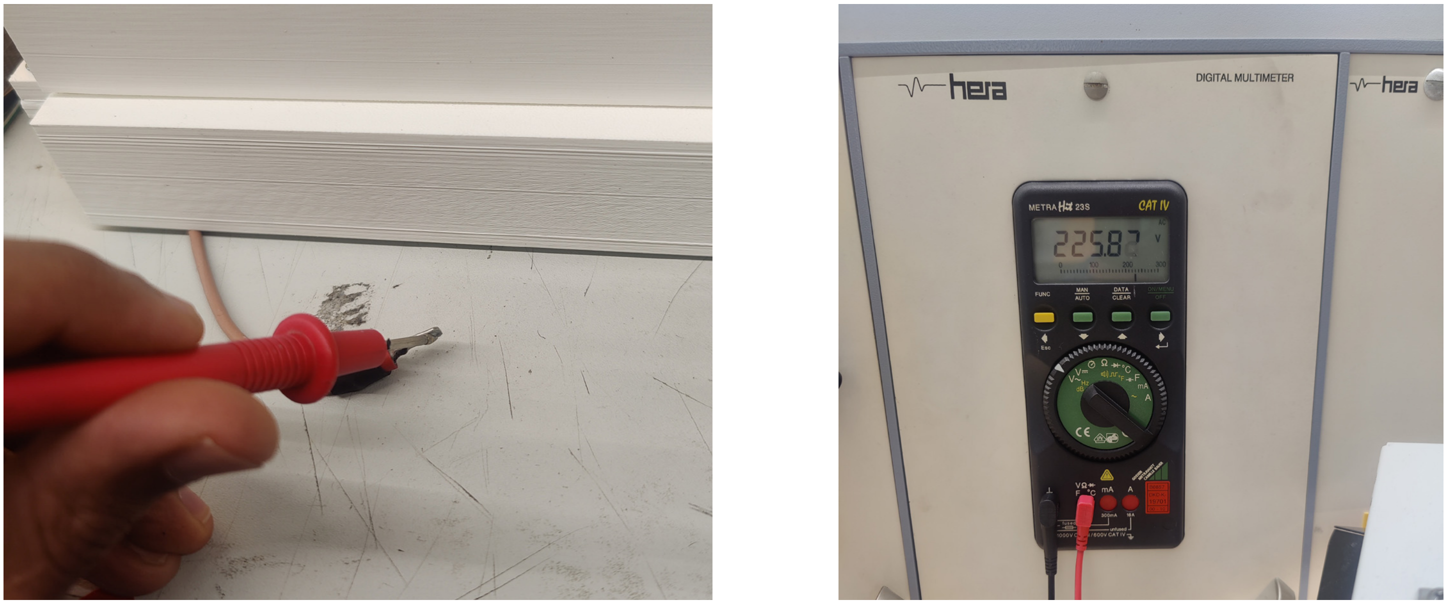


Figure 59: Voltage reading with the outer housing installed

Next the outer housing is taken out and the voltage is measured again (Figure 60). The voltage reading is ~ 1 V and this is usually attributed to ambient noise and internal circuitry effects.

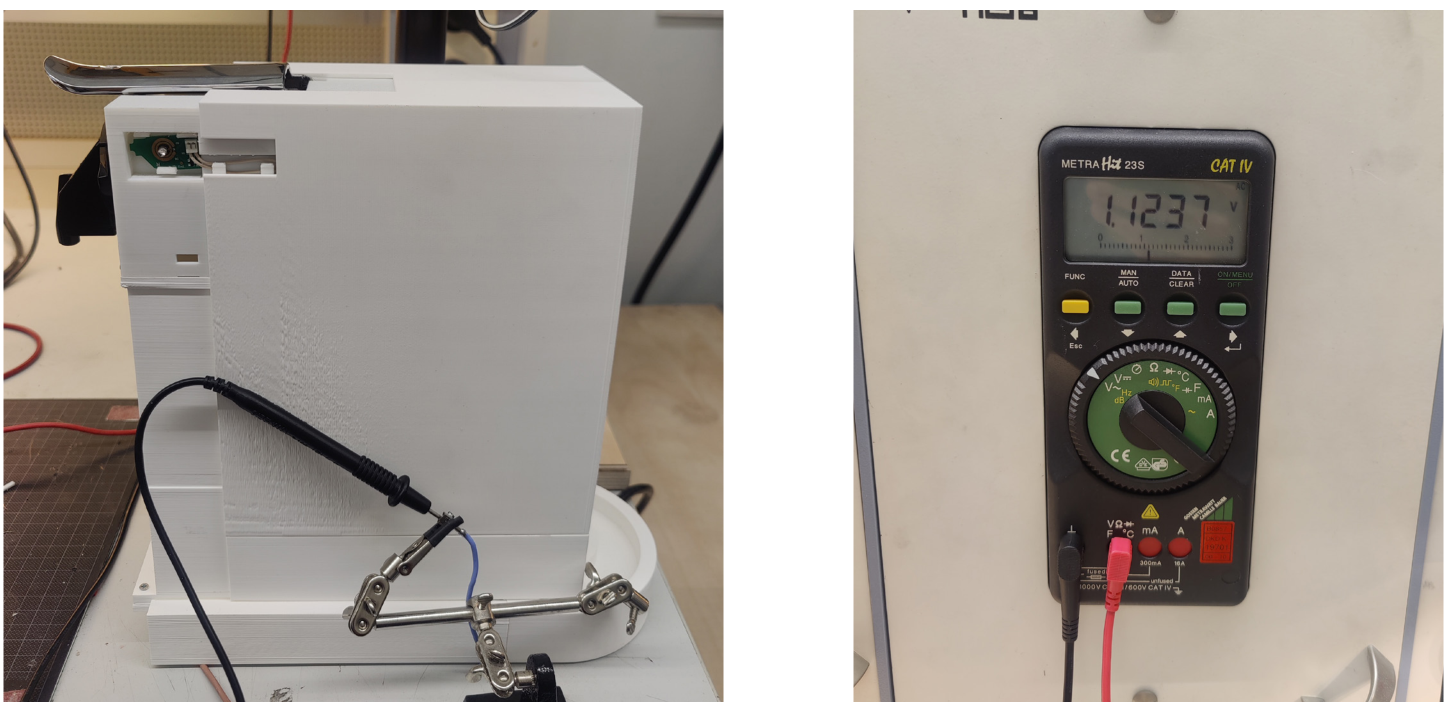


Figure 60: Voltage reading with the outer housing removed, thus disengaging the switch

Finally, the outer housing is installed again and the voltage reading is taken (Figure 61). The value is ~ 225 V which shows that the PTM switch has been activated and power is flowing out of it.

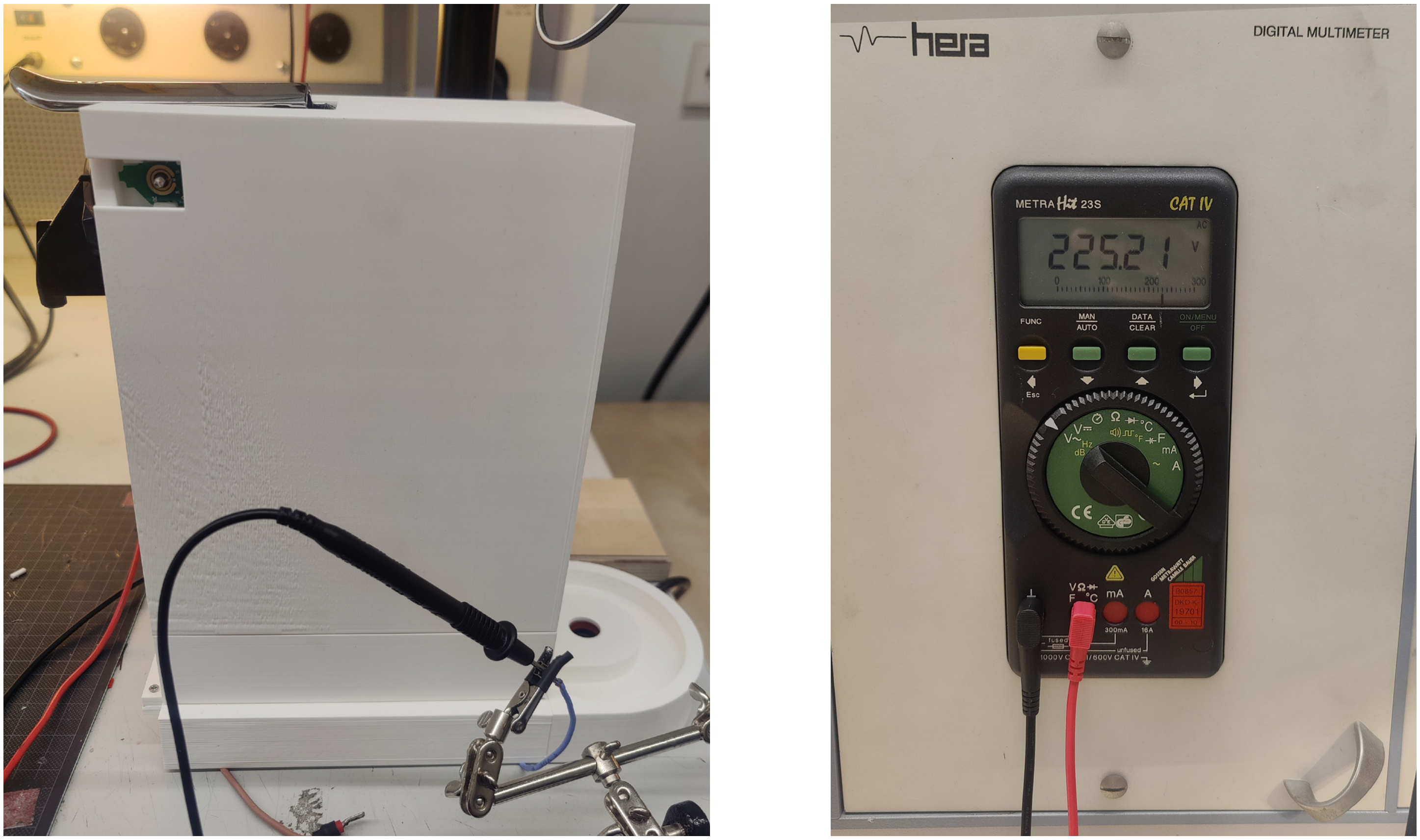


Figure 61: Voltage reading with the outer housing reinstalled

6.4 Test #2 - Evaluating the actuation capability of a bimetal

6.4.1 Objective

The objective of this test was to evaluate if a bimetal would actuate a pin in the vertical direction when heated. This is the idea envisaged to lock the housing when the boiler is hot. Since it is usually unsafe to run the coffee machine boiler without passing water through it, an alternate setup has been created to replicate this situation and actuation (Figure 62).

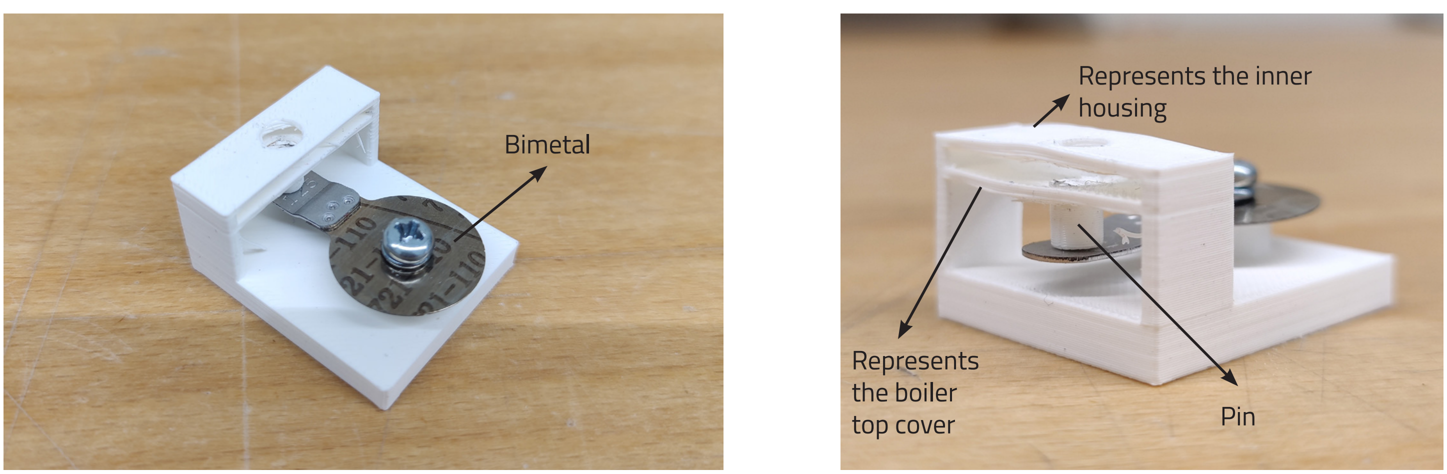


Figure 62: Setup to test the vertical actuation of the bimetal

6.4.2 Results

Figure 63 shows the setup with the housing lock model in place. As visible in the picture, the pin has not been engaged because the bimetal has not been heated. Figure 64 shows the setup as the bimetal is being heated, as seen from the rising pin. Another view is provided to show the bimetal in action (Figure 65).

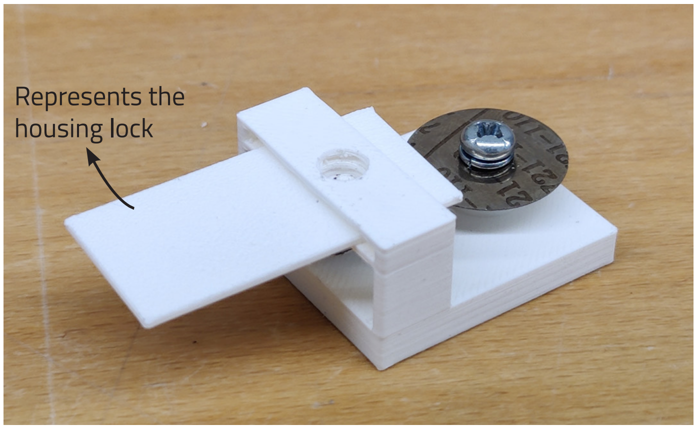


Figure 63: Setup with the housing lock model added

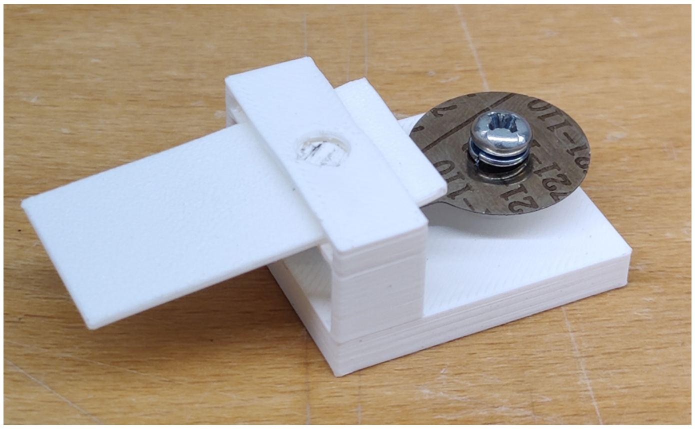


Figure 64: Setup with the bimetal heated and housing lock model secured by the pin

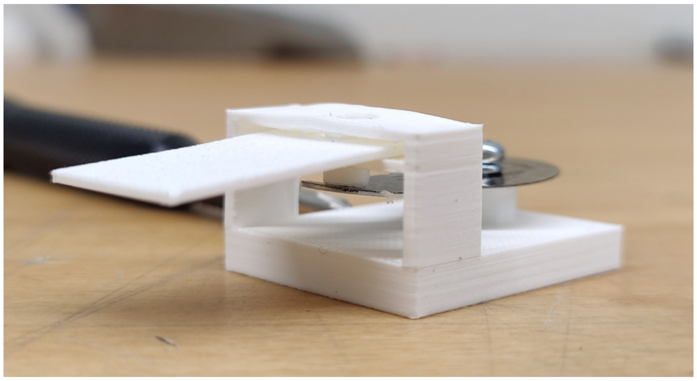


Figure 65: An alternate view showing the bimetal rising due to the input heat

After a certain point, the heat caused the setup to warp as it was 3D printed, and the actuation was ineffective.

6.4.3 Implication for the choice of bimetal

The above test demonstrated that the proposed actuation mechanism would function effectively to lift a pin resting on the tip of the bimetal.

Interestingly, it also suggested an alternative: using the bimetal from the steam iron instead of designing a bimetal strip from scratch. During design and prototyping, a decision was made not to use the steam iron bimetal because it lacked sufficient vertical movement (Appendix E). While this is still true, it is possible that the bimetal's length could be extended (Figure 66), which would result in sufficient vertical movement.

Figure 66: The proposed redesign for the bimetal in the second image to provide sufficient vertical movement

This was verified through another series of tests, the details of which can be found in Appendix G, and the results of which are shown below in Section 6.4.4.

6.4.4 Redesigned bimetal

The bimetal disc from the steam iron was retrofitted with a metal strip (Figure 67), and tests were conducted to see if this would achieve the required vertical displacements. The tests were positive, and through multiple iterations, the length of the metal strip was reduced until it was adequate to produce a vertical displacement of 8 mm. The result is the bimetal shown in Figure 68.

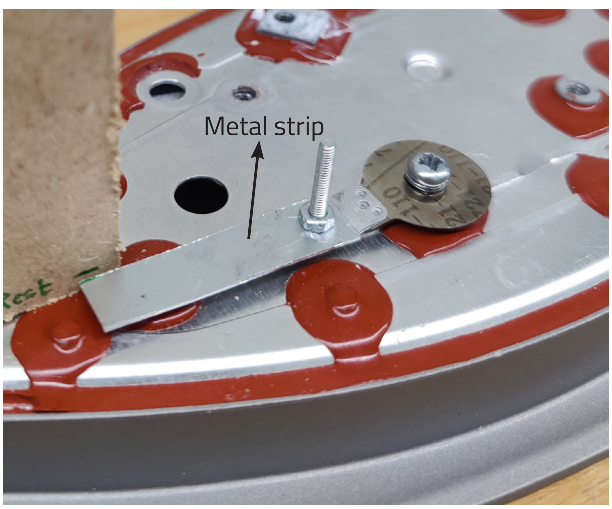


Figure 67: Metal strip attached to bimetal to test if required vertical displacement can be achieved

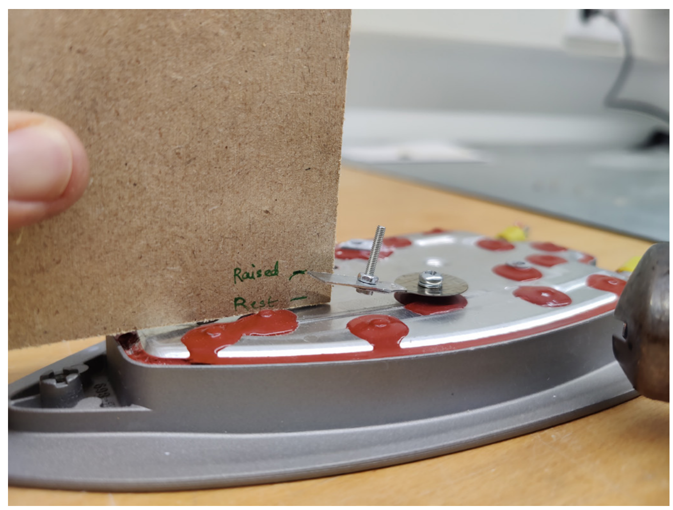


Figure 68: Length of the metal strip was reduced over multiple iterations until 8 mm of vertical displacement was obtained

6.5 Test #3 - Evaluating the weight holding capacity of the modified bimetal

6.5.1 Objective

This test's objective was to evaluate the maximum weight the bimetal could hold while providing a vertical displacement of 8 mm.

6.5.2 Results

Since the bolt weighed little, one bolt and five nuts were added in the first attempt (Figure 69). This did not affect the bimetal's deflection (Figure 69).

Figure 69: Result of adding one bolt and five nuts

As each nut weighed a small amount, it was decided that heavier material would be added for each round. Thus, a 7-gram nut was added, and it also did not affect the deflection (Figure 70).

Figure 70: Addition of a 7 gram nut to the bimetal, with no effect on the deflection

Finally, another 7-gram nut was added, and it also did not affect the deflection (Figure 71).

Figure 71: The bimetal carrying 15 gram of weight at its tip

6.6 Test #4 - Estimating the heat transfer capability of a model HTR (heat transfer ring)

6.6.1 Objective

In the prototype, a heat transfer ring (HTR) was added to transfer the heat from the boiler to the bimetal. According to the Magimix user manual, the boiler takes 25 seconds to heat up (Magimix User Manuals, n.d.) and at least another 30 seconds to pour a cup of coffee. Thus, in an ideal situation, the bimetal should have activated and locked the housing by the time a cup of coffee is prepared.

Thus, the objective was to check how well the heat transfer ring transmits the heat from the boiler to the bimetal by measuring the time it takes to do so.

In the prototype, the HTR is cylindrical and positioned within the inner surface of the boiler, thereby increasing the area of contact between the HTR and the boiler and enhancing heat transfer (Figure 47). Since we will not be using the boiler to generate heat but a hot plate, the HTR has been modified into a rectangle, as shown in Figure 72, with the bimetal mounted on top of it. This design increased the area of contact with the hot plate and has been dimensioned similarly to the HTR in the prototype.

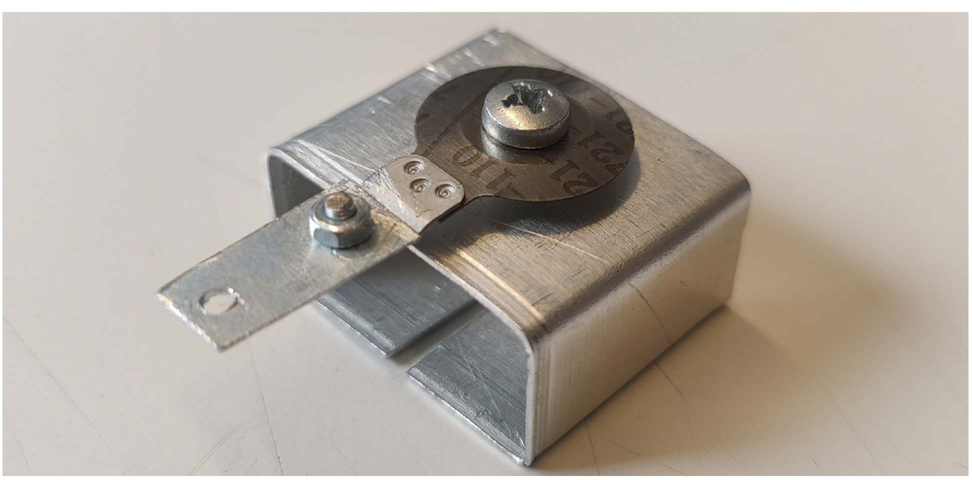


Figure 72: The model of the HTR built to maximise area of contact with a hot plate

6.6.2 Results

Once the appropriate hot plate setting was identified, the model was placed on top of it. While the initial expectation was that the HTR would transfer heat quickly and cause the bimetal to deflect, no deflection was observed after 6 minutes of maintaining the hot plate at 90-100 Celsius (Figure 73).

To check if the temperature was sufficient to cause deflection, the bimetal was placed directly on the hot plate, and deflection was observed within a minute (Figure 74). Thus, the HTR was unable to transfer heat quickly to the bimetal.

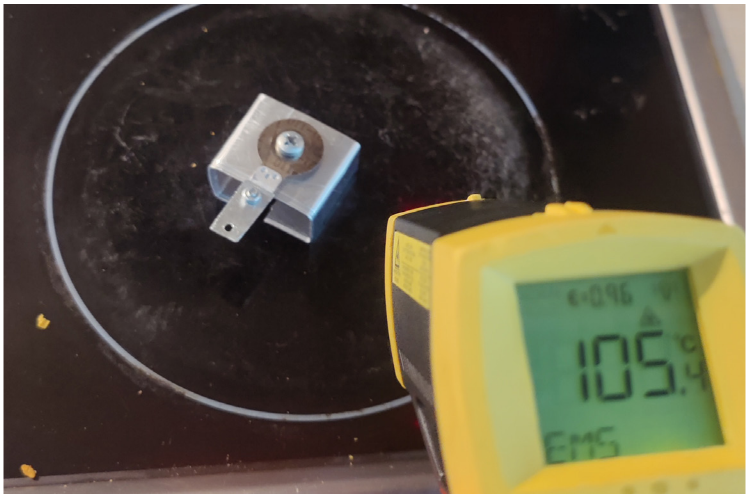


Figure 73: Model tested on the hot plate - shows no deflection after 6 minutes of constant heat supply

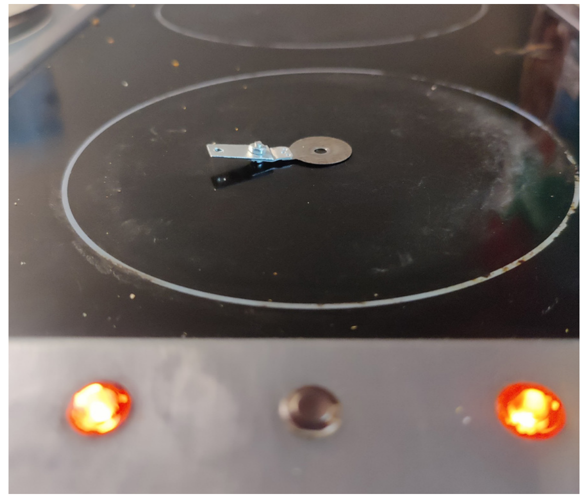


Figure 74: Bimetal on the hot plate reacted within minute of being placed

6.7 Test #5 - User testing: Evaluating the effectiveness of design cues

6.7.1 Objective

The goal of this test was to determine whether ideas that relied on design cues facilitated safe repair and whether safety instructions on the product effectively conveyed information. The ideas in question are as follows,

- The use of instructions at the back of the coffee machine
- Colour coding wire connections to aid in reassembly
- Using threaded connections to secure hoses
- Using different size thread connections between components to ensure the correct hose is connected
- Colour coding the ends of the hoses to indicate the correct orientation of attaching the hoses

This was achieved by involving participants in a mock repair task.

6.7.2 Task given to participants

Participants were given a background scenario: Their coffee machine has been dispensing coffee that is not hot enough, and they have identified the boiler and its hoses as the problem. They had just had a cup of coffee when the new components were delivered, and they decided to replace them immediately. Once they identified and isolated the components, they were asked to reassemble them along with the coffee machine.

6.7.3 Participants

6 students from TU Delft, having varying experience with repair

6.7.4 Data collected and analysed

The video recording was used to capture the participants' interaction with the prototype and observe things like: Did the cues aid in reassembly? If not, why? What mistakes were the participants making? How does this relate to the embodiment of the ideas?

Questions were also asked during the testing, depending on the situation. If the participant appeared stuck in a step, they were asked what was confusing them. If they made an interesting remark, they were asked to elaborate on it. This information was later used to fill the table shown below (Table 14). The results have also been colour-coded to indicate whether they were successful (green), partially successful (orange), or unsuccessful (red), along with the issue they faced or the mistake they made.

Additionally, after the test ended, participants were also asked for feedback on what they thought worked and did not work. This was intentionally open-ended to let the participants reflect on the disassembly and reassembly process. This information can be found in Appendix H and was used in Chapter 7 to reflect on the design of the prototype.

Table 14: Table used to summarise the key results of the user testing

Participant ID	Repair experience	Participant reads the instruction to press the repair button and follows it	Participant reads the warning about the housing being locked and waits	Participant notices the colour coded wires and PCB pins and uses them to correctly assemble the wires	Participant identifies that the hose is connected using threads during disassembly	Participant notices and correctly uses the colour coding and thread sizes to attach the correct hose in the appropriate orientation	Participant securely attaches the hose by tightening the threads

6.7.5 Results

Shown on the next page are the detailed results (Table 15) for the user testing. The salient points from the results are presented below,

1. Five out of six participants noticed the instruction to use the repair button as it was visible (Figure 75).
2. Three participants saw the warning that the outer housing would be locked if the boiler was hot. However, due to the absence of any information about the boiler's current temperature, they assumed it must be cooled down. Two did not see it due to the water tank, and one saw it but ignored it to read it later.
3. Five participants noticed and used the colour coding for the wires to correctly reassemble them. One could not see the colours due to dim surrounding light and relied on their memory to make the connections correctly,
4. Four participants did not understand that the hoses were connected using threads due to the absence of cues. One realised it was a threaded connection but was confused about which part to rotate because of the prototype's design (Figure 75).
5. All participants successfully used the colour coding to determine the hose orientation (Figure 75), but used different cues or their memory to determine the correct hose to attach between components. All participants rotated the threaded connection to its limit during reassembly, either subconsciously or

intentionally. The action was considered intentional if the participant said it out aloud, whereas doing this without speaking was considered a subconscious decision.

Table 15: Results from the user test

Participant ID	Repair experience	Participant reads the instruction to press the repair button and follows it	Participant reads the warning about the housing being locked and waits	Participant notices the colour coded wires and PCB pins and uses them to correctly assemble the wires	Participant identifies that the hose is connected using threads during disassembly	Participant notices and correctly uses the colour coding and thread sizes to attach the correct hose in the appropriate orientation	Participant securely attaches the hose by tightening the threads
1	Electronics and automobiles	Had no reason or explanation why they did not notice the instructions	Had no reason or explanation why they did not notice the instructions. Assumed the boiler was cool as there was no indication saying otherwise		Thought it was push/pull because it was a hose connection		All participants rotated the threads to its limit either subconsciously or with intent
2	Household electronics		Read the warning, however assumed that the boiler must have cooled down as there was no indication saying otherwise				
3	Consumer electronics		Read the warning, however assumed that the boiler must have cooled down as there was no indication saying otherwise		Because of a lack of cues, tried every possible motion to disconnect them until rotating it worked	Used the material of the threaded hoses to determine which hose connects to which part and the colour to figure out the orientation	
4	Consumer electronics		Did not see it behind the water tank and got distracted by the screws. Once pointed out assumed that the boiler must not be hot as there was no indication saying otherwise	Could not initially see the colour coding on the PCB. Used their memory to make the correct connections	Realised it was a threaded hose but did not know which part to rotate		
5	No experience repairing electronics of any kind				First tried to tug on the hose connectors. When nothing happened tried rotating them as it was unclear how they work	Used colour coding to confirm the orientation of the hoses. Selected the correct hose to attach between two components based on size and material	
6	Minimal experience with consumer electronics	Noticed the instruction, partially read it and pressed the button	Saw the warning but did not read it because they assumed it would be useful later – as it was placed below the first instruction about the repair button	Note: Initially assumed the colours are not uniquely assigned to each wire and connection (as is the case with most consumer electronics) and was thus hesitant	Did not know it was a threaded hose and just started twisting	Was not sure if the hose orientation matters, but because of the colour coding on the hose and the components assumed that it matters and followed it. Used size and material to select the correct hose to attach between two components	

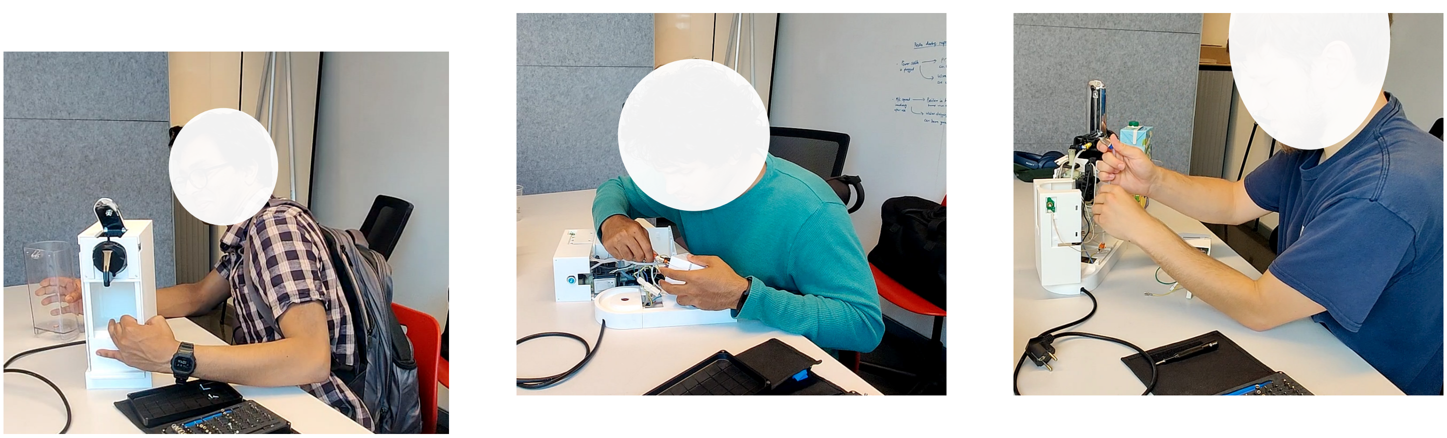


Figure 75: Participants interacting with the ideas - Realising instructions are present at the back (left), inspecting hose detachment mechanism (middle), using the colour coded hose to attach it in the correct orientation (right)

6.8 Evaluating the prototype using the modified disassembly map + risk assessment

Like the risk assessment analysis performed on the Magimix Citiz and Senseo Quadrante in Chapter 2, the prototype was also analysed. It is important to note that the modified disassembly map was created assuming all the hose connections are thread-based and the PTM switch connections are insulated. This differs from the actual prototype, which only had threaded connections for the hoses connected to the boiler (as mentioned in Section 5.2.1) and heat-shrink insulation for the PTM switch.

6.8.1 Repair and post-repair risks in the prototype

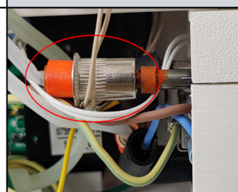
Figure 76 shows the modified disassembly map of the prototype, with the observation and risk assessment tables given below (Table 16 & Table 17)

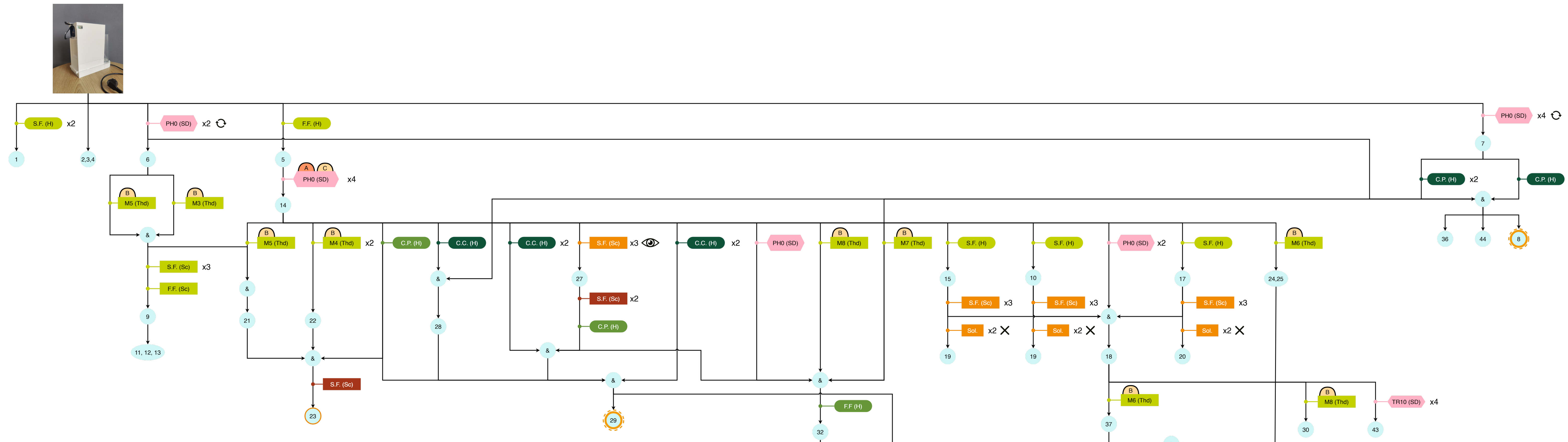
1. There are no risk zones in the disassembly map. The disassembly map of the Magimix Citiz had three risk zones (Figure 8) - one electrical risk zone, because internal components can be accessed with the power cable connected, and two thermal risk zones, because the housing can be opened while the boiler and residual water are hot. These risk zones have been eliminated by implementing safety interlocks that prevent the user from doing so.
2. Three unique risk steps were observed during testing. One risk step - no feedback on the boiler temperature leading to damage to the housing - causes both a repair risk and a post-repair risk.
3. The other risk step was caused by the prototype's design, specifically fouling between the housing lock and the internal wires and tubes during reassembly of the outer housing.

Table 16: Repair risks observed in the prototype

No.	Risk zone/step	Observed design feature	Image	Why is it problematic	Risk type	Severity	Rationale for Severity	Risk priority level (RAPEX)
1	A	No indication if the boiler is hot or not		The outer housing cannot be removed until the boiler cools down. While there is a warning that conveys this information, there is no indication of the boiler's temperature. If they assume the boiler has cooled down and force open the housing, they could expose themselves to being burned by the boiler	Thermal	2	Will require A&E care	Medium

Table 17: Post-repair risks observed in the prototype

No.	Risk zone/step	Observed design feature	Image	Why is it problematic	Risk type	Severity	Rationale for Severity	Risk priority level (RAPEX)
1	A	No indication if the boiler is hot or not		The outer housing cannot be removed until the boiler cools down. While there is a warning that conveys this information, there is no indication of the boiler's temperature. Thus participants would assume the boiler is cooled down and try removing the housing. This could damage the housing which will create problems during reassembly as the internal components are no longer protected from external elements	Electrical	4	Ingress of external elements like water could cause short-circuiting	Serious
2	B	No design cue on the hoses indicating that threaded connectors are used		Users might try pulling the hoses which can damage them. This can result in leakage during product use leading to short-circuiting	Electrical	4	Short-circuit can cause fire	Serious
3	C	Wires and hoses make it difficult to reinstall the outer housing		If the wires and hoses create obstacles, the user could end up forcing the outer housing to lock in place. This can damage electrical connections and hoses	Electrical	4	Short-circuit from damaged hoses	Serious



Components

1. Nozzle metallised cover
2. Coffee pod trash bin
3. Coffee cup holder
4. Excess liquid collector
5. Water tank
6. Water tank base panel
7. Coffee machine base panel
8. Power cable
9. Water tank gasket
10. Emptying program silicone button
11. Stainless steel ring
12. SS mesh
13. Plastic intake
14. Outer housing
15. Coffee dispensing silicone button - R
16. Emptying program button PCB
17. Coffee dispensing silicone button - L
18. Brewing assembly cover
19. Coffee dispensing button PCB - R
20. Coffee dispensing button PCB - L
21. Hose (Bluish white), Flowmeter - Water tank
22. Hose (Blue), Pump - Flowmeter
23. Flowmeter
24. Hose (White), Heater inlet connector - Water tank
25. Heater inlet connector
26. Bimetal strip
27. PCB cover
28. Power cable to PCB neutral wire
29. PCB
30. Pipe, Heater outlet connector - Brew group
31. Heat transfer ring
32. Heater top cover
33. Earthing metal strip
34. Heater unit
35. Heater bottom cover
36. PTM switch
37. Pipe, Pump outlet connector - Heater inlet connector
38. Vibration absorber - Pump outlet
39. Vibration absorber - Pump inlet
40. Pump
41. Vibration absorber - Pump back
42. Grey wire, Pump - PCB
43. Brew group assy
44. Power cable to PTM switch live wire

Legend

Motion type

- = Hand
- = Single motion tool
- = Multiple motion tool

Penalties

- = Product manipulation
- = Low visibility
- = Uncommon tool
- = Unreusable connector

Connectors

S.F = Snap fit
F.F = Friction fit
PH0 = Philips #0
C.P = Cable plug
TR10 = Tamper resistant
C.C = Cable connector
MX = Thread M3/M5
Sol = Soldered
SL2 = Slot 2mm

Force intensity

Low | Medium | High

Type of tool

(H) = Hand
(Sc) = Scalpel
Thd = Thread
(SD) = Screwdriver
Sol = Soldering iron

Repair step type

= Risk step

Source of risk

= Electrical risk
= Thermal risk
= Uninsulated connections
= Insulated connections

Figure 76: Modified disassembly map of the prototype

6.8.2 Ease of disassembly

Figure 78 compares the disassembly map of the Magimix Citiz and the prototype. For this analysis, the choice of priority parts was determined based on an analysis of Repair Monitor data from all countries and years across all Repair Cafes (Dashboard Repairmonitor, 2025). The most frequently repaired components, accounting for up to 80% of repairs, were considered priority parts. These components were the PCB (18%), Pump (17%), Brew group (15%), O-rings (11%), Boiler (8%), Hose (4%), Buttons (4%), Brew group gasket (4%) and Water tank gasket (3%).

As shown in Figure 78, the prototype features an open product architecture compared to the Magimix. This was made possible by optimising housing components and clumping the inner housing with the base of the coffee machine (Figure 77). In the Magimix, the brewing assembly cover also extends at the back to cover the internal components (Figure 77). To remove it, one must also remove the PCBs for the coffee dispensing buttons. By modifying it to cover only the brewing assembly and the Pump, internal components can be accessed more quickly. Hidden snap fits present in the Magimix have also been replaced with screws (example provided in Section 5.2), making it easier, safer and quicker to disassemble.

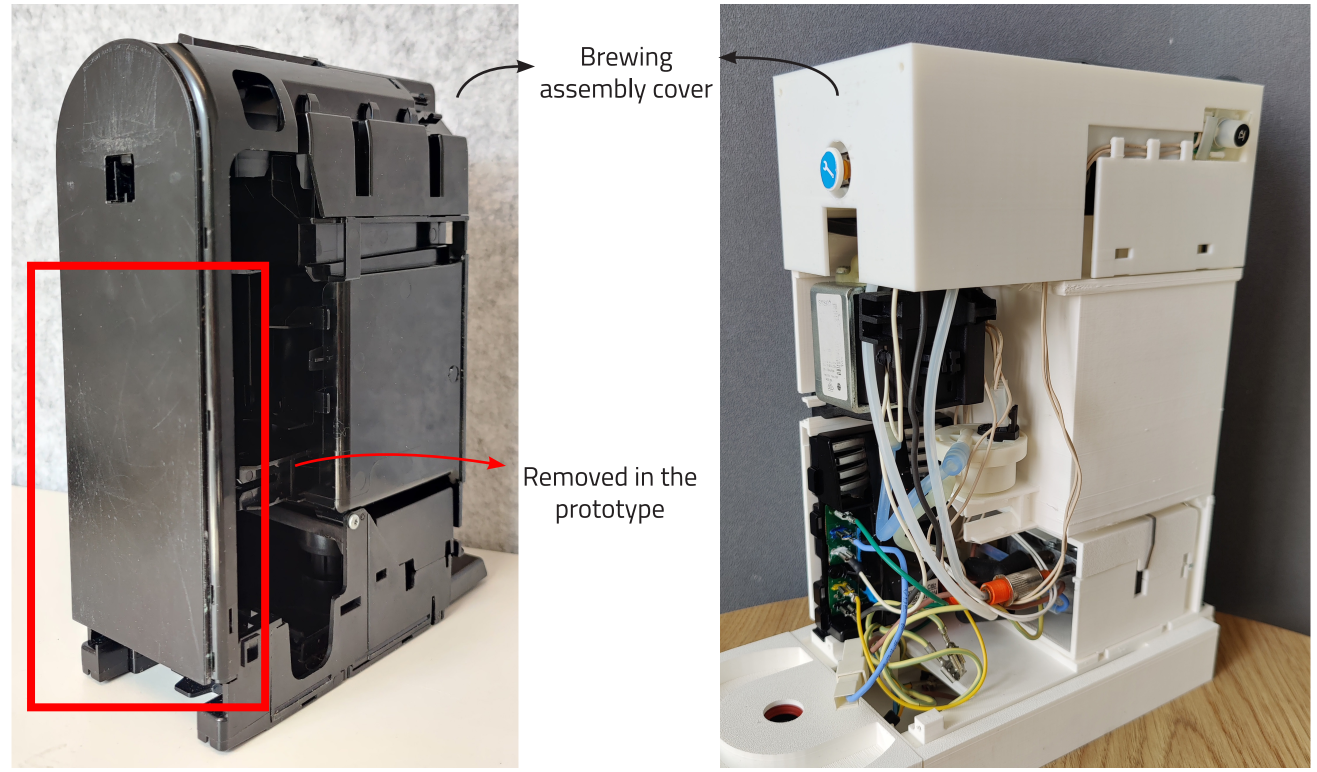


Figure 76: Back panel of the brewing assembly cover has been removed making it easier to access internal components

Figure 77: The inner housing is connected to the base in the Magimix. This is clumped in the prototype (Section 5.1)

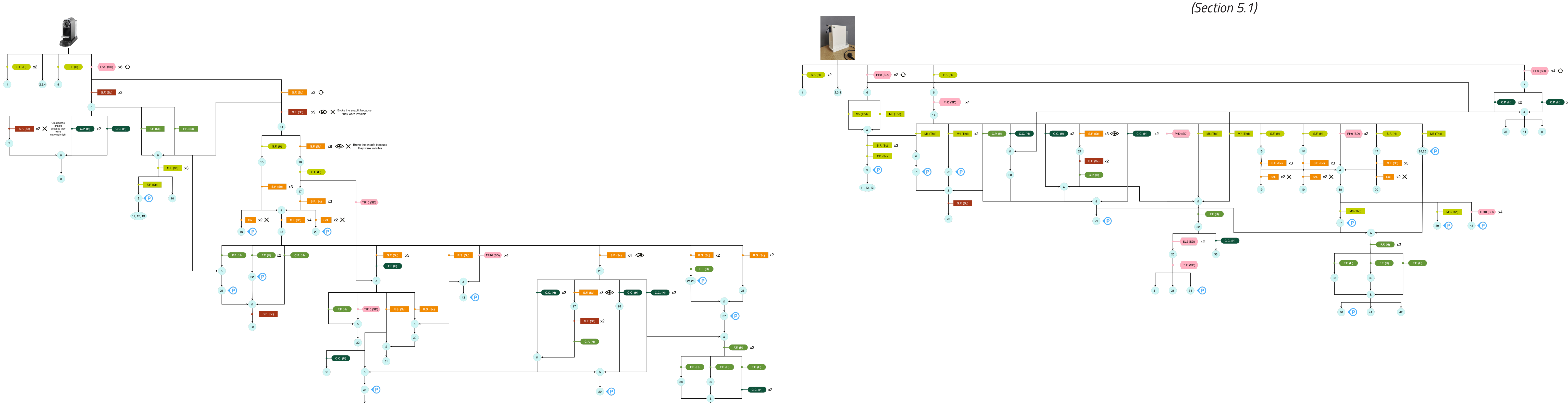


Figure 78: Comparison between the Magimix disassembly map (left) and the disassembly map of the prototype (right)

This concluded the evaluation and testing of the ideas implemented in the prototype. The results presented here, along with future opportunities, are discussed in the next and final chapter.

CHAPTER 07

WHAT WORKED, WHAT DIDN'T: REFLECTIONS ON DESIGNING FOR SAFER REPAIR

The final chapter reflects on the ideation process, the design of the prototype, and the effectiveness of the repair safety ideas. The ideation process is critically analysed, identifying several future opportunities to generate and test repair safety ideas. The prototype is analysed for ease of disassembly and the presence of safety risks, using the disassembly map and observations from user testing. The repair safety ideas are analysed with the help of the results from testing, reflecting on their success and failure. This reflection is then used to discuss how they can be applied to the design of coffee machines and other consumer electronics to make them safe for repair.

7.1 Reflecting on the ideation process

Chapter 4 of this report detailed the complete ideation process from idea generation to the final selection of ideas for testing. In the idea generation phase, 43 ideas were identified across the eight risks, which were eventually categorised into seven different solution spaces. Ideally, having many ideas at the end of the idea generation phase is beneficial, as it allows for evaluation through options like prototyping and testing. However, given the limited time available for this thesis, this option was not a possibility. Thus, three solution spaces were selected, and the ideas under each were evaluated to select one per risk. The evaluation was based on rough sketches and intuition to fill out a Harris profile, shortlisting 24 ideas for further refinement. This means that many potentially practical ideas may have been discarded early in the design process (see Appendix D). Future research into this topic can explore these ideas thoroughly and employ more robust evaluation methods to select ideas for refinement.

The 24 ideas that were selected were categorised under three distinct solution spaces and were refined by sketching them in three distinct coffee machine concepts. At this point, a choice had to be made on the way forward. One option was to prototype and evaluate each concept; the other was to select an idea (or a combination of ideas) per risk and combine them into a single prototype. The first option would have allowed us to evaluate and compare the three solution spaces on aspects such as effectiveness in risk reduction, ease of disassembly, product cost and complexity. However, this option would have also required a significant amount of time to execute. The second option, on the other hand, would require significantly less time but also result in the elimination of potentially practical ideas. The execution of option one thus remains a more insightful route to explore for the future.

As mentioned above, ideas from a single solution space or a combination of solution spaces were implemented into a prototype for testing. Shown below in Table 18 is a mapping of the ideas prototyped to the risks they aimed to eliminate.

Table 18: Mapping of ideas implemented to the risk they intended to eliminate

S. No	Risk	Idea selected
1	User receives an electric shock when accessing internal components during repair	Safety interlock switch that cuts power when housing is opened
2	User spills residual water to cause short circuiting during repair	Button that is pressed prior to repair that drains the water out + Instructions on using it
3	User burns themselves through intentional or unintentional contact with the boiler or water during repair	Housing is locked until the boiler does not cool down + Warning informing the user about it
4	User receives an electric shock when performing testing	Power can only flow if the housing is closed
5	User makes the incorrect electrical connections during reassembly	Colour code the connections
6	Hoses are not attached securely	Thread based connection (like Classic Gaggia)
7	Incorrect hose is attached between two components	Unique size threaded connection between two parts
8	Hose is attached in the incorrect orientation	Colour the hose cap and the corresponding part with the same colour

Throughout the ideation process, ideas were evaluated and selected to mitigate one risk. This was done because the focus was to select the most effective idea (based on the qualitative assessment) for a risk. However, as shown in Table 18, specific ideas also helped mitigate other risks. For example, Risks 1 and 4 are both mitigated by the idea of cutting power once the outer housing is removed. Similarly, the idea for Risk 2 - using the "Emptying program" to expel water from the system - also partially mitigated Risk 3 by directing hot water from the system into a container away from the user.

This opens up the possibility of a different approach to idea selection. If, instead of selecting the best idea for each risk, is there an approach that looks at selecting an idea that helps mitigate multiple risks? Such ideas were explored during the idea sketching phases (Appendix D, Figure 105). However, they were discarded because they did not meet the qualitative criteria established during the selection process. Suppose, in the future, one prioritises an approach that utilises the fewest number of ideas to target the most risks. In that case, new possibilities open up for exploration.

Finally, it was hypothesised that the implementation of solution space two (Eliminate risk step) would result in the risk location being shifted. This was illustrated through the example of the drawer connectors (refer to Section 4.4 and also shown in Figure 77), highlighting the possibility of the user receiving an electric shock if the connectors were faulty and needed to be replaced. This hypothesis was used as justification for not selecting any idea from this solution space. However, it should be tested in the future through prototyping, following the process outlined in Chapter 2.

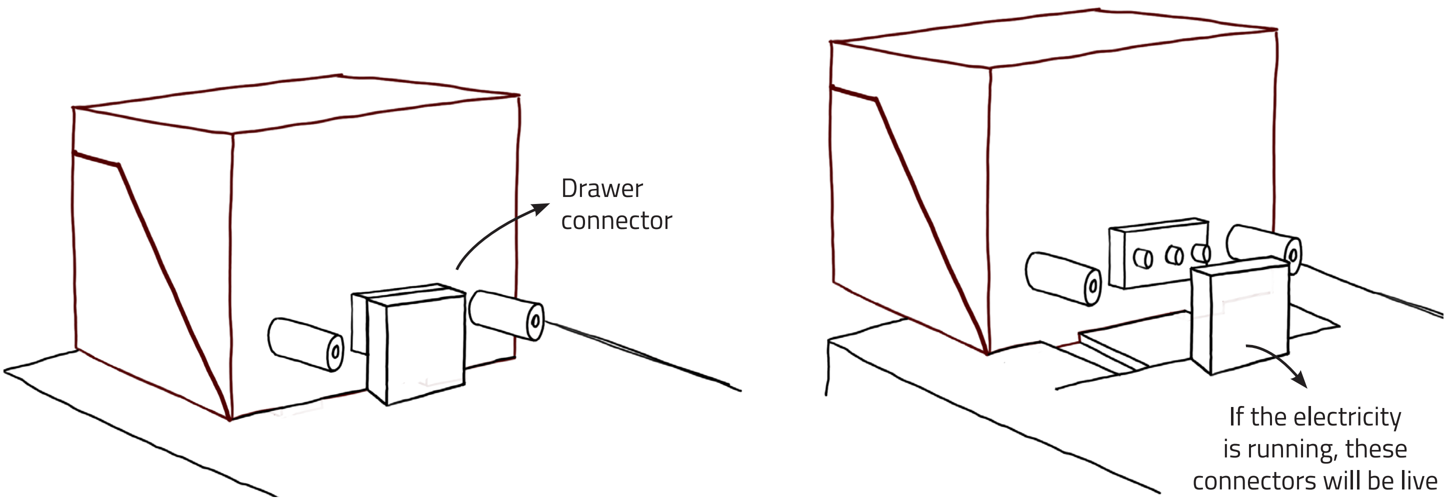


Figure 77: Possible new risk zone or risk step created by the implementation of the ideas from solution space 2

7.2 Reflecting on the prototype

Chapter 5 of this report detailed the embodiment of the repair safety ideas as it was the focus of the thesis. However, a few design decisions were also taken with ease of repairability in mind. Examples of these changes include modifications to the housing components and the use of screws instead of snap fits (covered in Section 6.8.2).

While the ease of disassembly was not directly evaluated during the user testing, observations were still made based on the participant's interaction. Additionally, when participants were asked for their feedback after the test (Section 6.7.4), they provided suggestions that were noteworthy and are discussed here. These suggestions can also be found in Appendix H.

1. Visible screws on the coffee machine body
   The safety instructions and warnings were placed at the back of the coffee machine with the idea that users would notice them when accessing the back to remove the screws. However, in the prototype, there were two sets of visible screws in the front - screws holding the brewing assembly cover and the screws connecting the inner housing to the base of the coffee machine (Figure 78).

Figure 78: Screws visible when the coffee machine is assembled

   A common theme during the user test was participants removing all the visible screws (observed in five out of six cases, Appendix H). This diverted attention away from the four screws at the back and, thus, also from the safety instructions. If attention is to be drawn to a particular element (in this case, the four screws at the back), there must be no similar elements present to compete for attention.

2. Method of securing the boiler unit
   In the prototype, the boiler unit is secured to the inner housing using a single screw (Figure 79). The idea was to simplify its disassembly. However, three participants did not believe that the boiler unit could be held by a single screw and spent time trying to find a second fastener or method by which it may have been secured. One justification they provided was that the boiler unit is crucial and thus requires stronger fastening or even redundancy. Another justification they gave was that they are accustomed to finding additional screws and hidden fasteners in products and were expecting the same here. The first justification can be tested by conducting force tests. The second justification will only be resolved

as more products are built with ease of disassembly in mind. In the meantime, cues can be used around the boiler unit to inform the user that this is the only fastener that needs to be removed to free it.

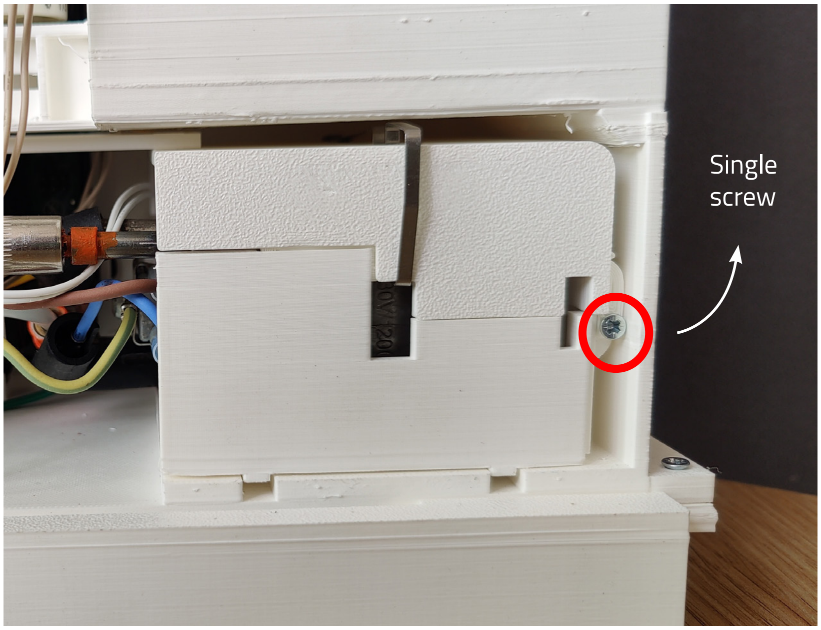


Figure 79: Single screws that holds the boiler unit together and secures it to the inner housing

3. Design cues for components
   As part of the user test, participants were provided with a picture of the boiler unit. The rationale behind this was that the participants would have seen how the boiler unit looked like when purchasing the part online and could reference it once they had it with them to replace the faulty component. While this was helpful for the participants to perform the task, they expressed a desire to be able to identify other components inside the coffee machine as well. Since the prototype utilised stickers to convey safety information and warnings on the coffee machine body, they argued that the same could be done for the components inside.

   In the same vein, participants also wanted design cues to help take out and reinstall components. In the prototype, four components slide out or pop out of their position. In the case of the task, the boiler unit relies on rails to slide in and out. Two participants did not identify this and had to spend time understanding how the boiler could be removed and reinstalled. A design cue, such as a text or arrow, would have simplified this.

   This also applied to the outer housing. Two participants struggled to identify that the outer housing could slide out. This was worsened by the presence of three sets of visible screws, as they employed a strategy of removing all screws to determine which parts became loose. If, in addition to the recommendation made in point 1, cues were provided - either through text and arrows or by designing the shape of the outer housing to convey that it can slide - this confusion could have been eliminated.

4. Better wire connection plugs
   During the user test, participants had to disconnect wire connections. Three participants struggled with this because of the design of the insulated connectors. As shown in Figure 80, the connectors either used insulated covers or a tiny snap fit. When participants had to disconnect them, they either believed it was heat-shrunk and could not be disconnected, did not know which part of the connector could be separated from the other, or thought it was soldered together and thus a permanent connection. This kind of confusion can be eliminated by using connectors that are easy to disconnect, like the ones

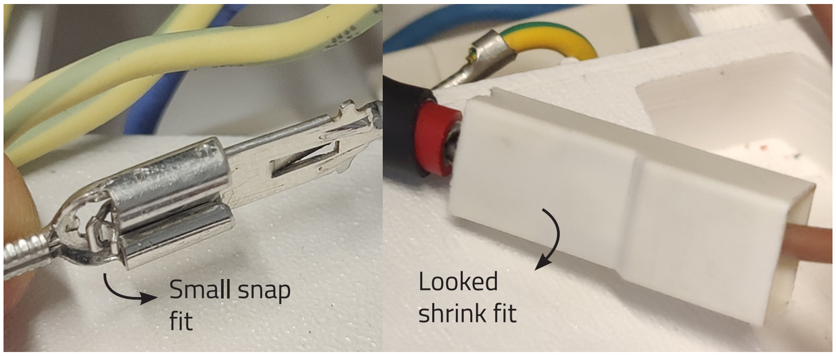


Figure 80: Cable connections that confused participants

Figure 81: Example of a cable connection that makes it obvious it can be disconnected

shown in Figure 81. Another option is to use design cues on the insulation to indicate how they can be separated.

5. Visibility inside the coffee machine
   During reassembly, one participant expressed a preference for performing a final check before installing the housing in place. This is done to ensure all wire and hose connections have been made and are in their correct places. However, this was challenging to achieve in the prototype due to the limited space available. While providing more space inside the coffee machine would allow for these checks and make it easier to manage wires and hoses, it also comes with additional costs in terms of a larger product and additional material. This is a trade-off that must be considered and can be tested by using two identical prototypes, except one has more internal space and visibility.

6. Clumping inner housing with the coffee machine base
   As mentioned in Section 5.1 and shown in Figure 78, the inner housing is secured to the coffee machine base using two screws located at the front. This was done to facilitate iterative design changes, as the parts can be 3D printed separately. However, during the user test, a consequence of this was that participants would remove these screws during disassembly. As mentioned in point 1, this can be hidden, which would eliminate this problem. However, it was noted that users appreciated the flexibility of separating the inner housing from the coffee machine base. Five out of six participants found value in separating the base, as they saw it as an additional component that was "in the way". This presents an interesting choice for future iterations. While clumping the inner housing with the base reduces the number of disassembly steps and makes the coffee machine more stable, the ability to disconnect the two components may give users the perception of progress and reduce visual clutter during disassembly. Like some of the suggestions made in this section, this is another design choice that needs to be tested with users to determine if it has any value.

7.3 Reflecting on the repair safety ideas

Chapter 6 covered the testing of the repair safety ideas, evaluating their effectiveness through functional and user testing. In this section, each implemented idea will be discussed, reflecting on its effectiveness and identifying opportunities for future work to improve repair safety in coffee machines.

7.3.1 Idea 1 - Switch to cut-off power when outer housing is opened

Risks targeted
User receives an electric shock when accessing internal components during repair
User receives an electric shock when performing testing

Embodiment design of the idea
A PTM switch, hidden inside the coffee machine base, is engaged when the outer housing is installed and is disengaged when the outer housing is removed.

Evaluation of the idea and embodiment
The switch performed as intended, and the justification for the same is provided below,

1. Results from Test #1 show that the switch cut off power to the internal components when the outer housing was taken out and allowed power to flow once the outer housing was reconnected.
2. The switch's location was also deliberately hidden from the naked eye, and its success at being invisible was observed during user testing. Participants did not immediately notice the switch, including in situations where participants were looking for it.

While this shows that the idea has merit in solving the identified risk in coffee machines, there is scope for improvement, which is highlighted below,

1. There was no indication or information given to participants that the coffee machine would only receive power if the outer housing were installed. As one participant pointed out during the user test, they would assume they made a mistake if they saw the coffee machine not running even after connecting the power cable to the supply. This can be easily avoided by providing information either at the back of the coffee machine or inside the machine, near the switch location.
2. Two participants expressed their desire to perform tests with the outer housing opened. They wanted to do so because they wanted to spot problems and rectify them immediately, which cannot be done with the outer housing in place. Thus, what they would like is to be able to override the safety interlocks set in place while taking full responsibility for the risks they expose themselves to. The last statement is key here, as in this scenario, the user is aware of the consequences of running the machine with its internal components exposed. Thus, any design intervention that allows the user to override the safety interlocks must be possible, with the user being made aware of the risks it entails. With this established, design solutions can be in many forms. One option is proprietary tools that allow the user to override the safety interlock, for example, by engaging the switch even after the outer housing has been removed. Another option is providing information inside the coffee machine that directs the user to the manual. The manual can then guide the user on how to override the safety interlock for future repair.

Other considerations for future explorations
While the PTM switch worked as intended, it is not the only method available to perform this task. Other kinds of switches also disconnect electrical connections when engaged or disengaged. Examples of these are magnetic reed switches, push-to-break (normally closed) switches and microswitches. Each switch has a different operating principle, size, and cost and thus has the potential to be a suitable alternative or

a better choice than the PTM switch used. This can only be determined by prototyping with these different switches and comparing the complexity and cost of the final design. It is important to note that this test should be conducted for every consumer electronic, as the product's embodiment and its context of use are also important criteria for evaluation.

7.3.2 Idea 2 - Button that is pressed prior to repair that drains the water out + instructions on using it

Risks targeted
User spills residual water to cause short circuiting during repair
User burns themselves through intentional or unintentional contact with hot water during repair

Embodiment design of the idea
The "Emptying program" that exists in the Magimix is simulated. Instead of following the default procedure of pressing and holding the two buttons that dispense coffee, a third (dummy) button is provided at the back of the machine. This is accompanied by an instruction informing users to press it before repair.

Evaluation of the idea and embodiment
The user test evaluated whether users noticed the button and the accompanying instructions. Based on these criteria, the idea was successful because five participants noticed the instruction and the button. This can be attributed to its location - positioned above the water tank, making it easily visible when accessing the screws.

One assumption made during the testing was that the coffee machine was always connected to the power. This is needed to run the "Emptying program". If the user disconnects the power cable from the mains, activating the program will have no effect. This can confuse the users and thus be inconvenient. One option to solve this is to add instructions that ask the user to connect the coffee machine to the power source.

Other considerations for future explorations
While the button + instruction combination worked during the test, there are other aspects to be considered,

1. A dedicated button was suggested because,
    a. It reduces or eliminates the need for the user to refer to a manual or follow a more complicated procedure to activate the program in its existing form
    b. It provides an opportunity to add a repair icon on the bottom. This may prime the user to think about their subsequent actions (probably making them meticulous and cautious).

    However, this also means an additional PCB, silicone button, wiring, and program modifications in the main PCB. This will impact cost, as well as product complexity, due to additional components. The PCB and button require space and a method of securing them to the housing. This has to be weighed with the option of simply providing an instruction at the back that teaches users to follow the standard "Emptying program" procedure or instructs them to refer to the user manual (where this procedure is detailed). This can be done through user testing to determine if the two options elicit significantly different responses from users.
2. Another alternative is to explore ideas that do not rely on the user to press the button. Actions such as removing the first two screws could auto-trigger the program, thus eliminating instances where the user forgets the step.
3. As mentioned above, the coffee machine needs to be connected to the power to run the "Emptying program". While adding text asking the users to do is an option, there is also a limit to the amount of

text and information that can be provided before it becomes chaotic and unhelpful. This balance needs to be investigated, or the other ideas generated during brainstorming need to be further explored.

7.3.3 Idea 3 - Housing is locked until the boiler does not cool down + warning informing the user about it

Risk targeted
User burns themselves through intentional or unintentional contact with the boiler ot hot water during repair

Embodiment design of the idea
A bimetal strip is used as both a temperature sensor and an actuating mechanism. The bimetal is connected to a component called the HTR (heat transfer ring), which transfers the heat from the boiler surface to the bimetal. This will cause the bimetal to deform when the temperature crosses a threshold value (dependent on the bimetal). This pushes a pin that passes through a hole in the outer housing (called a housing lock) and inserts itself into the inner housing, thus securing the outer housing in place.

A warning is also provided on the outer housing to inform the user that it cannot be removed until the boiler has cooled down.

Evaluation of the idea and embodiment
Multiple functionality tests were conducted to evaluate the idea,
1. Ability to provide adequate deformation
2. Ability to actuate a pin and lock a component in place
3. Maximum weight that the bimetal can hold at its tip
4. Ability of the HTR to quickly transfer heat to the bimetal

The first three tests were successful, as the bimetal could be easily modified to provide deflections ranging from 14 to 8 mm. It was able to actuate a pin and lock a component and could lift a 15 g weight at its tip while providing 8 mm of deflection. The last point was important because 15 grams may not sound like a lot, but a 5 mm diameter and 10.5 mm long pin (which weighs ~ 1 gram) made of steel can withstand 100 N of force (Figure 82) with a factor of safety equal to 2. While we do not expect the user to exert such large forces, it proves that the bimetal is capable of lifting an appropriately sized pin.
The fourth test did not succeed, as detailed in Section 6.6, and this presents the following opportunities for research,

1. Experimenting with the bimetal
   The bimetal used was from a steam iron and was designed to react to a specific temperature. If a bimetal is chosen that reacts at lower temperatures, the response time could be shortened and would be sufficient to match the time it takes the boiler to reach operating temperature.

2. Experimenting with mounting
   The bimetal is connected to the HTR, which, in turn, is connected to the boiler. From a heat transfer perspective, this is an additional resistance to the flow of heat and was also observed during testing. In addition to experimenting with the bimetal, this suggests an opportunity to explore alternatives to how the bimetal is connected to the boiler. For example, a way to directly connect the bimetal to the boiler can be achieved through boiler redesign or optimising the design of the HTR itself to improve heat transfer efficiency.

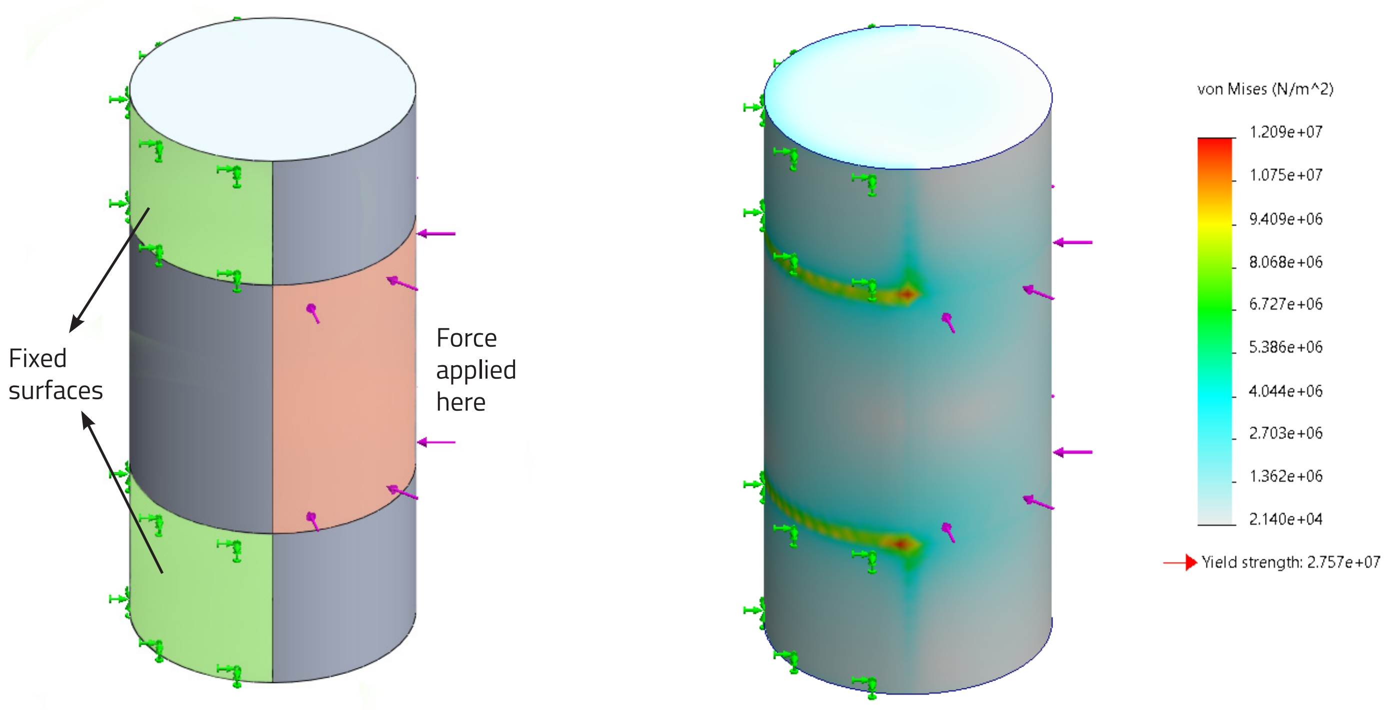


Figure 82: Stress simulation setup and result of a pin subjected to 100 N of force, while having 2-point of contact

The user test, on the other hand, evaluated whether users noticed the warning and their response to it. Five out of the six participants did not interact with the warning as intended, and given below are the explanations and possible solutions,

1. Participant did not see the warning or ignored it
   Two participants did not see the warning because it was placed behind the water tank. One solution is to either make it more visible by placing it above it or by making the warning stand out (through contrast, for example).

   Another participant noticed the warning but ignored it, assuming it would be important for later. They reasoned this because the warning text was placed below the instructions to use the "Emptying program" button and thus thought it was a second step to be followed. This misinterpretation can be resolved, for example, by placing this information closer to the first instruction. Another option is asking users to read the second instruction at the end of the first instruction.

2. Participants assumed the boiler was cooled down and proceeded to take out the outer housing
   Once the five participants were asked to read the warning, they immediately assumed that the boiler must be cool. They reached this conclusion because they had no information suggesting otherwise. This led to a few minutes of confusion when the outer housing refused to open. A solution to this would be to provide feedback on the boiler's temperature, allowing users to determine when they can remove the housing. Examples include a light-based indication or a live temperature reading at the back.

Another problem encountered during user testing, as covered in the risk assessment table, is the difficulty in reinstalling the outer housing in its original position. This occurred due to the presence of wires that obstructed the housing lock from sliding into place (Figure 83). Presented are three example approaches to solve this problem,

1. In Appendix D, Design Decision 8 examines two options for the outer housing: one where the outer housing slides out from the back and another where it slides out from the side (Figure 84). The option to have it slide out from the back was chosen because it made it easier to place fasteners at the back, allowing for safety information to be included along with it. Having the housing open from the side was still a possibility. However, it would have required the width of the Magimix to be increased (also covered in Decision 8). Given that the current approach of removing the outer housing has its challenges, a design where the outer housing is removed from the side can be explored.
2. Another option is to redesign the shape of the housing lock. Currently, the front face of the housing lock is flat, which makes it easier for it to snag onto wires (Figure 85). If this shape is changed, for example, to be more triangular, it could help it push wires away as it slides forward.
3. A dedicated tunnel for the housing lock can be added to the inner housing (Figure 86), which forces the user to divert wires and tubes around it, thus clearing the way for easy reassembly.

Finally, similar to the PTM switch, two participants expressed the need for an option to override the safety interlock. This is another avenue that requires ideation and testing.

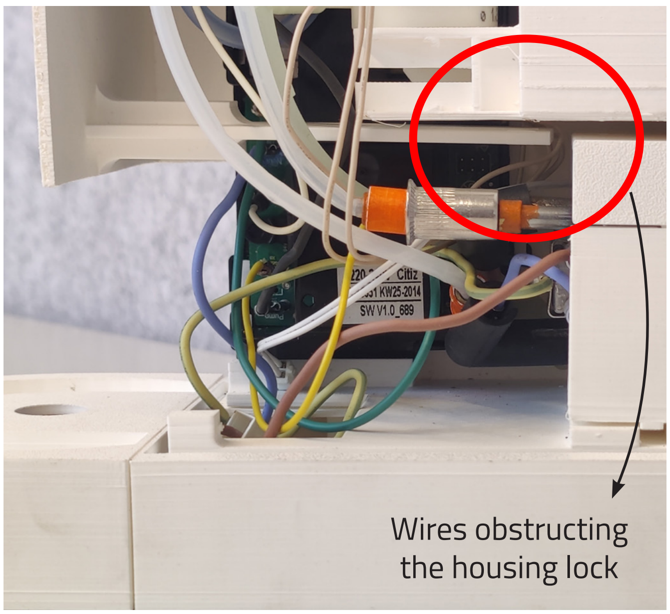


Figure 83: Difficulty faced reinstalling the outer housing because of interfering wires

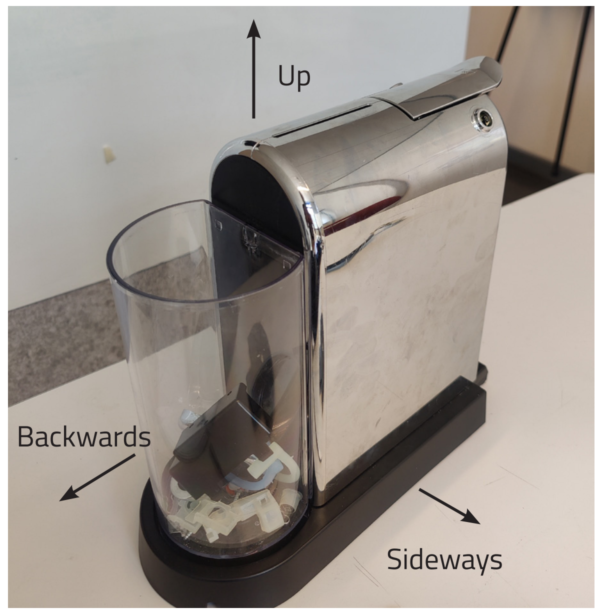


Figure 84: Possible directions to open the housing

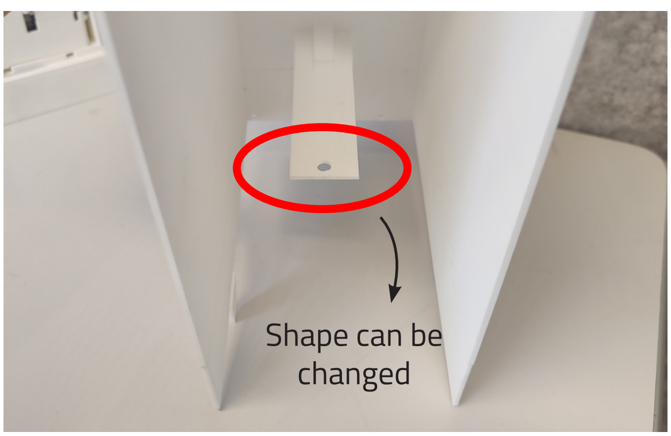


Figure 85: Flat face of the housing lock can be changed to make it more triangular - will help push wires away

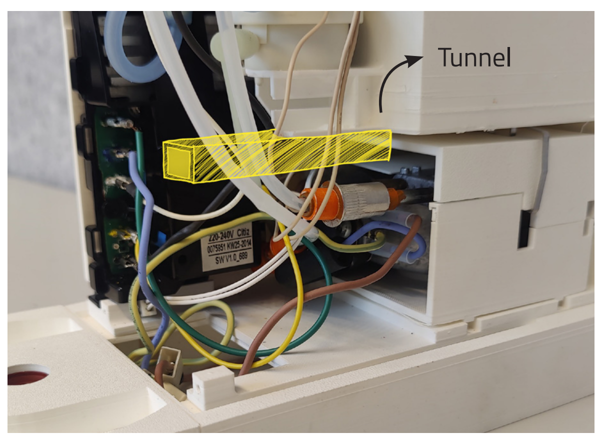


Figure 86: Tunnel created in the inner housing to direct wires around it, thus making space for the housing lock

Other considerations for future explorations
While the bimetal worked as intended, further refinement is needed to address the observed issues. Additionally, it is worth noting that this is not the only method available to perform this task. Examples of alternatives include a combination of a temperature sensor and actuator, as well as a shape memory alloy. While shape memory alloys work passively like bimetals, a temperature sensor and actuator would require power to work (unless passive alternatives exist). Like the alternatives to the PTM switch, these options also need to be evaluated through prototyping and comparing the complexity and cost of the final design. This test should be conducted for every consumer electronic, as the embodiment of the product and its context of use are also important criteria for evaluation.

Another opportunity to explore is the actuation mechanism itself. In the prototype, a pin was used to lock the outer housing; this is not the only way the housing can be locked, with other options including a latch that is triggered by the bimetal or, as explored during ideation, a cover for the fasteners that hide it until the boiler has cooled down. These are also alternatives that can be explored in conjunction with the method of detecting temperature.

7.3.4 Idea 4 - Colour code the wire connections

Risk targeted
User makes the incorrect electrical connections during reassembly

Embodiment design of the idea
All the wire connections in the prototype were assigned a unique colour, and the corresponding connection point on the PCB was painted with the same colour. The pin on the wire was not colour-coded. However, the painted connection points were only a test of the idea, and a more suitable embodiment can be seen in Figure 87, where the connection points have an insulated cover that is colour-coded.

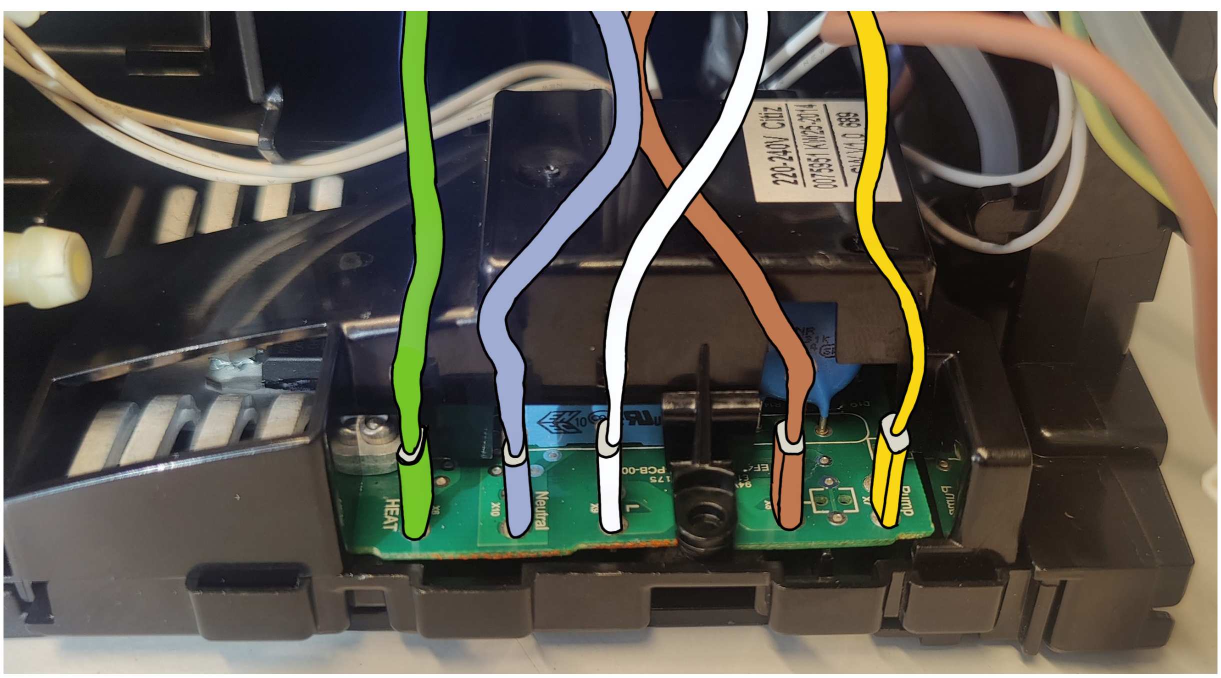


Figure 87: Wires and corresponding connection points have been colour coded to ensure maximum visibility

Evaluation of the idea and embodiment
Five out of the six participants immediately noticed and identified the colour coding on the wire connections and used it to reassemble them correctly. One participant did not notice it at first because the connection points on the PCB were under shadow (low visibility). However, once they could see the colour, they identified it for what it was. This demonstrates that the idea can be effective in helping users make the correct wire connections.

There are two drawbacks to this idea that were not tested. One was the visibility of the colours on the PCB (a problem faced by one participant during the test). Depending on the location of the coffee machine in the user's home, this can be a problem. The magnitude of the problem can only be determined by testing the effect of varying lighting conditions on the perception of the colours. Another alternative is to reposition the PCB such that it is exposed to more ambient light. The second drawback is the perception of the colours for a person with colour blindness. None of the participants suffered from colour blindness, and the colours were also not chosen to be accessible to people with the condition. Thus, this is another area that warrants further exploration.

Other considerations for future explorations
While the embodiment prototyped and tested above has shown to work in avoiding the identified risk, there are also other ways of implementing the idea. A list of possible options has been listed below,

For the wire
1. Wire insulations have distinct colours
2. Wires all have the same colour but have colour-coded heat shrink bands
3. Wires have the same colour, but the metal connector at the end has a specific colour

For the connection point
1. The connector has a specific colour that matches the wire
2. Painting or printing colour indicators around connection points that match the wire
3. Applying stickers or printed labels near the connection point

There are a total of nine possible combinations from the options presented above. Only one combination - wire insulations have different colours, and the connector has a specific colour that matches the wire - was tested. Since all the nine combinations could work just as effectively, they need to be evaluated, assessing the added cost to the product.

7.3.5 Idea 5 - Thread based connection for the hoses

Risk targeted
Hoses are not attached securely

Embodiment design of the idea
The ends of the hoses and their attachment to the component were retrofitted with male and female threaded connectors. This was done to test the idea rather than make it functional. Ideally, the connectors were envisioned as shown in Figure 88.

Evaluation of the idea and embodiment
Two aspects of the idea were evaluated during user testing. First, whether the participant identified the connection as thread-based. Second, whether the participant tightened the connection during reassembly.

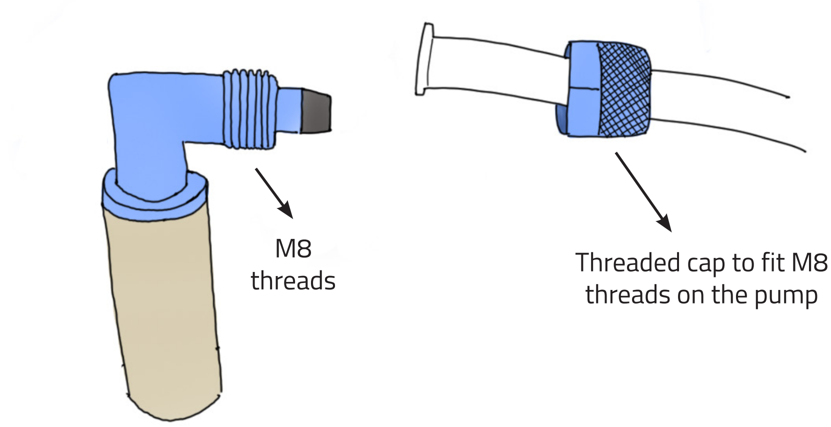


Figure 88: The hose attaching to the pump also has a cap with internal threads which is coloured blue

For the first aspect, participants did not identify the nature of the connection. They thus attempted to disconnect the hoses by trying different methods, such as pulling and twisting. They identified its correct nature through close inspection, by trying to randomly rotate the connector and succeeding, or by examining the image of the boiler unit and noticing the threads on the inlet and outlet. While the prototype involved a retrofitted connection, aesthetically, it was not far from how the actual connection was envisioned. This suggests that there is an opportunity to redesign the connectors to make it easier to identify their nature and method of disconnection.

For the second aspect, it was observed that all participants tightened the connections to their limit. In some cases, participants did this while voicing out their intent to do so. In other cases, participants did this subconsciously. This suggests that users tighten threaded connections, which justifies using them to connect hoses securely.

In conclusion, the idea could be used for securing hoses and can be further optimised for ease of use.

<u>Other considerations for future explorations</u>
The idea of using threaded connections is not new, and inspiration was drawn from the Classic Gaggia coffee machine. While this proves that the idea is feasible, it also raises questions about its cost. The Classic Gaggia costs between € 450 and € 500, which is three times the price of a Magimix Citiz machine. Thus, one needs to consider the cost impact of the idea, factoring in different material options such as brass and aluminium.

7.3.6 Idea 6 - Unique size threaded connection between two parts

<u>Risk targeted</u>
Incorrect hose is attached between two components

<u>Embodiment design of the idea</u>
Every hose had a unique thread size on its two ends. The corresponding connection point on the components thus also had the same thread size. An example of this can be seen in Figure 89, taken from the prototype.

<u>Evaluation of the idea and embodiment</u>
The goal during testing was to observe if participants recognised the difference in thread sizes and used that as a design cue to select the correct hose. One aspect that was overlooked was the difference in

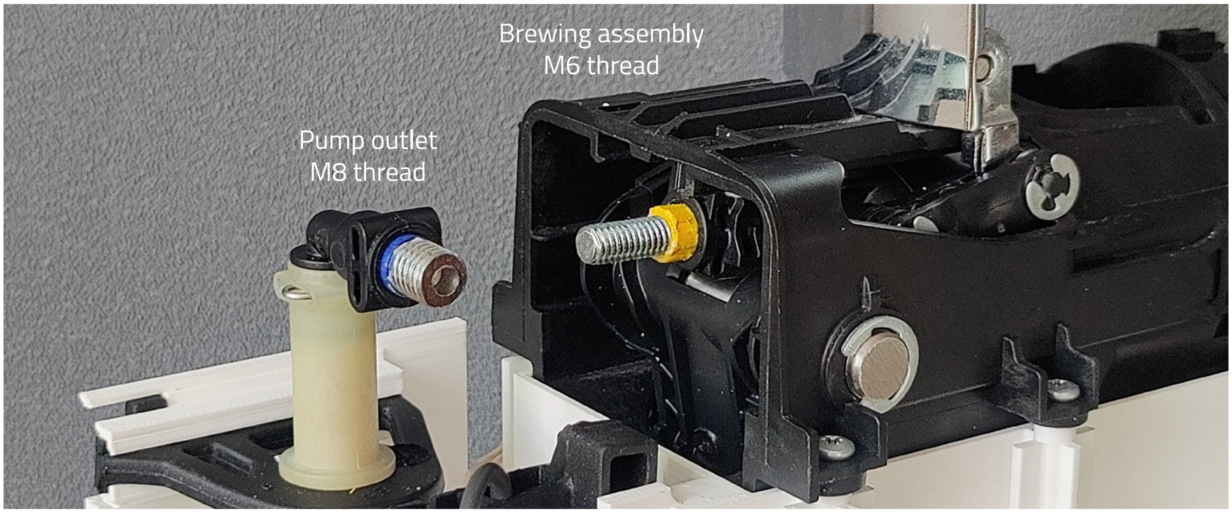


Figure 89: Hose for the boiler inlet (left) and boiler outlet (right) with the appropriate female-thread component

thread material and shape. As shown in Figure 90, the connector for the M8 thread was made of metal and was larger, whereas the connector for the M6 thread was made of plastic and was smaller in size. This additional variable (material) was not accounted for while making the test protocol. Thus, in three user tests, it was not easy to identify which feature the participant used to select the correct hose.

That being said, features like size or material can be used as design cues to help users identify the correct hose. Additionally, using different-sized threads also means that an incorrect hose cannot be attached to the wrong component, as the size mismatch would prevent it from happening. Thus, different-sized threads are a potential option.

The effectiveness of this idea is also strengthened by the idea evaluated in Section 7.2.7, where the reasoning will be discussed.

<u>Other considerations for future explorations</u>
As mentioned above, two variables were inadvertently introduced in the user test; therefore, it was not possible to determine which variable contributed to the desired goal. Evaluating if there is a difference in effectiveness is a direction for future exploration, as both options could have an impact on cost.

Another thing to consider is the sizes assigned to each hose. Since the connections need to have unique sizes, it can start getting difficult as the number of hoses increases. A large thread size would not be favourable, as it occupies space. Similarly, a small thread size might also be inconvenient as it could make it difficult for the user to release them. Thus, the optimal sizes need to be determined through independent research, but also depending on the space available inside the coffee machine.

7.3.7 Idea 7 - Colour the hose cap and the corresponding part with the same colour

<u>Risk targeted</u>
Hose is attached in the incorrect orientation

<u>Embodiment design of the idea</u>
Every component in the Magimix had only one hose connecting it to another component. Thus, each component was given a unique colour - orange for the boiler, blue for the pump, and yellow for the brewing assembly. All hose connection points on the component were assigned the component's colour. A hose

Figure 90: Hose ends are colour coded based on which component they are attached to

connected to a component was then assigned that colour for the corresponding end of the hose. For example, if a hose was connected between the boiler and the pump, then one end of the hose was orange while the other end was blue. This is shown in Figure 90.

<u>Evaluation of the idea and embodiment</u>

The goal during testing was to observe whether participants recognised the different colours on the components and were able to match them with the colours on the hoses. All participants were able to identify this and make the connection correctly. In one situation, a participant wondered whether the hose orientation made a difference. However, because of the colours, they decided to follow the colour coding.

While this idea is effective in itself, it also helps strengthen the idea evaluated in the previous section. Let us assume that colour coding was not used to help in attaching the hoses in the correct orientation. In its fully disassembled state, the Magimix has at least six hoses, all of which have a unique thread size at their ends. Suppose the user needs to attach a hose between the pump and the boiler. In that case, they must initially check all the hoses to identify the correct size, which can be a frustrating process. Now, if the hose ends are also colour-coded, the user only has to choose one hose - the hose with orange and blue ends. They can now easily check whether the hose fits on the pump inlet or outlet based on the thread size and apply the same logic to the boiler.

The converse also applies. If the user does not know which components need to be connected, they can choose one hose - let us say the one with an orange and blue end. They can now identify the corresponding colour on the components and use the thread size to connect it at the correct point.

<u>Other considerations for future explorations</u>

While the use of colour coding was shown to be effective during user testing, a method of implementing this was not explored or suggested. Given below are a few ways in which this can be done,

1. Adding coloured rubber/plastic sleeves near the threaded ends
2. Hose has a different outer jacket colour, and having the corresponding part on the component match it
3. Using anodised aluminium or plastic-coated metal connectors in different colours
4. Painting or dying the threads

These approaches should be evaluated from the lens of effectiveness and robustness in the future. Evaluating their effectiveness is important as each idea would have a different cost impact - using anodised aluminium would cost more than painting the threads. At the same time, anodised aluminium would retain its colour longer than painted threads, which would wear down with use.

7.4 Final reflection - Applicability to coffee machines and other electronic products

The ideas prototyped and tested in this thesis demonstrate potential applications to other coffee machines. The use of an interlock switch to cut power when the housing is removed was shown to be effective in addressing electrical safety risks. Its implementation is supported by the availability of various switch types that can adapt to differing product geometries. Similarly, programming a command to empty residual water, either through an automated routine or a user-initiated action, is a good option for addressing thermal and electrical hazards. Since this idea is already present in the Magimix, it is not unrealistic to assume that it can be implemented across other machines as well. The idea to lock the housing when the boiler is hot requires further experimentation and testing to refine it. Similar to the interlock switch, other options are also available to perform the same function, each offering its flexibility from a design perspective. The intervention that utilised design cues (colour-coding wire and hose connections) and threaded connectors worked well during testing. They can enhance user safety during reassembly and minimise the likelihood of post-repair failure.

Beyond the specific case of coffee machines, the tested ideas suggest broader applicability across consumer electronics. The interlock switch is particularly relevant for products that are difficult to unplug due to their size or are hard-wired into position, such as refrigerators, wall-mounted televisions, and washing machines. The idea of emptying residual liquids before disassembly can be extended to appliances with water-handling systems, including dishwashers, humidifiers, and kettles. In cases where the residual water cannot be automatically pumped or drained out, such as steam irons, the use of design cues to warn users of residual liquid may offer a safer alternative. The principle of thermally locking access to hot components is also transferable to devices such as microwave ovens, toasters, and personal care appliances that contain internal heat sources. Low-complexity strategies such as colour coding and varying the size of threaded connectors are broadly applicable across electronics with internal connectors and hoses, supporting correct reassembly and reducing safety risks.

While this thesis examined the effectiveness of one idea for each repair safety risk, the entire process offers valuable insights for designers. Thus, with this project, future designers have a starting point to design safe to repair products by

- Using the risk identification methodology to identify safety risks or
- Taking inspiration from the ideas explored to mitigate the risks or
- Drawing insights from the design decisions made to prototype the ideas or
- Building on the results obtained from testing

Having this starting point is important because products will increasingly remain in circulation through repair; thus, the responsibility to ensure user safety during these interactions becomes a critical part of design practice. With the help of these tools, a designer would have a spectrum of safe repair choices available to them. These choices would help them integrate repair safety as a design consideration from the beginning, alongside performance, cost, and usability.

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APPENDIX

Appendix A - Project brief

DESIGN FOR our future

TU Delft

Personal Project Brief – IDE Master Graduation Project

Name student Hrishyank Umashankar Shetty **Student number** 5,904,595

PROJECT TITLE, INTRODUCTION, PROBLEM DEFINITION and ASSIGNMENT
Complete all fields, keep information clear, specific and concise

Project title Redesign of a coffee maker for repair safety

Please state the title of your graduation project (above). Keep the title compact and simple. Do not use abbreviations. The remainder of this document allows you to define and clarify your graduation project.

Introduction

Describe the context of your project here; What is the domain in which your project takes place? Who are the main stakeholders and what interests are at stake? Describe the opportunities (and limitations) in this domain to better serve the stakeholder interests. (max 250 words)

Circular economy is a system of resource production and consumption that promotes resource circulation over the traditional linear consumption model. This helps reduce waste and preserve finite resources. Repair plays a key role in this by extending product lifespans through component replacement or fixes. This approach also appeals to consumers, as highlighted by a 2020 European survey, which found that nearly 77% of consumers would rather repair their products than purchase new ones. Despite strong public interest, however, consumers shy away from performing repair. A prime example is the coffee machine, the most repaired product in the EU in 2024 (Repair Monitor, 2025). Notably, 36% of repairs for the coffee machine required simple interventions such as descaling or cleaning. While these activities are simple to perform, the design of the coffee machine pose several barriers. One of the major barriers is the safety risk associated with performing at-home repairs. Research from Bolanos Arriola et al. (2019) and Ingemarsdotter et al. (2021) has shown for example, that current coffee machine designs do not support users to correctly reassemble components thus leading to post-repair risks like electric shocks and fire. This is concerning as it conflicts with the new laws supporting the consumer's right to repair. To resolve this conflict, there is thus a need to relook at the design of existing coffee machines, from the perspective of safety during and after repair.

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Problem Definition

What problem do you want to solve in the context described in the introduction, and within the available time frame of 100 working days? (= Master Graduation Project of 30 EC). What opportunities do you see to create added value for the described stakeholders? Substantiate your choice.
(max 200 words)

Coffee machines pose several barriers to repair such as,

1. They possess multiple safety hazards such as mechanical, temperature, and electrical risks

2. Existing designs do not adequately safeguard users from safety risks occurring during repair (through exposure to safety hazards) or post repair (by preventing incorrect repair)

3. Critical components containing safety hazards are deeply embedded in the product architecture, leading to difficulty in performing repair

Addressing this limitation for consumers to perform self-repair is the problem that the project aims to address.

Assignment

This is the most important part of the project brief because it will give a clear direction of what you are heading for. Formulate an assignment to yourself regarding what you expect to deliver as result at the end of your project. (1 sentence) As you graduate as an industrial design engineer, your assignment will start with a verb (Design/Investigate/Validate/Create), and you may use the green text format:

Identify design related safety issues in coffee machines and redesign a coffee machine to make repairability safe and easy for consumers with limited repair experience performing at-home repair.

Then explain your project approach to carrying out your graduation project and what research and design methods you plan to use to generate your design solution (max 150 words)

In the course of accomplishing the above result, the following four research questions will be investigated
1. What existing design features make the coffee machine unsafe for repair
2. What do failproof design solutions look like for the case of a coffee machine
3. How can safety information be effectively communicated to the consumer through a medium other than a safety manual
4. What are the implications of implementing failproof design solution on product cost and complexity

To answer these research questions, the following methods will be used
1. Desktop and field research (visiting Repair Cafes)
2. Product teardowns using the modified disassembly map as a tool for analysis
3. Hotspot mapping (repairability and safety)
4. Prototyping
5. Evaluating redesigns through user testing, hotspot mapping or qualitative assessment metrics

Appendix B - Steps for risk to occur

Presented here are the table that show the steps needed for a user to be exposed to a risk during repair. Items marked in yellow and orange represent steps that were common across multiple risks. Solving for these would help mitigate all the associated risks.

Table 19: Risk steps that have to be fulfilled to expose the user to the repair risks identified in the Magimix

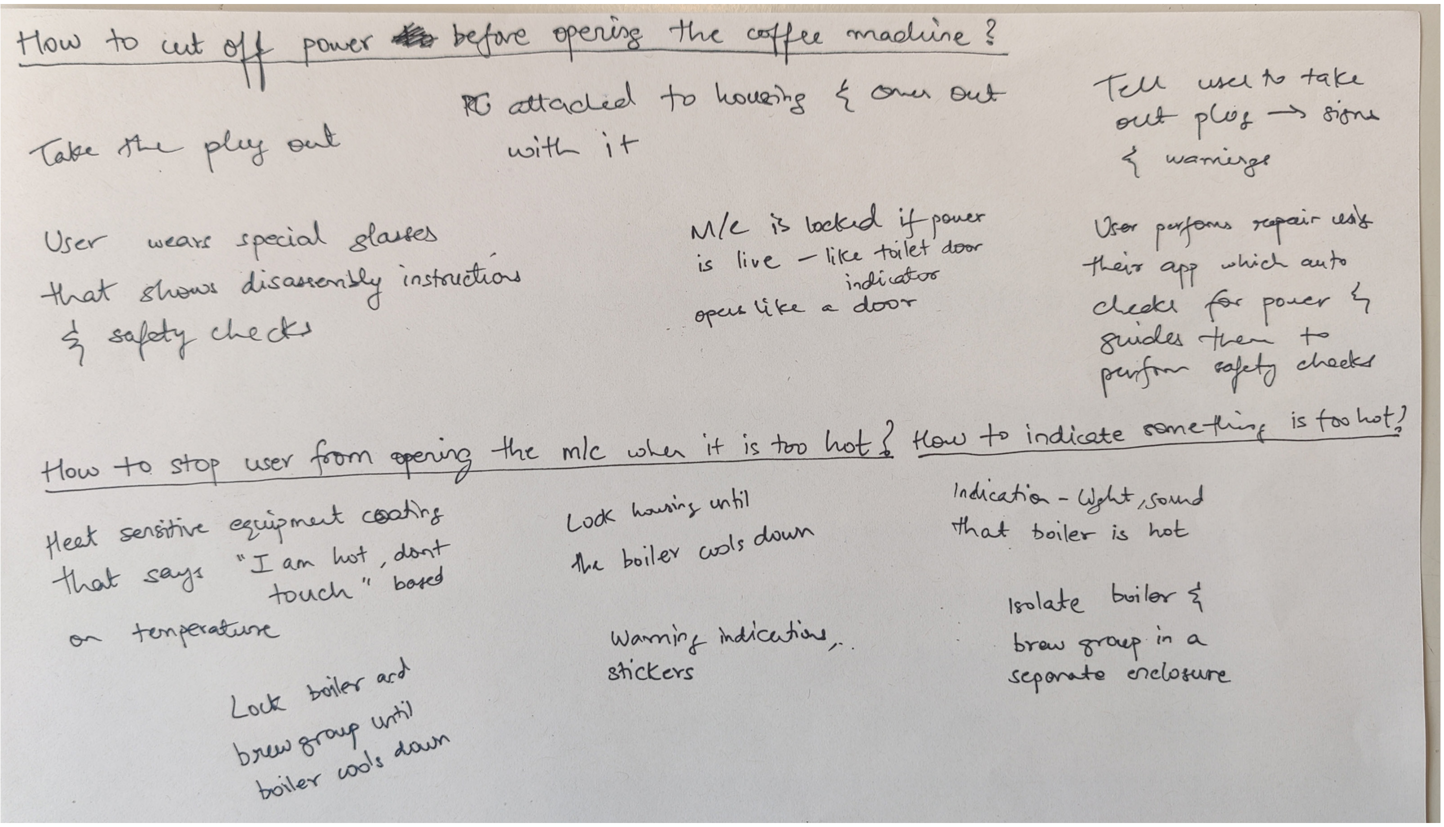
Risks during repair - Magimix					
S. No	**Risk zones/steps**	**Observed design feature**	**Why is it problematic**	**Steps for injury scenario to occur**	**Risk type**
1	A	Hidden snapfits in Power cable panel cover	User is inclined to insert their finger into a gap to make it easier to release other snapfits - Can cause pinching	User inserts their finger into a small gap	Mechanical
				Results in an injury requiring first aid	
2	B	Part with thick snapfit to hold power cable in place inside the base panel	The thick plastic of the part requires a large force and a multiple simultaneous-motion disassembly action to release it - Can lead to cuts	Disassembly action causing scalpel edge to slide across skin	Mechanical
				Scalpel cuts the skin	
3	D	Multiple hidden snapfits for the Polycarbonate (PC) side panel	Multiple snapfits along the perimeter of the PC side panel make it difficult to release the snapfits one at a time, prompting users to instinctively use their fingers to keep any gaps free – Can cause pinching	User inserts their finger into a small gap	Mechanical
				Results in an injury requiring first aid	
4	C	Unprotected metal cable connectors – Earthing connector and 5 connections to the PCB	The connectors require force to take out or reattach. They have sharp projections that a user has to press against with their fingers – Can lead to cuts	Hold the uninsulated connector and pull with force	Mechanical
				Cut from the metal connector	
5	E	Unprotected metal cable connectors – Earthing connector and 5 connections to the PCB	Potential to electrocute the user if the machine is still connected to the power supply and the user touches the metal connector	User leaves the power cable live	Electrical
				User bypasses the power cable connections	
				User touches an exposed connector	
6	Z1	Unprotected metal cable connectors – Earthing connector and 5 connections to the PCB	Metal connector can touch other metallic components/connectors inside the product and cause a short-circuit	Connectors touch each other inside the product	Electrical
7	Z1	The PC side panels are accessible after the screws holding the base and the body of the coffee machine are removed	The internal components and PCB are accessible to a user before the power cable connections are taken out. Touching the unprotected cable connectors can lead to electrocution	User leaves the power cable live	Electrical
				User bypasses the power cable connections	
				User touches an exposed connector	
8	F	Cover over the 5 uninsulated PCB connectors may not fit snugly because it interferes with the connector wires	If the snapfit cover is not put in place correctly, it can leave the uninsulated PCB connectors exposed to the user the next time they open the product for repair. This can lead to electrocution.	User leaves the power cable live	Electrical
				User bypasses the power cable connections	
				Snapfit cover gets loose and exposes connectors	
				User touches an exposed connector	
9	Z2	Residual water in the hose, pump or boiler can spill out when parts are disconnected or product is moved	If the power connections have not been taken out, this water can cause short-circuits and sparking	User leaves the power cable live	Electrical
				User bypasses the power cable connections	
				Residual water in the system	
				Part containing residual water is accessed	
				Water leaks onto exposed connector	
10	Z3	Residual water in the boiler or associated hoses can spill out when parts are disconnected or product is moved	If the coffee machine is opened immediately after use, hot water can spill out – Can lead to burns	User opens immediately after using or without letting it cool	Thermal
				Residual water in the system	
				Part containing residual water is accessed	
11	Z3	Residual water in the brew group is hot and exposed when accessed	If the coffee machine is opened immediately after use, contact with hot water in the brew group can lead to burns	User opens immediately after using or without letting it cool	Thermal
				Significant quantity of residual water is present in the brew group	
				Brew group is accessed	
12	Z2	Boiler is not protected from one side	If the coffee machine is opened immediately after use, the user can burn themselves by touching the boiler during its repair	User opens immediately after using or without letting it cool	Thermal
				User needs to replace the boiler (From Repair Monitor data)	
				User touches the boiler without protection	
13	G	JURA standard retaining springs used for holding pipes and connections in place	The springs sometimes tend to widen, making it difficult to reattach. This either requires a lot of force or manipulation from the user – Can lead to cuts	Retaining spring does not reattach normally	Thermal
				Force of inserting retaining spring leads to cuts	

Table 20: Risk steps that have to be fulfilled to expose the user to the repair risks identified in the Senseo

Risks during repair - Senseo					
S. No	**Risk zones/steps**	**Observed design feature**	**Why is it problematic**	**Steps for injury scenario to occur**	**Risk type**
1	Z1	Power cable connections can be kept connected while accessing other components	If an uninsulated connection is accidentally touched by the user while performing repair, they can be electrocuted	User leaves the power cable live User bypasses the power cable connections User touches an exposed connector	Electrical
2	A	All wire connectors are uninsulated metal	Potential to electrocute the user if they accidentally touch it while performing repair	User leaves the power cable live User bypasses the power cable connections User touches an exposed connector	Electrical
3	Z1	Boiler is unprotected and exposed	If the boiler is still hot when the coffee machine is opened, the user could accidentally burn themselves when performing repair	User opens machine immediately after using User accidentally touches the boiler	Thermal
4			If the boiler is still hot when the coffee machine is opened, the user could burn themselves when replacing the boiler	User opens machine immediately after using User has to replace the boiler	Thermal
5	C	Top panel covering the buttons have multiple hidden snapfits	The hidden snapfits require a large force to release that could lead to cuts. Additionally, for the snapfits that have been released, a tools needs to be put in place to keep the snapfits free. If not done, it closes back and can pinch the user.	User has to access top panel Disassembly action causing scalpel edge to slide across skin Scalpel cuts the skin	Mechanical
6	Z1	Liquid can leak out when removing hoses	If the power cable has not been disconnected, leaking water can create a short circuit which is problematic.	User leaves the power cable live User bypasses the power cable connections Residual water in the system Part containing residual water is accessed Water leaks onto exposed connector	Electrical
7	Z1	Liquid can leak out when removing hoses	If the machine is opened immediately after use or without it cooling down, the water can be hot which can burn the user.	User opens immediately after using or without letting it cool Residual water in the system Part containing residual water is accessed	Thermal
8	Z1	Water in the boiler spills out when taking out hoses	The boiler stores water in it which can be hot if accessed shortly after use. This can cause burns to the user	User opens machine immediately after using User has to replace the boiler Residual water in the system	Thermal
9	Z2	Residual water in the brew group is hot and exposed when accessed	If the coffee machine is opened immediately after use, contact with hot water in the brew group can lead to burns	User opens immediately after using or without letting it cool Significant quantity of residual water is present in the brew group Brew group is accessed	Thermal
10	G	Position of the Top cover screws causes interference between screwdriver and coffee pad piercer	When trying to put the scew, the coffee pad piercing tool causes cuts in the user's hands	User has to access the top panel Removing screw causes cuts due to projection	Mechanical

Appendix C - Ideas from brainwriting & brainstorming session

Shown below are the ideas generated during the individual brainwriting session



How to cut off power before opening the coffee machine?

Take the plug out

PC attached to housing & comes out with it

Tell user to take out plug → signs & warnings

User wears special glasses that shows disassembly instructions & safety checks

M/c is locked if power is live – like toilet door indicator opens like a door

User performs repair using their app which auto checks for power & guides them to perform safety checks

How to stop user from opening the m/c when it is too hot? How to indicate something is too hot?

Heat sensitive equipment coating that says "I am hot, dont touch" based on temperature

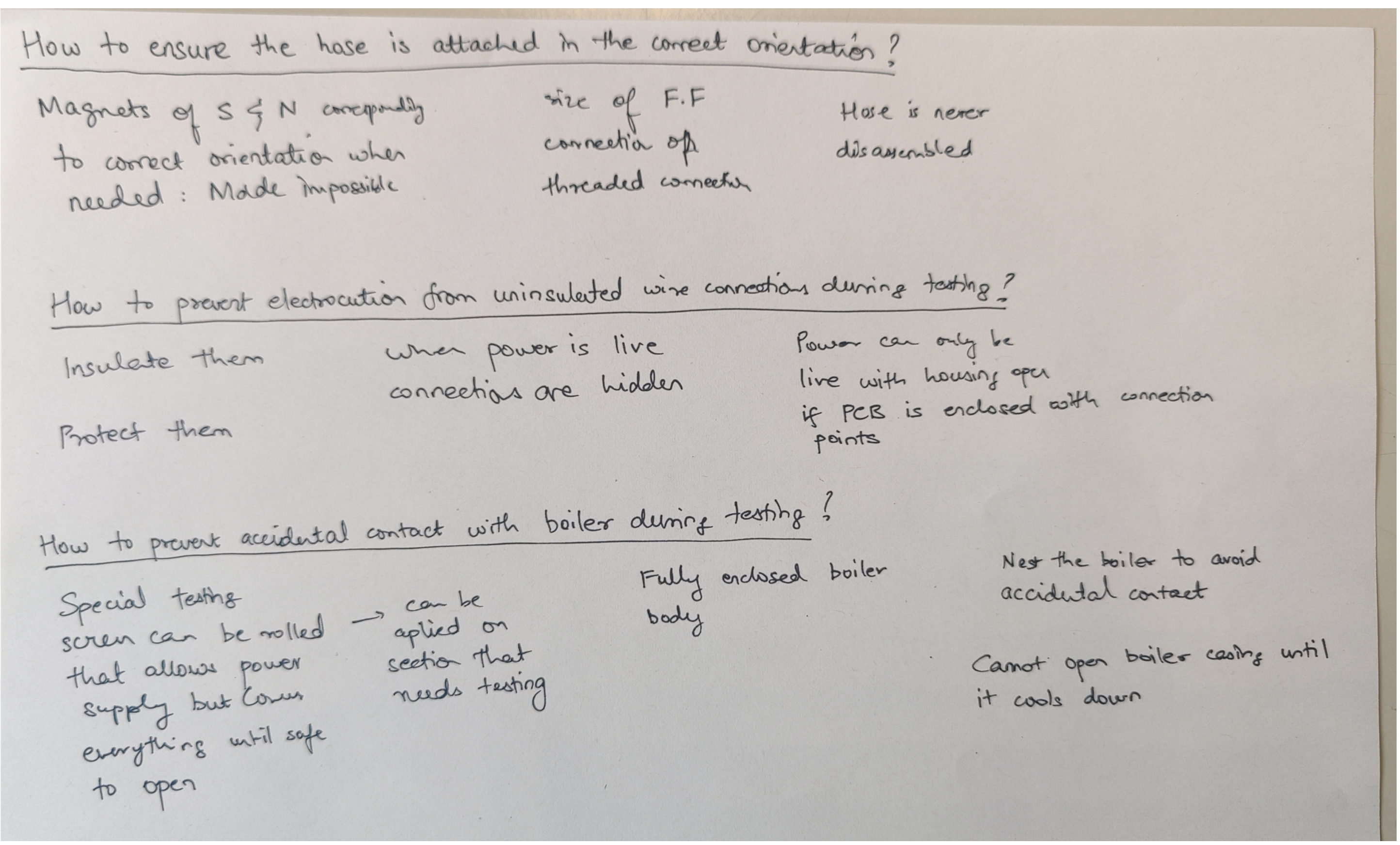
Lock housing until the boiler cools down

Indication – light, sound that boiler is hot

Lock boiler and brew group until boiler cools down

Warning indications, stickers

Isolate boiler & brew group in a separate enclosure



How to ensure the hose is attached in the correct orientation?

Magnets of S & N correspondly to correct orientation when needed : Made impossible

size of F.F connection of threaded connection

Hose is never disassembled

How to prevent electrocution from uninsulated wire connections during testing?

Insulate them

Protect them

When power is live connections are hidden

Power can only be live with housing open if PCB is enclosed with connection points

How to prevent accidental contact with boiler during testing?

Special testing screen can be rolled that allows power supply but covers everything until safe to open → can be aplied on section that needs testing

Fully enclosed boiler body

Nest the boiler to avoid accidental contact

Canot open boiler casing until it cools down

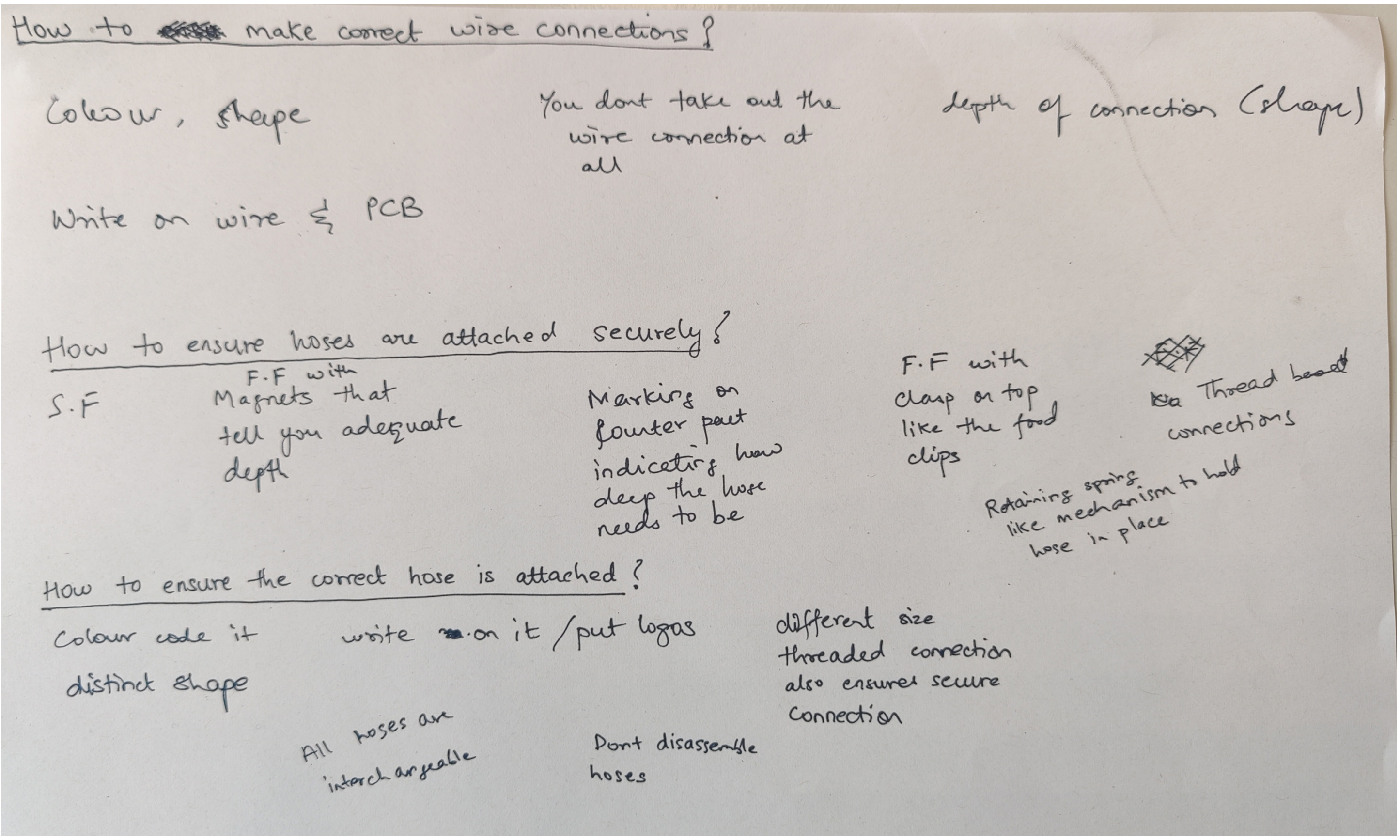


Figure 91: Ideas generated during the individual brainwriting session

Shown below are the ideas generated during the group brainstorming session along with the risk scenario presented to the particpants

User forgets to unplug the power cable and electrocutes themselves on uninsulated connections

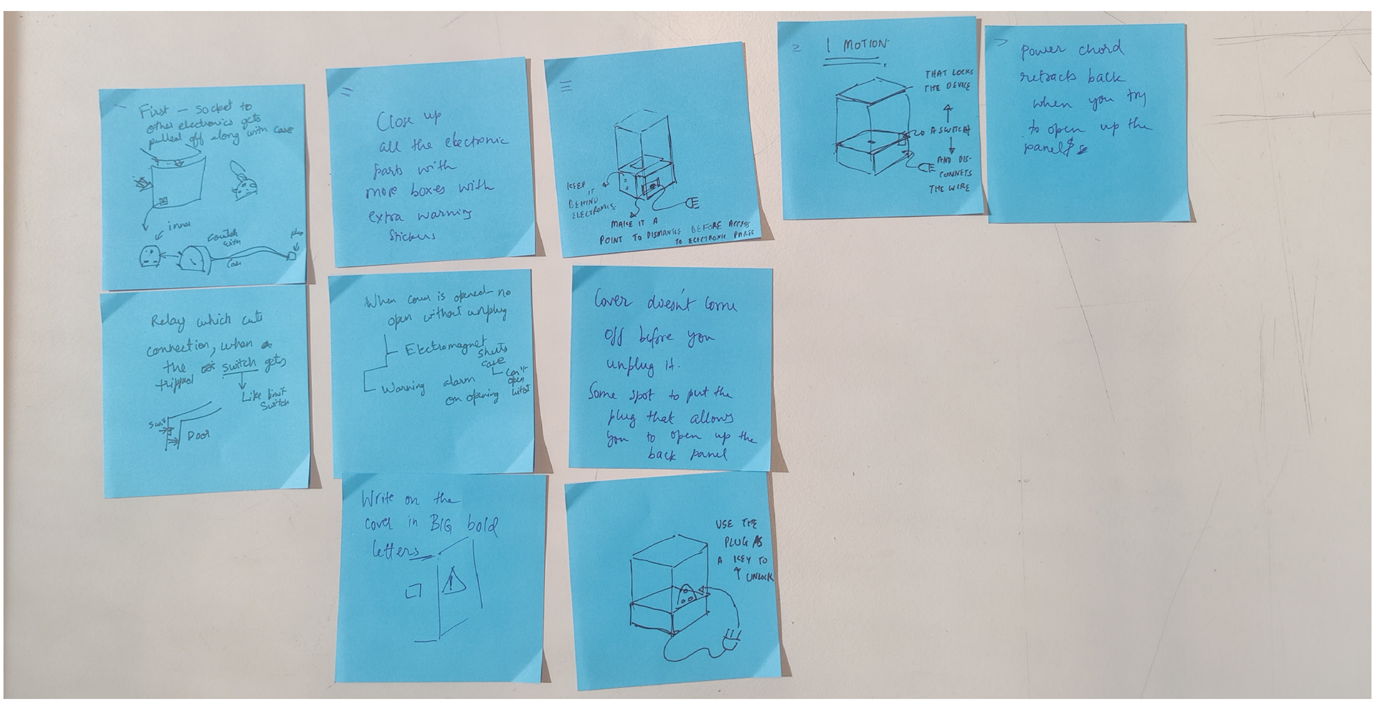


Figure 92: Ideas for Risk 1 - User receives an electric shock when accessing internal components during repair

User forgets to unplug the power cable and spills residual water onto connections when disconnecting hoses causing short circuiting

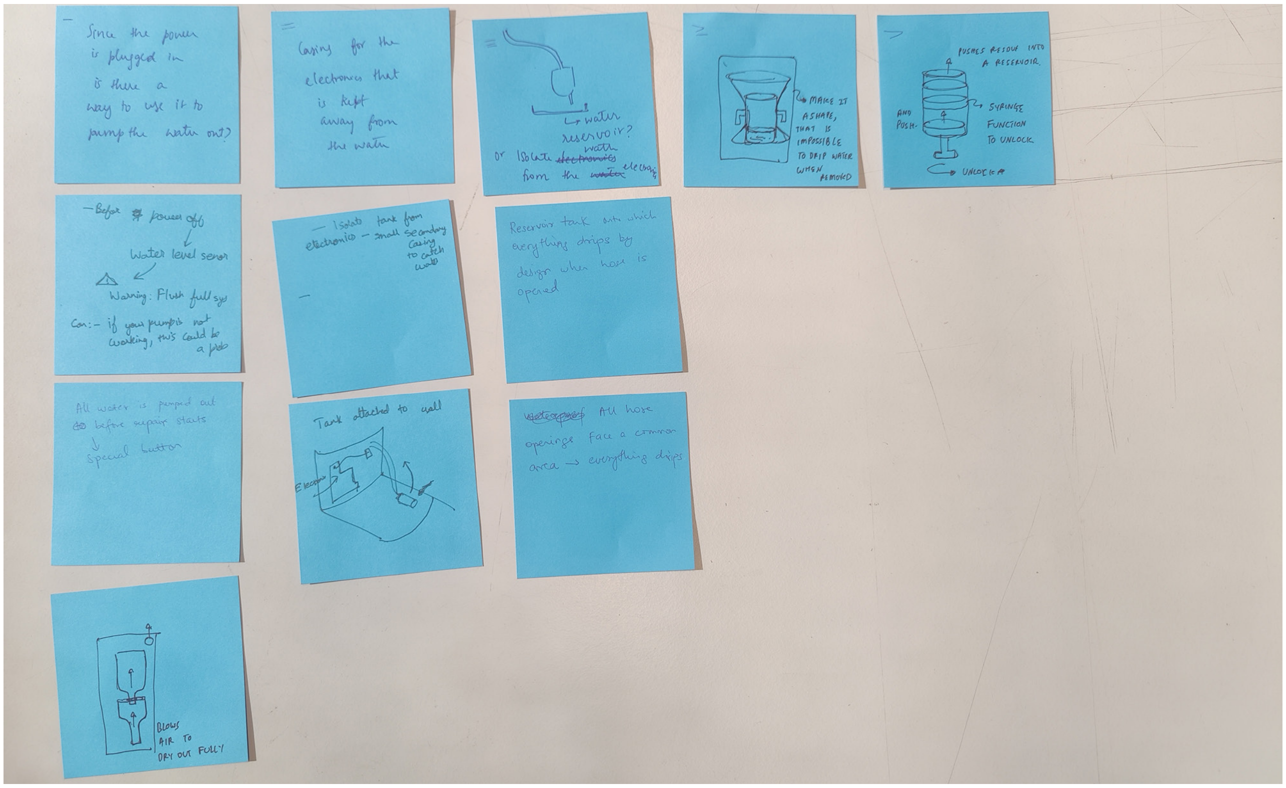


Figure 93: Ideas for Risk 2 - User spills residual water to cause short circuiting during repair

User burns themselves on the hot boiler through intentional or unintentional contact & User burns themselves on the hot water that is still in the system when disconnecting hoses

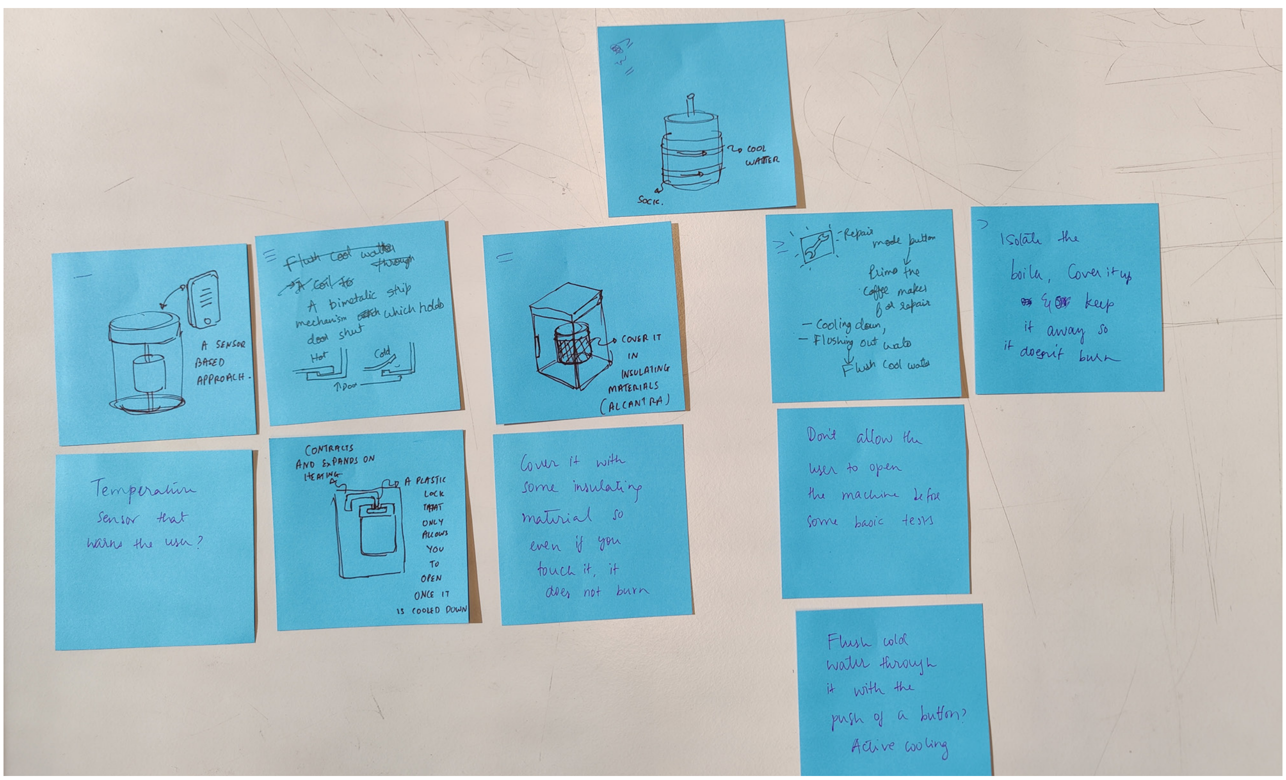


Figure 94: Ideas for Risk 3 - User burns themselves through intentional or unintentional contact with the boiler or water during repair

User conducts testing with the housing open and electrocutes themselves on uninsulated connections

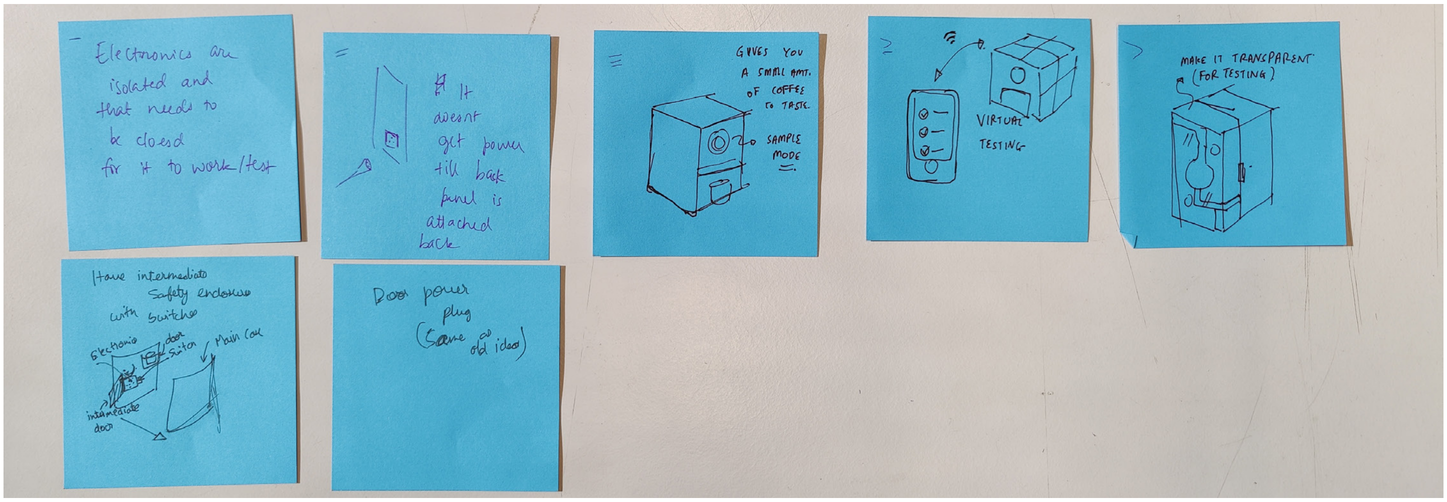


Figure 95: Ideas for Risk 4 - User receives an electric shock when performing testing

User makes the incorrect electrical connections during reassembly

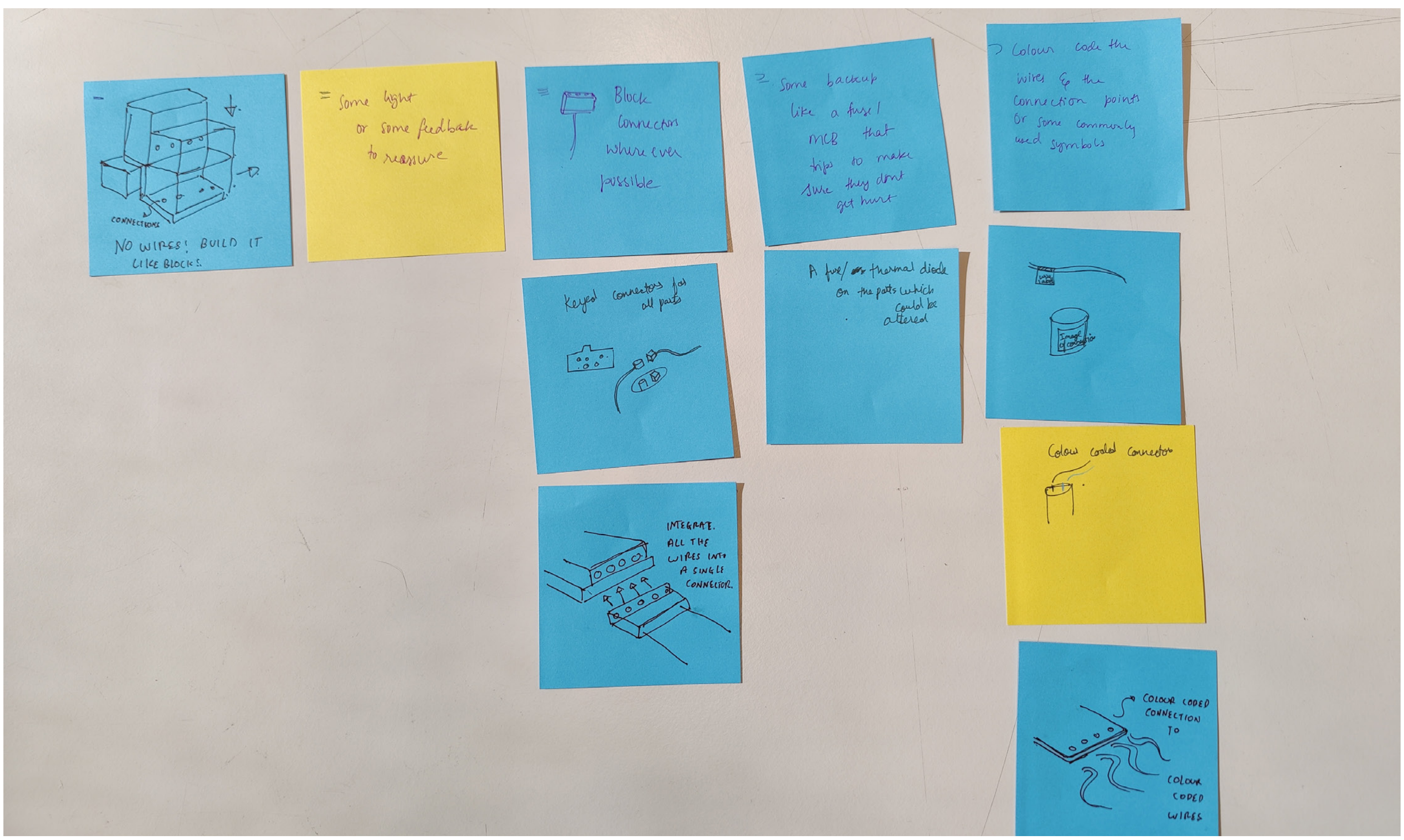


Figure 96: Ideas for Risk 5 - User makes the incorrect electrical connections during reassembly

Water leaks during product use because the hoses are not connected securely during reassembly

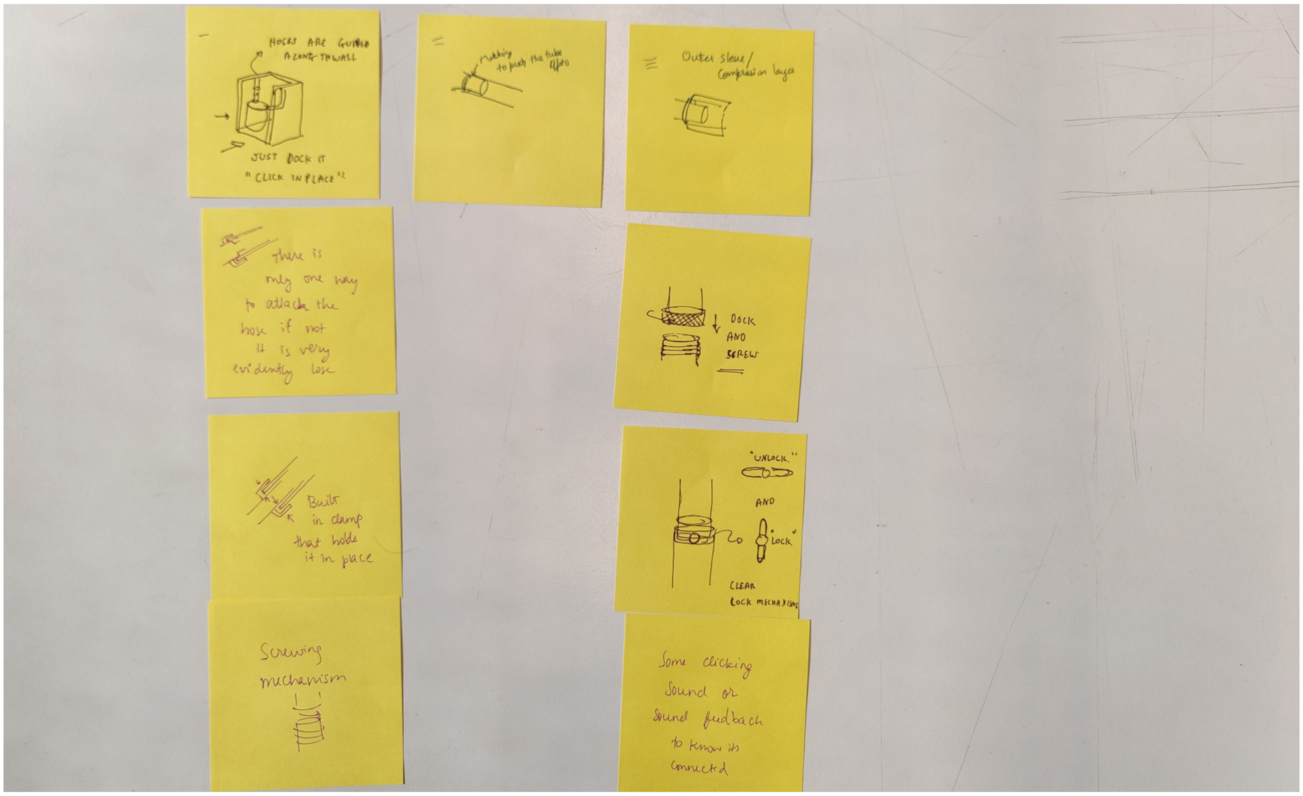


Figure 97: Ideas for Risk 6 - Hoses are not attached securely

Water leaks during product use because the incorrect hose is attached between two components during reassembly

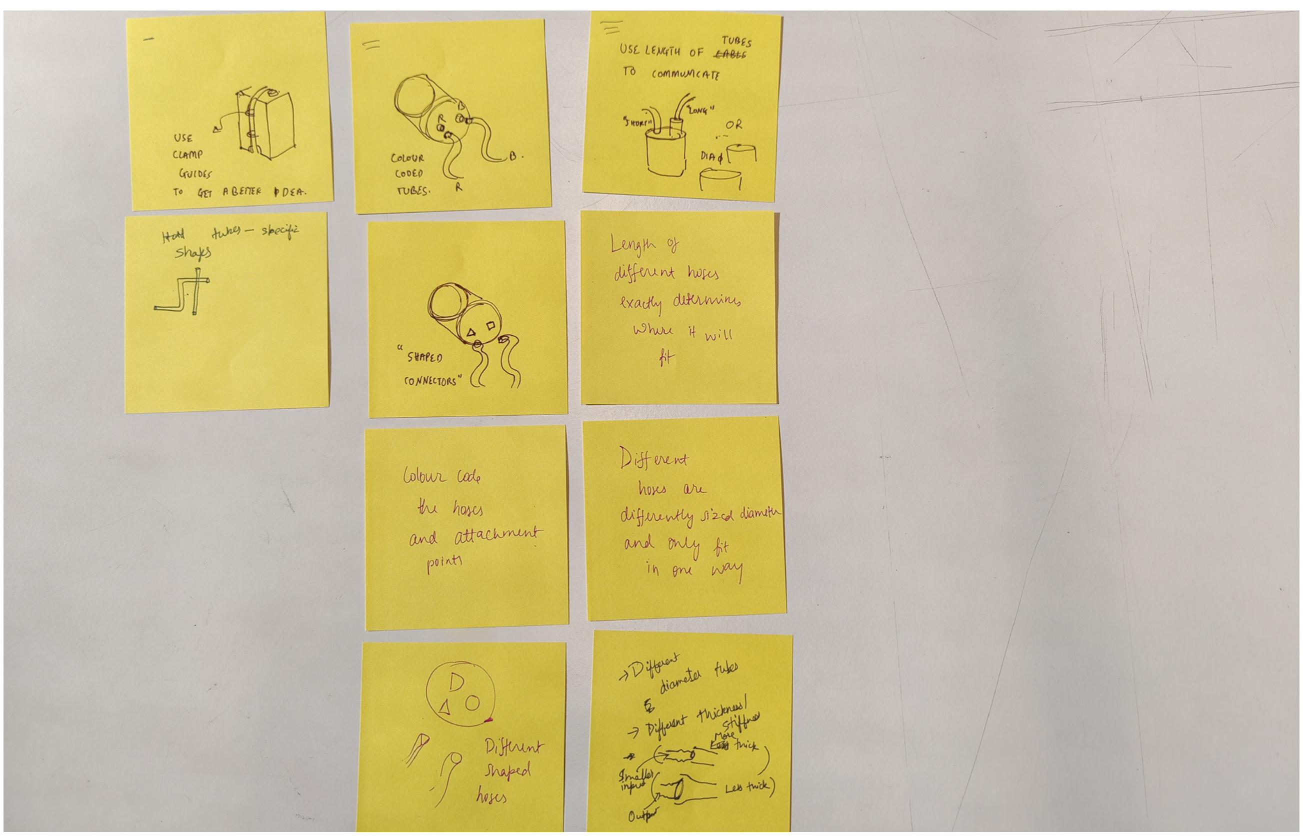


Figure 98: Ideas for Risk 7 - Incorrect hose is attached between two components

Water leaks during product use because the hose is attached in the incorrect orientation during reassembly

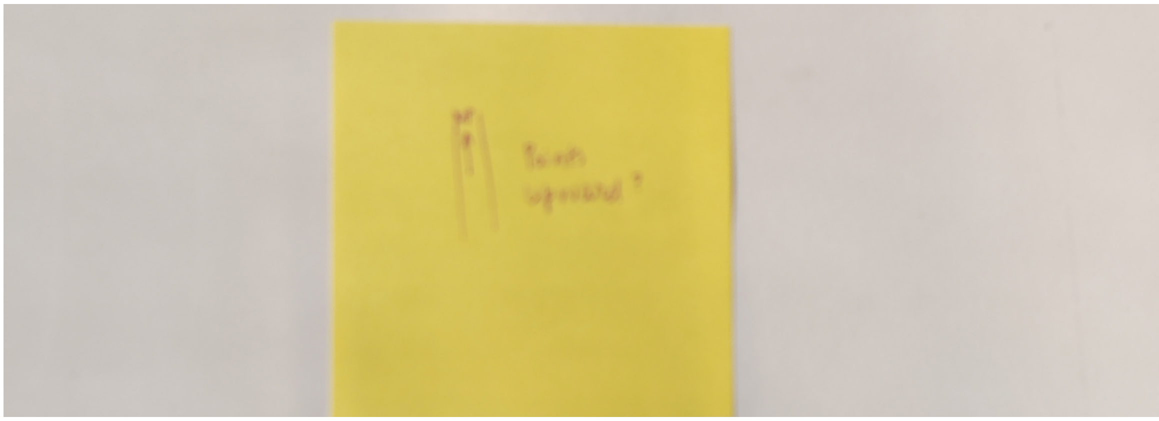


Figure 99: Ideas for Risk 8 - Hose is attached in the incorrect orientation

Once these ideas were generated for each risk, they were separated into common groups with the goal of identifying solution spaces. The categorisation for each risk can be seen below,

Risk	Ideas: Cut off power source	Ideas: Insulate	Ideas: Design cues	Ideas: Eliminate the risk step
User receives an electric shock when accessing internal components during repair	Fasteners for housing also serve as electrical connection point for power cable Power cable connections serve as fasteners for the housing Housing fasteners are hidden until power cable is unplugged Power cable connections impede further disassembly of the housing unless disconnected Opening housing also cuts-off the power from the power cable M/c is locked if the power cable is plugged: For example use electromagnet Relay switch that cuts power when door is opened Power cable is connected to the housing: Taking it out, takes the power cable out	Insulate the electrical connections	Indication - light or sound, to warn that power cable is still plugged Cover uninsulated components and add warning labels on it Opening the back panel pulls on the power plug	User does not have access to the wire connection points and never has to interact with them

Risk	Ideas: Drain the water	Ideas: Insulate	Ideas: Design cues	Ideas: Eliminate the risk step	Ideas: Catch the water
User spills residual water to cause short circuiting during repair	Syringe like component that pulls/pushes water out of the system Button that is pressed prior to repair that drains the water out	Waterproof the electrical connections	Warning indications that there could be residual water and to use the emptying program	Electronic components are kept far away from potential water dripping sources When back panel is opened, components carrying water move along with it, away from the electronics Pipe opening shape that makes it impossible for water to drip out	Reservoir tank into which water drains by design All water inlets/outlets face a common area so that water drips into a single tank

Risk	Ideas: Prevent access until cool	Ideas: Insulate	Ideas: Design cues
User burns themselves through intentional or unintentional contact with the boiler or water during repair	Housing is locked until the boiler does not cool down Only boiler and brewing group are locked out until boiler cools down Button that is pressed prior to repair that allows access only once the boiler is cool - naturally or by passing cold water through it	Boiler is enclosed in an insulated material that the user never needs to opens	Heat sensitive material that shows the text "I am hot, dont touch" based on its temperature Indication that machine is still hot and should not be opened Warning indications for boiler and brew group that they could be hot

Risk

Ideas

User receives an electric shock when performing testing

Insulate

Connections are insulated

Eliminate the risk step

When power is live, these connections are hidden

Power can only be live with the housing open if the PCB is enclosed

Transparent body - no need to keep the housing open

Check repair effectiveness through a mobile app

Power can only flow if the housing is closed

Risk

Ideas

User makes the incorrect electrical connections during reassembly

One way - right way

Use cable plugs with unique shape for each connection

Design cues

Write on the wire & the PCB

Colour code the connections

Feedback that the connections have been made correctly

Eliminate the risk step

Wire connections are never taken out when component is taken out

Failsafe

Presence of a fuse or MCB that trips if there is a mistake

Risk

Ideas

Hoses are not attached securely

One way - right way

Use snap-fit connections

Thread based connection (like Classic Gaggia)

F.F hose with an additional clip like the food clips

Use something like the retaining springs in the Magimix to ensure tight connection

Design cues

F.F with magnets that inform you of the correct depth of attachment

Marking on the counterpart indicating how deep the F.F hose needs to be inserted

Latch that turns colour when rotated and also squeezes the hose in place

Eliminate the risk step

Hoses are never disassembled unless they need to be replaced

Risk

Ideas

Incorrect hose is attached between two components

One way - right way

Unique size threaded connection between two parts

Hose length determines where it can exactly fit

Design cues

Hose cap and mating part have a unique shape

Colour the hose cap and the corresponding part with the same colour

Write the connection it is responsible for

Eliminate the risk step

Hoses are never disassembled unless they need to be replaced

Standardise

All hoses are interchangeable

Risk	Ideas		
	One way - right way	**Design cues**	**Eliminate the risk step**
Hose is attached in the incorrect orientation	Made impossible to connect in the wrong orientation: using different size threaded connections on each end of the hose	Hose cap and mating part have a unique shape Colour the hose cap and the corresponding part with the same colour Use different materials on the two ends of the hose as a design cue	Hoses are never disassembled unless they need to be replaced

Figure 100: Ideas compiled and organised from the two creative sessions

Once solution spaces were identified for each risk, the ideas for all risks were stacked vertically. Solution spaces that were common across risks were placed along the same column to highlight commonalities, and the results can be seen below,

Risk	Ideas				
User receives an electric shock when accessing internal components during repair	**Cut off power source** Fasteners for housing also serve as electrical connection point for power cable Power cable connections serve as fasteners for the housing Housing fasteners are hidden until power cable is unplugged Power cable connections impede further disassembly of the housing unless disconnected Opening housing also cuts-off the power from the power cable M/c is locked if the power cable is plugged: For example use electromagnet Relay switch that cuts power when door is opened Power cable is connected to the housing: Taking it out, takes the power cable out	**Insulate** Insulate the electrical connections	**Design cues** Indication - light or sound, to warn that power cable is still plugged Cover uninsulated components and add warning labels on it Opening the back panel pulls on the power plug	**Eliminate the risk step** User does not have access to the wire connection points and never has to interact with them	
User spills residual water to cause short circuiting during repair	**Drain the water** Syringe like component that pulls/pushes water out of the system Button that is pressed prior to repair that drains the water out	**Insulate** Waterproof the electrical connections	**Design cues** Warning indications that there could be residual water and to use the emptying program	**Eliminate the risk step** Electronic components are kept far away from potential water dripping sources When back panel is opened, components carrying water move along with it, away from the electronics Pipe opening shape that makes it impossible for water to drip out	**Catch the water** Reservoir tank into which water drains by design All water inlets/outlets face a common area so that water drips into a single tank
User burns themselves through intentional or unintentional contact with the boiler or water during repair	**Prevent access until cool** Housing is locked until the boiler does not cool down Only boiler and brewing group are locked out until boiler cools down Button that is pressed prior to repair that allows access only once the boiler is cool - naturally or by passing cold water through it	**Insulate** Boiler is enclosed in an insulated material that the user never needs to opens	**Design cues** Heat sensitive material that shows the text "I am hot, dont touch" based on its temperature Indication that machine is still hot and should not be opened Warning indications for boiler and brew group that they could be hot		
User receives an electric shock when accessing internal components during repair		**Insulate** Connections are insulated		**Eliminate the risk step** When power is live, these connections are hidden Power can only be live with the housing open if the PCB is enclosed Transparent body - no need to keep the housing open Power can only flow if the housing is closed Check repair effectiveness through a mobile app	

Figure 101: All ideas arranged to identify commanilities

Once this was done, a few modifications were made to the above ideas.

If a risk did not have any ideas for a particular solution space, for example, Risk number 5 having no ideas under "Insulate", an attempt was made to generate ideas that would fit this solution space. This attempt was successful in the case of Risk 4 – "User receives an electric shock when accessing internal components during repair", where an idea was generated for the solution space "Design cues".

Additionally, it was observed that ideas under one solution space could also fit under another solution space. For example, in Risk number 3, the idea generated for the solution space "Insulate" involved covering the boiler in an insulating material. However, this idea also eliminates the interaction between the user and the boiler, which can lead to burns. It would thus also fit under the solution space of the "Eliminate the risk step". In such instances, the solution space was appropriately colour-coded with two colours, denoting its dual nature. The result of the above amendments can be seen on the next page.

Risk | Ideas

User receives an electric shock when accessing internal components during repair

Cut off power source
- Fasteners for housing also serve as electrical connection point for power cable
- Power cable connections serve as fasteners for the housing
- Housing fasteners are hidden until power cable is unplugged
- Power cable connections impede further disassembly of the housing unless disconnected
- Opening housing also cuts-off the power from the power cable
- M/c is locked if the power cable is plugged: For example use electromagnet
- Relay switch that cuts power when door is opened
- Power cable is connected to the housing: Taking it out, takes the power cable out

Insulate
- Insulate the electrical connections

Design cues
- Indication - light or sound, to warn that power cable is still plugged
- Cover uninsulated components and add warning labels on it
- Opening the back panel pulls on the power plug

Eliminate the risk step
- User does not have access to the wire connection points and never has to interact with them

User spills residual water to cause short circuiting during repair

Drain the water
- Syringe like component that pulls/pushes water out of the system
- Button that is pressed prior to repair that drains the water out

Insulate
- Waterproof the electrical connections

Design cues
- Warning indications that there could be residual water and to use the emptying program

Eliminate the risk step
- Electronic components are kept far away from potential water dripping sources
- When back panel is opened, components carrying water move along with it, away from the electronics
- Pipe opening shape that makes it impossible for water to drip out

Catch the water
- Reservoir tank into which water drains by design
- All water inlets/outlets face a common area so that water drips into a single tank

User burns themselves through intentional or unintentional contact with the boiler or water during repair

Prevent access until cool
- Housing is locked until the boiler does not cool down
- Only boiler and brewing group are locked out until boiler cools down
- Button that is pressed prior to repair that allows access only once the boiler is cool - naturally or by passing cold water through it

Insulate
- Boiler is enclosed in an insulated material that the user never needs to opens

Design cues
- Heat sensitive material that shows the text "I am hot, dont touch" based on its temperature
- Indication that machine is still hot and should not be opened
- Warning indications for boiler and brew group that they could be hot

User receives an electric shock when accessing internal components during repair

Insulate
- Connections are insulated

Design cues
- Light that blinks when the connectors are not covered

Eliminate the risk step
- When power is live, these connections are hidden
- Power can only be live with the housing open if the PCB is enclosed
- Transparent body - no need to keep the housing open
- Power can only flow if the housing is closed
- Check repair effectiveness through a mobile app

User makes the incorrect electrical connections during reassembly

One way - right way
- Use cable plugs with unique shape for each connection

Design cues
- Write on the wire & the PCB
- Colour code the connections
- Feedback that the connections have been made correctly

Eliminate the risk step
- Wire connections are never taken out when component is taken out

Failsafe
- Presence of a fuse or MCB that trips if there is a mistake

Hoses are not attached securely

One way - right way
- Use snap-fit connections
- Thread based connection (like Classic Gaggia)
- F.F hose with an additional clip like the food clips
- Use something like the retaining springs in the Magimix to ensure tight connection

Design cues
- F.F with magnets that inform you of the correct depth of attachment
- Marking on the counterpart indicating how deep the F.F hose needs to be inserted
- Latch that turns colour when rotated and also squeezes the hose in place

Eliminate the risk step
- Hoses are never disassembled unless they need to be replaced

Incorrect hose is attached between two components

One way - right way
- Unique size threaded connection between two parts
- Hose length determines where it can exactly fit

Design cues
- Hose cap and mating part have a unique shape
- Colour the hose cap and the corresponding part with the same colour
- Write the connection it is responsible for

Eliminate the risk step
- Hoses are never disassembled unless they need to be replaced

Standardise
- All hoses are interchangeable

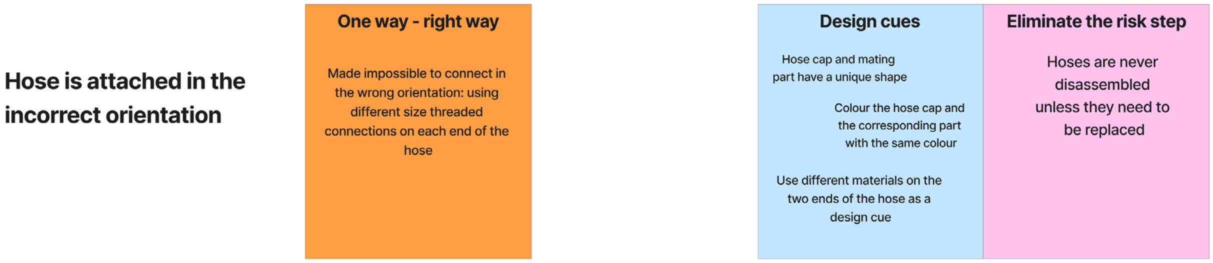


Figure 102: All ideas after modifications and amendments were made

Appendix D - Idea selection for concept generation

As explained in section 4.2, an insight generation exercise was conducted by exploring the ideas through concept sketches. To do so, it was thus important to select one idea for each risk under each solution space.

First, ideas under each risk were explored through rough sketches. This was done to identify possibilities and create an overview of opportunities that each idea provides. The results can be found below.

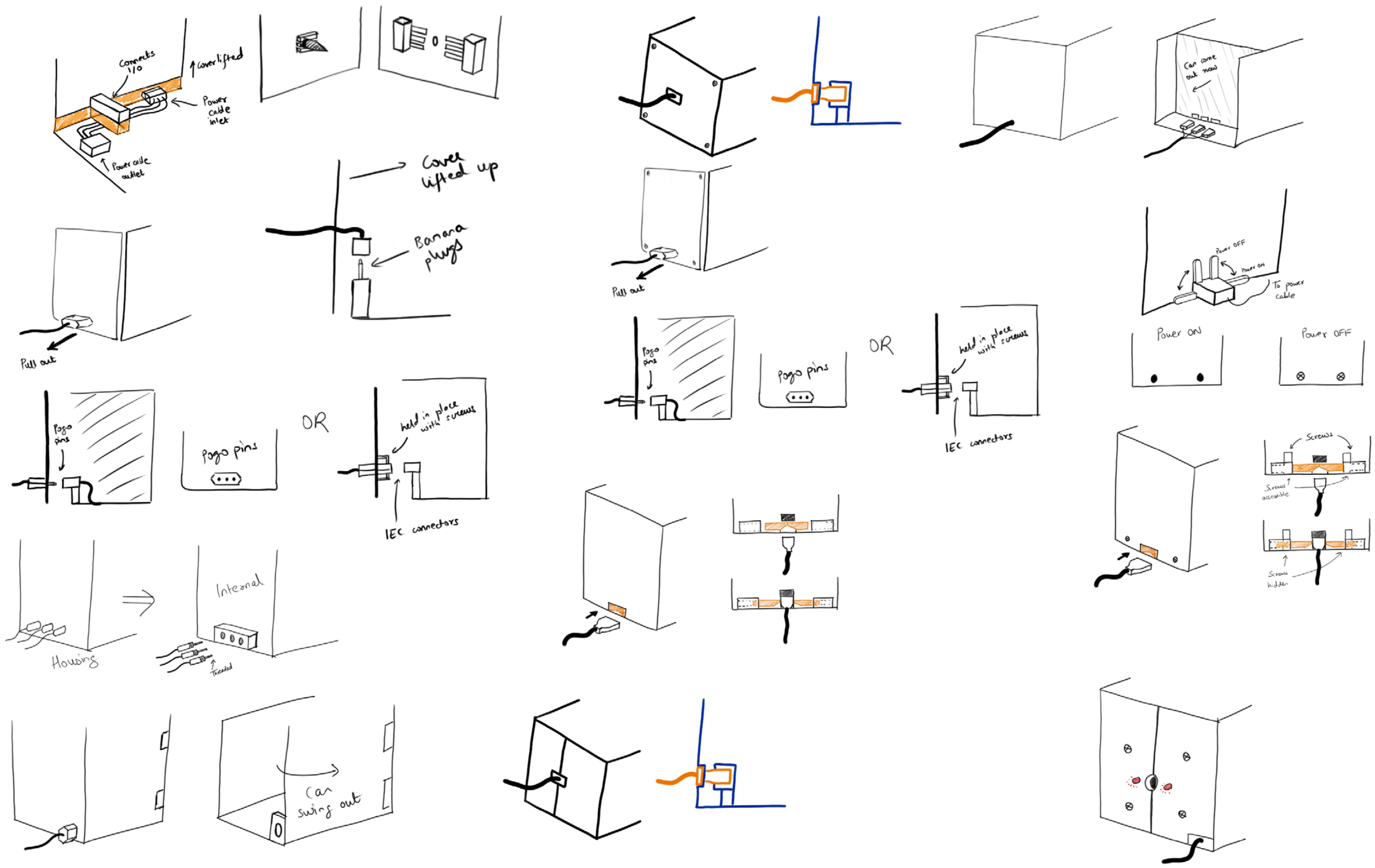


Figure 103: Exploratory sketches for Risk 1 - User receives an electric shock when accessing internal components during repair

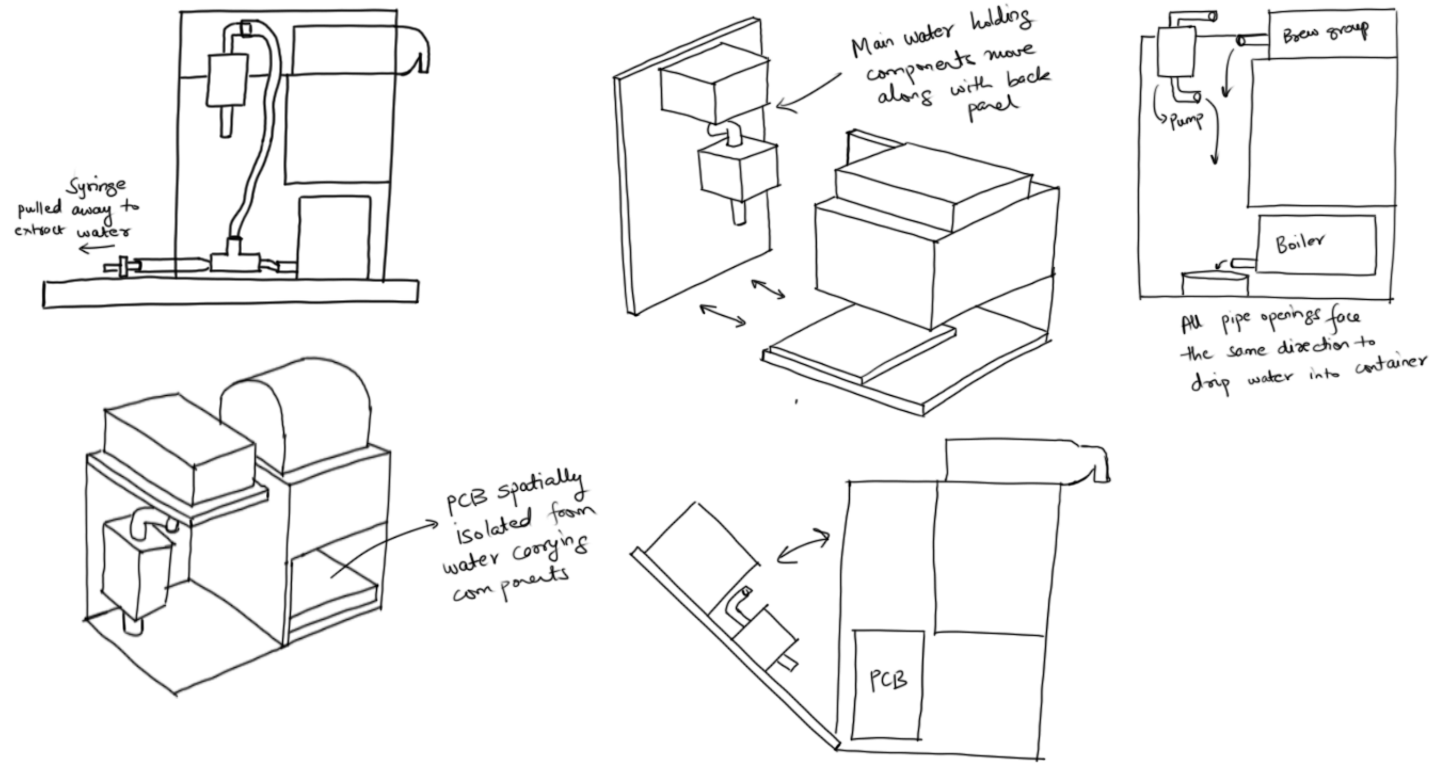


Figure 104: Exploratory sketches for Risk 2 - User spills residual water to cause short circuiting during repair

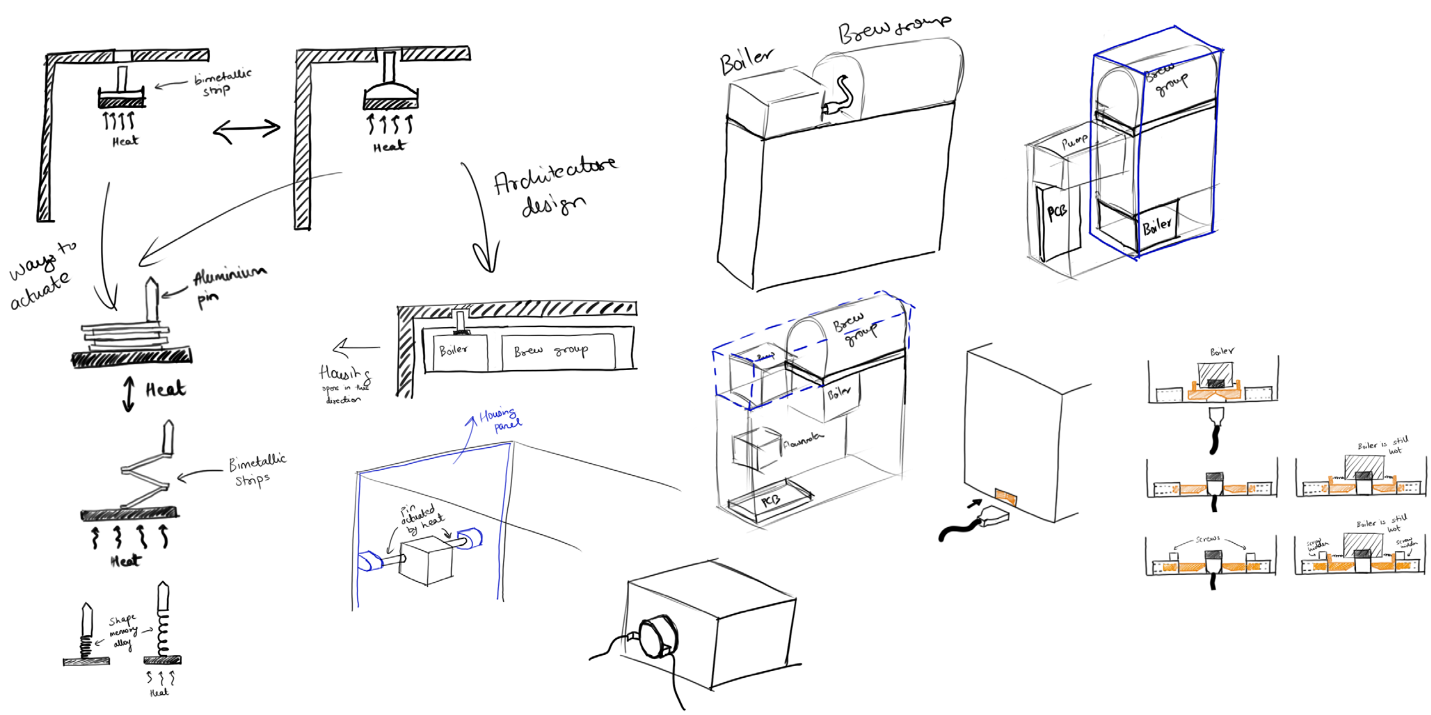


Figure 105: Exploratory sketches for Risk 3 - User burns themselves through intentional or unintentional contact with the boiler or water during repair

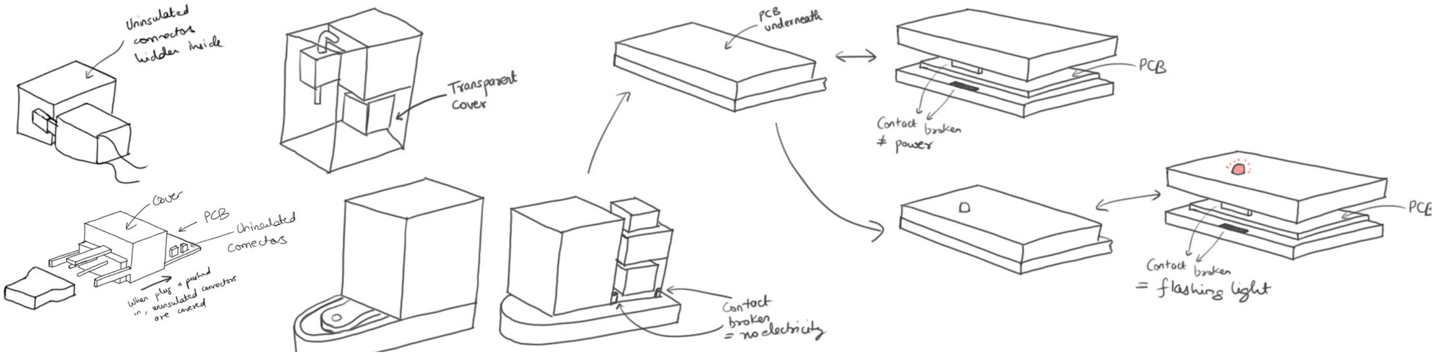


Figure 106: Exploratory sketches for Risk 4 - User receives an electric shock when performing testing

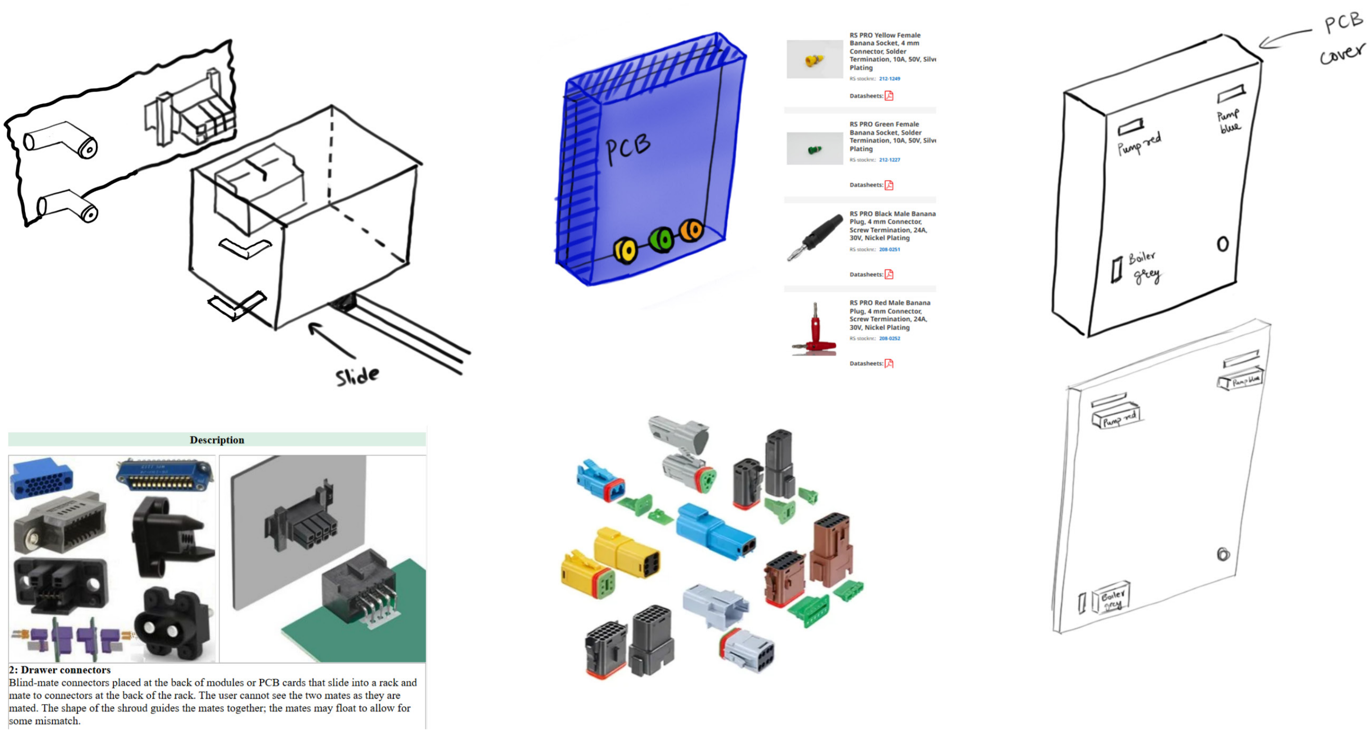


Figure 107: Exploratory sketches for Risk 5 - User makes the incorrect electrical connections during reassembly

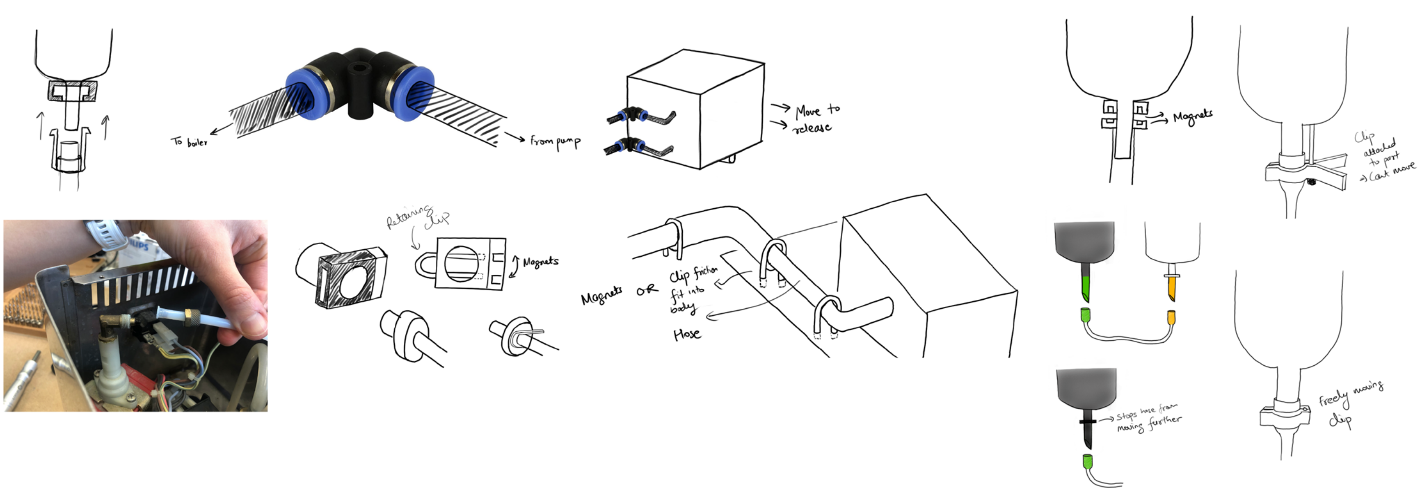


Figure 108: Exploratory sketches for Risk 6 - Hoses are not attached securely

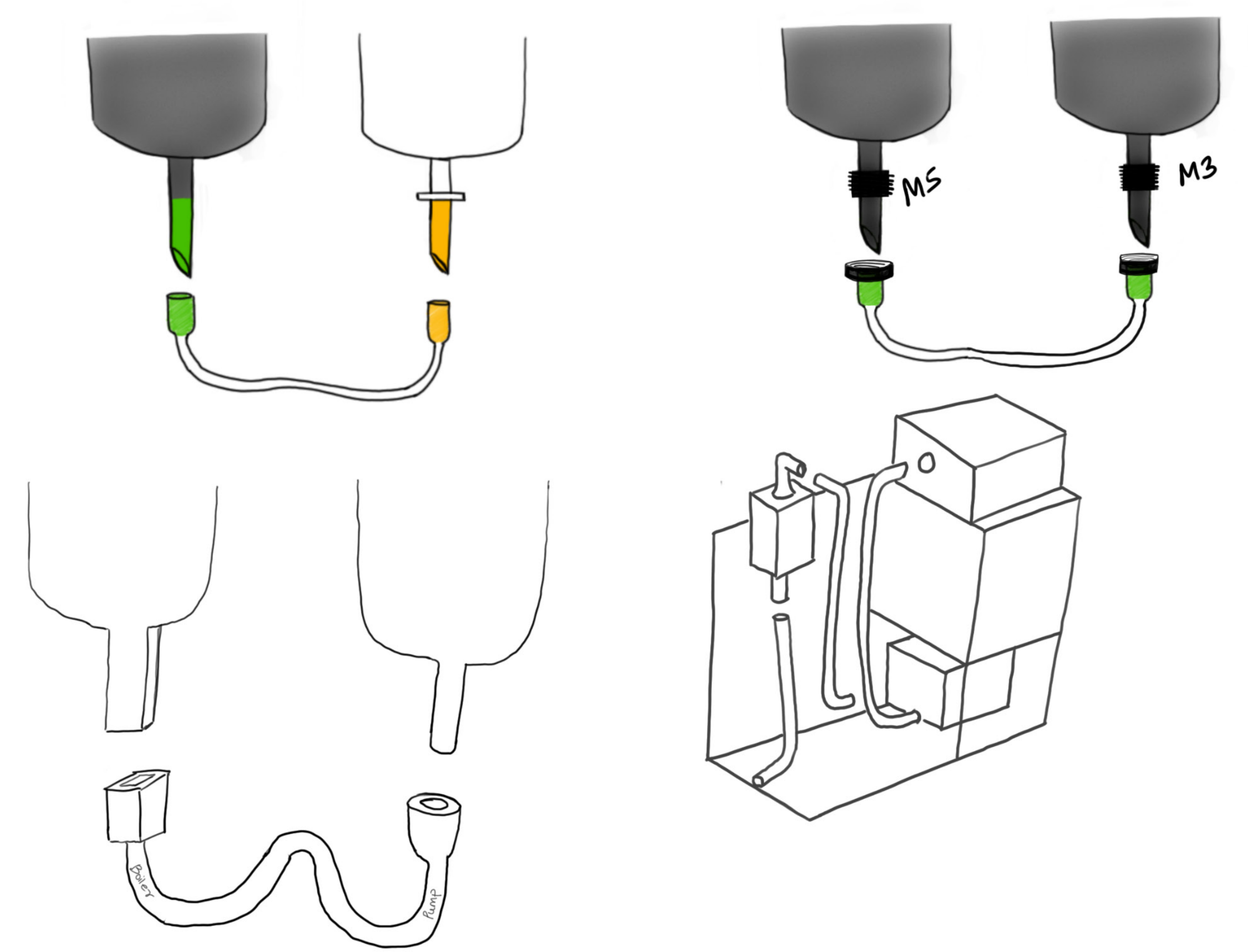


Figure 109: Exploratory sketches for Risk 7 & 8 - Incorrect hose is attached between two components & Hose is attached in the incorrect orientation

This preliminary exploration was used to help select ideas for each solution space. A Harris profile was used to compare the ideas with the criteria for selection drawn from the relevant program of requirements and desires. Since ideas were evaluated against other ideas within the same solution space, they were graded similarly against the requirements. However, they differed against the desires, which were thus used as the criteria. In cases where there was only one idea for a solution space, it was selected by default. The results of this evaluation for each solution space are shown on the following pages.

	Risk 1: User receives an electric shock when accessing internal components during repair	Indication - light or sound, to warn that power cable is still plugged				Cover uninsulated components and add warning labels on it				Opening the back panel pulls on the power plug			
	Criteria	-2	-1	1	2	-2	-1	1	2	-2	-1	1	2
Desires	Minimise cognitive load on the user during the repair process			X				X		X			
	Solution should be difficult to circumvent or ignore				X			X			X		
	The solution should be simple				X				X		X		
	The solution should be cost-effective			X					X			X	
		Selected											

	Risk 3: User burns themselves through intentional or unintentional contact with the boiler or water during repair	Heat sensitive material that shows the text "I am hot, dont touch" based on its temp.				Indication that machine is still hot and should not be opened				Warning indications for boiler and brew group that they could be hot			
	Criteria	-2	-1	1	2	-2	-1	1	2	-2	-1	1	2
Desires	Minimise cognitive load on the user during the repair process			■				■				■	
	Solution should be difficult to circumvent or ignore			■				■				■	
	The solution should be simple		■						■				■
	The solution should be cost-effective		■					■					■
										Selected			

	Risk 5: User makes the incorrect electrical connections during reassembly	Write on the wire & the PCB				Colour code the connections				Feedback that the connections have been made correctly			
	Criteria	-2	-1	1	2	-2	-1	1	2	-2	-1	1	2
Desires	Minimise cognitive load on the user during the repair process			■				■				■	
	Solution should be difficult to circumvent or ignore			■					■				■
	The solution should be simple				■				■			■	
	The solution should be cost-effective				■				■			■	
						Selected							

	Risk 6: Hoses are not attached securely	F.F with magnets that inform you of the correct depth of attachment				Marking on the counterpart indicating how deep the F.F hose needs to be inserted				Latch that turns colour when rotated and also squeezes the hose in place			
	Criteria	-2	-1	1	2	-2	-1	1	2	-2	-1	1	2
Desires	Minimise cognitive load on the user during the repair process			■				■				■	
	Solution should be difficult to circumvent or ignore			■				■					■
	The solution should be simple			■					■		■		
	The solution should be cost-effective			■					■		■		
						Selected							

	Risk 7: Incorrect hose is attached between two components	Hose cap and mating part have a unique shape				Colour the hose cap and the corresponding part with the same colour				Write the connection it is responsible for			
	Criteria	-2	-1	1	2	-2	-1	1	2	-2	-1	1	2
Desires	Minimise cognitive load on the user during the repair process				■			■				■	
	Solution should be difficult to circumvent or ignore				■			■			■		
	The solution should be simple		■						■				■
	The solution should be cost-effective	■							■				■
						Selected							

	Risk 8: Hose is attached in the incorrect orientation	Hose cap and mating part have a unique shape				Colour the hose cap and the corresponding part with the same colour				Use different materials on the two ends of the hose as a design cue			
	Criteria	-2	-1	1	2	-2	-1	1	2	-2	-1	1	2
Desires	Minimise cognitive load on the user during the repair process				■			■				■	
	Solution should be difficult to circumvent or ignore				■			■			■		
	The solution should be simple		■						■				■
	The solution should be cost-effective	■							■			■	
						Selected							

Figure 110: Harris profile for the ideas under the solution space "Design cues"

	Risk 2: User spills residual water to cause short circuiting during repair	Electronic components are kept far away from potential water dripping sources				When back panel is opened, components carrying water move along with it, away from the electronics				Pipe opening shape that makes it impossible for water to drip out			
	Criteria	-2	-1	1	2	-2	-1	1	2	-2	-1	1	2
Desires	Minimise cognitive load on the user during the repair process				■				■				■
	Solution should be difficult to circumvent or ignore		■				■						■
	The solution should be simple				■	■				■			
	The solution should be cost-effective				■	■				■			
		Selected											

	Risk 4: User receives an electric shock when performing testing	When power is live, these connections are hidden				Transparent body - no need to keep the housing open				Power can only be live with the housing open if the PCB is enclosed			
	Criteria	-2	-1	1	2	-2	-1	1	2	-2	-1	1	2
Desires	Minimise cognitive load on the user during the repair process				■				■				■
	Solution should be difficult to circumvent or ignore				■	■							■
	The solution should be simple		■						■			■	
	The solution should be cost-effective		■						■			■	
										Selected			

		Check repair effectiveness through a mobile app			
	Criteria	-2	-1	1	2
Desires	Minimise cognitive load on the user during the repair process				■
	Solution should be difficult to circumvent or ignore	■			
	The solution should be simple	■			
	The solution should be cost-effective	■			

Figure 111: Harris profile for the ideas under the solution space "Eliminate risk step"

	Risk 1: User receives an electric shock when accessing internal components during repair	Fasteners for housing also serve as electrical connection point for power cable				Power cable connections impede further disassembly of the housing unless disconnected				M/c is locked if the power cable is plugged: For example use electromagnet			
	Criteria	-2	-1	1	2	-2	-1	1	2	-2	-1	1	2
Desires	Minimise cognitive load on the user during the repair process				■			■			■		
	Solution should be difficult to circumvent or ignore				■	■							■
	The solution should be simple		■						■		■		
	The solution should be cost-effective			■				■			■		

		Power cable connections serve as fasteners for the housing				Housing fasteners are hidden until power cable is unplugged				Relay switch that cuts power when door is opened			
	Criteria	-2	-1	1	2	-2	-1	1	2	-2	-1	1	2
Desires	Minimise cognitive load on the user during the repair process			■				■					■
	Solution should be difficult to circumvent or ignore	■				■						■	
	The solution should be simple				■			■					■
	The solution should be cost-effective			■			■						■
										Selected			

		Power cable is connected to the housing: Taking it out, takes the power cable out			
	Criteria	-2	-1	1	2
Desires	Minimise cognitive load on the user during the repair process				■
	Solution should be difficult to circumvent or ignore			■	
	The solution should be simple				■
	The solution should be cost-effective			■	

	Risk 2: User spills residual water to cause short circuiting during repair	Syringe like component that pulls/pushes water out of the system				Button that is pressed prior to repair that drains the water out			
	Criteria	-2	-1	1	2	-2	-1	1	2
Desires	Minimise cognitive load on the user during the repair process			■					■
	Solution should be difficult to circumvent or ignore	■				■			
	The solution should be simple		■						■
	The solution should be cost-effective			■					■
						Selected			

	Risk 3: User burns themselves through intentional or unintentional contact with the boiler or water during repair	Housing is locked until the boiler does not cool down				Only boiler and brewing group are locked out until boiler cools down				Button that is pressed prior to repair that allows access only once the boiler is cool - naturally or by passing cold water through it			
	Criteria	-2	-1	1	2	-2	-1	1	2	-2	-1	1	2
Desires	Minimise cognitive load on the user during the repair process			■				■					■
	Solution should be difficult to circumvent or ignore				■			■			■		
	The solution should be simple			■				■			■		
	The solution should be cost-effective			■				■			■		
		Selected											

	Risk 6: Hoses are not attached securely	Use snap-fit connections				Thread based connection (like Classic Gaggia)				F.F hose with an additional clip like the food clips				Use something like the retaining springs in the Magimix to ensure tight connection			
	Criteria	-2	-1	1	2	-2	-1	1	2	-2	-1	1	2	-2	-1	1	2
Desires	Minimise cognitive load on the user during the repair process				■				■				■				■
	Solution should be difficult to circumvent or ignore		■ **Can break**						■			■				■	
	The solution should be simple			■				■				■				■	
	The solution should be cost-effective				■			■				■			■		
						Selected											

	Risk 7: Incorrect hose is attached between two components	Unique size threaded connection between two parts				Hose length determines where it can exactly fit			
	Criteria	-2	-1	1	2	-2	-1	1	2
Desires	Minimise cognitive load on the user during the repair process			■				■	
	Solution should be difficult to circumvent or ignore				■				■ ***
	The solution should be simple			■					■
	The solution should be cost-effective			■					■
		Selected because it ties in with prev. risk				*** Only if all connections have unequal lengths			

Figure 112: Harris profile for the ideas under the solution space "Eliminate root cause of the risk"

Appendix E - Design decisions made for the prototype

This Appendix covers the decisions behind the design of the prototype shown in Chapter 5. Some of these decisions were made prior to 3D printing the components, and some were made during assembly.

<u>Decision 1: Type of switch</u>

The first decision to be made was the type of interlock switch to be used. The requirement was a switch that would cut off power when the outer housing was taken out. While many different switches meet this criteria, two switches were easy to use to design an interlock system and are explained below,

1. Magnetic reed switches
   Two magnetic pins are encased in a hermetically sealed tube, which touch each other when a strong enough magnet is brought close to it. When they touch, an electrical circuit is completed between the two ends of the switch, allowing power to flow (Figure 113). When the magnet is taken away, the pins separate, and the connection is broken. In the context of the prototype, this would translate to having a magnet on the outer housing. When the outer housing is in place, the magnet is positioned close to the reed switch, activating it. When the outer housing is taken out, the magnet is no longer near the switch, and thus the connection is broken.

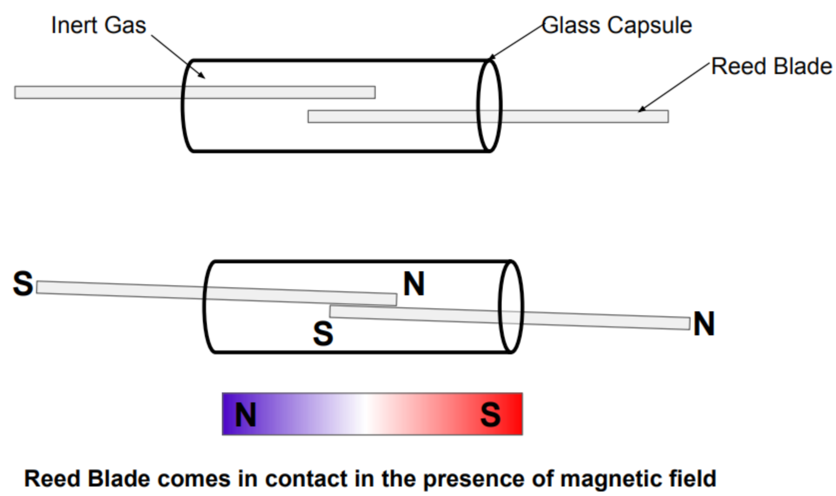


Figure 113: Working of a magnetic reed switch (Admin, 2024)

2. Push-to-make (PTM) switches
   As the name suggests, in these switches, the connection is made between two ends of the switch when the trigger is pressed. Releasing the trigger causes the contact to break again. Another variant maintains the connection even after the trigger has been released, requiring the user to press the trigger again to release it. Its possible implementation for the prototype has already been explained.

Since both would have resulted in a similar design for the outer housing, a decision was made based on cost. The Magimix coffee machine operates on 220-240 V and 1260 W (Magimix User Manuals, n.d.), which corresponds to a maximum current of ~ 6 A. A reed switch that can handle this voltage and current costs ~ € 21 (RS PRO, n.d.), while a PTM switch costs ~ € 3 (TRU COMPONENTS, n.d.). Now, a cheaper reed switch may exist. However, since the focus was on checking whether the use of an interlock switch made repairs safer, the PTM switch was procured and prototyped.

Decision 2: Visibility of the switch

Once the switch was selected, it was important to decide if the switch would be visible to the user or not. Since we do not want the user to either intentionally or unintentionally complete the circuit once the outer housing has been removed, it was decided to conceal the switch and make it difficult to access.

Decision 3: Orientation of the switch

There were two relevant options for the orientation – pointing up or pointing sideways (Figure 114). The switch must be activated when the outer housing is in place. Although these switches typically require low force to be triggered, the ease of applying the force depends on the manner in which the outer housing is installed. The existing outer housing weighs ~ 400 g in total, which is roughly 2 N of force when supported on two points. Thus, if the switch is pointing up, the weight of the outer housing would not be sufficient to push the trigger. Thus, once the housing is put in place, it would be lopsided and would require the user to push down on the side resting on the switch.

Additionally, placing the switch vertically would require over 4 cm of space to account for the switch and the wires originating from it. This would necessitate a taller base. On the other hand, having the trigger point sideways allows for a shorter base. It makes the outer housing installation more seamless. The user installs the outer housing and then starts attaching it using screws. This will automatically push the housing into the switch and activate it without being visible to the user. Thus, this was chosen as the orientation of the switch.

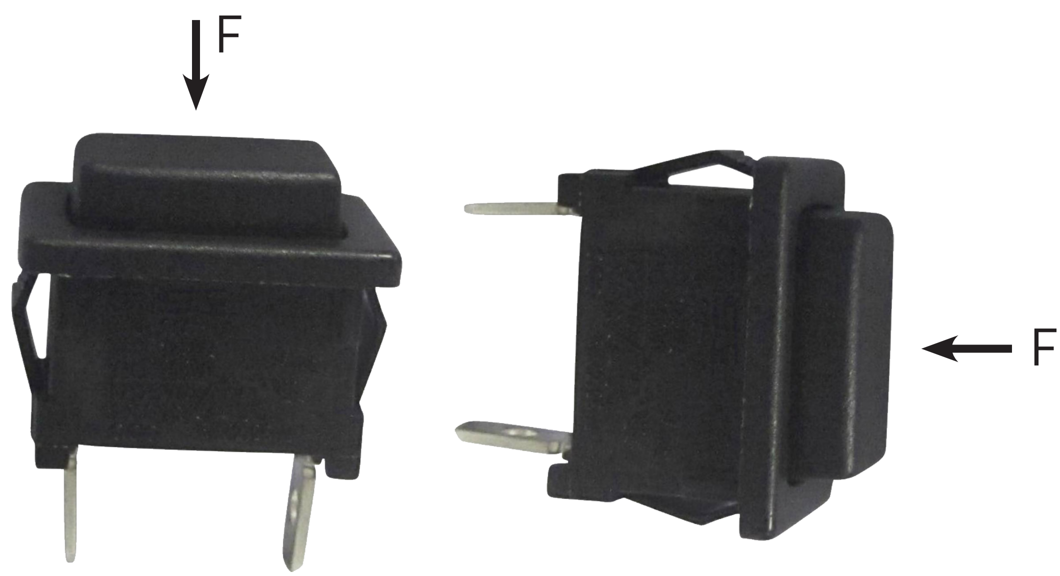


Figure 114: Orientation options for the PTM switch

Decision 4: Shape of the outer housing

There were two obvious choices for the outer housing shape – curved like the Magimix or box-shaped (ANALYSING COFFEE MACHINES FOR REPAIR SAFETY RISKS). The decision to choose the box shape was one of convenience, as it was easier to 3D model and thus also easier to make changes, with a higher print quality. Ultimately, the shape of the outer housing does not affect the implementation of the ideas and can therefore be designed as desired.

Figure 115: Two options for the shape of the housing

<u>Decision 5: Connection between the inner housing and base of the coffee machine</u>

In the Magimix, the inner and outer housings must first be separated from the base to free them from one another. This allows access to the internal components. This can be done by removing four oval screws and pulling the inner and outer housings out from their friction fits. The housing also sits inside the base, and there is no space underneath the housing to hold any components (Figure 116).

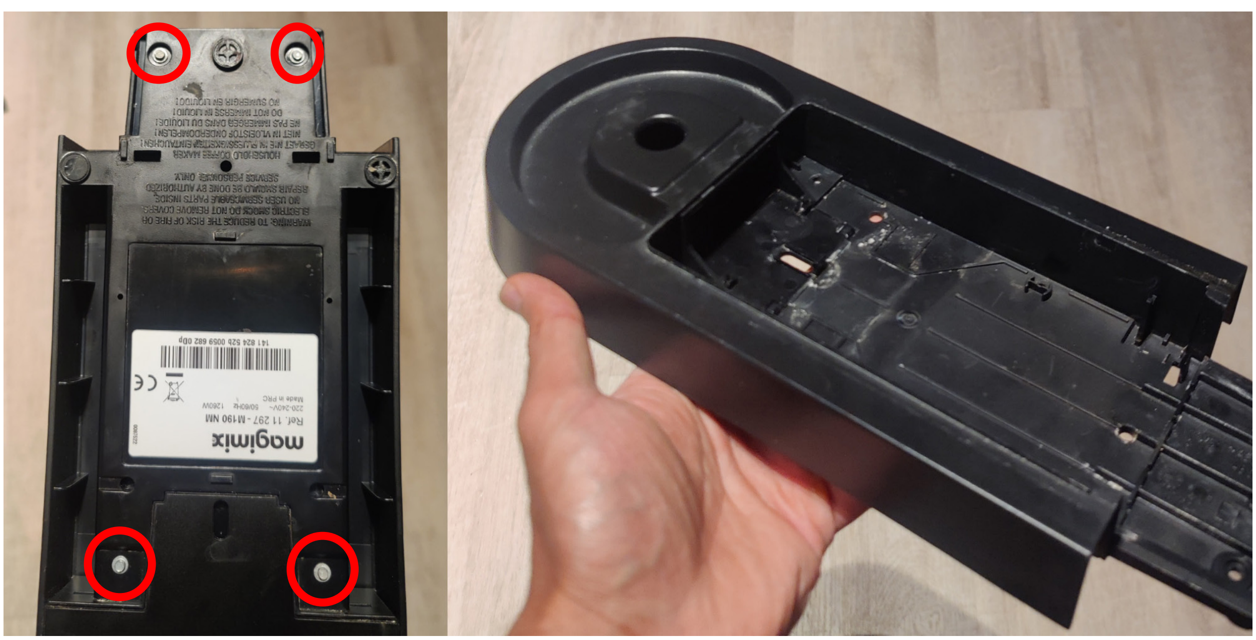


Figure 116: Four screws underneath the Magimix that need to be removed and the lack of space to place a switch

For the prototype, it was decided that there should be space in the base, underneath the housing, to conceal the generally moderate-sized PTM switch. Also, it was decided to integrate the inner housing with the base so that the user does not have to turn the machine around to access the screws underneath, which simplifies the repair process.

The additional space in the base also means that a user wishing to replace the power cable connectors or the interlock switch can simply turn the machine around, remove the screws, and perform the replacement.

<u>Decision 6: Location of the boiler</u>

In the concept sketches for "Eliminate the root cause of the risk", the boiler has been placed behind the brewing assembly. This was done to improve the access to the outer housing, which would make it easier to lock it using a pin actuated from the boiler.

However, in designing this arrangement, it was observed that space was wasted inside the coffee machine, making it longer (Figure 117). Additionally and more importantly, a pin in this orientation would only be held by 1 point of contact (Figure 118) when it is pulled by the outer housing. This is not the strongest or most secure method for locking a component.

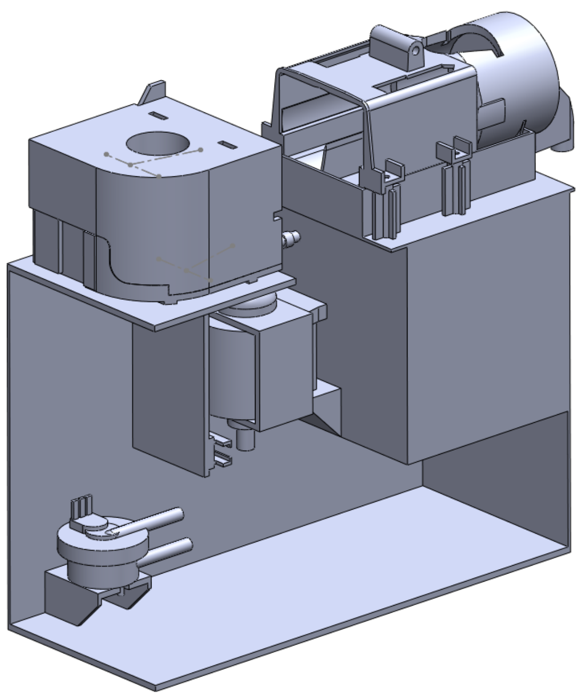


Figure 117: Old design has a lot of space unutilised with the boiler behind the brewing assembly

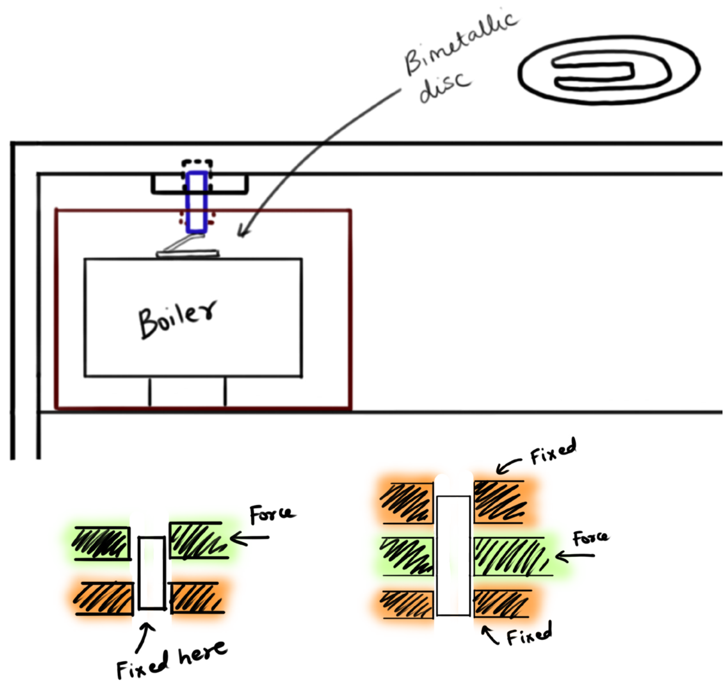


Figure 118: 1-point vs 2-point of contact for the pin

It would be more stable if the pin had two points of contact – one from the boiler and one from the inner housing. While this can be achieved by having the pin actuate sideways (Figure 119), it would also require a spring to reset the pin once the boiler cools down.

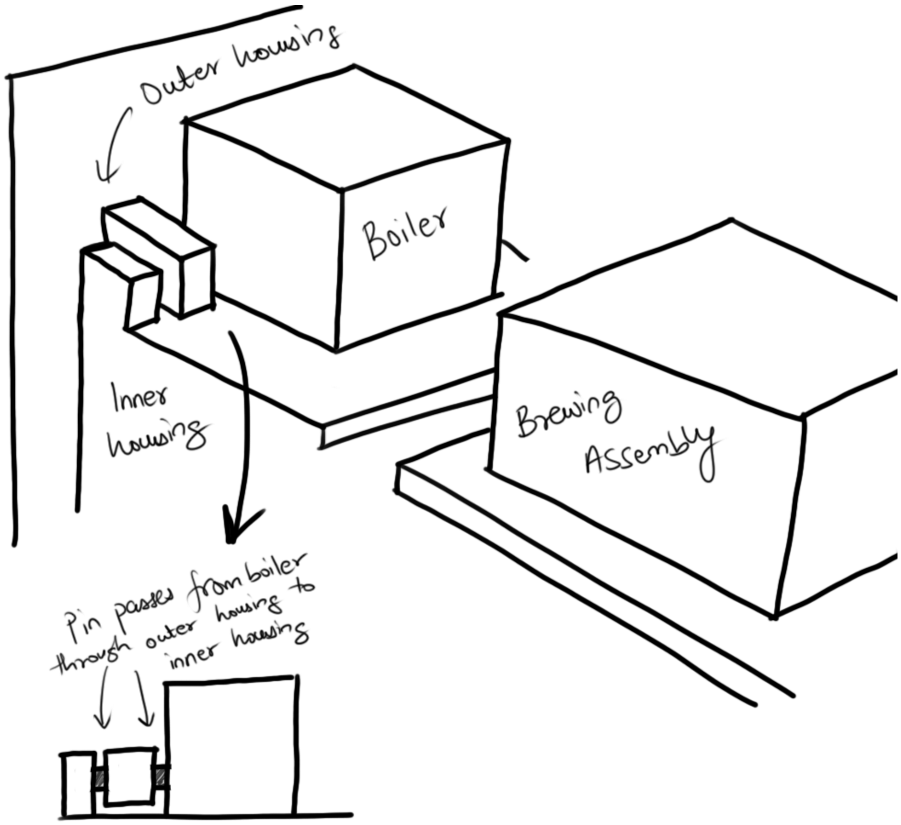


Figure 119: Sideways pin could create a 2-point contact with inner housing with the boiler unit placed behind the brewing assembly

For these reasons, a decision was taken to utilise the existing arrangement and architecture of the Magimix. If the ideas can be implemented with the existing design, it also proves that the coffee machine can be made safer with minimal changes. Thus, the boiler was returned to its original location (Figure 120).

Since the outer housing had to be locked in a way that sandwiches it between the boiler and the inner housing and uses gravity to reset the pin to the starting position, the only available option was utilising an extrusion from the housing that slides into place between the boiler and the inner housing (Figure 120).

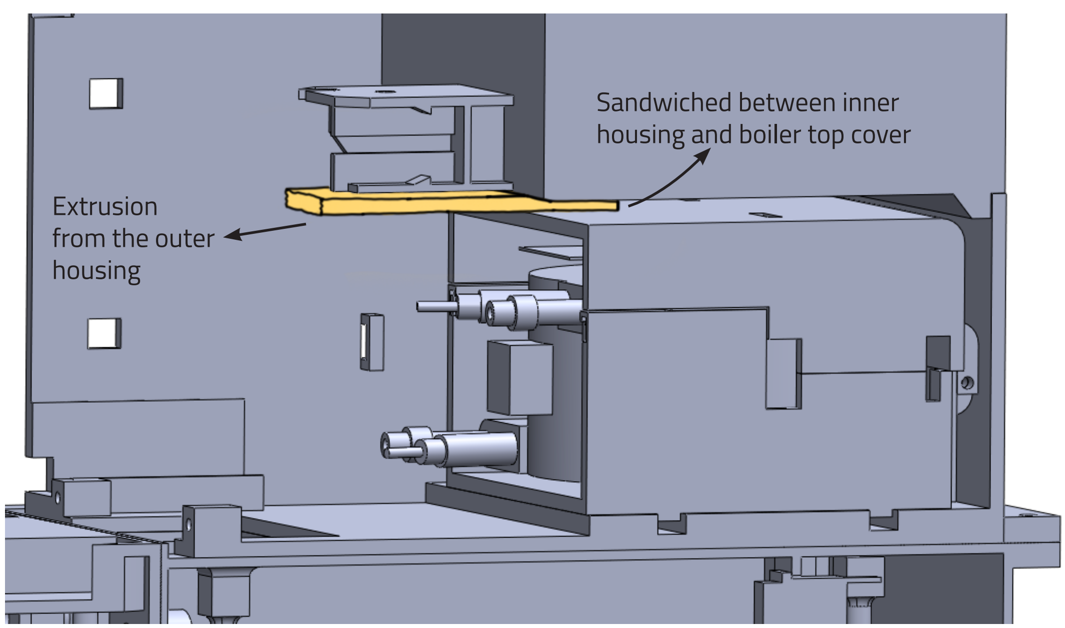


Figure 120: Boiler in the original location with a projection from the housing inserting itself between the boiler and the inner housing

Decision 7: Vertical movement required by the bimetal

If we wanted to lock the outer housing, a pin had to pass through it at some point. To ensure the pin remains stable when the outer housing is pulled, it requires two points of contact, as opposed to one point of contact (explained in Decision 6). The top cover of the boiler is 2 mm thick, and 2 mm is required from the inner housing. If the part of the housing being locked by the pin is also 2 mm in thickness, at least 8 mm (with clearances) of vertical movement is required from the bimetal (Figure 121). This amount of movement was not possible from the bimetal disc used in the steam iron, which meant that a bimetal strip had to be designed for our application.

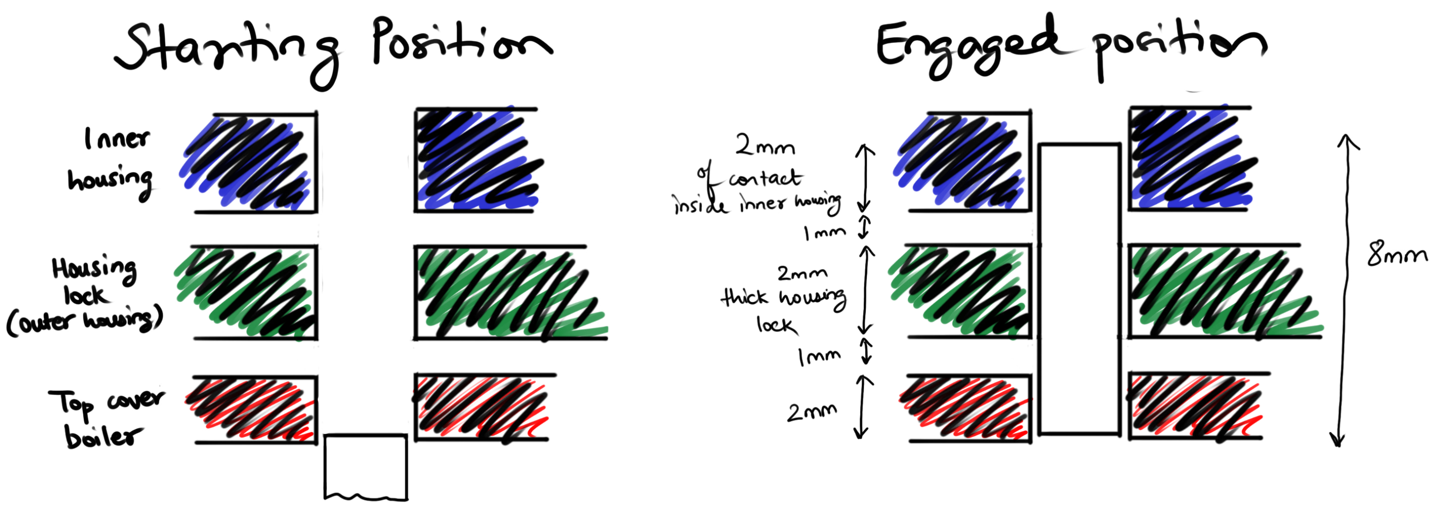


Figure 121: Minimum vertical movement required for the pin to create a secure lock

The bimetal was designed using Kanthal's Thermostatic Bimetal Handbook (Kanthal, 2008). Using the formulas mentioned on pages 100 and 102, a bimetallic strip from Kanthal 230 was designed, having 8 mm of vertical travel and producing 1 N of force. The bimetal was designed to deform within the temperature range of 40–90°C to account for the slow response of a bimetal to temperature changes, thus ensuring that the strip locks the housing before the boiler reaches peak temperature. The dimensions of the bimetal depend on the length of the strip and the proportion of the temperature used to generate force and deflection. This iteration can be seen in Table 21 below.

Table 21: Calculation to determine dimensions of the bimetal strip

KANTHAL 230		
Travel	8	mm
Force	1	N
Temp difference	50	(40 - 90 C)
Length of strip	70	mm
Specific deflection	2.27 x $10^{(-6)}$	
Modulus of elasticity	135000	N/mm2

Proportion of temperature used for deflection	Thickness (mm)	Width (mm)	Stress (MPa)	Angle @ full deflection (deg)	Length reduction due to deflection (mm)
0.6	0.42	26.26	91.94	21.83	5.02
0.5	0.35	30.25	114.92	26.19	7.19
0.7	0.49	25.72	68.95	18.71	3.70
0.8	0.56	29.54	45.97	16.37	2.84

Another variable that was estimated was the reduction in length at full deflection. The name is a misnomer, but what it means is the reduction in the horizontal distance because the strip is now inclined (Figure 122). This was important to know because it would affect the location of the pin – we do not want the bimetal strip to lose contact with the base of the pin when it is completely deflected because of its "length reduction" (4.1 Idea generation).

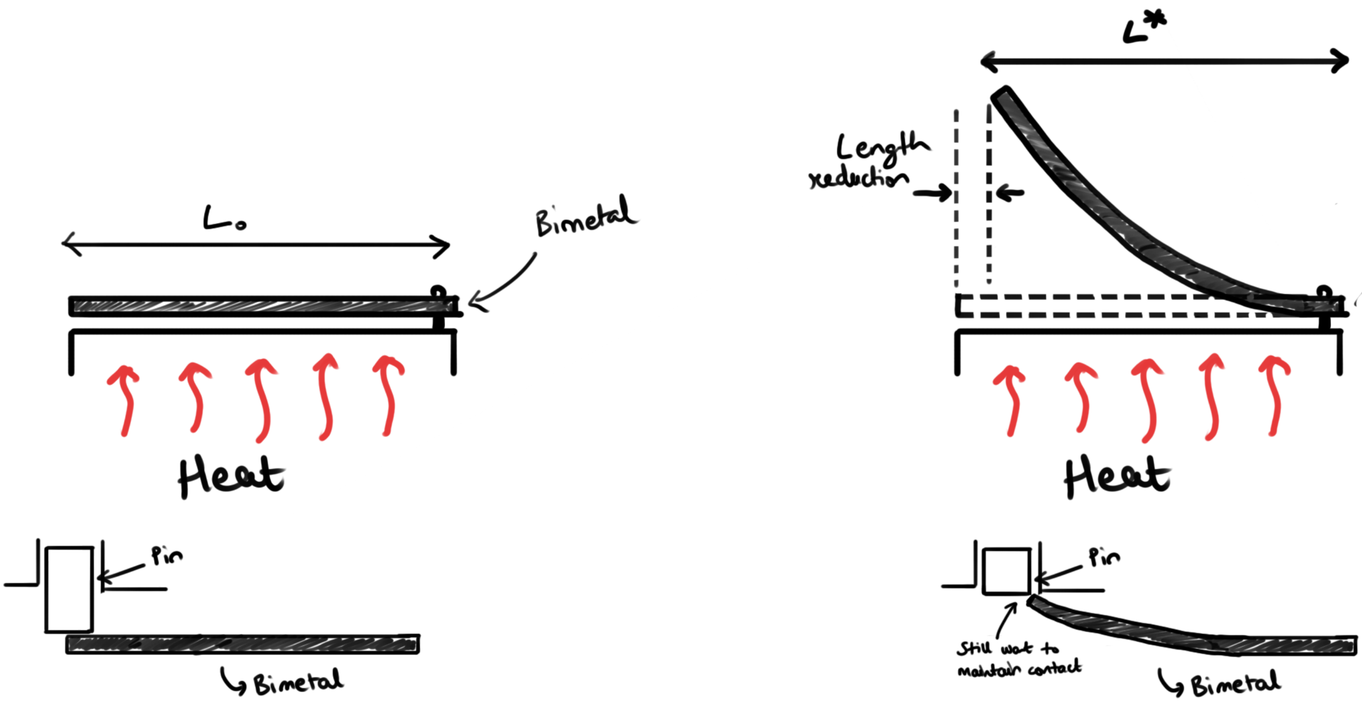


Figure 122: "Length reduction" and it effect on pin location

<u>Decision 8: Direction of detaching outer housing</u>

We wanted the outer housing to "move away" from the inner housing once it had been freed. This meant that we had 4 directions it could move – up, sideways and backwards. Since the housing had to be locked between the boiler and the inner housing, this meant that the outer housing could only move backwards or sideways.

Among the two sides, one side is used as a supporting wall for the PCB, pump and other components. Thus, two options remained – backwards or sideways away. However, the outer housing cannot be slid away from the inner housing freely when it is removed. This is because of the location and method of actuating the switch.

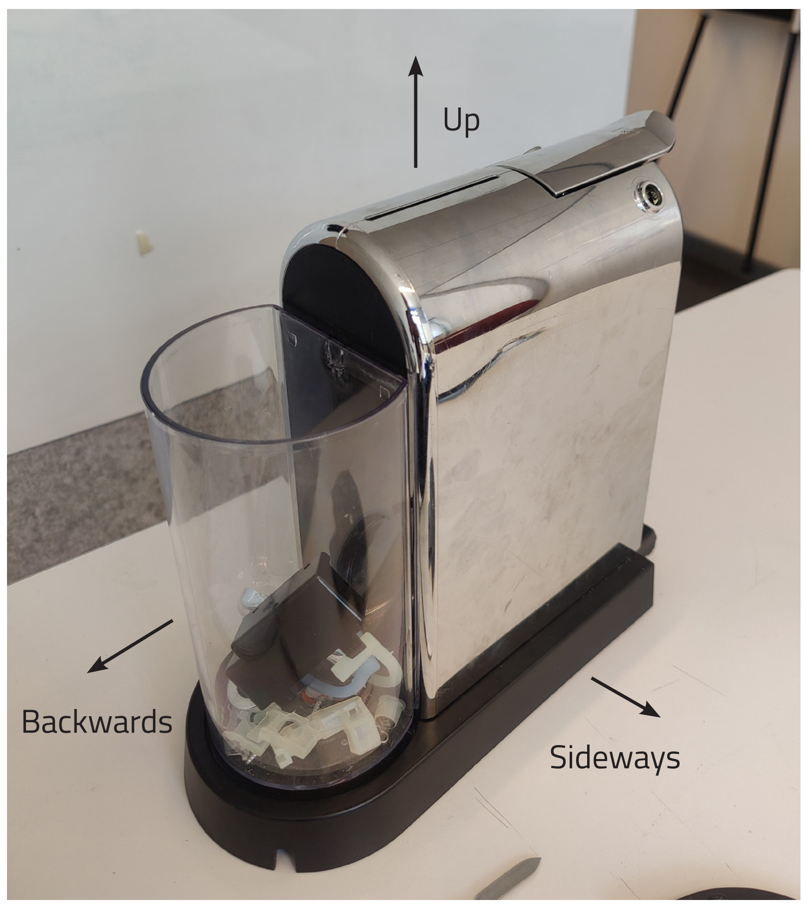


Figure 123: Possible directions to open the housing

In one of the previous points, it was decided that the switch would be placed pointing sideways and hidden underneath the base of the coffee machine. This means that a portion of the outer housing must project into the base (Figure 124) so that it can push against the switch (let's call it the switch trigger). Thus, at some point, the outer housing will need to be lifted to release the switch trigger from the base before it can be removed.

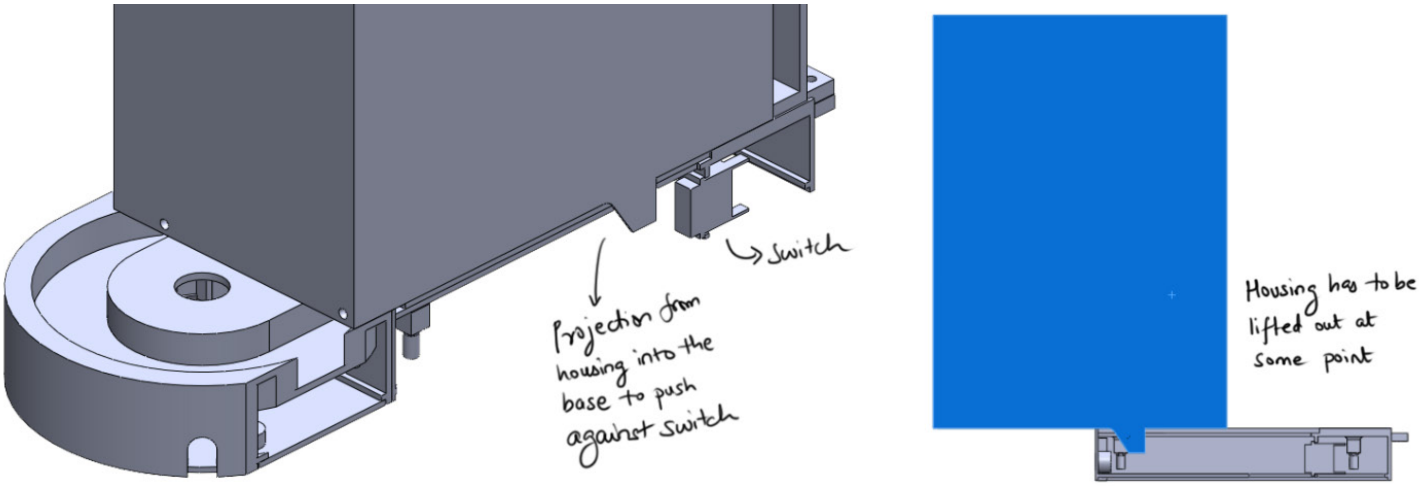


Figure 124: Example of how the switch trigger could look and its impact on the method of taking the housing out

Another design decision to note is the use of a projection from the outer housing that sandwiches itself between the boiler and the inner housing (Decision 6). In such a design, the outer housing will first slide away until the projection (which we call the housing lock) is free from any obstacles, and only then can it be lifted (Figure 125).

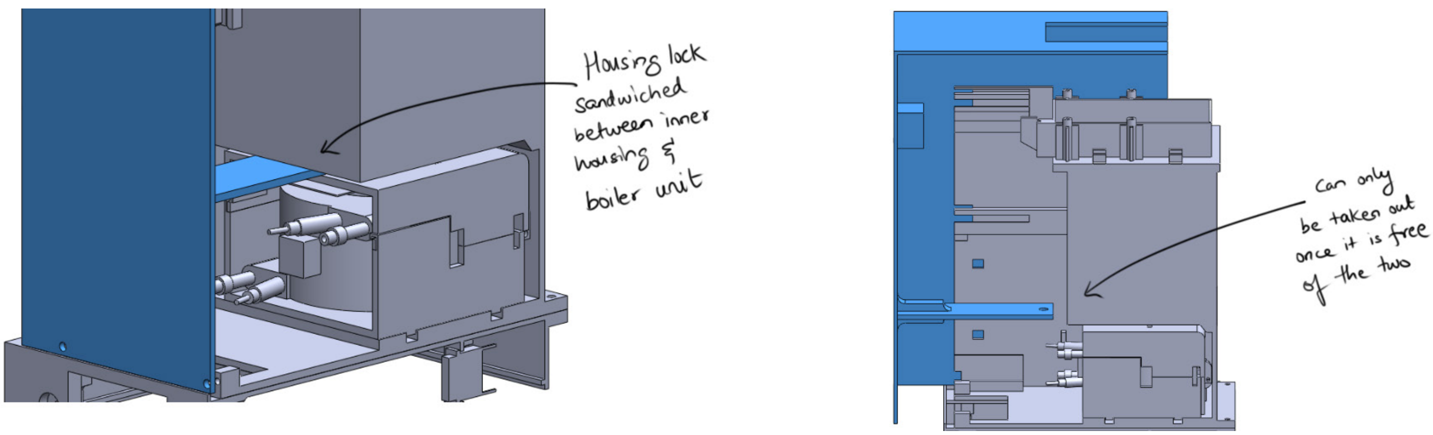


Figure 125: Example of how the housing lock could look and its impact on on the method of taking the housing out

These two design decisions create a mutually interfering constraint – the switch trigger prevents the outer housing from sliding horizontally beyond a certain point and would require the outer housing to be lifted up, but the outer housing needs sufficient horizontal travel to allow the housing lock to be freed, else it would prevent the outer housing from being lifted. To satisfy both conditions, the switch trigger must be positioned further away from the end face of the housing lock (Figure 126).

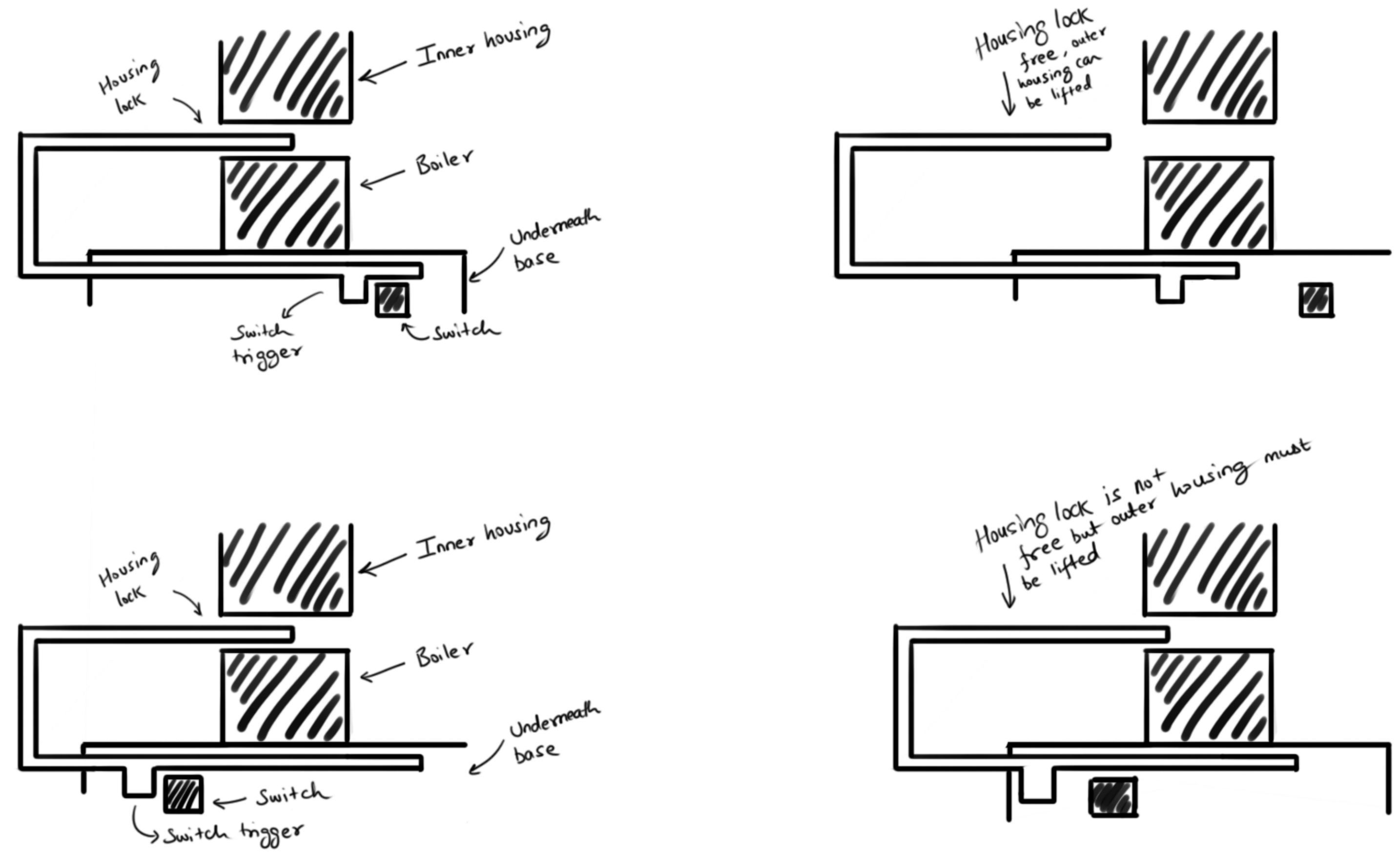


Figure 126: Example of how the position of the housing lock and the switch trigger could impact the method of taking the outer housing out

Given these constraints, both remaining options still apply. However, the width of the coffee machine (~8.5 cm) does make a setup where the outer housing opens sideways cramped. To evaluate this, the coffee machine was modelled in SolidWorks, and the result is shown in Figure 127 in the form of a simplified

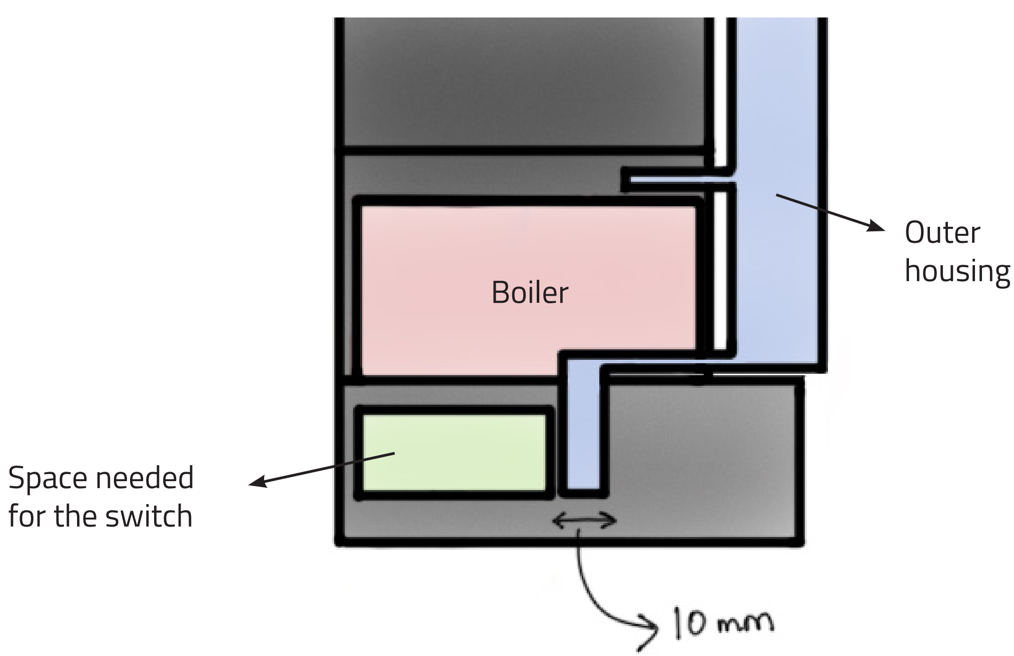


Figure 127: View of the coffee machine from the back and how the outer housing would look. Given the limited space, the switch trigger would be very thin

sketch. While space is available to incorporate a switch trigger, its size would be small. It would require precise design to ensure that the switch trigger is located after the end face of the housing lock. In addition to this, there were a few advantages to having the outer housing open from the back,

1. Having the outer housing slide out from the back would allow fasteners to be placed at the back to secure it in place. This would also serve the purpose of hiding them from the user's view, thereby improving aesthetics. Another advantage is that it now allows the use of warning stickers and informational text to be added to the back of the machine, which the user would read when removing the screws.
2. Having the fasteners at the back of the coffee machine would mean that the user would have to take out the water tank before accessing the fasteners. This was not a risk in the existing design of the Magimix because the user was forced to rotate the coffee machine to reveal the bottom screws. If they had forgotten to take out the water tank, it would cause the water to spill while the coffee machine is still sealed. Suppose the redesign places the fasteners away from the back of the device. In that case, there is a possibility that the user will forget about the water tank, remove the outer housing, and then spill water, which could lead to short-circuiting.

While there are ways to have an outer housing that opens sideways but have the fasteners placed at the back of the coffee machine, for convenience and ease of prototyping, an outer housing that moves backwards was chosen. It is important to note that, in this particular situation, if the outer housing sliding from the back causes problems, an alternative solution is readily available for testing.

<u>Decision 9: Width of the inner housing and position of the boiler</u>

Once it was decided that the outer housing moved backwards, away from the inner housing, we needed to see if the housing lock had sufficient space to travel towards the boiler without any obstruction. When the existing dimensions of the Magimix were used, it was observed that the centre of the boiler was close to the PCB and positioned in line with the connection points on it. This meant that the housing lock would have to travel through wires without getting obstructed, which seemed unlikely. To overcome this, the width of the inner housing was increased by 10 cm, and the boiler was elevated by 2 cm to give a clear line of sight for the housing lock (Figure 128).

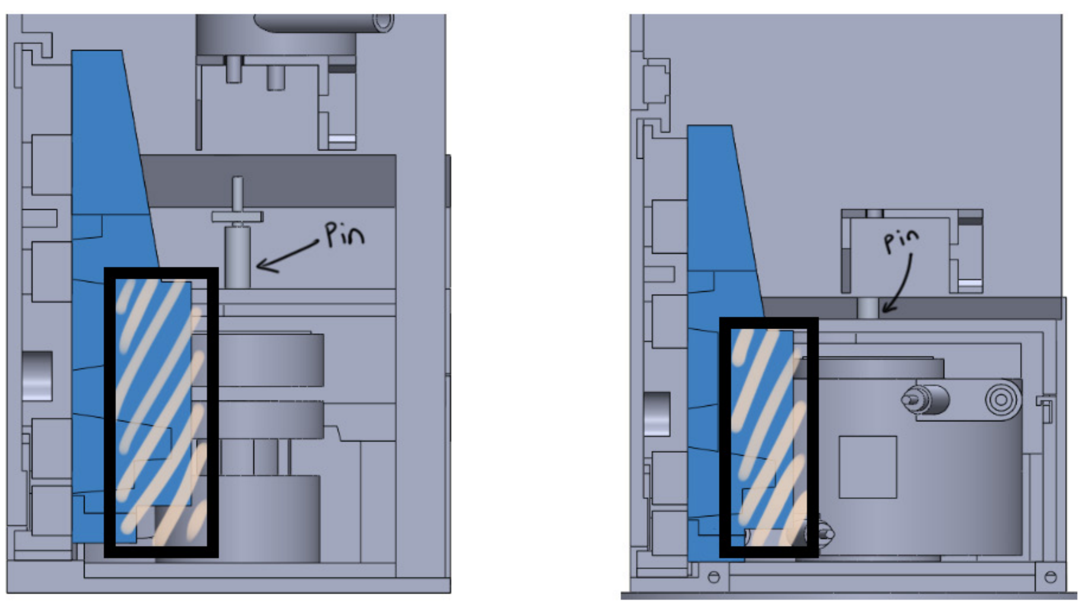


Figure 128: Comparison between the original design and the new design with the extra width and height for the boiler, as viewed from the back. The pin now has a clear line of sight.

At this point, increasing the width of the coffee machine also means that an outer housing that slides from the side is now a possibility. However, since the first prototype's primary function was to evaluate the effectiveness of risk-eliminating ideas, Decision 9 still stands unaltered.

Decision 10: Method of attaching brewing assembly cover to the inner housing

In the first iteration, the brewing assembly cover was attached to the inner housing using four snap-fits, like the method used in the Magimix (Figure 129). The assumption was that these would not break as the location of the snap-fits was known to us.

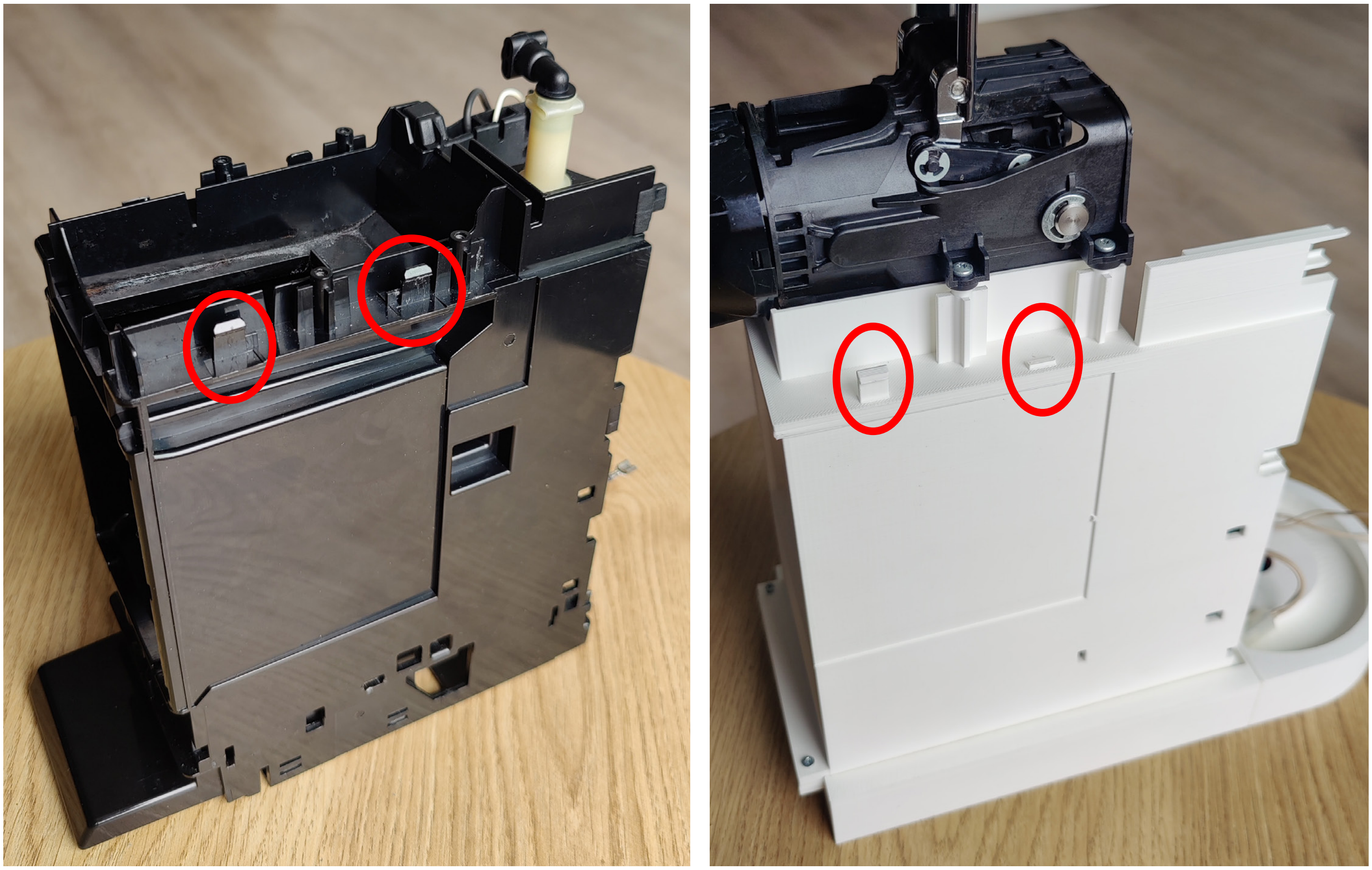


Figure 129: Snap-fits used in the Magimix and the Prototype (two snapfits are present symmetrically opposite the ones that are visibile. In both cases one snap-fit broke during use

However, despite this, one of the snap-fits broke. While this can be attributed to 3D-printed snap-fits, it still raises questions on its strength despite knowledge of its location and method of removal. Thus in the next iteration, these snap-fits were replaced with two screw connections (Figure 130).

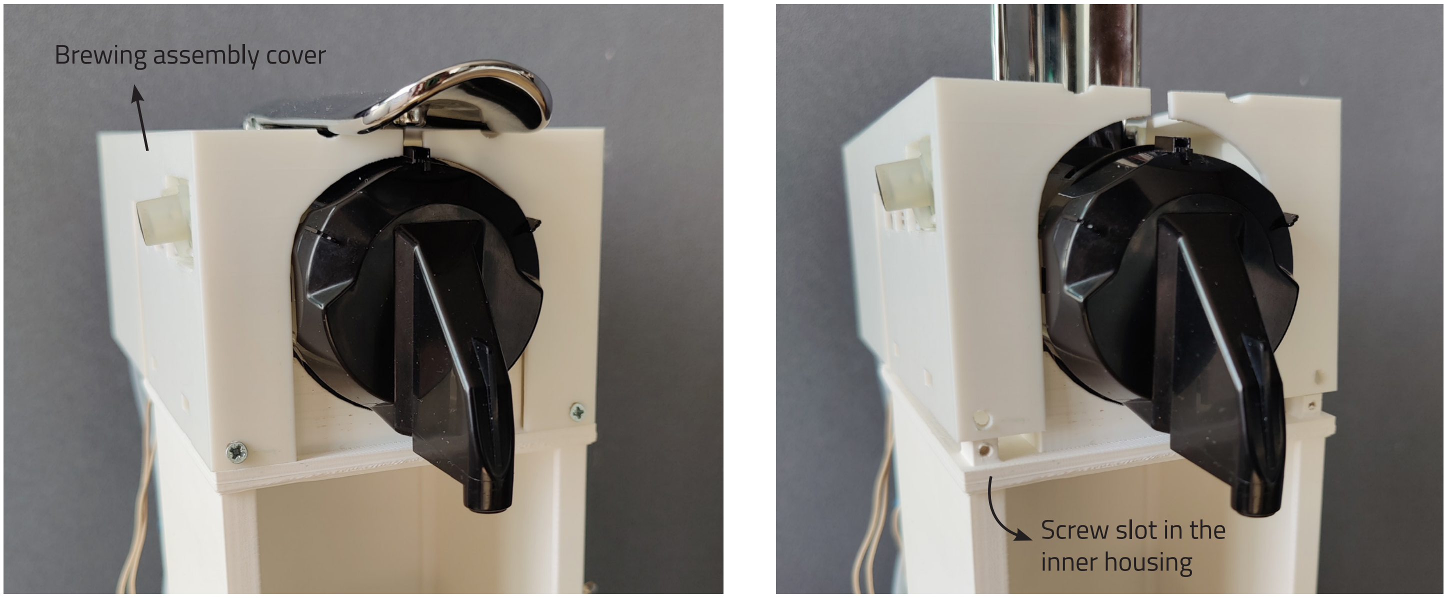


Figure 130: Two threaded connection points were provided to allow the brewing assembly cover to be attached to the inner housing

<u>Decision 11: Method of attaching the PTM switch to the base</u>

In the product's manual, a mounting hole was mentioned as the method of attachment. Following these guidelines, a slot was created for the PTM switch inside the base (First Prototype). However, during the attachment, this slot broke, and the switch was glued into place as a temporary measure for testing.

Figure 131: Broken slot for PTM switch and temporary measure used to hold it in place

Appendix F - Setup and procedure for all the tests

Test #1 - Evaluating the safety switch to cut power

Setup

To test this, the following equipment were used,

1. The prototype with the live wire from the PTM switch and the neutral wire from the power cable exposed (Figure 132)
2. A multimeter
3. A mains voltage source

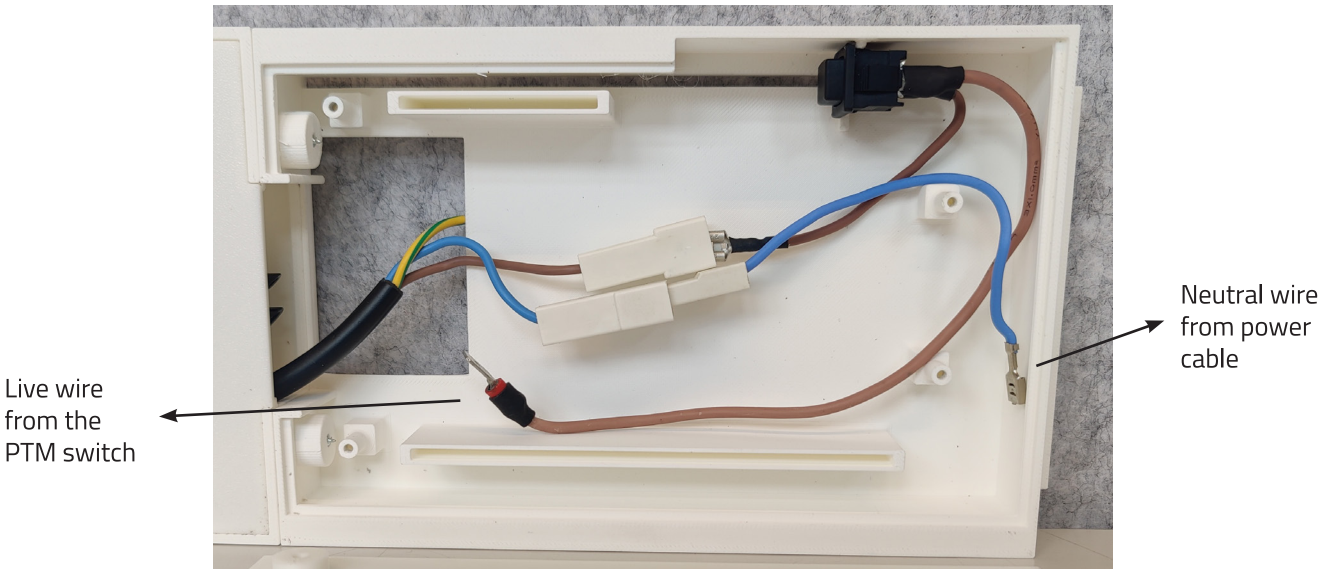


Figure 132: The live wire from the PTM switch and the neutral wire from the power cable

Procedure

1. Remove the base cover of the coffee machine and expose the live wire from the PTM switch and the neutral wire of the power cable. These wires will not be connected to any component and will be lying free.
2. Close the outer housing of the coffee machine to engage the switch.
3. Connect the power cable to the AC supply.
4. Using a multimeter, test the voltage between the live and neutral wire.
5. Take out the outer housing of the coffee machine.
6. Using a multimeter, check the voltage between the live and neutral wire.
7. Re-attach the outer housing
8. Using a multimeter, check the voltage between the live and neutral wire.
9. Disconnect the power cable from the AC supply.

Test #2 - Evaluating the actuation capability of a bimetal

Setup

To test this, the following equipment were used,

1. 3D printed model representing a simplification of the boiler top cover and inner housing components (Figure 134).
2. 3D printed rectangle representing a simplification of the housing lock
3. 3D printed pin
4. Bimetal taken from a steam iron
5. Hot air gun

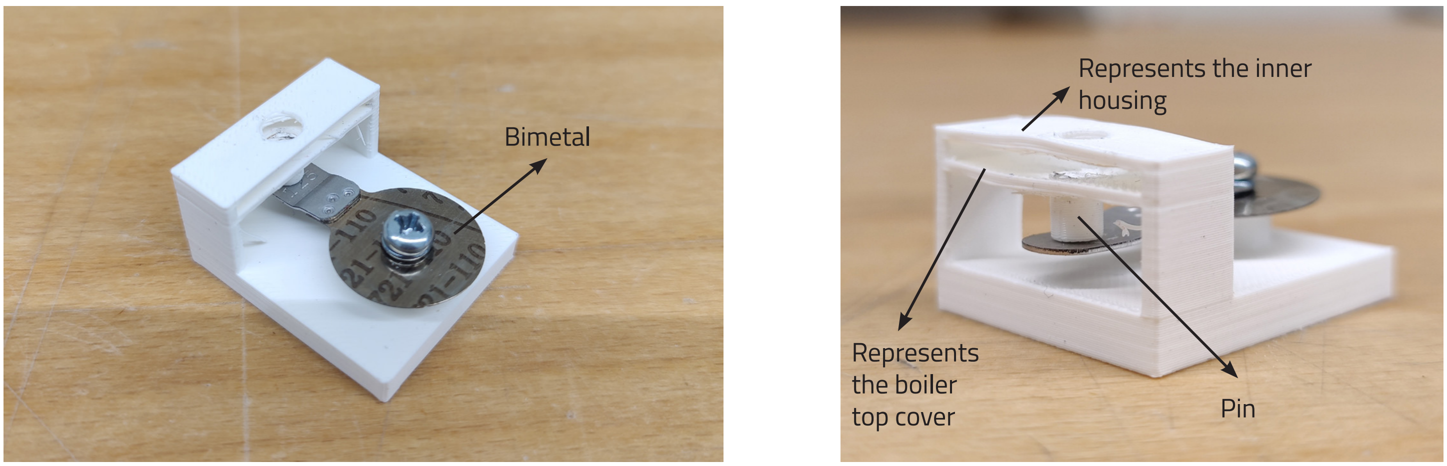


Figure 133: Setup to test the vertical actuation of the bimetal

Procedure

1. 3D print a setup where the bimetal in the steam iron is bolted in place, and a pin is placed at its tip.
2. The housing lock model is put into place.
3. Using a heat gun, hot air is blown onto the bimetal until it expands and pushes the pin up.
4. When the pin is up, the housing lock model will be pulled away from the setup to see if it has been locked in place.
5. Once the bimetal cools down, the housing lock model will be pulled away again to see if it has been freed.

Test #3 - Evaluating the weight holding capacity of the modified bimetal

Setup

1. The bimetal with a length of 36 mm having a hole at the front to hold a M2/M3 bolt (Figure 134)
2. Steam iron to mount the modified bimetal
3. Hot air gun
4. A board with the 8 mm deflection marked to ensure the bimetal is providing the required deflection
5. Single bolt and multiple nuts

Figure 134: Bimetal strip with a hole in the front

Procedure

1. Mount the bimetal onto the steam iron
2. Turn on the hot air gun and wait till the bimetal stops deflecting
3. Record this deflection as the "Unloaded" deflection
4. Take the bolt and measure its weight
5. Add the bolt to the hole at the tip of the bimetal
6. Turn on the hot air gun
7. Verify that the bimetal is providing the unloaded deflection
8. Measure the weight of a single nut and add it to the bolt
9. Repeat steps 6-8 until the bimetal provides a vertical deflection less than the unloaded deflection. This is the maximum weight this particular bimetal can hold.

Test #4 - Estimating the heat transfer capability of a model HTR (heat transfer ring)

Setup

1. Model of the HTR with the bimetal mounted onto it
2. Hot plate to provide constant heat
3. Infrared temperature sensor to measure the temperature of the hot plate
4. Device to measure the time (mobile phone in this case)
5. A board with the 8 mm deflection marked

Procedure

1. Switch on the hot plate and determine the setting at which the temperature reaches and remains at 90 Celsius
2. Determine the time it takes to reach 90 Celsius using the infrared temperature sensor and a timer
3. Wait for the hot plate to cool down
4. If the hot plate takes more than 25 seconds, example it takes 60 seconds, turn on the hot plate and wait until 25 seconds are left (at the 35 second mark)
5. Place the HTR with the bimetal on top of the hot plate and start the timer
6. Stop the timer once the bimetal reaches full deflection.

6.7 Test #5 - Testing the effectiveness of design cues

6.7.3 Setup

1. Coffee machine prototype
2. Required tools for disassembly
3. A camera to record the test
4. A picture of the boiler unit to help identify it

6.7.5 Procedure

Figure 135: A pin can be inserted to lock the outer housing for the user test

1. Participants were given a background scenario – Their coffee machine has been dispensing coffee that is not hot enough and they have identified the boiler and the hoses as the problem. They have just had a cup of coffee when the new components have been delivered to them and they have decided to replace it immediately.
2. A picture of the boiler was provided to aid in identification along with required tools. They were asked to talk out aloud as they perform the tasks to collect their thoughts about the design cues.
3. Using the hole at the front of the coffee machine (Figure 135), the outer housing was locked by passing a pin.
4. The outer housing remained locked until participants observed the warning instruction at the back or asked for help.
5. Once the participants isolated the boiler and the hoses, they were given the components back again and asked to reassemble it.
6. The test ended once the coffee machine was reassembled.
7. Participants were asked their final thoughts about the test and the usefulness of the design cues.

Appendix G - Additional tests performed after Test #2

Test #2 (Section 6.4) ended with the idea of using a modified version of the bimetal from the steam iron to act as the prime mover. This Appendix details the process and the tests that were conducted to arrive at the design shown in section 6.4.6.

Test #1 - Evaluating the vertical displacement of the modified bimetal

Objective

The objective of this test is to evaluate if the modified bimetal can provide a vertical displacement of 8 mm.

Apparatus

1. Steam iron bimetal with a metal strip attached to it (Figure 136)
2. Steam iron to mount the modified bimetal
3. Hot air gun
4. A board to mark deflection of the bimetal
5. Scale and marker

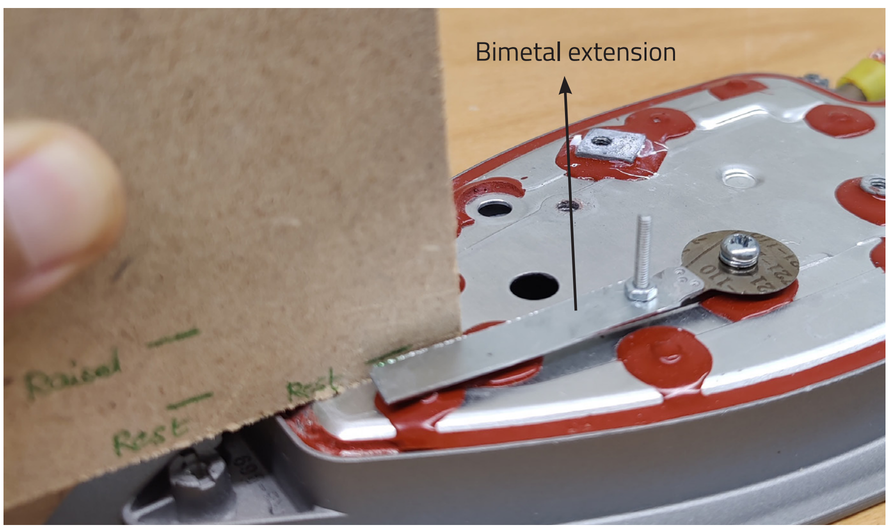


Figure 136: Redesigned bimetal for the test

Procedure

1. Mount the bimetal onto the steam iron
2. Measure the length from the mounting point till the tip of the bimetal strip - referred to as "Length"
3. Mark the position of the bimetal tip on the board - and name it as "Rest"
4. Turn on the hot air gun and wait till the bimetal stops deflecting
5. Mark the final position of the bimetal tip on the board - and name it as "Raised"
6. Measure the deflection - distance between "Rest" and "Raised"
7. If the deflection is greater than 8 mm, reduce the length of the extension attached to the bimetal and repeat the experiment from step 3 until you get a deflection of 8 mm.

Result

The experiment started with the length of the bimetal equal to 67 mm (Figure 137). Over subsequent rounds of trials, the length of the bimetal was reduced, and the results can be seen in Table 22.

Table 22: Relationship between length of the bimetal and the vertical deflection

Experiment number	Length of the bimetal (mm)	Vertical deflection (mm)
1	67	14
2	56	12
3	36	7-8

Figure 137: Deflection of the bimetal at different lengths

Appendix H - Results from the user test

Figure 138: User interaction and information observed and collected during the user testing

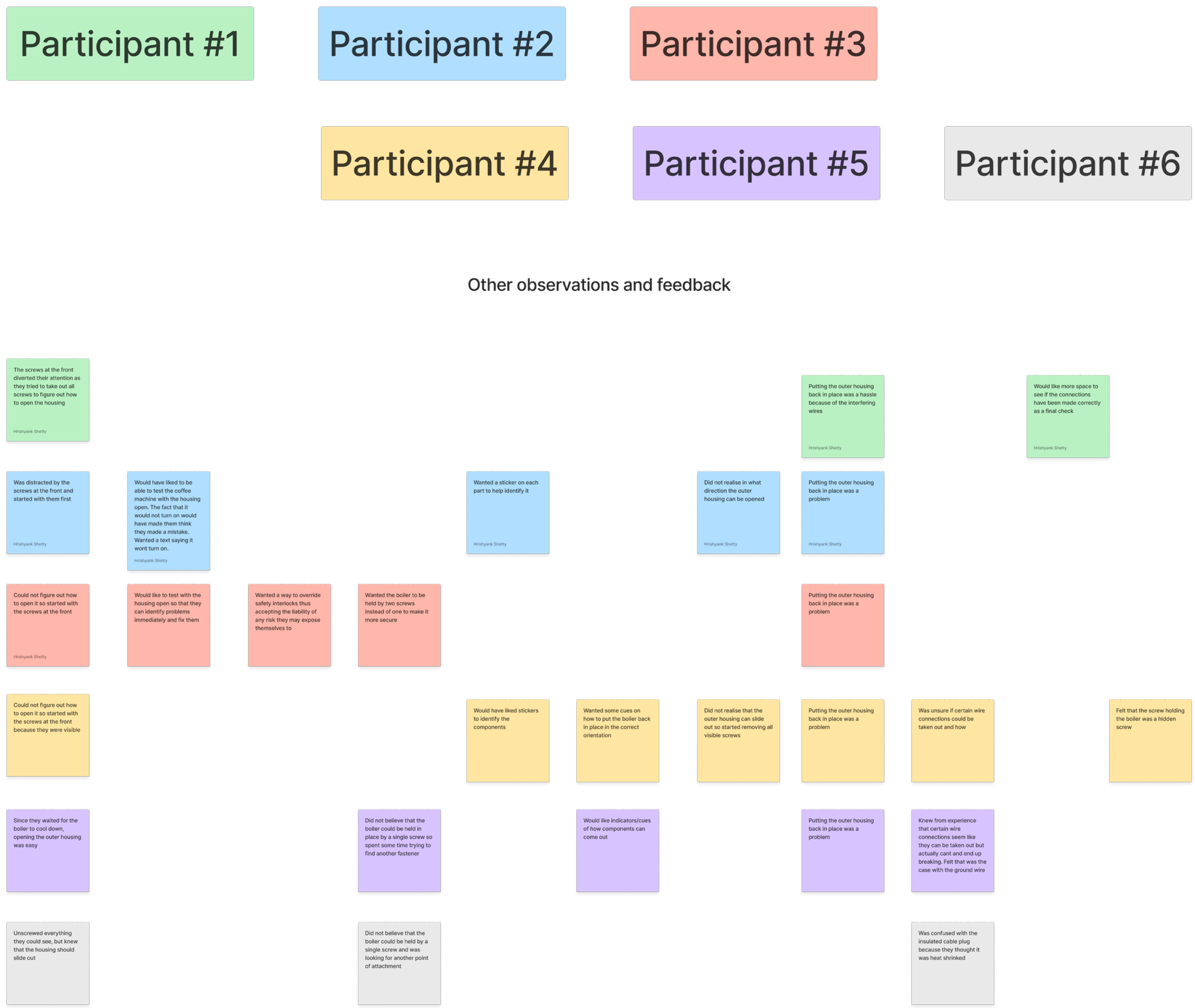


Figure 139: Feedback given by users after the test. Information has been organised so that common feedback are in the same column