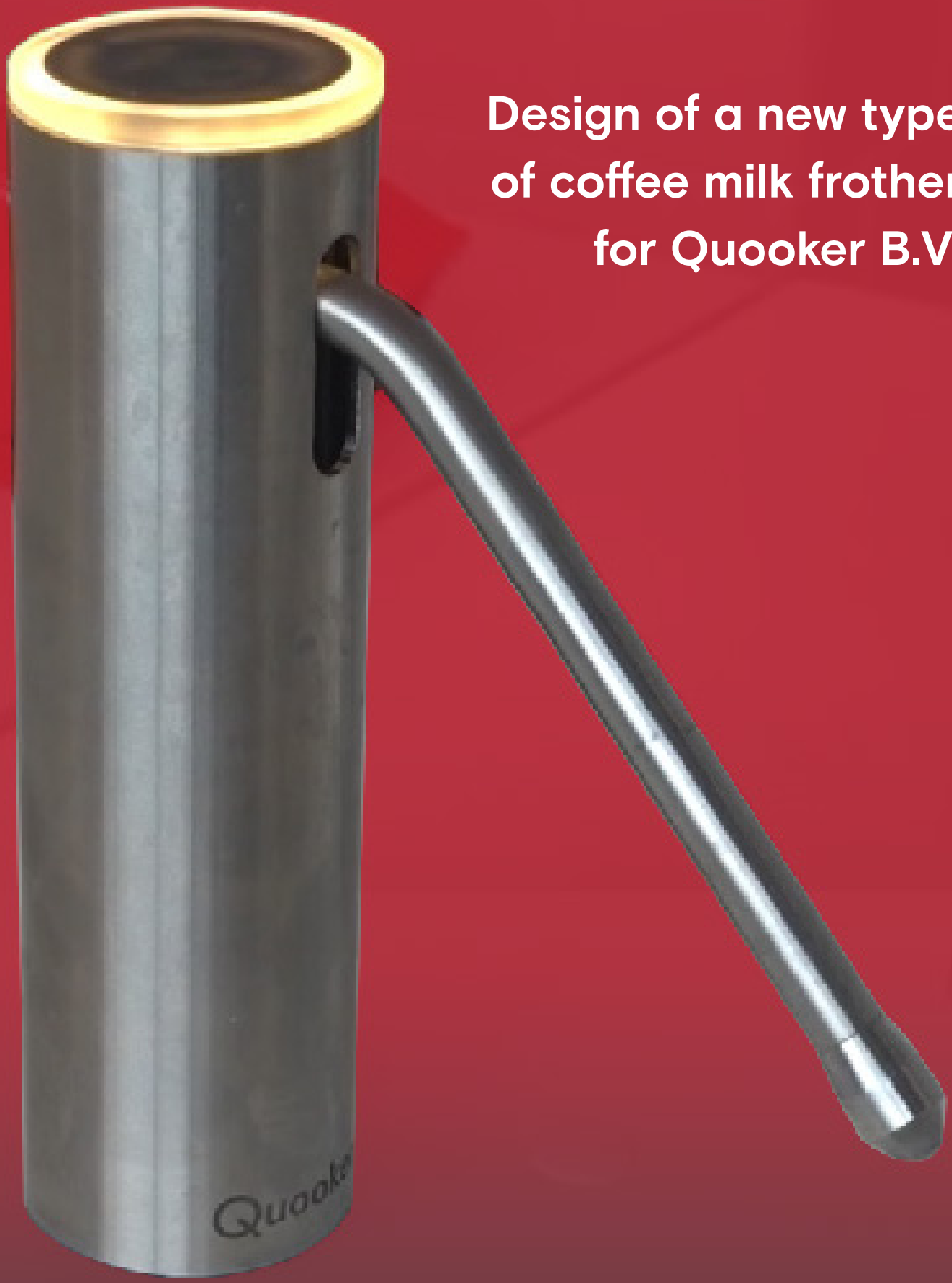
Design of a new type of coffee milk frother for Quooker B.V.



Master thesis by Pepijn Huis in ‘t Veld

Master Thesis

Design of a new type of coffee milk frother for Quooker B.V.

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Also, the colleagues and personnel of the IDE the faculty unconditionally came to help when a though technical problem needed to be solved, were the reason that a functioning integrated prototype was achieved.

Lastly, I want to thank all my fellow students, friends and relatives that helped to get insights in the quality of my idea's, concepts and prototype, while constantly be bothered by my stories about my daily visit at Quookers headquarters in Ridderkerk.

Summary

Almost every adult human being is drinking coffee, a caffeine rich, bitter drink to get through the day. To top up caffeine levels during a short break at work or to authentically enjoy the distinctive taste and aroma of freshly milled coffee beans. To sweeten up the coffee, milk and milk alternatives are added to counter the bitterness by adding sweetness and fluffy texture. Before the milk can be poured over the coffee it needs to be prepared, from cold storage, it needs to be heated and aerated, also known as frothing.

Quooker, a company that developed and sells a water tap, which can serve cooled, carbonated and boiling water, without any hassle. The innovative mindset from the start of the company is ever so present and is therefore looking into opportunities to broaden its kitchen portfolio.

During this project and report the possibilities for a new type of milk frother is explored that makes use of the existing boiling water ecosystem. Which will theoretically provide several key benefits when competing with regular milk frothers. In the first phase of the project the coffee context is researched, and existing solutions are studied. A list of requirements are drawn up to set specifications for the novel design. The technical specifications could be easily set, however the expected coffee quality is a highly subjective topic. Even with professionals the perfect cappuccino does not exist.

With the gathered knowledge solutions that incorporate the potential benefits of the integration with the Quooker reservoir are explored. Resulting in three potential concepts that are evanluated with potential consumers. There could be concluded that certain aspects of all the concepts would form a promising combination of solutions. The optimized concept is further developed to prove its life worthiness as a product. A high-fidelity integrated prototype was created to show the feasibility of the solutions and to gather opinions of the frothing principle, aesthetical language and interaction. Giving a head start for further future development if the need for a milk frothing addition is deemed necessary.

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Introduction

1. Introduction

1.1. Assignment

In the last few decades, the premium barista coffee experience entered the homes of the ordinary consumer. Meaning that tastier coffee can now be enjoyed at home without the skills and expensive machines found in cafés. Nespresso cup-based systems and fully automatic coffee machines replaced the less technologically advanced percolators and filter-based machines, providing more flavourful coffee with ease in smaller machines. With this shift towards more quality, the perception of coffee is changing at home. The process which took home-barista's a lot of skilled activities is now replaced with less and simpler steps.

Quooker, the market leader in boiling water taps, is looking into joining this coffee market. With their extensive knowledge on providing boiling water without using any countertop space, Quooker is trying to create the same experience for coffee. Their products are intuitive to use, as well as taking safety and sustainability into account. In addition to the coffee, Quooker also wants to be able to provide fresh frothed or heated milk. So that their coffee system can make any type of coffee. The market position that Quooker wants to take can be seen in figure 1.

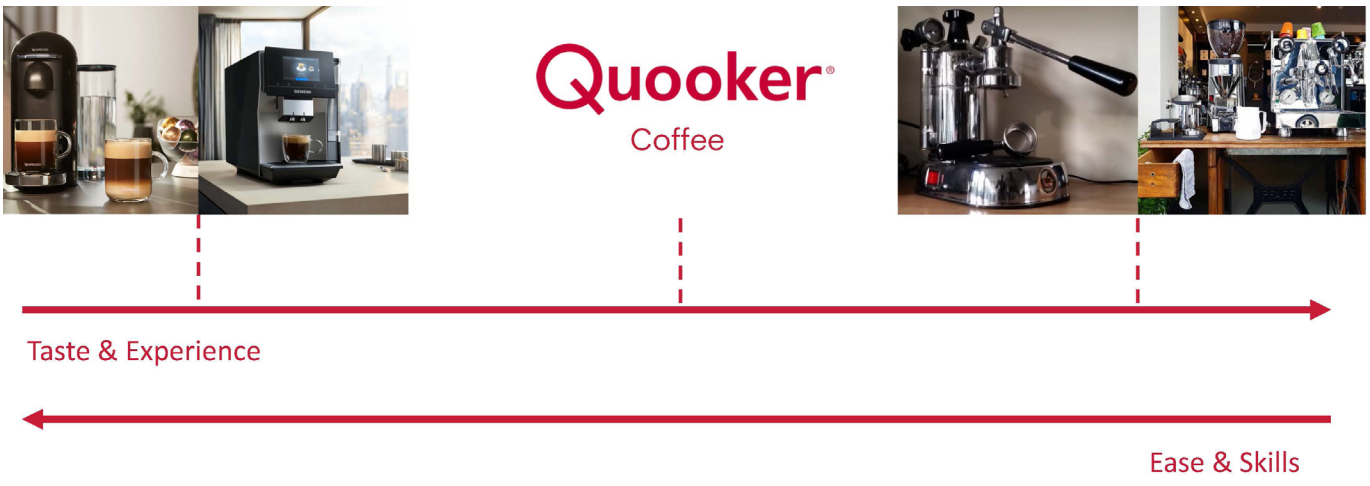
For the assignment Quooker wants a first design and technical exploration of how this milk frother could be embodied, with a working prototype and a clear proposal that Quookers engineers can take to further development and production.

1.2. Problem definition

The main goal of the project is to develop an integrated concept of a new type of milk steamer for creating high quality coffee beverages with ease while minimizing precious space on kitchen counter. The concept should match Quookers design, their principles and the needs of their current and potential customers. To achieve these three major challenges need to be tackled.

The first major challenge is finding a beneficial way of using the existing kettle to froth milk. The instant boiling water is kept at an optimum temperature for flow and efficiency, not for coffee and steam production. Coffee machines make use of dedicated boilers that are mostly smaller and have a dedicated function.

Figure 1 : Quooker Coffee market position



Secondly, there is no existing example of a household milk frother that can be compact by placing the steam production under the countertop. Creating this novel product of which it's use is easy and understandable while also fitting in Quookers current design language is going to be challenge. The overall shape and size of the product will depend on the approach taken to create froth milk and the insight gathered from potential users.

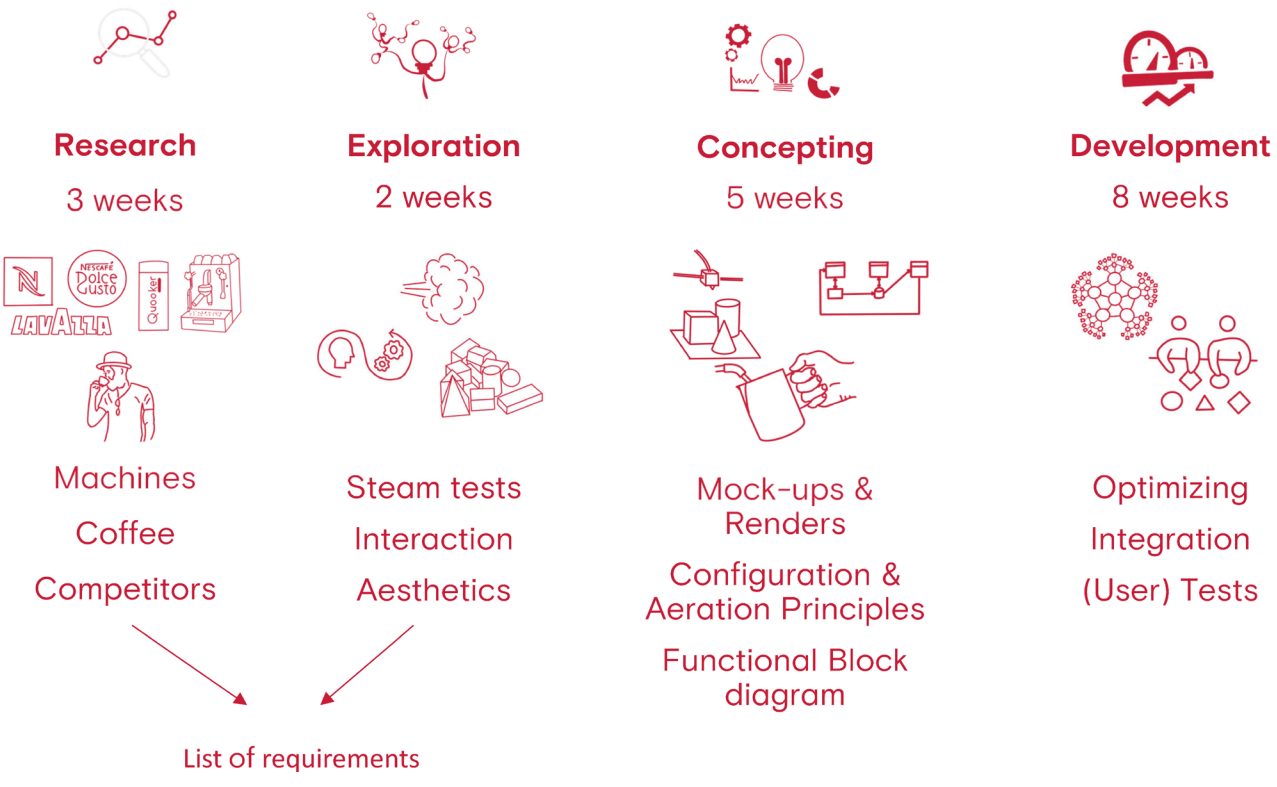
The third challenge arises when using milk, a 'dirty' ingredient. After making frothed milk everything that meets it should be thoroughly cleaned to prevent the forming of blockages and spoiled milk contaminating the beverage. In the design the parts that must be cleaned should be minimized and preferably be easy to clean or dishwasher safe.

1.3. Project Approach

The initial approach of the project was to pass four phases of research exploration concepting and final product development (figure 2). In the research phase coffee machines, the coffee context and competitors are researched. During exploration experiments are conducted to get a better understanding of the coffee machines and the first steps towards the new type of milkfrother are taken.

Combining the insights form these two phases the requirements for the milkfrother are determined.(Chapter 2 to 8) After which the concepting phase starts. In that point in the process the design of the interaction of the on-counter device and a steam generator are still parallel as the steam producing prototypes are safe enough to conduct user tests with. (Chapter 9) In the development phase the on-counter device is embodied into a realistic product and the steam generator can safely and reliably provide steam for milk frothing. Ending with an integral prototype that can be used conduct user tests, gain milk frothing insights and to proof the frothers concept feasibility. (chapter 10 to 12)

Figure 2 : Project approach



1.4. Project Requirements

The milk frother requirements will be presented throughout the research and exploration phases. The complete list of all the requirements can be found in appendix A. All requirements are numbered and related to a category that are taken from the “List of Requirement’s” method from the Delft Design guide (van Boeijen et al. , 2013). The categories and their letter can be seen below.

List of Requirements

Nr	Requirement or Wish	
A		**Peformance** What main functions does the product need to fulfill?
B		**Envriomeent** What kind of enriomental influences does the product need to withstanc
C		**Life in Service** With what intensity will the product be used, and how long should it last
D		**Maintenance** Is maintenance nessasary and possible?
E		**Target product costs** What is a realistic price for the product
F		**Transport** What requirements are set by transport of the product
G		**Quantity** What is the amount of units produced
H		**Product Facilities** Should the product be designed for existing production facilities
I		**Size and Weight** Are there bounderies for the size and weight of the product
J		**Aestetic aperance and finish** Which preferences do buyers and users have
K		**Materials** Should certain materials be used?
L		**Ergonomics** What requirements result from observing and understanding handeling of the product
M		**Safety** Should specific precoutions be taken with regard to the safety of users and bystanders?

Research phase

2. Quooker introduction
3. Coffee context & properties
4. Coffee market in the Netherlands
5. Coffee machines analysis
6. User insights

In this phase theoretical and practical information is gathered to find a position of the new milk frother in the coffee context.

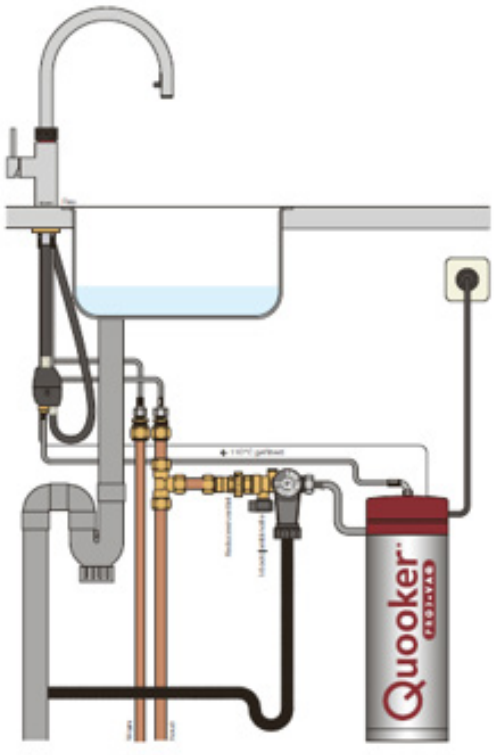
2. Quooker Introduction

Quooker is a family-owned company that designs and produces boiling water taps for consumer kitchens. Its headquarters and assembly plant is located in Ridderkerk, the Netherlands. More than 650 employees are working on the mission to provide every household with the luxury of instant boiling water. The primary business is focused on the European market, complemented by two intercontinental offices that are opened in Hong Kong and the Middle East.

The first Quooker taps and kettles were designed and manufactured in the basement of Henri Peteri's house in the 80's. Even though the company has grown a lot. This inventive and radical approach still lives in the company. Niels and Walter both sons of Henri, took over their father's business with Niels in the lead of the technical side and Walter of the commercial side of the product. The taps and boilers are still designed and assembled in Ridderkerk, while actively diving into opportunities to improve, and expand their current product offering.

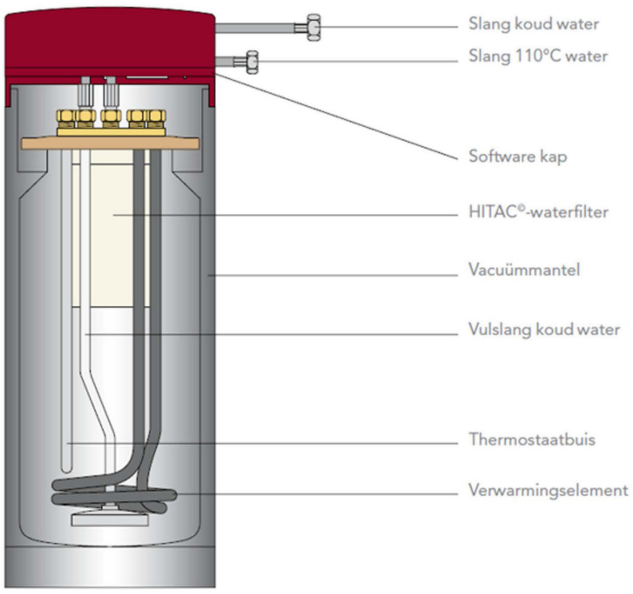
2.1. Quooker kettle system

In figure 3 an installation overview of a Quooker 3-liter kettle with a separate tap is shown. The kettle is connected to the cold-water lines with a pressure reduction valve, tap and an overpressure valve that releases the overpressure in the sewage. The pressure reduction valve is used to manage fluctuating pressures when multiple taps are opened at the same time and to achieve a lower base pressure for less stress on the kettle's parts. The water mains pressure is around 2,5 bar at ground level in the Netherlands, this pressure can in or decrease in apartment buildings where the water needs to be pumped upwards to reach all the residents. Sometimes reaching peaks of 6 Bar.



< *Figure 3 : Quooker system*

Figure 4 : Quooker Kettle



Inside the Quooker the water is heated to 108 °C with a heating element. To keep the water below the boiling point it is kept at a pressure of 8 Bar. The pressure is achieved by the expanding water of higher temperature and the overpressure valve releases the excess water. An array of thermometers senses the temperature at different height levels and the electronic circuit controls the heater. The magnetic valve to let the water flowing out of the tap. At the taps nozzle the water cools down to 100 °C and starts boiling due to the pressure drop.

2.2. Kitchen industry

Quookers products are mostly sold and installed together with a new kitchen. Because the system is fixed to the kitchen en main water line its relation is similar as with for example a dishwasher, stove or non-instant boiling tap. This product category has its benefits, yet also it is downsides for the company. The benefit of a fixed item is that a larger investment can be made as there is expected that the product will function a long time with the kitchen. However, this longer expected lifetime also poses a challenge that the product must withstand long lifetime of exposure to water, cleaning and wear and tear. It is a shared responsibility of the product's design and the user to get to this longer life. Therefore, Quooker (2022) provides instructions on its website, which the user can use to perform the installation and larger maintenance by itself. The activities are not too difficult to follow and can prevent more expensive visit of a Quooker mechanic or plumber. For the repair of failed internal parts, a mechanic can pay a visit to conduct repairs.

Requirements.

The following requirements can be taken from Quooker and the kitchen industry. A Quooker milk frother will also be connected to the mains waterlines and must be able to encounter a minimum of 10 years of use without failing. Small maintenance such as descaling certain parts must be able to be conducted any user. The user should be able to do larger maintenance, with the help of clear instructions.

C1	Requirement	The product must last for at least 10 years
C3	Wish	The product should at least keep functioning for one average kitchen lifespan (13,3 years)
D2	Requirement	Small maintenance must be conducted by the user
D3	Requirement	Large maintenance should be conducted by the user with the help of a video manual
D4	Requirement	A Quooker mechanic must be able to conduct large maintenance during a Quooker service appointment

3. Coffee context & properties

3.1. Coffee beverage contents

Coffeeshop expo (n.d.) describes there is no clear date of which coffee is consumed by humans. The legend is that in the 6th century in Ethiopia, goats were found restless after eating red berries. The berries are protecting themselves against fungi with caffeine, a bitter tasting alkaloid. Herders also tried the berries, and later adopted the dried berries in their diet by soaking in liquid and drinking them

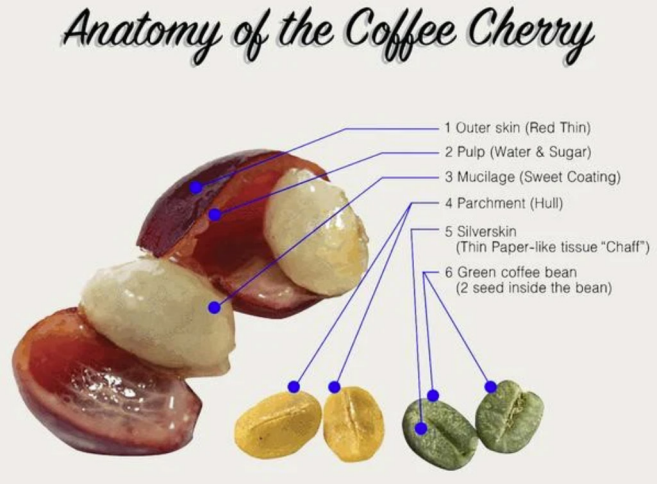
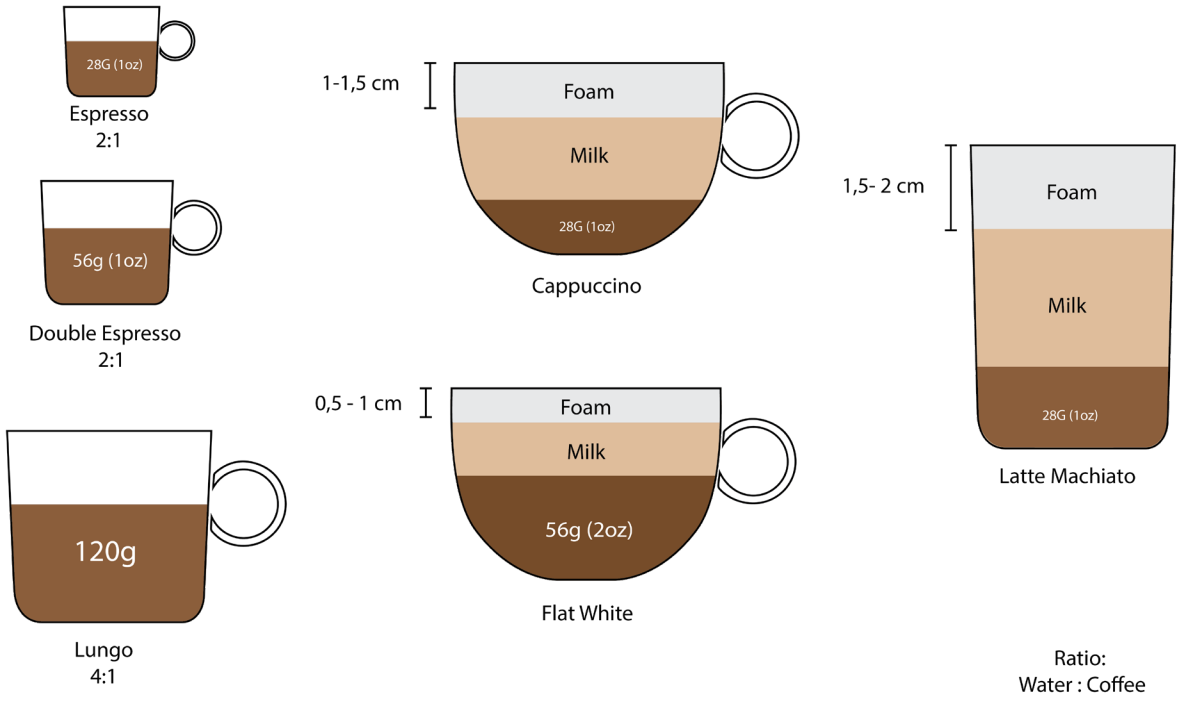


Figure 5 : Coffee Bean contents

Steven Sauer (2020) made an illustration showing the contents of the coffee plant's berry and is shown in figure 5.
Nowadays before drinking coffee the red berry is dried and the inner bean is removed. The green coffee is then roasted to caramelize the sugars that are found in the bean. The substance inside of the berry is also transferred to the bean, meaning that when more caffeine or sugars are present the roasted bean later also has more bitter and caramellike flavour.

After roasting the coffee beans are milled and coffee can be brewed using a variety of methods. For making a cappuccino these brewing methods are of importance, however it is not in the scope of this project to discuss all the options. What is of importance is analysing the type of beverages that can be made with coffee and what people expect when ordering or making an Espresso, Lungo or Cappuccino.

Figure 6 : Coffee Beverages



Therefore, figure 6 shows a few types of coffee beverages and their ingredient.
The ratios of the beverages are both based on the article of Matt from Coffee Improved (n.d.) and the 'Barista's Handbook' made by Giraffe Coffee academy of which the table can be seen in Appendix B. The ratio's shown are not set in stone or protected. Matt explains that at Starbucks for example an Espresso is severed with a shot 22,2 ml shot of coffee and the traditional Italian serving is seen as 25ml.

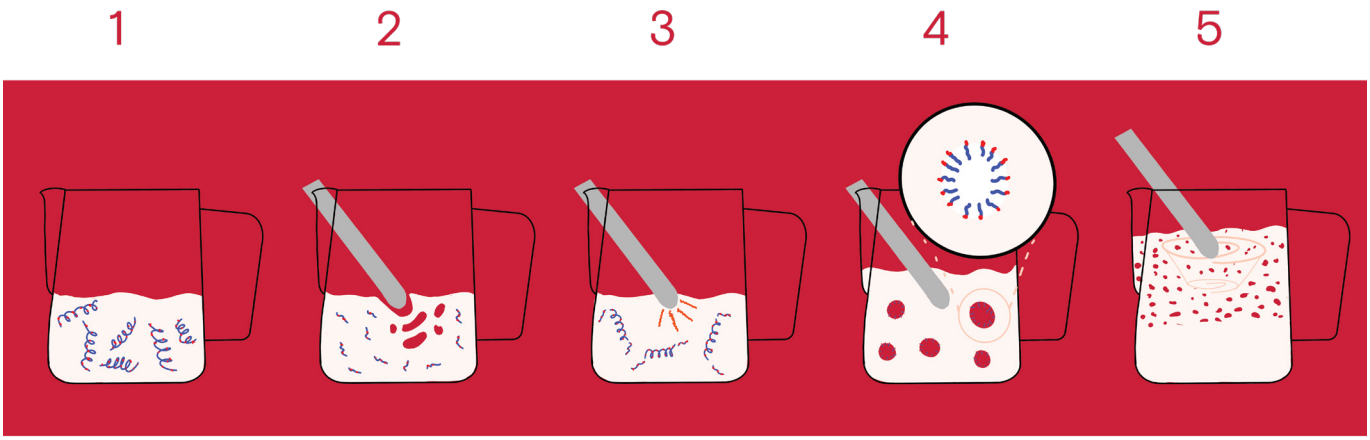
With milk the serving is even less predetermined. The visit to Giraffe's milk foam barista workshop explained that serving a customer with a perfectly filled cup is more important than meeting the exact amount of liquid. The layer of foam on top of the coffee is also not set, however the amount of foam, or aerated milk on top of the drink varies per beverage. With for example having the flat white as the least amount of foam and the latte macchiato having the most.

3.2. Milk frothing principle

Before discussing how to make milk froth, the content of milk needs to be discussed. According to Briticana (2021) milk is a liquid secreted by mammals to nourish their young before they can eat and digest their mature diet. Milk contains everything an animal or human needs to survive and grow, meaning it Is rich in fat's, proteins and sugars.

Milk froth is a foamy substance, meaning that air is trapped inside the liquid. It uses the proteins and fats found in milk to trap the air inside.
Tilly, a professional barista trainer at Giraffe coffee academy of which the visits are documented in appendix B and research conducted by Thao, Bhesh & Bansa (2020) explain the milk frothing process for coffee beverages. In figure 7 the process is shown when performed by a barista with a steam wand and a milk jug.

Figure 7 : Milk froth process



3.3. Alternative milk types

The milk-based coffee beverages are not only served with milk produced by cows. Nowadays many alternative drinks are available in supermarkets. The Dutch consumers association (2022) discusses the differences between all the types of 'drinks'. As 'milk' is a protected term in the food industry and may only refer to the liquid that originates from animals. In table 1, from The Dutch consumers association with additions by Voedingscentrum (2022), the nutritional values of the drinks can be seen.

The differences in fat and protein contents are a key factor in the frothing characteristics for coffee milk. Only the protein level of soy milk comes close to full-fat and skimmed milk, thus trapping air inside the milk replacements harder when comparing to cow milk. The fat levels of all the replacements, no option comes close to full fat cow milk, making it harder to make a stable froth.

Still, it is possible to make a thick froth cappuccino with the alternative milks. Cooks Illustrated (n.d.) discuss that all alternative milks have an additive that helps with froth creation. "For froth, Gellan is the key" (Petre, A. ,2019). Gellan is a fermented sugar that can be found naturally and bonds to calcium found in the milks to create froth. Gellan gum is found to be food safe; it can slow down the digestive system. Tilly the barista from giraffe discussed that the milks alternatives would burn at lower temperatures than cow milk and the process of capturing air must be quicker.

Oatly (2022), a brand of alternative drinks does not use Gellan in their barista version of oat milk. They use beta glucans, a kind of carbon hydrates that are not digestible (fibres) that traps air into the milk and can be found in plants and wheats. The main differences between the alternative 'drinks' can be found in figure 8.

Table 1 : Nutricious values variety of milks

Average (per 100ml)	Full fat milk	Skimmed milk	Soydrink	Almond drink	Oat drink	Coconut Drink	Hazelnut Drink
Energy	61	46	38	20,1	46,3	44	46,7
Saturated Fats	2,2g	1g	0,3g	0,1g	0,2g	1,4g	0,2g
Unsaturated Fats	1,2g	0,5g	1,6g	1,2g	0,9g	0,2g	1,9g
Sugars	4,5g	4,7g	1,4g	1,1g	4,1g	4,1g	2,3g
Fibers	0g	0g	0,5g	0,3g	0,7g	0,3g	1,2g
Proteins	3g	3,4g	3,3g	0,5g	0,6g	0,2g	0,5g
Salt	0,1g	0,11g	0,1g	0,12g	0,1g	0,11g	0,07g
Calcium	124mg	123mg	73mg	77,6mg	60mg	0mg	0mg
Vitamin B2	0,4mg	0,45mg	0,05mg	0,11mg	0,04mg	0mg	0mg
Vitamin B12	0,45µg	0,45µg	0,13µg	0,25µg	0,09µg	0µg	0µg
Vitamin D	0µg	0µg	0,19µg	0,44µg	0,19µg	0µg	0µg

Burns at 70 °C
Pasteurised
Can have different levels of fat

Cowmilk

Burns at 65°C
Less fat and proteins then milk
Added rapeseed oil
Oatly uses beta glucans

Oat milk

Protein levels same as Cowmilk
Less amount of fats
Less calcium
Added Gellan emulsifier for frothing

Soy Milk

Less amount of proteins
Similar amount of fats and sugars as milk
Rich in vitamin D
Added Gellan emulsifier for frothing

Almond Milk

Burns at 65 °C
Comparable Sugar and Fats
No proteins
Added Gellan emulsifier for frothing

Coconut Milk

Figure 8 : Alternative milks and their charactaristics

Requirements

The conditions to create milk froth are identified, heat and air are used to make a foamy texture by trapping air in the liquid. Milk burns at 70 degrees Celsius and should not be heated more. Different coffee beverages contents different amount of milk froth and volume increase. Milk alternatives can be used for milk frothing, however it is mandatory to buy the barista version of the “drinks” as the general product does not contain enough proteins and fats to create froth. Thus, the requirements the following are added to the list.

A1	Requirement	The product must heat milk to 70 degrees Celsius
A2	Requirement	The product must aerate milk to create froth
A3	Requirement	The product must also be able to froth with replacement milk types
A5	Requirement	The serving size must be enough to one serving of every type of coffee beverage
D1	Requirement	After every serving the product must be cleaned easily

4. Coffee market in the Netherlands

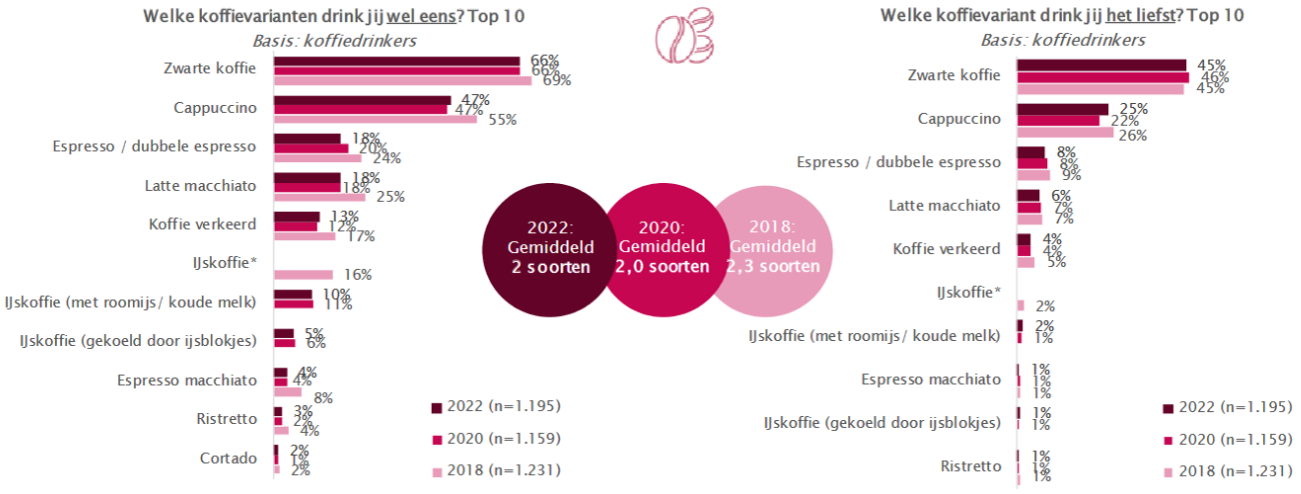
A brief market study is conducted to get a better understanding on the facts and figures in the coffee industry. The most interesting numbers are shown with more general numbers can be found in appendix C. Due to cultural differences in coffee consumption the numbers of the Netherlands are discussed, as this is Quookers main country of operation.

4.1. National dutch coffee survey

In the Netherlands the national association for coffee and tea conducts reports insights of the market with an annual survey (Koffie & Thee Nederland, 2022). The survey is conducted with 1520 participants in a variety of ages to provide a representative view of the average Dutch citizen. The following graphs are taken from their report of 2022)

Figure 9 shows the beverage type that is drank most of coffee in the Netherlands. The 'black coffee' is drank the most with 66%, it is also the most desired beverage type with 45% of the drinkers having it as their favourite drink. Cappuccino comes second with 47% of drinkers sometimes consuming a cappuccino and the favourite of 25% of the coffee drinkers. The difference between sometimes consuming a cappuccino and the amount of drinker having it as their favourite is quite large with 20% which raises the question why it is more consumed than favourited. Is this because a good tasting cappuccino is not available to every drinker or does the difference come from drinkers sometimes switching up their beverage. The other types of coffee are less popular with an espresso being third with only 8% and a latte macchiato fourth with 6%.
Looking at the most common brewing method machine that uses a filter (37%) and filter pads (17%) are still the major source of the drank coffee in the Netherlands (figure 10). The use of capsule-based machines has increased with 6% within 2 years, this is at the cost of the filter and filter pad machines that both decreased with 4%. Fully automatic machines also has a slight increase of 3% in comparison to 2020.

Figure 9 : Beverage types consumption and favorites



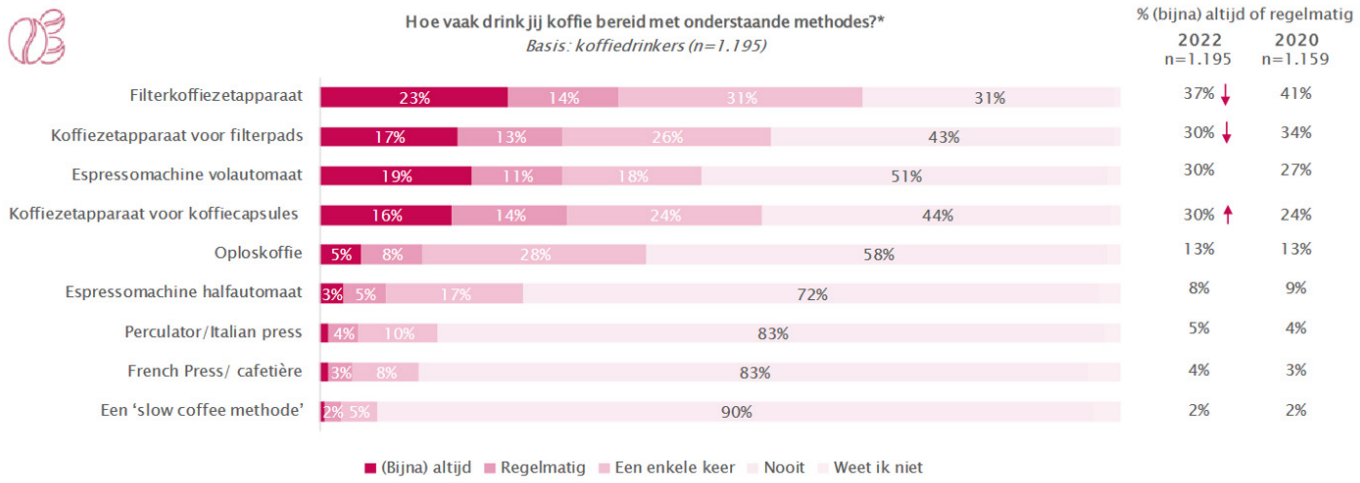


Figure 10 : Brewing methods

4.2. Quooker customers survey

Before the start of this project Quooker also conducted a survey under Its customers. The survey consisted of 147 participants that owned a Quooker. Under the Quooker owners, the coffee statistics looked a bit different than the average Dutch citizen (figure 11). The most used coffee machine Is a fully automatic machine with the cup-based machine placed second. The ratio of filter-based machines has a slightly higher than the remaining type of machines.

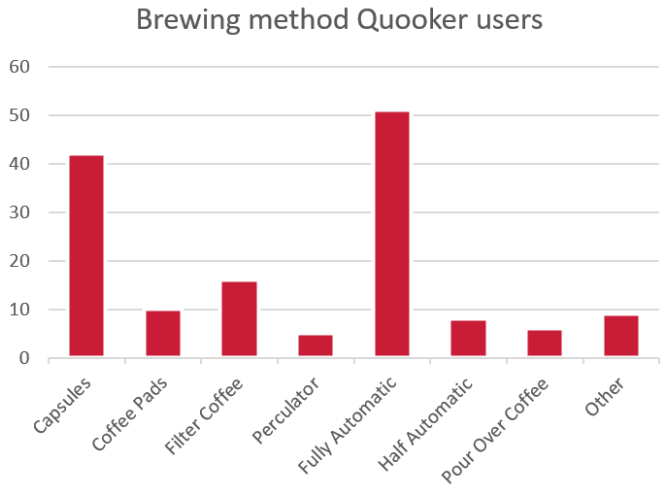


Figure 11 : Brewing method Quooker users

5. Coffee machines analysis

Figure 12 shows a few categorized milkfrother that are available on today's market. Milk frothers exist in variety of sizes and shapes mostly placed together with a coffee machine. Yet the frothers are using different working principles to heat and aerate the milk. In most of the machine's steam is used to heat the milk, however pre heat or electric heating is also used to get the milk to temperature. Aeration is performed in a variety of ways. Mostly using a rotational mixer that spins the milk or a venturi that take on air and inject it into the milk or just by the flow of the steam as often seen in traditional espresso machines used by barista.

5.1. Milk froth machine tests

To get a better understanding of the taste and experience using the machines I assessed one of each group. The machines were bought second hand, or new. With most of them already present at Quooker's coffee lab. The goal was making a regular cappuccino with the most standard settings. Full fat long shelf-life cow milk was used to make the cappuccino. The result was evaluated based on taste, froth texture and machine experience and scored on a scale of 1 to 5.

In table 2 the scores of the frothers are shown. The scores all average out between 2,83 and 3,83. Which is logical as for example the products that have a higher score in taste are often more expensive and harder to clean. All products made it to market products with an average score between 1 and 2,5. There is no frother yet that scores high on average, with the Senseo Electrical milk frother scoring the best with 3,5 out of 5.

Figure 12 : Milk frothing machines

Capsules, Milk powder

Steam wand, Induced air

Steam wand

Separate product

Integrated and Automatic

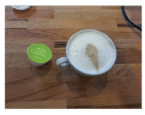
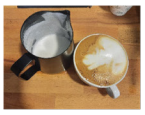
	Necafe Dolce Gusto	Senseo	Delongi M120	San Remo Competition	Lavazza LM7000	Senseo	Lattiz
							
							
Price	4 (€50)	4 (€50)	5 (€150)	1(€5000)	3(€250)	4(€75)	1(€2000)
Taste	0	0	3	5	4	4	2
Ease of use	5	5	3	1	3	4	5
Experience	2	2	4	5	3	4	2
Time	4	5	3	3	3	3	4
Cleaning	5	4	2	3	2	4	5
Score	3,33	3,50	3,33	3,00	3,00	3,83	3,17

Table 2 : Frothing peformance competitors machine's

Figure 13 : Milk frothing machines using a Whisk

5.2. Frothing principles on the market

Three frothing methods that use steam and froth milk without any skill of the user needed were further examined. As this is one of the main requirements of the milk frother. In figure 13 to 16 the machines can be found. The machines were categorised using the following principles: whisk, venturi and moving pipe.

Whisk

The Lavazza LM7000 and the Melitta Bistro (figure 13) use a combination of steam for heating and a whisk for aeration to create milk froth. It is a relatively easy method for the machine, however it adds a lot of separable components that have to be cleaned. The Lavazza machine has the option to change the amount of milk and froth, by using the buttons. It does not measure the temperature, and as shown in chapter 9.3 it frothing procedure is time based. The whisk is powered by a motor which could be controlled to change the frothing level. The Melitta uses a different approach, it uses a steam driven turbine to turn the whisk and the steam is later injected in the milk for heating.

Venturi (Milk)
Most of the fully automatic coffee machines have a milk frother function that uses a container or silicone hose to partially froth milk and flow directly into the glass. These frothing machines use the venturi effect to suck milk from a container into an aeration chamber. In the case of the Jura E8 machine sucks milk from a separate container with a silicone hose. The milk steam mixture is then released to an aeration chamber in which the milk is creating a vortex and the warmed milk frothed. The Philips LatteGo is also using a venturi to suck the milk, however the hose and aeration chamber is integrated in the container which consists of two easily separable parts that can be cleaned.

Figure 14 : Venturi thats draws milk

Venturi (Air)
A venturi effect is also used in a different configuration. In the Krups Carbon and Siemens EQ3 the venturi effect injects air into steam. When the steam air mixture enters the milk in a glass the milk is heated and areated. The Delongi M120 machine in chapter 7.1, also used this priniciple, however these machines do not require the user to hold a seprate jug at a specific place. The aeration process is controlled by the milk froth itself. The increasing volume rises the milk level in the glass which on its turn blocks the air intake hole for the venturi. Stopping the aeration when the glass is full. Cleaning wise this extra channel in the steam wand is prone to cloggs and should be througly cleaned after each use. The Siemens wand can easily separated and put in the diswasher and Krups even has an automatic cleaning program that uses steam and a disinfectant to flush the pipe after use.

Figure 15 : Venturi draws air

Vernturi (Air Pump)
Sage also uses a method of air injection in steam to froth milk automatically. However instead of injecting the air in the wand and jug itself, it injects air before the steam air mixture enters the steam wand. By placing the venturi injector in the machine, the process is not controlled by the froth itself and is therefore controlled by an air pump. Since the steam wand does not have to house the venturi channels cleaning is much easier, requiring a flush of inside by a steam purge and a quick wipe of the outside.

Figure 17 : Venturi areates steam

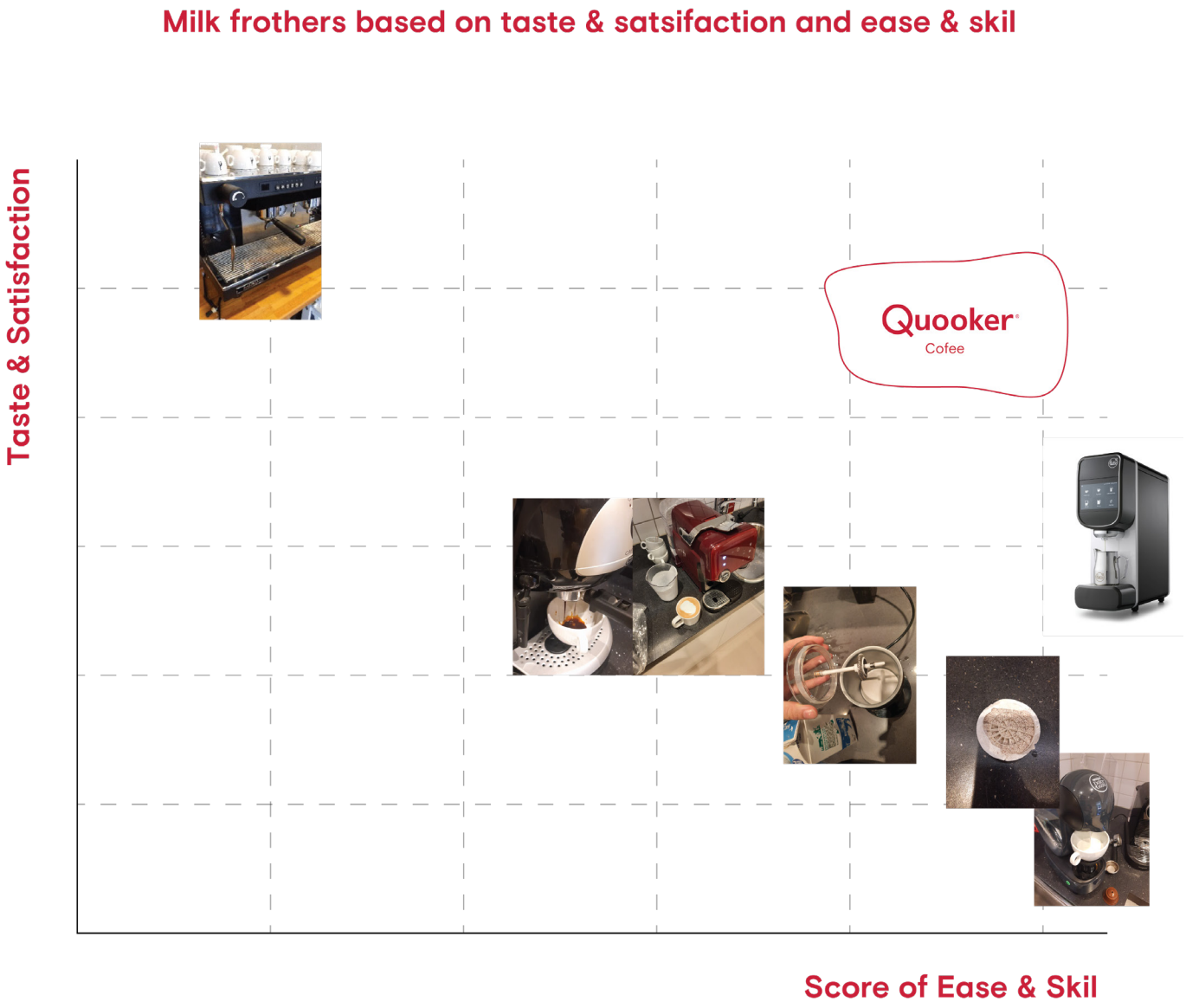
Moving Pipe (or milk)
In the professional coffee business, the milk frothing process is also automated to serve more customers with less trained staff. Two expensive machines mimic the barista by moving the steam wand and even tilting the milk jug. The perfect moose is taking the automation a level further by weighing the milk and sensing the type of milk before frothing to get the best result. The result is a quality milk froth and only a steam wand to clean.

Figure 16 : Perfect moose moving wand

Requirements

To get a better grip on what competitors are doing the results from the Competition's milk froth tests the results are placed on the axis shown in figure 18. When plotting the scores from table 2 the graph is as follows. Quookers Coffee market position as discussed in the assignment in chapter 1 is now placed with it's competitors. It needs to perform better with less skill required. The maximum sale's price of a Quooker milk frother is now set to be higher than a capsule based coffee machine's milk frother, at €300. However more research neeeds to be conducted with potential buyers and distributors what a system can costs.

Figure 18 : Quooker Coffee market position graph



Requirements

E1	Requirement	The milkfrother addition must not cost more than €300
E2	Wish	The milkfrother addition should not cost more than a separate milkfrother
G1	Requirement	There is expected that the milkfrother is sold to 50% of the people buying Quookers Coffee machine which is 20 percent of total tap sales. (300.000 * 20% * 50% = 30,000

6. User insights

6.1. Interview setup

Three Interviews were conducted to get a better understanding of who is a typical Quooker owner. Why did they buy their Quooker? And what is their relationship with coffee (machines). In the relation with coffee and coffee machines, a discussion is held to see what the Quooker customers perceive as quality.

The decision was made to conduct the Interviews over the phone, since conducting physical interviews is time consuming, and not necessary to reach the desired results. During the interview notes were taken for documentation, and afterwards the participants were asked If they want to share a picture of their kitchens to also get a better visual understanding. The full content of the interviews can be found in appendix D.

6.2. Interview conclusions

The reason the interviewees chose their coffee machines is mostly based on taste and the ease of the brewing method.
A capsule-based machine was chosen because it has the convenience of not having to maintain a fully automatic machine while having the possibility to try a lot of different flavours.

One participant was almost in love with their fully automatic machine she had received as a gift. She was happy enough to buy a new one after the first was decommissioned after 10 years of use. The perception of still using ‘fresh’ beans that are not milled, without having to go through all the milling and brewing steps was the main reason of use. The piston machine was bought as the participant had experience with the piston espresso brewing method from a student working in a café and liked to consciously brew a coffee from bean to coffee to add emotional value to the qualitative coffee.

Figure 19 : Kitchens of the interviewees

In terms of milk, all the participants had experimented with various products, all ending up with a version of Nespresso's Aerochino shown in figure 20. According to the participants no skill and not much hassle is needed to produce decent quality milk froth.

The participant with the machine that had a steam wand did not use It anymore as the cleaning process was too much effort. One Aerochino was always stationed next to the coffee machine while the other two were stored out of sight in a nearby cabinet. For milk, the small portioned sterilised semi skimmed milk was favourite to make cappuccino's as it could be stored for a longer time. None of the participants had any alternative milks at home.

Figure 20 : Nespresso Aerochino

Requirements

The requirements that can be drawn from the user interviews are mostly focused on the design and use of the milk frother. The frothers cleaning process must be easy and preferably fast. The safety requirements will also be of importance as the product uses hot steam that can potentially harm the user.

A3	Requirement	The product must be easy to clean
J1	Requirement	The product must look premium with preferably the use of metal instead of plastics
L1	Requirement	The product must be fast in use
L2	Requirement	The user must be able to use the product without any skills or training
L3	Requirement	The product must be cleaned with regular cleaning supplies
L4	Wish	The product should be cleaned within 10 seconds
M1	Requirement	The product must not harm the user in any way
M2	Requirement	When steam used it must be clear to the user that it is not safe to come near the steam exit
M3	Requirement	The product must communicate that surfaces can be hot

Exploration phase

7. Steam production calculations & tests
8. Ideation

In this phase a series of tests provide techincal specifactions that helped to supplement the already set requirements and the exploration of potential solutions are peformed.

7. Steam production calculations & tests

Before physical testing it is wise to gather theoretical knowledge on what influences the steam is creation process. Basic thermodynamic calculations were conducted. First focusing on latent heat, the energy required for a phase transfer and afterwards the energy transfer when heating water with an electric heating element. The practical side of making steam is also examined by studying a Quooker kettle, an existing coffee machine and two heat block system's that were fed by hot water provided by a Quooker kettle.

7.1. Steam Energy Calculations

When making calculations the two situations were examined. First the production of steam using steam using an electric heater is examined. The second system examined, is the energy lost when an aluminium heat block is kept at a constant temperature and is losing energy to its environment.

A heating element of 1000[W] is used to create steam at 140 °C from 1cm^3 water at 100 °C as shown in figure 21. The density of water is set at 1 [ml g^{-1}] and the specific heat capacity is 4,186 [J cm^{-3} K^{-1}] and the Specific latent heat at 140 °C is 2144 [J kg^{-1}]

First the specific heat capacity formula is used to increase the water's temperature with 40 °C. When filling in the formula the result is 334,88 J

$$\Delta Q=1[cm^3] * 4{,}186\ [J\ cm^{-3}\ K^{-1}\ ] * 40\ [K] = 334{,}88\ [J]$$

Secondly the specific latent heat coefficient is used to determine the amount of energy needed to change the phase of liquid water into steam also known as Latent heat.

$$Q= 1\ [cm^{-3}] * 2144\ [J\ cm^{-3}\ ] = 2144\ [J]$$

As can be seen the amount of energy to change water to steam (87%) is significantly higher than heating the water 40 °C (13%). Lastly the amount of time the process take to transfer 1ml into steam can be calculated with the energy provided by the electric heating element. Which is 2,4 seconds which is 24,2 ml per minute.

$$(2144\ [J] + 334{,}88[J]) / (1000\ [Js^{-1}])=2{,}4\ [s]$$

In an ideal world the heating element transfers its rated power value of electric energy to the water at 100% efficiency. In the real world this is not the case and the specifications of the heating block affect the time of coming up to temperature and the maximum of dry steam that can be created. The basic thermodynamics calculations can help to pragmatically get a sense of how much energy is lost due to conduction, convection with air and convection with water.

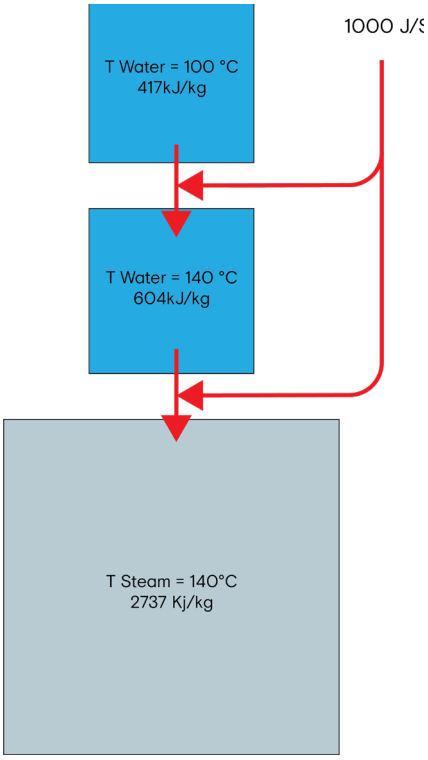


Figure 21 : Steam Energy Transfer

Heating Element losses

As an example, system the DeLongi coffee machine heating block in figure 22 is taken. The electric heating element first heats up the element to 140 °C and is then keeping the aluminium block at a constant temperature of 140 °C. The block weights 127g and has a contact surface with the air of 55,8 cm2 and was taken from the CAD model. Through the block water 100 °C is flowing. Heat is conducting through 2 tubes with a length of 0,33 [m] and an outside and inside diameter of 4 and 2 [mm]. The tubes are made of polytetrafluoroethylene which is also known as Teflon and shorter written as PTFE.

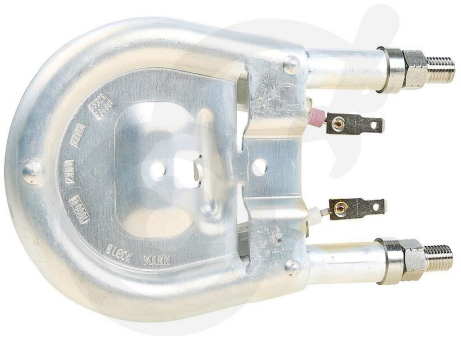


Figure 22 : Delongi Heating Element

The heat up time of the element can be calculated with the specific heat capacity of the material and the weight.

$$\Delta Q = 127[g] * 4{,}186\ [J\ g\ K^{-1}] * 120\ [K] = 13670\ [J]$$

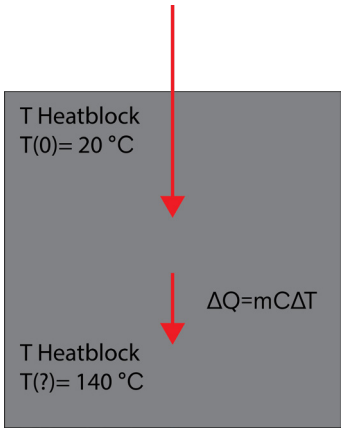


Figure 23 : Heatblock Heating

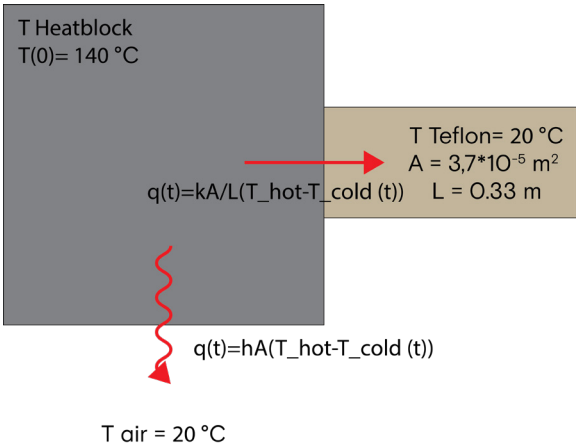


Figure 24 : Heatblock Heat Loss

With a heating element of 1000 J S^{-1} heating the mass of aluminium takes 13,7 seconds. The aluminum heating element loses heat to the air and Teflon tubes, the system is shown in figure 25. The specific heat transfer coefficient is used to determine the energy loss through convection.

$$\Delta Q(1) = 10\ [JS^{-1}\ K^{-1}\ ] * 0{,}05\ [m^2] * (140\ [°C] - 20[°C]) = 67\ [J\ S^{-1}]$$

The loss is 67 [W] which is 6,7% of 1000 [W] and is quite significant. Thus making sure the heating element is well isolated will increase the efficiency of the heating element.

The PTFE tubes conduct energy away from the heating element with the thermal conductivity coefficient of PTFE and the formula for conduction the energy lost per second can be calculated. The transfer coefficient of PTFE is 0.22 [J S^{-1} K^{-1}]

$$\Delta Q(1) = 0.22\ [J\ S^{-1}\ K^{-1}] * 3{,}7 * 10^{-5}\ [m^2] * 0{,}33\ [m] * (140\ [°C] - 20[°C]) = 0{,}003\ [J\ S^{-1}]$$

With only 0,003 [W] the energy loss is very small in comparison to the losses due to convection.

7.2. Quooker steam test

Before designing a milk frothing specific system, existing Quooker system was studied. The goal was to learn how the system operates and what it takes to get steam flowing out of the tap. This was achieved by heating the kettle to 140 °C and opening the electronically controlled valve.

During the test the original electronics that manage the heating element were bypassed by a separate thermostat that had one thermocouple placed in the bottom of the thermometer tube. The circuitry managing the tap's input and solenoid valve was not changed.
The result was a tap that was spitting high pressure steam (figure 25). The pressure was too high for comfort, and after switching of the heating element the well-insulated kettle was not cooling down and steam was still coming from the tap. When the intake tap was also closed the amount of steam could be kind of controlled.

Figure 25 : Tap Spiting Steam

7.3. Coffee machine steam test

One of the coffee machines capable of making milk froth with steam was further examined from a technical point of view. The machine a Lavazza LM7000 designed and manufactured by AEG. First the machine was disassembled to learn how the machine creates and controls steam for frothing and afterwards the machines milk froth function was deeper researched by measuring the time and temperature power draw of the machine during frothing (figure 26). A more elaborate report of the analysis of the machine can be found in appendix E.
The results from the test can be seen in table 3. The disassembly of the product resulted in a better understanding of how the machines parts use water and electrical energy to a jug of frothed milk. A visual representation of the system can be seen in figure 27.
The disassembly of the product resulted in a better understanding of how the machines parts are transforming water and electricity in a jug of frothed milk. A visual representation of the system can be seen in figure 27.

Figure 26 : LM7000 Peformance Test

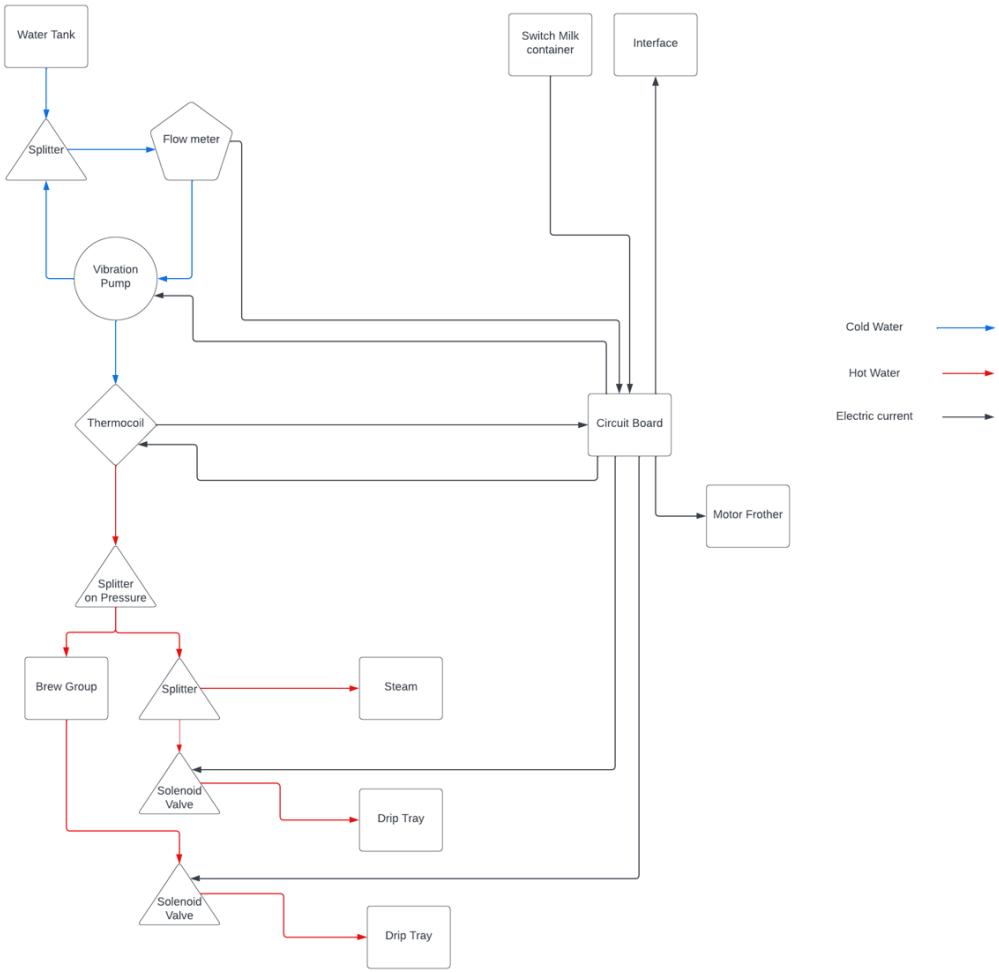


Figure 27 : Lavazza LM7000 Schematic

Heating from Cold			
Time	49	S	
Temperature	128,7	°C	
Power	1220	W	
Coffee			
Time	17	S	
Temperature Thermoblock	119,9	°C	
Temperature Coffee	61,4	°C	
Power	1200	W	Turns on after serving
Milk			
Heating time	17	S	
Time Frothing	60	S	
Temperature Thermoblock Start	138,8	°C	
Temperature Thermoblock Min	117,2	°C	
Temperature Thermoblock Max	164,7	°C	
Temperature Thermoblock End	145,7	°C	
Temperature Milk Start	9,6	°C	
Temperature Milk End	99,2	°C	
Power	1200	W	Switches off after 15 seconds, after 30 seconds on again.

Table 3 : Temperature and timing when frothing

A few conclusions of the functioning of the coffee maker can be drawn.
The machine is not having an advanced heating control. It switches the heating element on and off, no variable power drawn was measured. The exact point when it starts or stops heating needs to be further studied.

The thermocoil is used as a buffer for hot water. During the coffee serving it only switched on after the serving was completed. The thermal energy stored in the thermocoil when heated was high enough to pour one serving. For steaming the milk, the thermocoil was heated to a higher temperature and the motor was pulsing slower.

The steaming time was exactly 60 seconds and when measuring the milk's temperature, it became too hot (99 °C). Which was caused by not pouring enough milk in the container.

7.4. Thermocoil steam tests

With the gathered knowledge from the coffee machine a first setup of a Quooker kettle and a thermocoil is built. The Quooker kettle is designed with an operating temperture slightly above the temperature of boiling water. Increasing the temperature to make the kettle produce steam stresses parts and seals which are below specified. The goal for this test is to study the behaviour of adding a heatblock after the Quooker.

The two thermocoils used are a philip heatblock boiler of 1400 watts, which is suitable for the EP1220 coffee maker (onderdelen.nl a ,2020) and a specific steam heatblock rated 1000 watts from the brand delgoni. (Onderdelen.nl b, 2022). The schematical setup of the test can be seen in figure 28 and figure 29 shows the thermocoil connections. A Hengstler Grado 923 thermostat in combination with a K-type thermo couple switches a relay that turns the heating element on and off. A separate digital thermometer with a K-type thermocouple is used to probe the temperatures at various locations.

Figure 29 : Thermostat and Thermometer

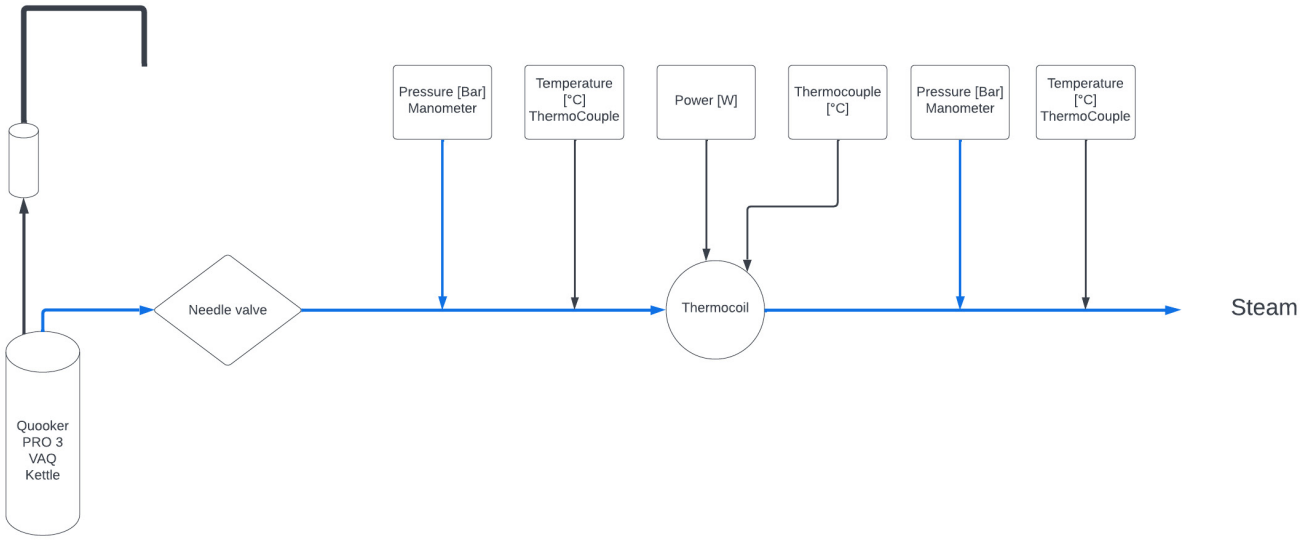


Figure 28 : Test setup Schematic

Phillips EP1220 Thermocoil

push fit connectors and silicone tubes. As shown in figure 30. The heater was fixed on a wooden board with a clamp. It was possible to create steam with the setup.
The following lessons were taken.

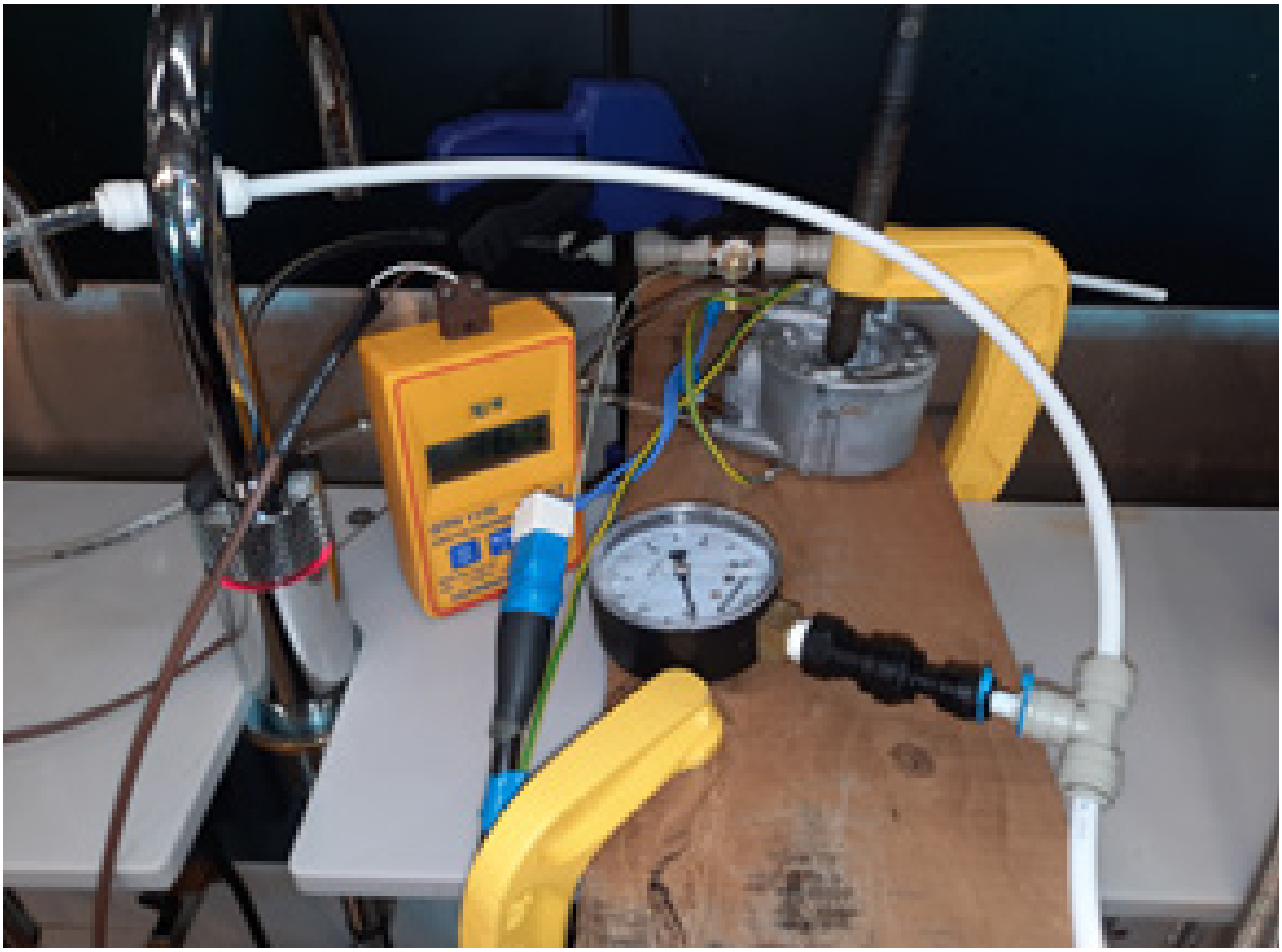


Figure 30 : Phillips EP1220 Thermocoil Test

- All the tubes and connections were softened after a few seconds after heating up. Long duration steaming was not advisable as the connections were taking on leaks, of high temperature water and steam.
- When the needle valve is completely open 1500W only heats the water to 60 °C and the thermostat showed 100 °C
- The measurment instruments were varying a lot, occasionally more than 10 °C
- With the thermocoil it is possible to create steam however due to condenstation in the lines after the heater and evaporation inside the spool the steam pressure was fluctuating and shooting out water once per few seconds
- The thermocouples used had a slow response time. After closing the relay the themerature would still rise with 20 °C

Delongi Steam Heater

With lessons from the philips heater the delongi heater is specifically designed for steam production was used to create a second thermocoil setup. The same control system was used with the Hengstler thermostat. The heater's screw connections were used to connect a steam wand from the Decent Coffee machine (Decent, 2022). A coupler piece had to be manufactured on a lathe to be able to contect the Quooker kettle's M12 x 1.25 thread with the delongi's M8.

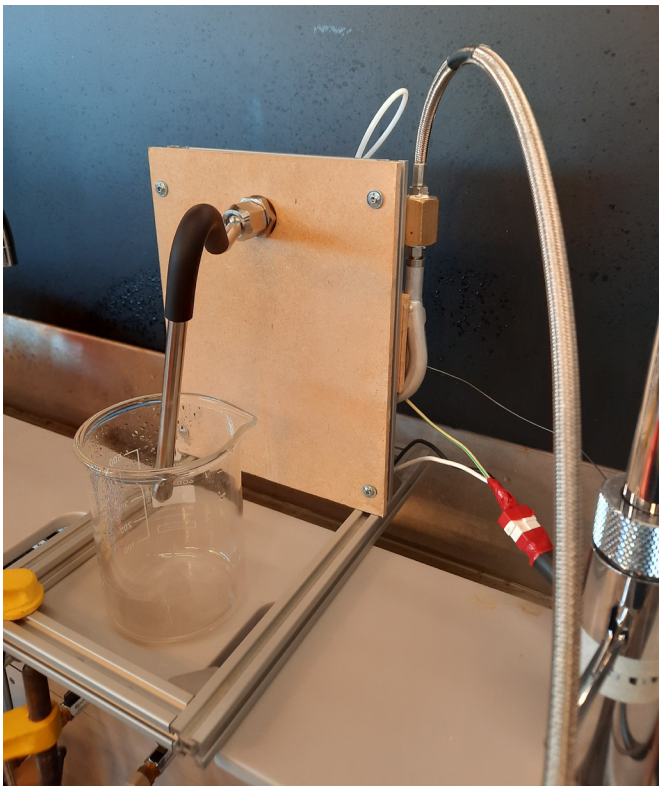
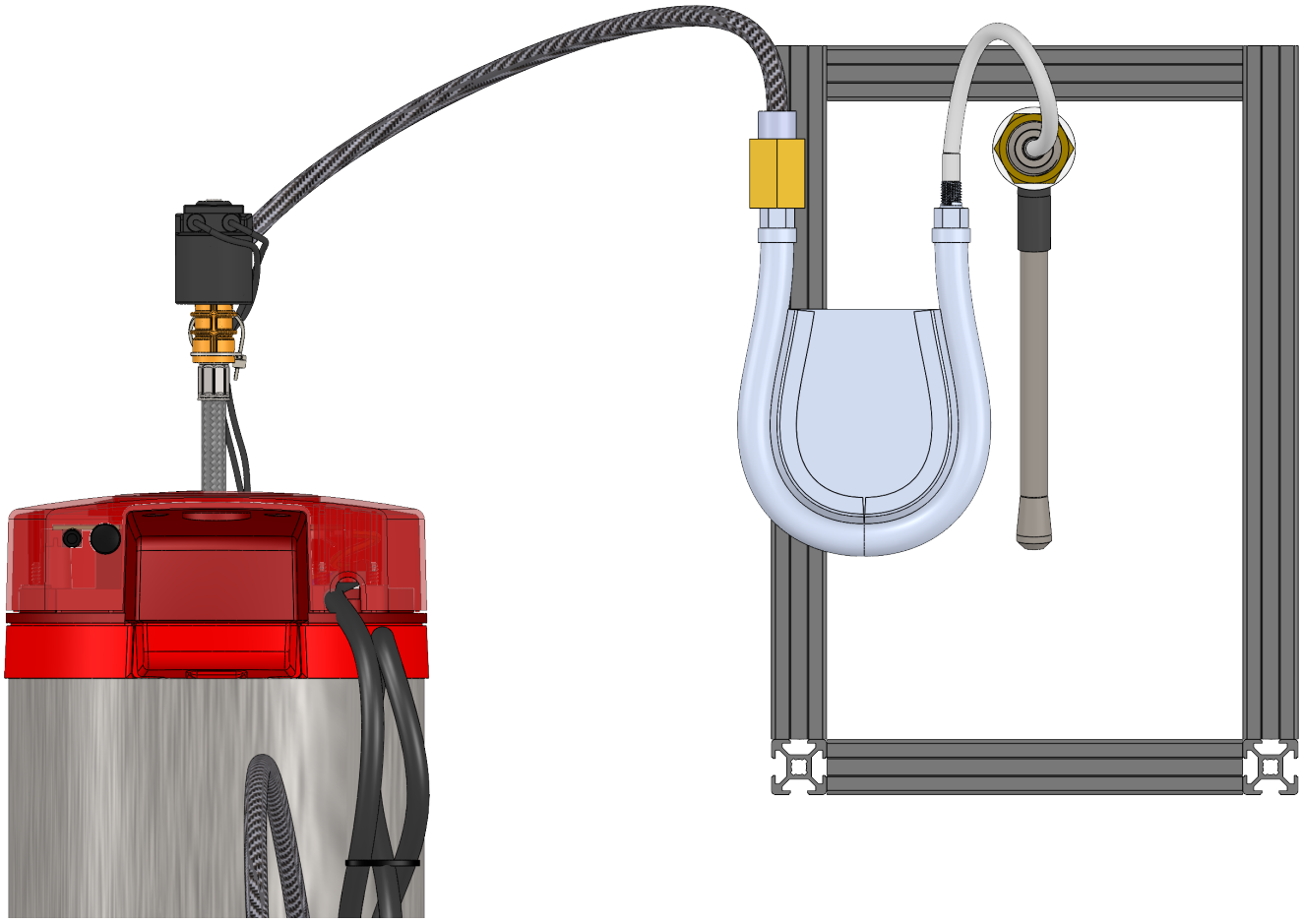


Figure 32 : Delongi Steam element Test

Figure 31 : Delongi Steam element Test setup



The following lessons from this setup were taken:
The pressure of the steam was quite low. It was possible to froth milk, however the froting took longer than with machine that uses a boiler for steam creation.

The shape of the heater did not suffer from the condensation problem in the phillips thermocoil. However the thermosat still had problems keeping a constant temperature. Fluctuating between 10°C below the setpoint and 30°C above

•The brass coupler worked without any leakages, however the coupler could conduct heat to the hose connected to the kettle, losing energy to heat water and making the hose to hot to touch.

The magnetic valve in the Quooker system closes after a set amount of time. A connected tap's knob was needed to open the magnetic valve, as in boiling water tapping. For the future setup the magnetic valve needs to be constantly open or controllable without the kettles circtuit board.

Requirements

With the lessons taken from the calculations and steam production tests the following requirements are set.

B1	Requirement	The product must remain functional when working with steam at 140 °C
B2	Wish	The product should resist cleaning agents commonly used in the kitchen
K1	Requirement	Stainless steel must be used for contact with milk
K2	Requirement	Plastics that are used and come into contact with hot steam must be able to cope with high temperatures 140°C
K3	Wish	The use of easily milled brass should be minimized

8. Ideation

8.1. On counter device ideation

Before deciding on which milk frothing method was further examined in the concepts a quick ideation was conducted to see what shape the milk frother would get above the counter. It should meet Quookers design vision requirement J2 being geometric and not too complex shape. Later the shapes could be quickly placed in CAD (Computer Aided Design) software as the shapes are not having a lot of features.

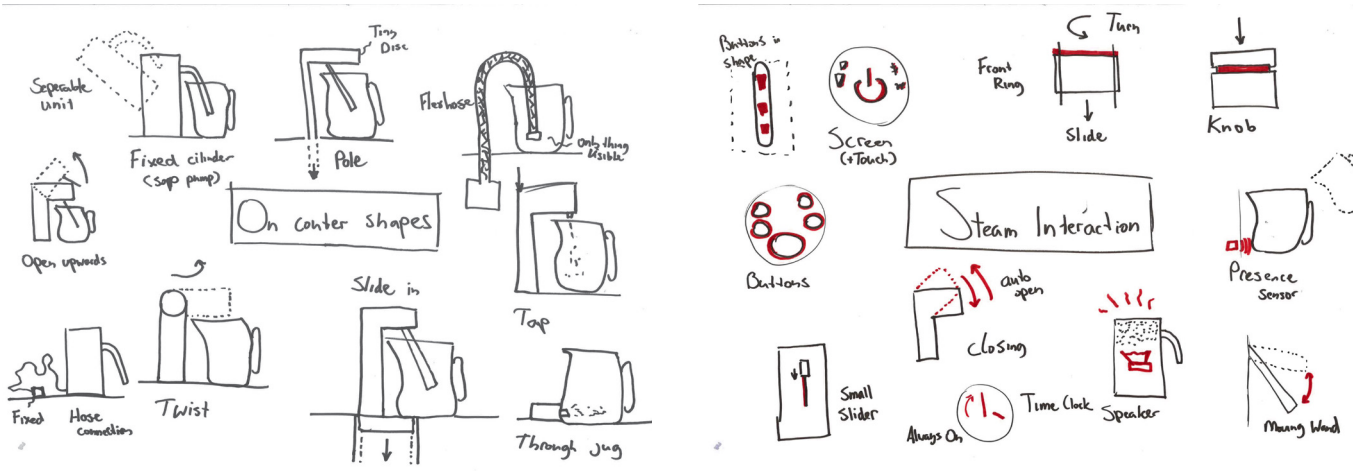


Figure 33 : Ideation Steam and Configuration

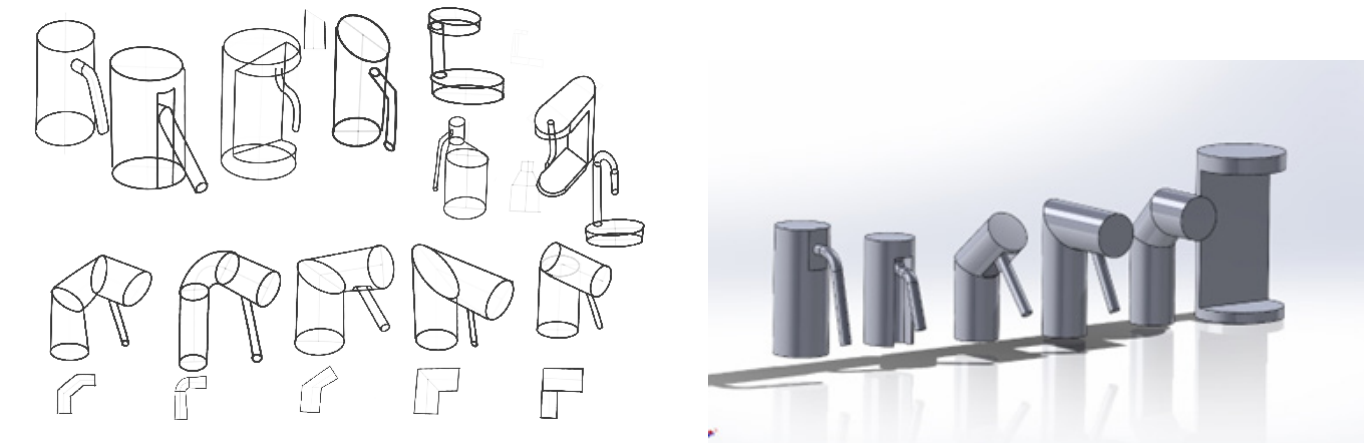


Figure 34 : Ideation Shape on counter device

8.2. Frothing principle ideation

From the frothing principles discussed in chapter 7.2 the following conclusion was drawn to continue with in the concepts. Ideas on which mechanisms could solve the motion of the frothing method and can be seen in figure 35.

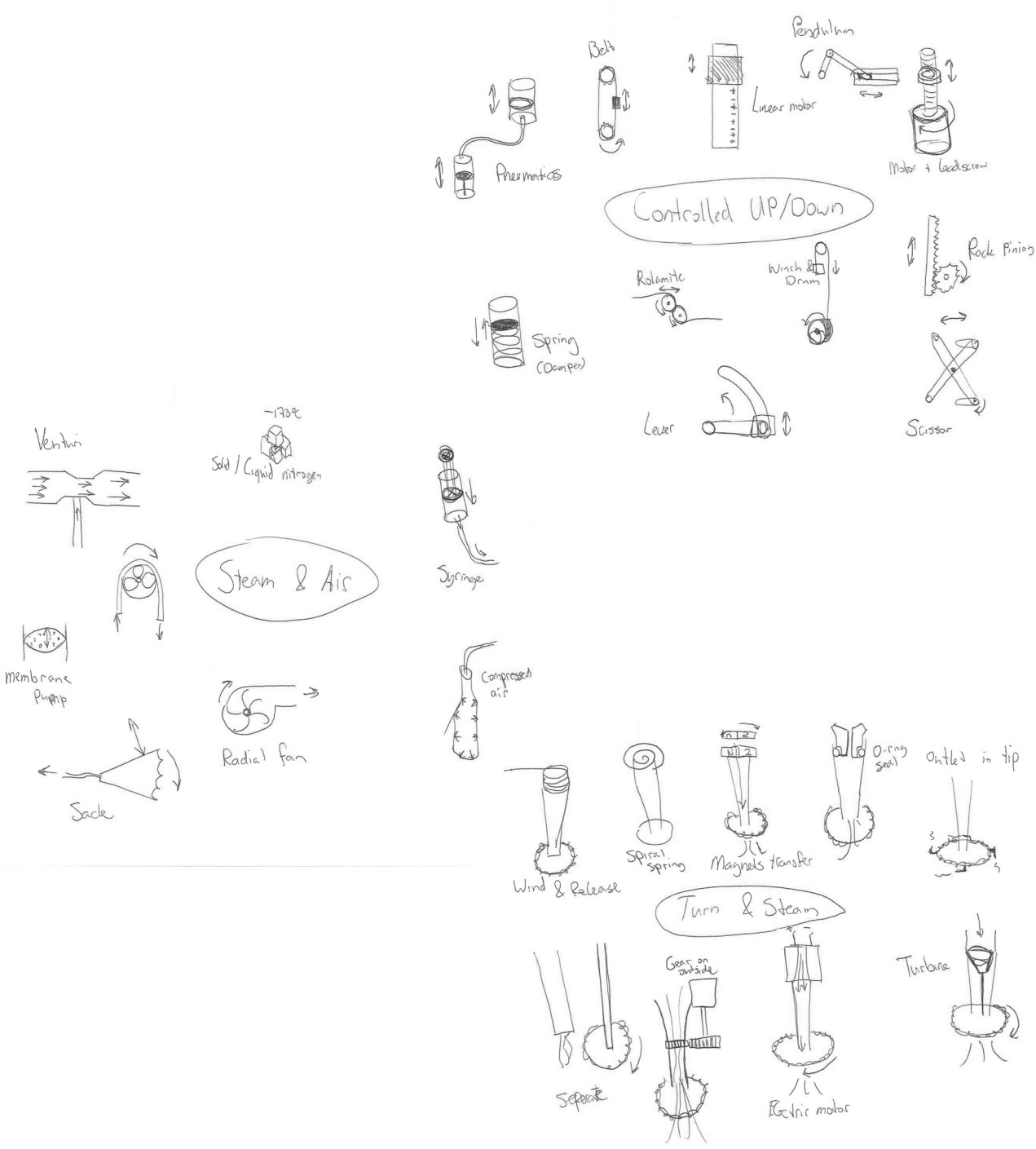


Figure 35 : Ideation Frothing Principles

8.3. Envicionsed scenario

A possible solution direction was drawn out in a scenario to be able to determine the functions that the milkfrother need to fulfil (figure 36). It was also used as a conversation starter within Quooker to discuss if the usage of a separate milk jug will be accepted by the user. In comparison to the coffee machines that directly dispense frothed milk into the cup.

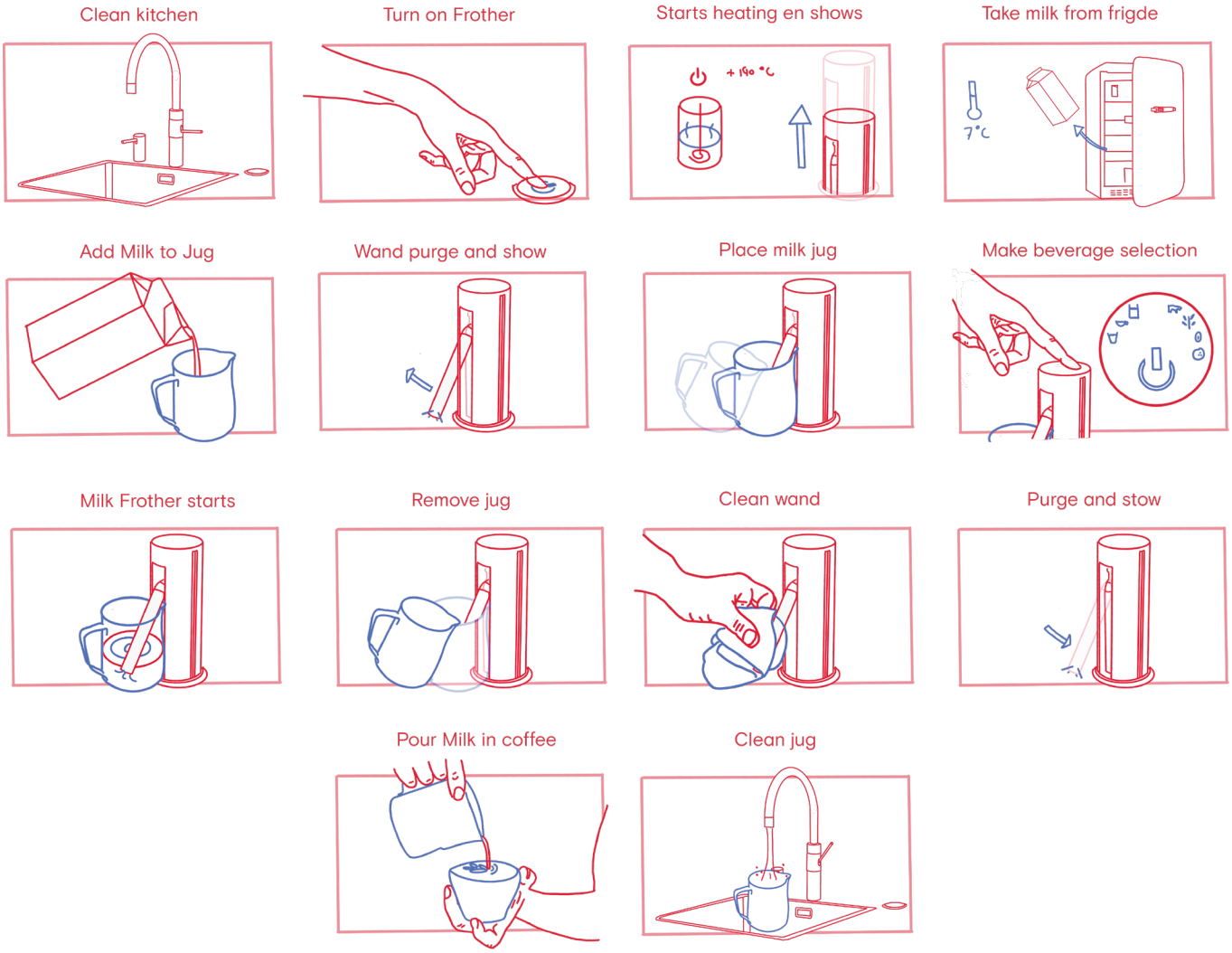


Figure 36 : Envisioned scenario

8.4. Frother function tree

Figure 37 shows the function tree of the envisioned milkfrother. Steam production and the transportation of the fluids/gasses is placed underneath the kitchen counter. The Aeration function to automatically froth milk without any skill is depending on the frothing principle. Above the counter the frothing and user interactions will take place. As well as the cleaning and storing functions that the milkfrother is going to perform. The scenario discussed in chapter 9.3 is used as a basis for the tree. A larger version can be found in appendix F.

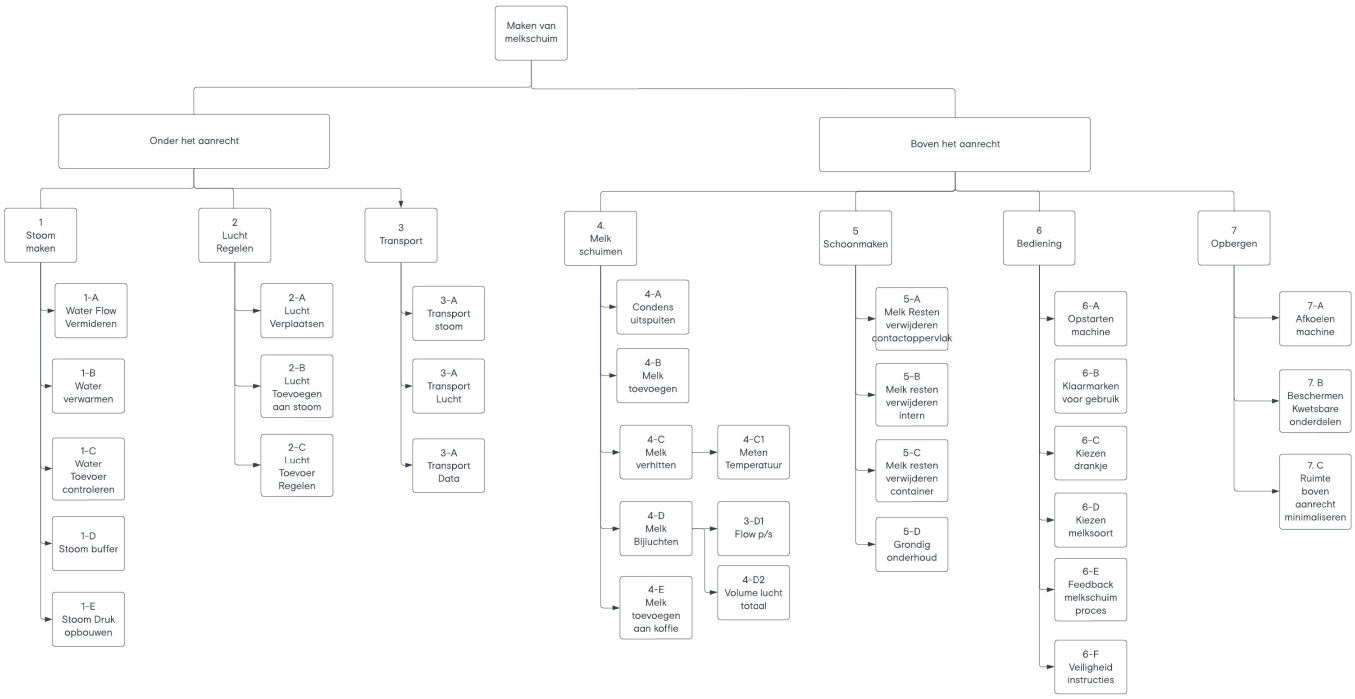


Figure 37 : Function Tree

8.5. Morphological chart

The idea's generated in chapter 9.1 and the function three from chapter 9.4 are combined to form a morphological chart (figure 38) that acts as a starting point for the concept development. The coloured lines from a functioning of the milkfrother with the series of solutions.

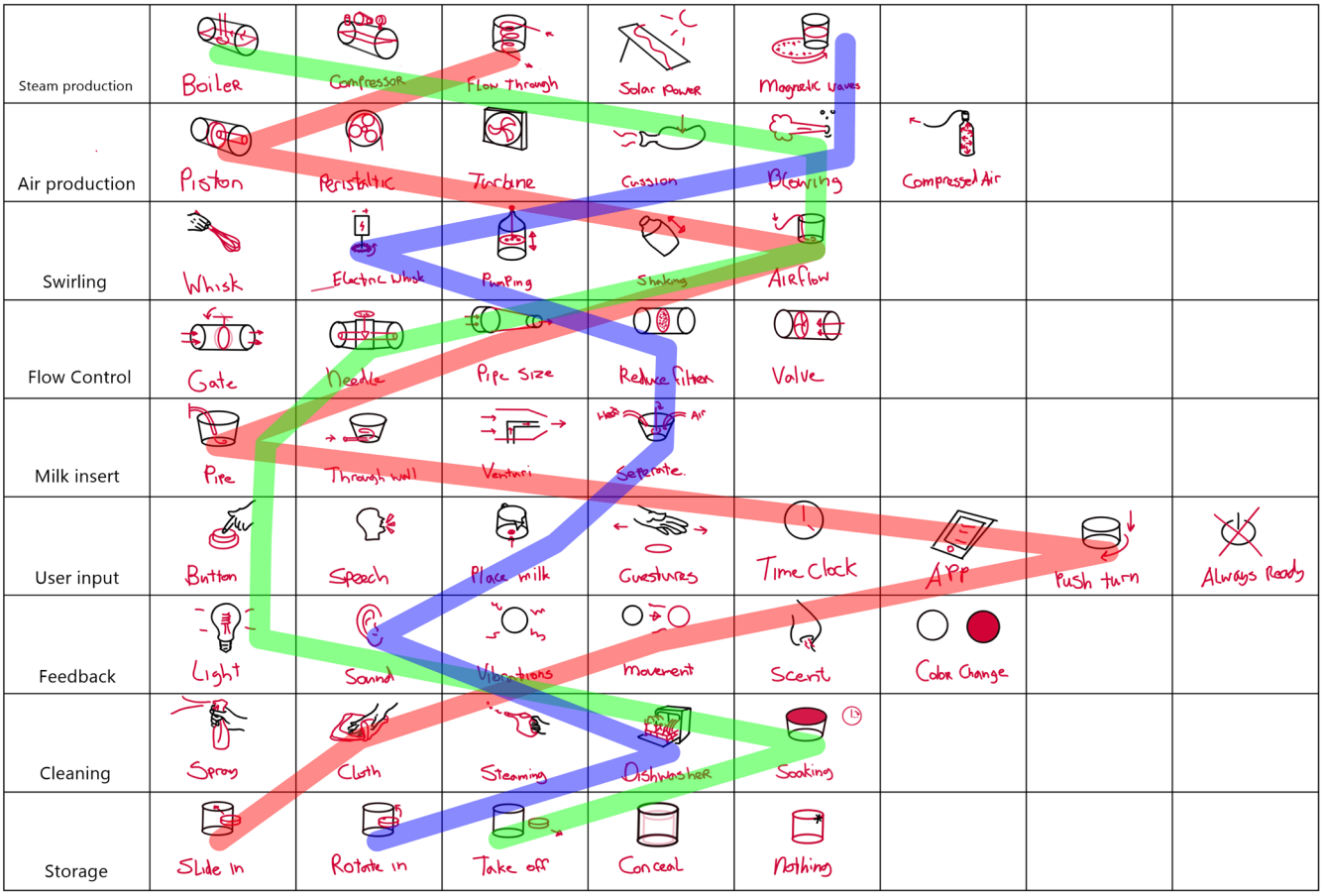


Figure 38 : Morphological Chart with function solutions

Concepting phase

9. Conceptualization

In this phase the concept's interaction and a first technical embodiment is shown. Afterwards a cost price estimation is given based on 30.000 pieces both manufactured and purchased parts.

9. Conceptualization

9.1. Concepts 1: Smart & Minimalistic

Interaction

The first concept can be stowed away into the kitchen countertop. To achieve this all the parts, must be able to retract and extend in and from the main cylinder shape. The user's interaction is also minimized, meaning that the frothing process goes fluently without any thoughts. However, this also means that no personalisation can be done to the drink and just like the Nespresso Aerochino can only make one type of milk froth. Figure 39 shows the full process of making a jug of milk froth. The feedback for the user is provided by a LED ring placed on top of the cylinder. Its interaction characteristics such as colour and blinks are not designed yet.

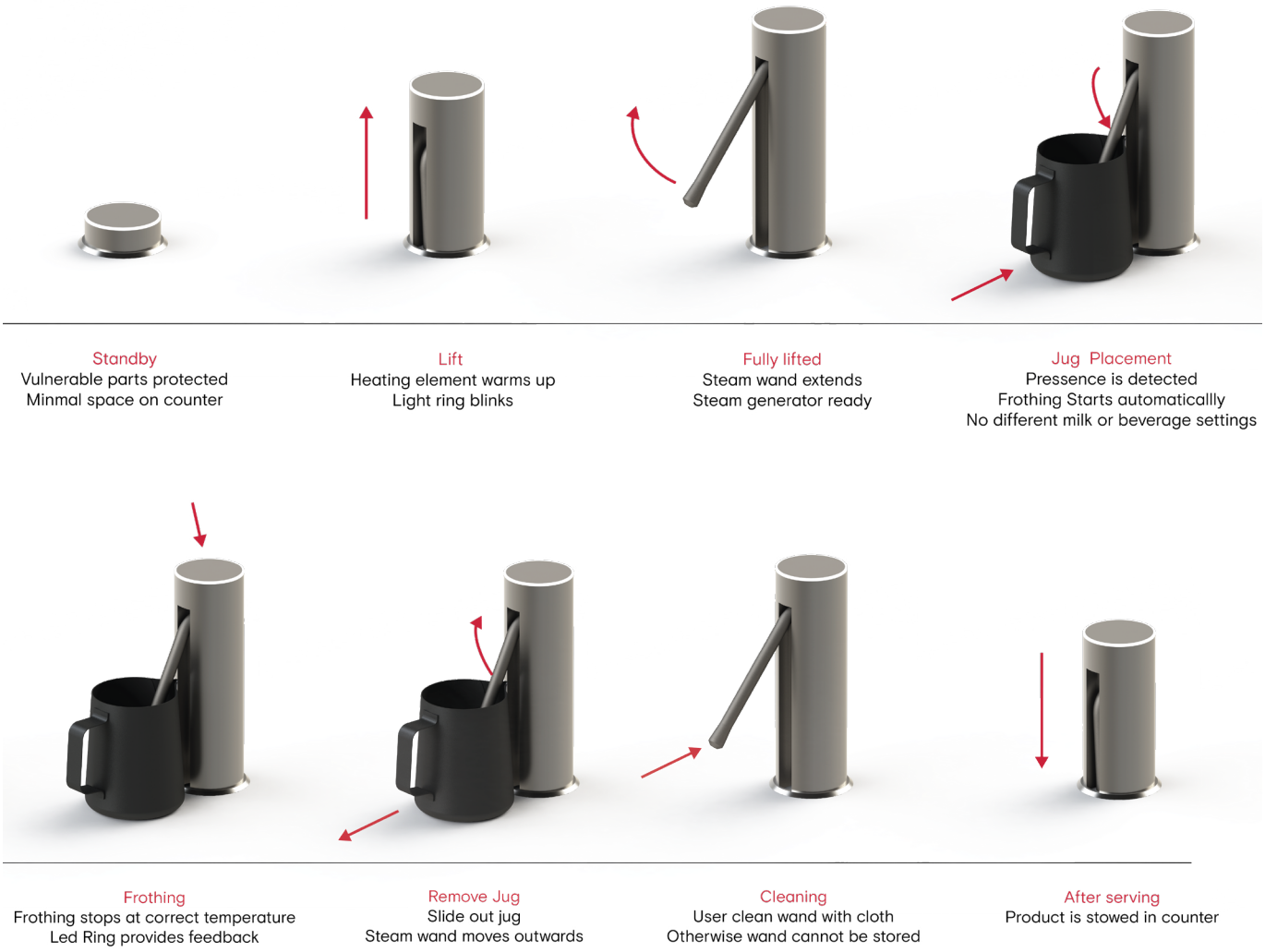


Figure 39 : Concept 1 frothing process

Mechanism

The first concept is providing aeration by adding air to the steam flow before it enters the milk. This is realised by a venturi injector and an air pump powered by an electric motor. The Sage Barista Touch coffee machine is taken as an example that uses this frothing method. A disassembled venturi found in the Sage machine can be seen in figure 41. It is already used in coffee machines and with more space available under the counter it is not further researched in the concept phase.

The on-counter part of the frother can be retracted for storing it when not in use (figure 40). Two grooves on the exterior of the product guide the product up and down inside the guide ring (orange) that is installed in the counter. A stop piece (green) is stopping the movement when the product is extracted too much. The movement is actuated by the user and when complete the steam wand pops out of the base.

The steam wand swivels around an axis and is mechanically actuated to make the placement of the milk jug possible. The rotational force is provided by a rotary spring (pink) that is complemented with a rotary damper (yellow) to smoothen the motion. While stored and frothing an electronically moved solenoid piston (blue) is keeping the wand in place.

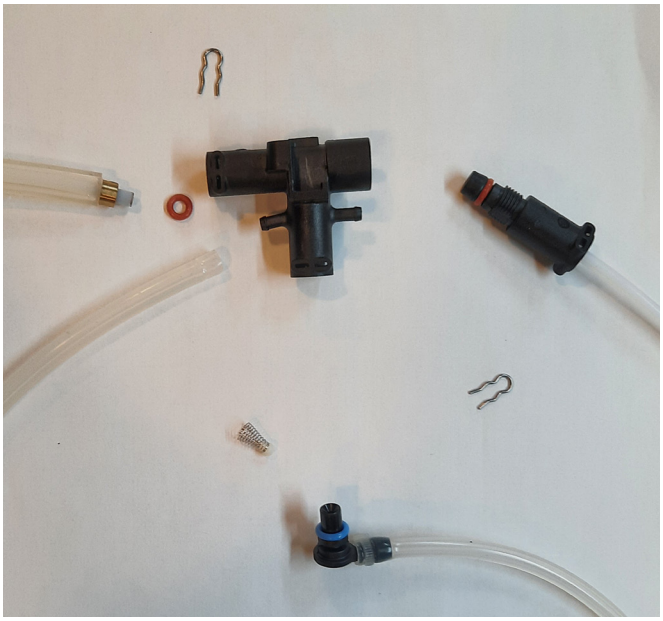


Figure 40 : Sage Venturi Disassembled

An estimation of the cost price was made with the injection moulded parts having an investment of €30.000The estimation was made using the calculator of custom part (2022). Investment price for the small pieces a mould's investment is around €10.000. Material costs are expected to be €0.30 per part and production costs 1/3 of material price at €0.10. The less critical air pump and the solenoid can be purchased for €1 and €0,5 (Alibaba, 2022). Totalling €5,80 per frothing principle when producing 30.000 pieces (Table 4).

What	Price
Tooling investments	€ 30.000
Small injection moulded parts	€ 2
Material price & Manufacturing	€ 2
Air pump	€ 1
Solenoid	€0.5
Spring Damper	€0.3
Total (30.000 pieces)	**€5.8**

Table 4 : Concept 1 Cost price

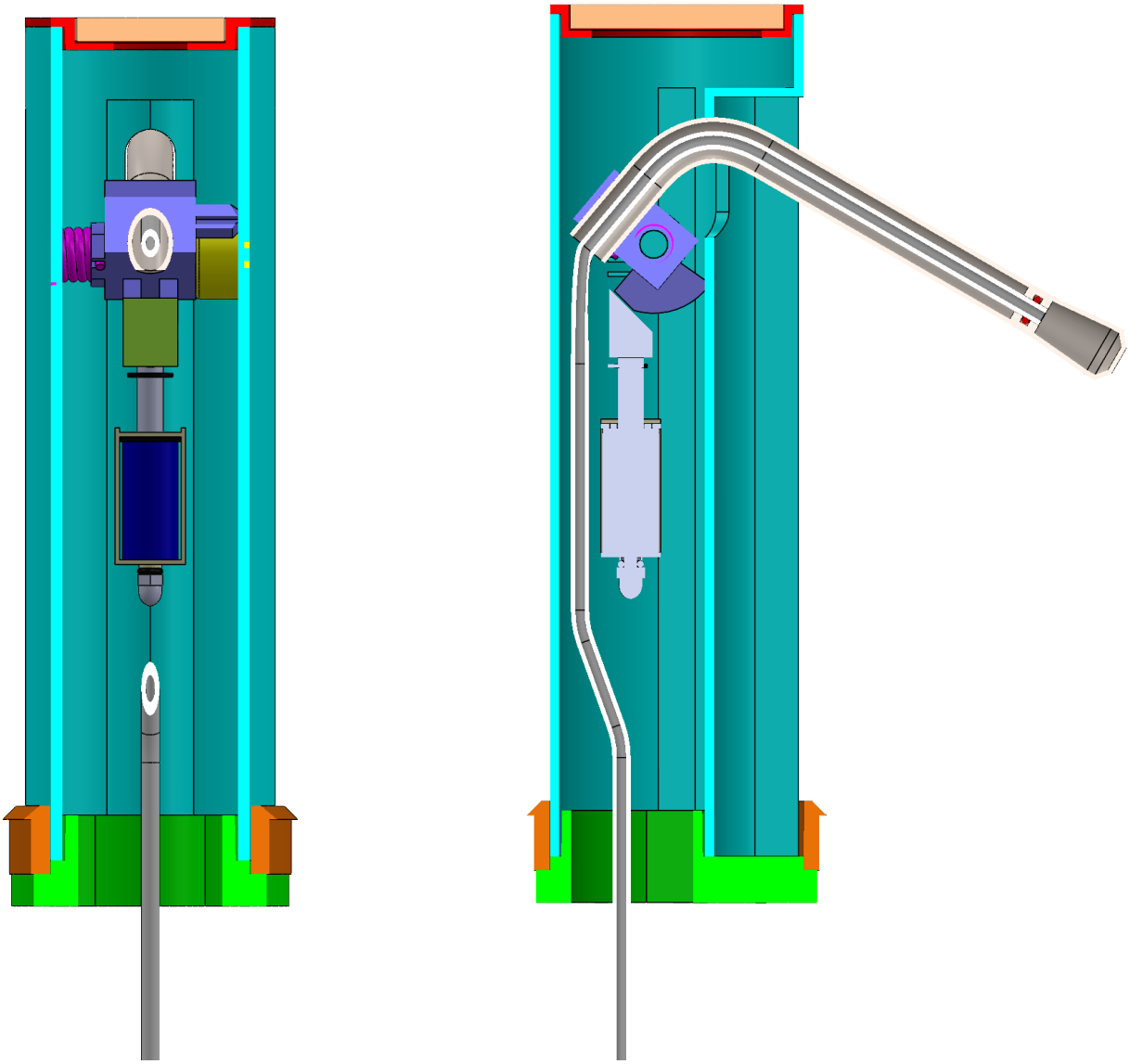


Figure 41 : Concept 1 on counter mechanism

9.2. Concepts 2: Classic Whisk

Interaction

The second concept is more traditional with a steam powered whisk that also heats the milk. The whisk is removable to make cleaning possible. The geometric and simple often found at Quooker needs to be turned towards the user to start heating. When placing the jug the whisk has to enter from above, this meant that the top part of the shape had to hinge open to make this possible. The user's feedback is provided by a Led ring placed in the knob that can be used to alter the frothing settings. The ring's inspiration comes from Quooker's new Front tap. Figure 42 shows the full frothing process.

Figure 42 : Concept 2 frothing process

Mechanism

In the second concept (figure 43), aeration is achieved by a rotating whisk. The rotating movement can be achieved in multiple mechanisms, in the concept the Melitta Bistro is taken as an example as it uses the steam power to both whisk and heat the milk at the same time. It's approach with a turbine does not need a complex mechanism with a sealed motor shaft that does not let steam escape. Instead, a turbine (green) with its bearings (white) are housed in a closed chamber (orange) with a detachable hollow pipe (black) and whisk axis (grey). Steam enters the chamber by a polytetrafluorethylene (PTFE) hose that is coming from the steam generator, drives the turbine and can escape through the pipe in the milk.

The parts that make up this mechanism need to be custom fabricated. In the case of the bistro machine all the parts are made from polyamide and polyphenylene sulfide which can withstand the high temperatures. Parts production price is mostly coming from the investments required to manufacture the moulds. The injection moulded pipe is deeper than the other parts with a bayonet feature and is expected to be more expensive at €20.000. Totalling €8,1 when producing 30.000 pieces. (Table 5)

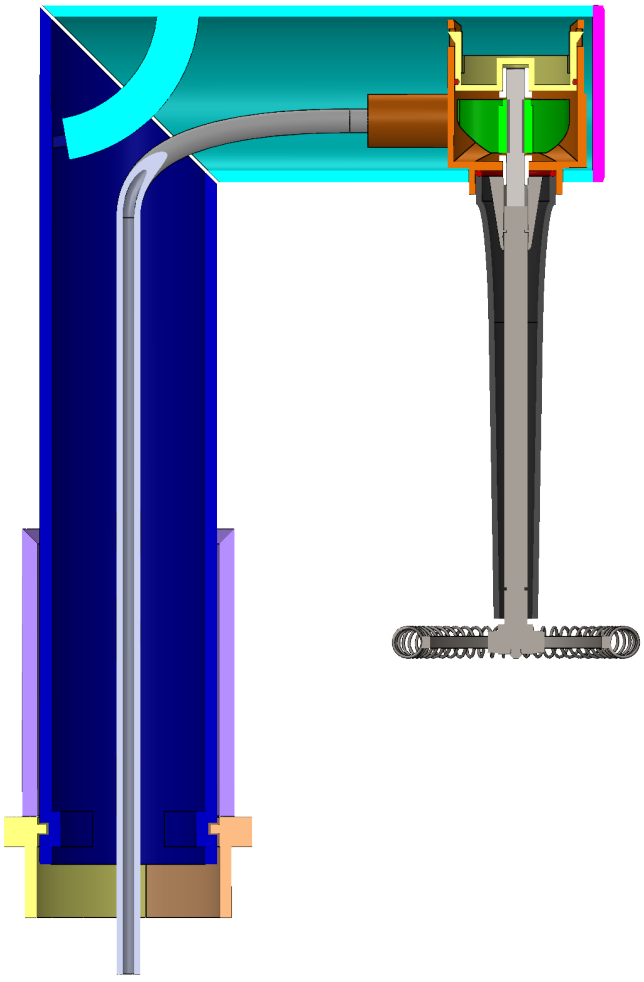


Figure 43 : Concept 2 Mechanism

What	Price
Tooling investments	€ 50.000
(3 times small & simple)	€ 3
(1 time deep)	
Small injection moulded parts	
Material price & Manufacturing	€ 3
Metal rod	€ 1
O-rings	€0.1
Total (30.000 pieces)	**€8.1**

Table 5 : Concept 2 Cost price

9.3. Concept 3: Mechanical Barista

Interaction

The third concept is coming most close to the frothing process performed by the barista in a café. The steam wand that only ejects steam is placed at a specific height in the jug and by creating a vortex with the pressure the milk is aerated. The selection of the milk and beverage type is now clearly presented with back-lid buttons. The whole unit can be removed from the countertop leaving only a small connector piece. The full frothing process with this concept can be seen in figure 44.

Figure 44 : Concept 3 frothing process

Mechanism

A mechanism with a motor driven leadscrew and two sliding axis was further examined to move the pipe up and down. parts are widely used in for example 3D printers and the motion can be precisely controlled without being too fragile.

In figure 45 two section views of the mechanism can be seen. The motor providing the rotary motion is a Sanyo SY20STH42-0804Asteppermotor, the lead screw is 6mm diameter with a lead of 2 mm. The carriage shown in red is holding the pipe, lead nut and is sliding on two hardened stainless-steel rods of 4 millimetres. Linear ball bearings (LM4UU) provide a smooth travel up and down and make sure the pipe lead screw is only loaded vertically. The parts can all be bought at for Misumi a mechanical hardware retailer. As can be seen in the model a PTFE pressure hose moves the steam from the inlet at the bottom to the wand's tip, as is done in the Steam wand from the Decent Coffee machine, shown in figure 46.

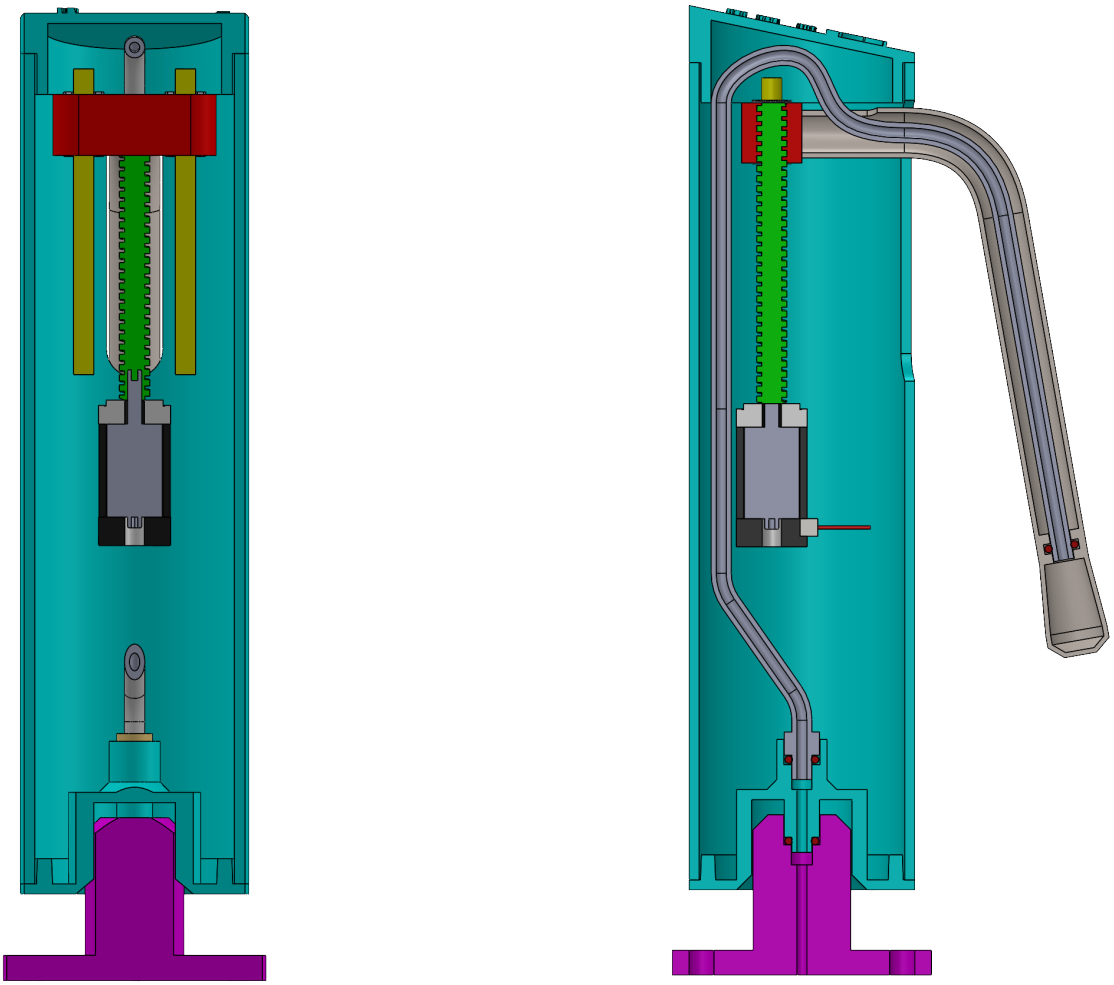


Figure 45 : Concept 3 Mechanism

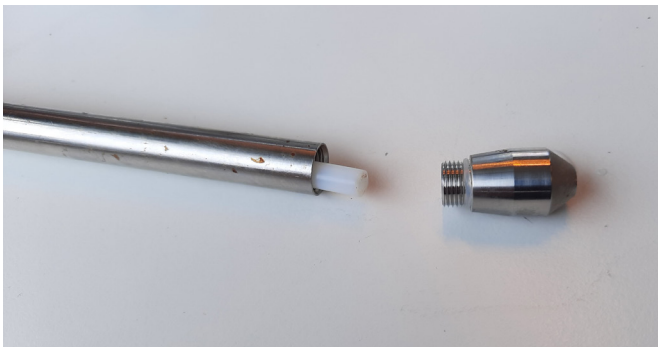


Figure 46 : Decent Steam wand

Minimizing the amount of connections and seals necessary. The connection to the steam outlet placed in the counter is also designed and functions the same as the pressure hoses already used in coffee machines. The fixations of the mechanism to the outer housing part are not yet designed, as well as the mechanism fixating the device to the outlet while steaming. This concept is quite expensive as buying an electric stepper motor that is small and durable together with the lead axis and bearing comes at a price of €34 for only the frothing principle. (Table 6)

What	Price
Sanyo SY20STH42-0804A	€ 15
Bearing (2x)	€ 14
Lead Screw	€ 7
Linear Rods	€ 5
Total (30.000 pieces)	**€ 34**

Table 6 : Concept 3 Cost price

9.4. Quooker concept evaluation

Within the Quooker company multiple employees from different departments were asked to review the developd concepts. The goal of the review was to first to gather opinions on what a Quooker product should look like and how it functions. Secondly it was a moment in which I could show my progress to employees which could later aid me further in the project.

Method

The annotated concept posters were handed to the testers as well as the 3D printed mock-ups. The test users were asked to evaluate the concepts on the following categories. The User experience, Fit with Quooker, Complexity and the frothing principle. The users had to grade the categories on a scale from 1 tot 5 points and their reasoning for the grade was discussed and documented.

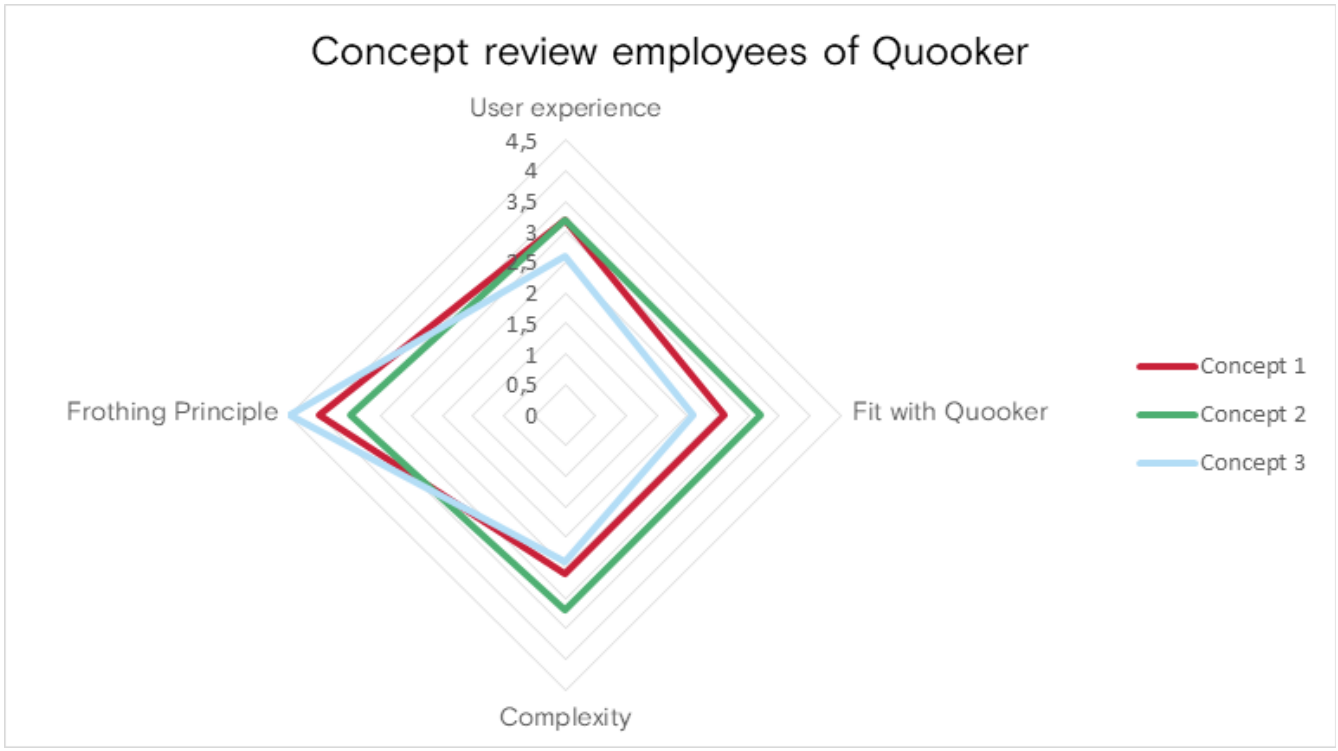
The test users asked working in the departments: Research and Development (3x), Production (1x) Business Information Management (1x)(figure 47)

All three concepts did not score to well with the highest average score of 3 out of 5. Figure 48 shows the average grades given by the test users. The best ranked concept is the whisk concept however the test users were not convinced by its frothing performance. The third concept of the moving wand was graded with a high frothing performance yet, the experience and complexity were scored low. The first concept with the added air is ranked in between. The filled in assesment sheets can be found in appendix G,




Figure 47 : Quookers Employees evaluating concepts

Figure 48 : Concept evaluation grades



Conclusions & discussion

User experience

Even though no clear assignment was provided the test users tried out all the mock-ups and found that the placement of the milk jug is difficult. The steam wands in concepts 1 and 3 have little clearance with the countertop and therefore the jug needs to be tilted to make the placement possible, which results in spillage of the milk. Concept two also encountered the problem that it has more cleaning steps as the whisk must be removed washed and placed back and when the jug is removed the dirty wand is prone to leaking frothed milk on the counter as more milk residue will remain on the whisk coil. More work must be done to optimize the placement and minimizing the required steps to take.

Fit with Quooker

The fit with Quooker, the main insight from this test was quite dispersed between the test users. The ‘not’ product designers mostly focused on founding similarities with the current Quooker design and feel while, the user from the R&D department were looking at the bigger picture. When looking at familiarities with the current products concept 2 with its interaction embodied in a ring was found familiar and buttons that are explicit in their function are not the Quooker style. The bigger fit with Quooker was not found in the whisk frothing principle as it does looks fragile, not premium and has a lot of cleaning steps. As well as the removability and storability of concept 1 and 3 is not Quooker like. Quookers products are something to be proud of and should not need to be stored and removed from sight.

Complexity

The complexity and frothing principles of the concepts were harder to evaluate by the test users, from a technical point all the engineers were already starting to come up with solutions to make the concepts work. While the other employees interpreted the complexity on amount and difficulty of the tasks needed to be fulfilled to make a jug of frothed milk.

9.5. User concept evaluation

Next to Quookers employees the interaction aspect of the concepts are evaluated by Quooker's customers, two interviewees of chapter 8. The evaluation is focussed on the interaction and if the concepts, a new archetype of a milkfrother are understandable and if they would see themselves using and purchasing it.

Method

Before the test an informed consent form was signed, which explains the goals and contents of the test and how the participant's data is gathered, and how it may be used.
The participants were asked to play out how they would make four cappuccino’s from start to end using the Nespresso Aerochino and 3d printed models of the three concepts. The required steps to take were handed in to the users in text without any suggestive handlings. For example, a step, "place the milk jug" does not state how the task needs to be performed.

Per model the interaction was recorded using a video camera on a tripod, and the participants were asked to speak out their thoughts, so the motives of their actions are known. The camera was focused on their hands as it is the area of interest. The models are placed on a test station shown in figure 49.

After each concept the participants are asked to fill out a score form which grades the models on their useability, design and the fit with their kitchen elaborated with a written explanation. After all models were tested a few more questions were asked in a short interview, gathering concluding insights, which will aid in the further development of the milk frother. The list of tasks and filled grading form can be found in appendix H.

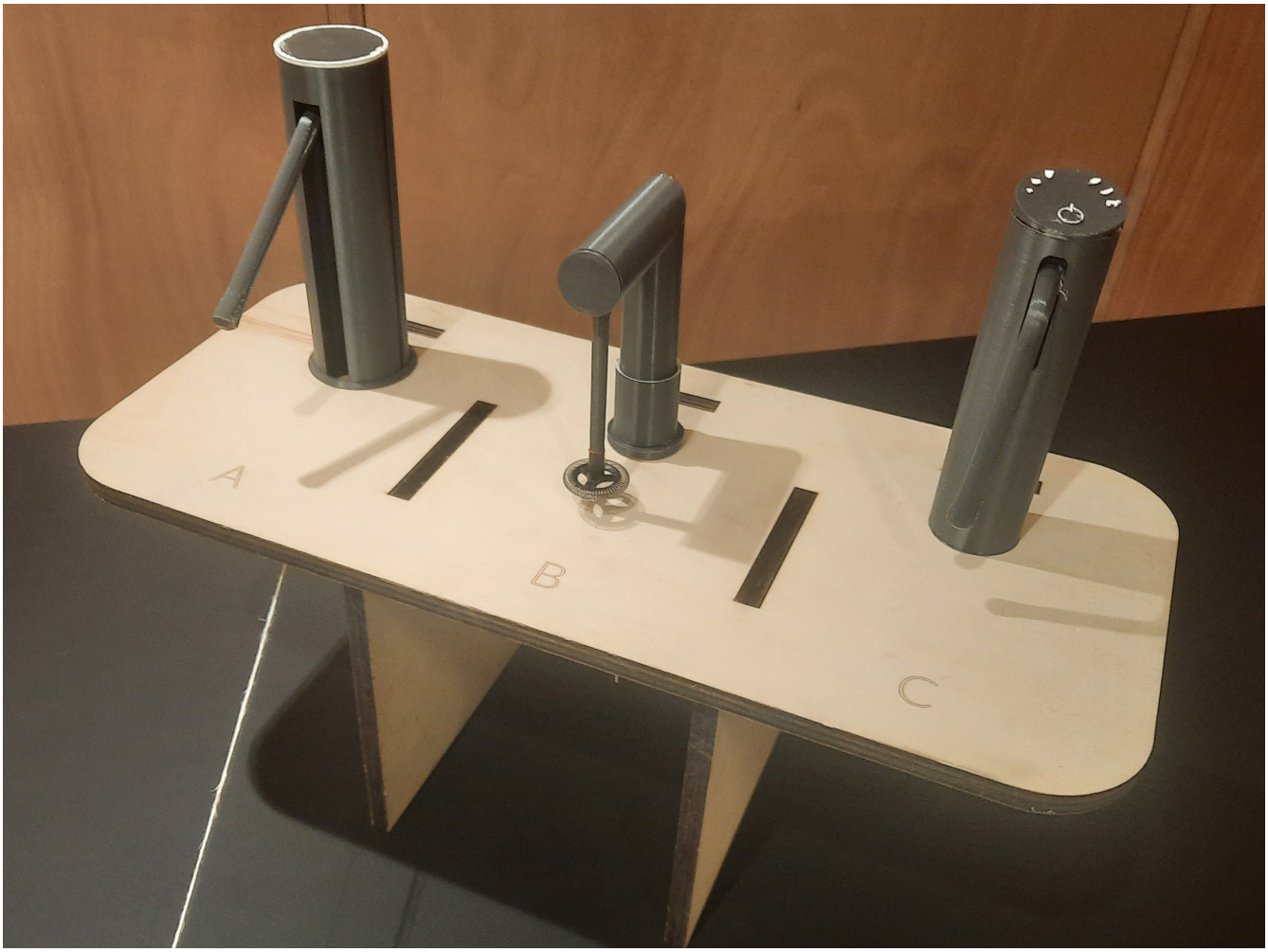


Figure 49 : 3D printed models for interaction tests

Results

Two participants conducted the user interaction test with the models. Both chose their own Aerochino unanimously as the best with a perfect score on all the categories. Concept 3 as the best new type of milkfrother usable and concept 2 the worst. The grades and stills from the testing footage can be seen in table 7 and figure 50.

Conclusions & discussion

As already became clear in the evaluation at Quooker, placement of the jug is not easy and will result in spillage of milk. Without any explanation before the first use the users were not confident that they successfully made a cappuccino with all the concepts, however it was clear that the model is a milk frother and when shown once the interaction already became much more fluent and more confident.

The major insight from the concluding interview is that the participants do not want a fixed milkfrother as an extra fixed appliance in their kitchen. A coffee machine would be okay, however adding a fixed appliance that can cannot be easily fixed when it breaks worries the participants. When their Nespresso Aerochino breaks down, they can easily by a new one or take it to the store to get it fixed. Also, the upfront investment is much lower with the electronic device.

After the interviews in chapter 8 the concern that a steam wand that need cleaning after each serving would lead to scepticism by the potential buyers, the participants were not that negative towards the steam wands. As they did not forget the cleaning steps during the tests and the Aerochino also requires cleaning after milk is frothed. One point that was mentioned is that cleaning requires a separate cloth as the normal kitchen dishcloth is too dirty and came with the question if Quooker and the product will facilitate a place to store the cloth.

Aerochino	Participant 1	Participant 2
Comfortable	7	7
Comfortablillity	7	7
Amount of Steps	7	7
Fits in my kitchen	7	7
Fits with my Quooker	7	7
Overall grade	**7**	**7**

Concept 1	Participant 1	Participant 2
Comfortablillity	4	3
Clearity	1	1
Amount of steps	5	5
Fits in my kitchen	7	4
Fits with my Quooker	7	5
Overall grade	**6**	**4**

Concept 2	Participant 1	Participant 2
Comfortablillity	2	2
Clearity	2	3
Amount of steps	5	5
Fits in my kitchen	2	4
Fits with my Quooker	2	2
Overall grade	**3**	**4**

Concept 3	Participant 1	Participant 2
Comfortablillity	5	5
Clearity	5	5
Amount of steps	1	6
Fits in my kitchen	7	4
Fits with my Quooker	7	4
Overall grade	**6**	**5**

Table 7 : User tests grades

Figure 50 : User interaction test footage

9.6. User concept evaluation

Table 7 shows the weighed grades given to the concepts. The grades are based on the feedback provided by Quooker's employees, users and my own opinion.

Table 8 : Concept assesment

	Weight	Concept 1	Concept 2	Concept 3
User Experience	30%	7	6	8
Frothing Performance	30%	8	6	5
Complexity / Durabillity	20%	6	6	4
Fit with Quooker	20%	8	4	6
		7,3	**5,6**	**5,9**

Concept 1 scores high on the fit with Quooker and expected frothing performance, as the aeration can be easily controlled by the venturi and air pump. The fit with Quooker is high as it is an innovative way to automatically aerate milk with a minimum amount of counter space. However, the mechanism to tilt the wand automatically is a complex one when actuated by the device itself, and the user experience with all the automized steps is not yet optimal.

Concept 2 scores just sufficient. Using a steam powered whisk is adding a lot of steps to the user experience and the aeration control to create quality froth is not that high as heating and rotating function are intertwined. The whisk does not fit well with Quooker as it does not provide a premium feel and needs to be separated for thorough cleaning.

Concept 3 scores high on frothing as it uses the same principle barista's use in their cafe's it does require a tall device with a complex mechanism to control the aeration that needs to be well maintained to function the expected life span. The mechanism is also more expensive than the other concepts. Even though Quookers employees did all believe in the fact that the on-counter device should be separable the users are hesitant to put a milk frother as a fixed item in their kitchen. Especially complex sliding devices which are prone to catching dirt. The buttons that specifically explain their function are desired by the users, however it is not a great fit with Quooker which has more secrecy in their push-push-turn mechanism to get boiling water.

9.7. Optimized concept

Instead of continuing developing one concept further the successful parts of three concepts are combined in one more optimized concept that taken as a base for the development phase of the project. In figure 50 the optimized concept and its features can be seen.

The tilting wand with the venturi aeration is chosen as the frothing principle. However, device will not be sliding into the counter, but can be separated. The wand does not have to enter a cavity and will provide a less complex outer housing shape that can be easily cleaned. The connection with the counter must be further explored, if it will be connected to the counter, coffee machine and even possibly the tap itself. The buttons placed on top to choose the beverage type are placed on the side to make them less explicit. Yet the whole top will be as a button serving to control the steam and possibly actuating the tilting motion of the wand. Keeping the led ring as a feedback indicator which is familiar from Quookers current taps.

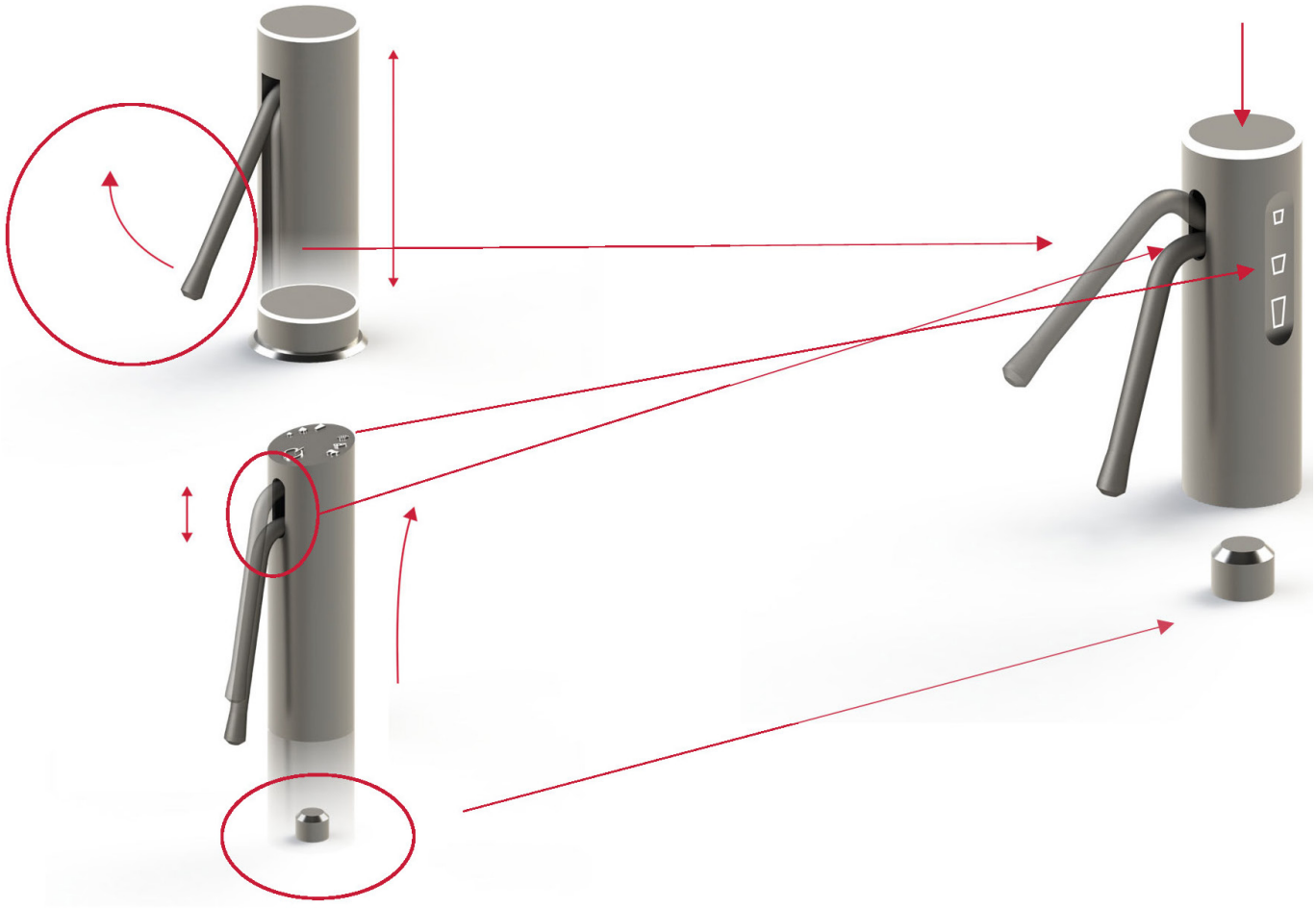
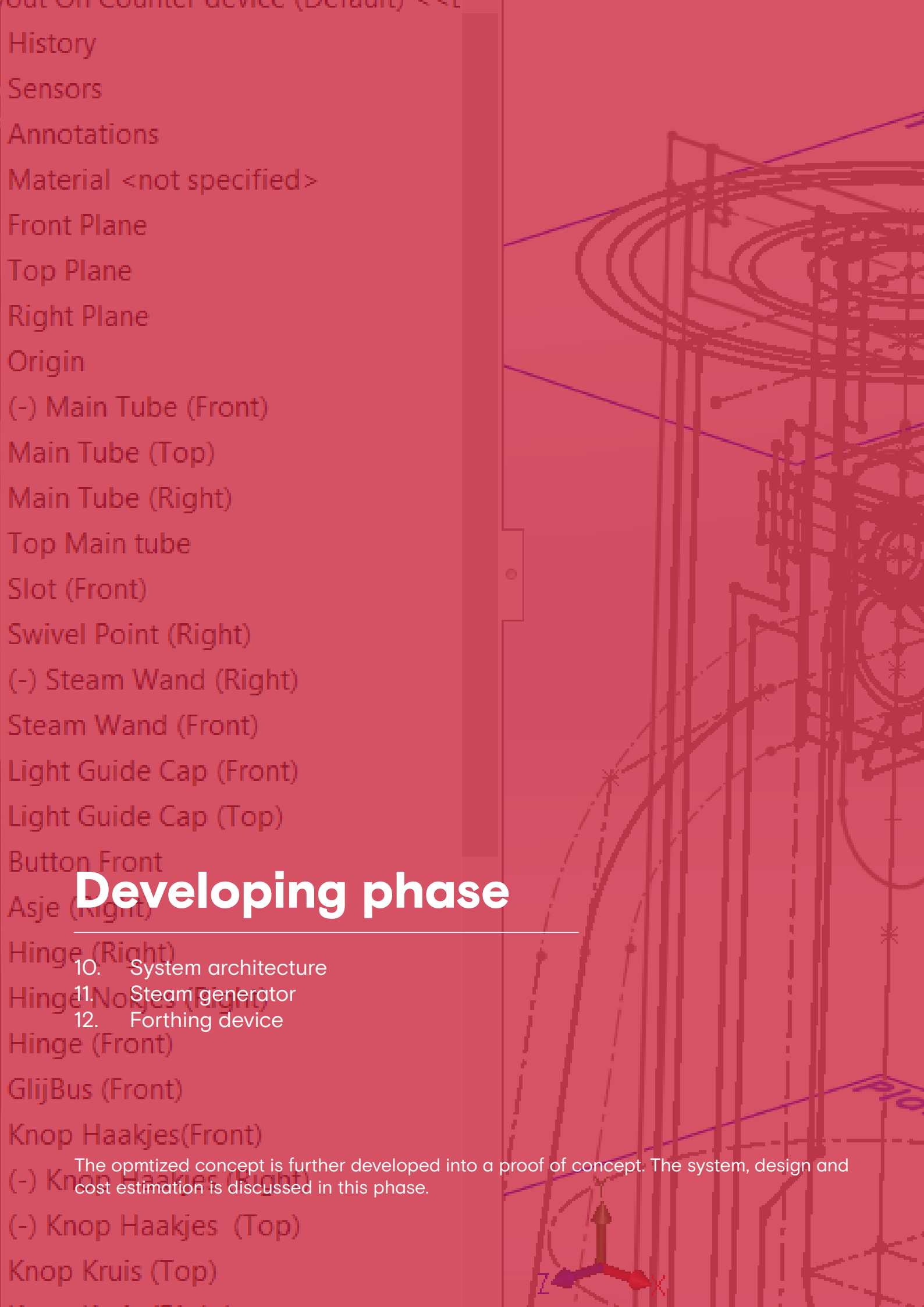


Figure 51 : Concept optimisation



Developing phase

10. System architecture
11. Steam generator
12. Forthing device

The opmtized concept is further developed into a proof of concept. The system, design and cost estimation is discussed in this phase.

10. System architecture

A function three of the entire milk frother system can be seen in figure 51. Every block fulfils a function and converts energy, materials or information to eventually make a jug of milk froth. One conversion is seen in figure 52. This chapter discusses the contents of the system and why it is designed in this configuration. The system is discussed in the following sub systems power and steam, milk ingredient, aeration, cleaning and information. The larger visual can be seen in appendix H.

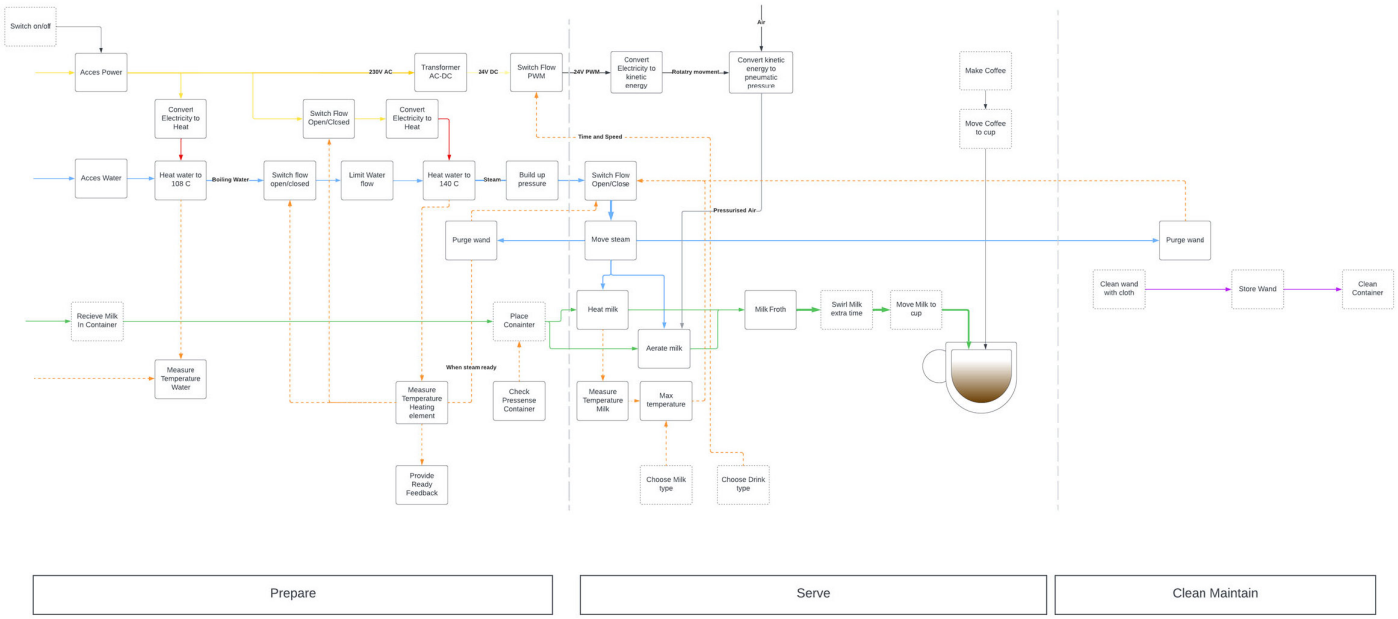


Figure 52 : Function Tree of envisioned milk frother (larger version Appendix H)

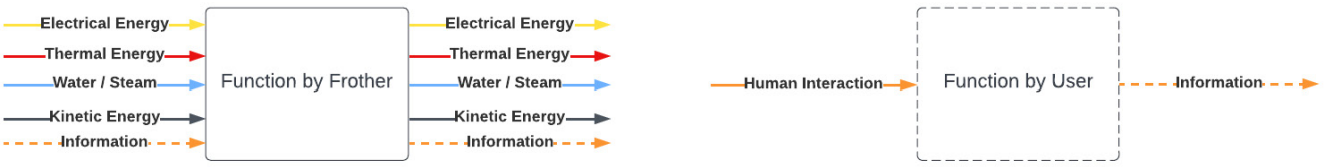


Figure 53 : One function in the function three

10.1. Electrical & Steam system

Figure 54 shows the electrical sub system. Electric energy is used to heat the water accessed from the mains waterlines of 15 °C to 108 °C. It is performed by a Quooker kettle. The 'boiling' water is controlled by opening a magnetically controlled valve. As water is not needed at 2 L per minute the flow needs to be drastically minimized to around 1 ml per second or 6ml p minute. To make clean dry steam like an existing espresso machine steam wand, the temperature of the water needs to rise with 40 °C and the phase change need to achieve. An extra flow through heater is needed to convert more electrical energy to heat. To control this process an electrically controlled relay is switching on the flow of electricity. The steam flow will also be controlled to make sure it only escapes the steam wand when desired. The steam outlet can be blocked resulting in a pressure build up that needs to be maximised, to prevent leakages due to the higher stress on parts. This is done using an over pressure valve that opens when a certain pressure on the system is achieved. This part of the electrical system that is powered on a 230 volts alternating current. To power the less demanding components a transformer converts the 230V Ac to a lower direct current of 24 volt.

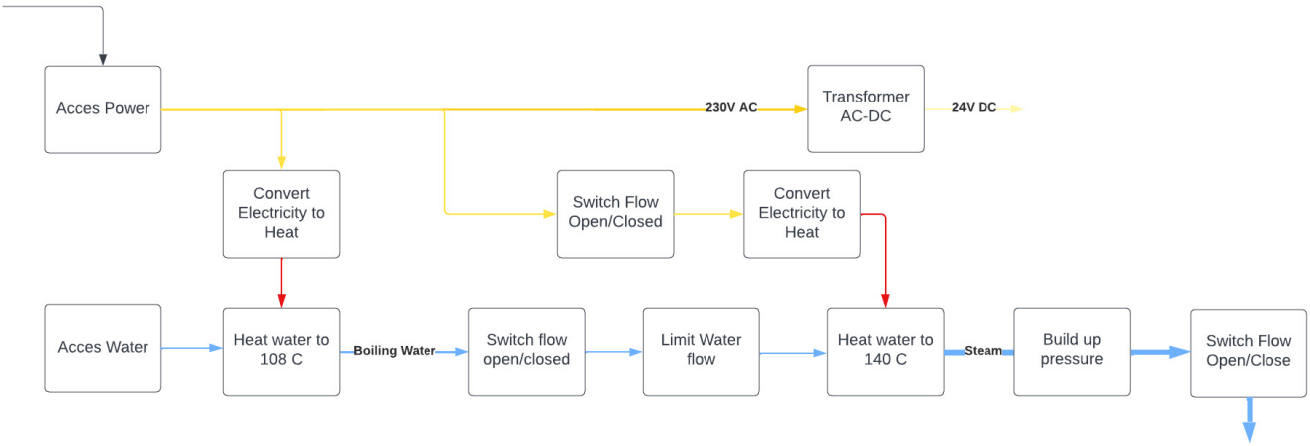


Figure 54 : Electrical Energy & Steam sub system

10.2. Milk system

Figure 55 shows the milk sub system. Cold Milk at 7 °C is added to the system by the user manually, as it was decided that the frother does not store the milk and keeping it chilled. The milk is added to a jug and is placed in the frother. Steam and air gets added to the milk to heat and possibly froth it. When the froth finished the user can swirl the milk to get a more even froth and it is manually added to a cup of coffee entering the system by the user.

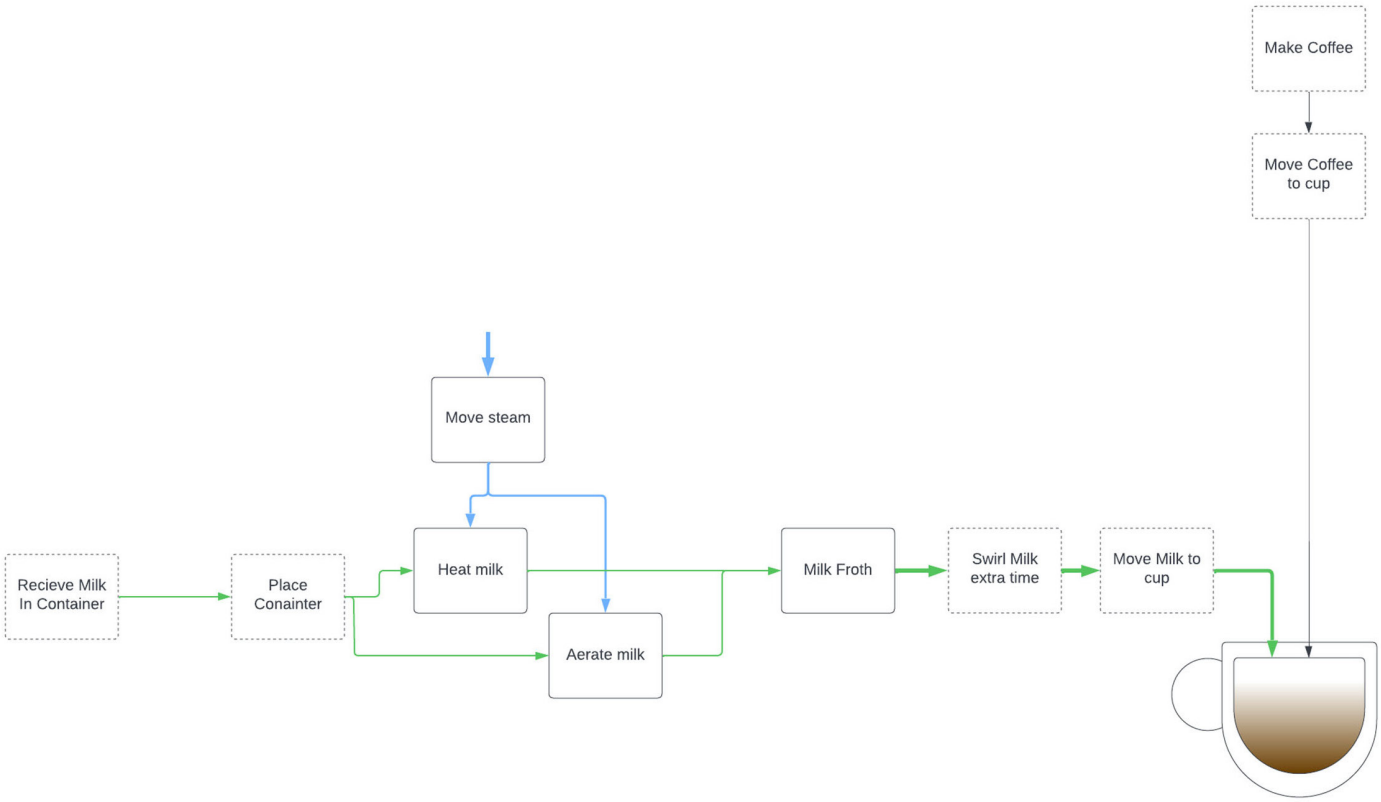


Figure 55 : Milk Sub system

10.3. Aeration system

Figure 56 shows the aeration sub system. Aeration is performed using an electric motor that drives a pump. The electric motor is converting electrical energy into rotational kinetic energy. The pump is converting the rotary movement into air pressure with 3 diaphragm pump's that are placed in a circle. The air is added to the milk to make the froth. The air volume is regulated by powering the motor with a varying direct current. This is created by switching a low voltage digital signal incredibly fast though a transistor and results in an average voltage. This principle is also known as pulse width modulation.

10.4. Cleaning system

Figure 57 shows the cleaning sub system. The cleaning steps that must be performed every time a beverage is made are also placed in the function tree. First before the milk jug can enter the steam wand the condensation created by cooling down has to be flushed out the system (purging), by opening the steam valve and is done when the machine is sufficiently heated up. After the beverage is made the system needs to be flushed again as milk has possibly entered the steam wand. This time it is controlled by the user when it is performed, followed by a wipe of the steam wand to remove the leftover milk residue.

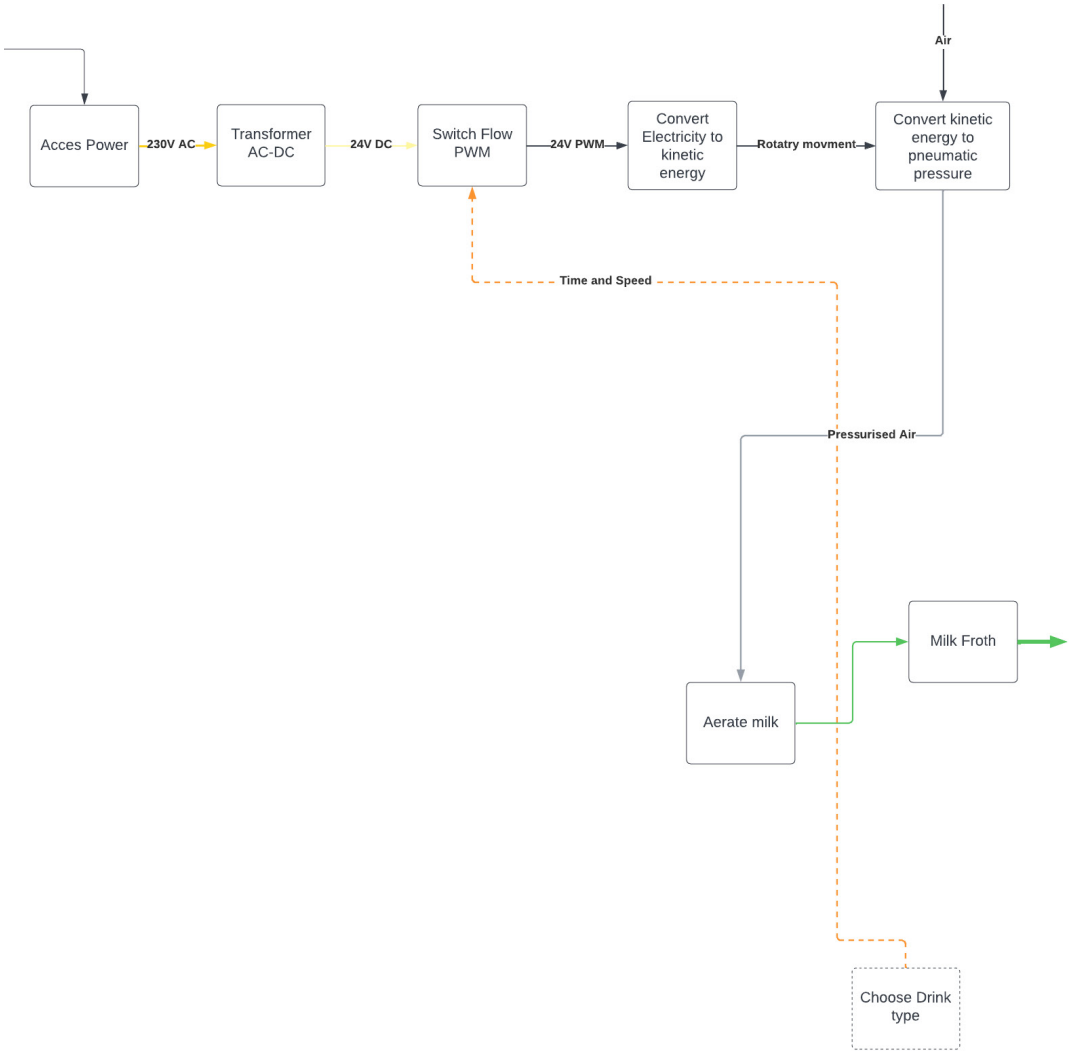


Figure 56 : Aeration Sub System

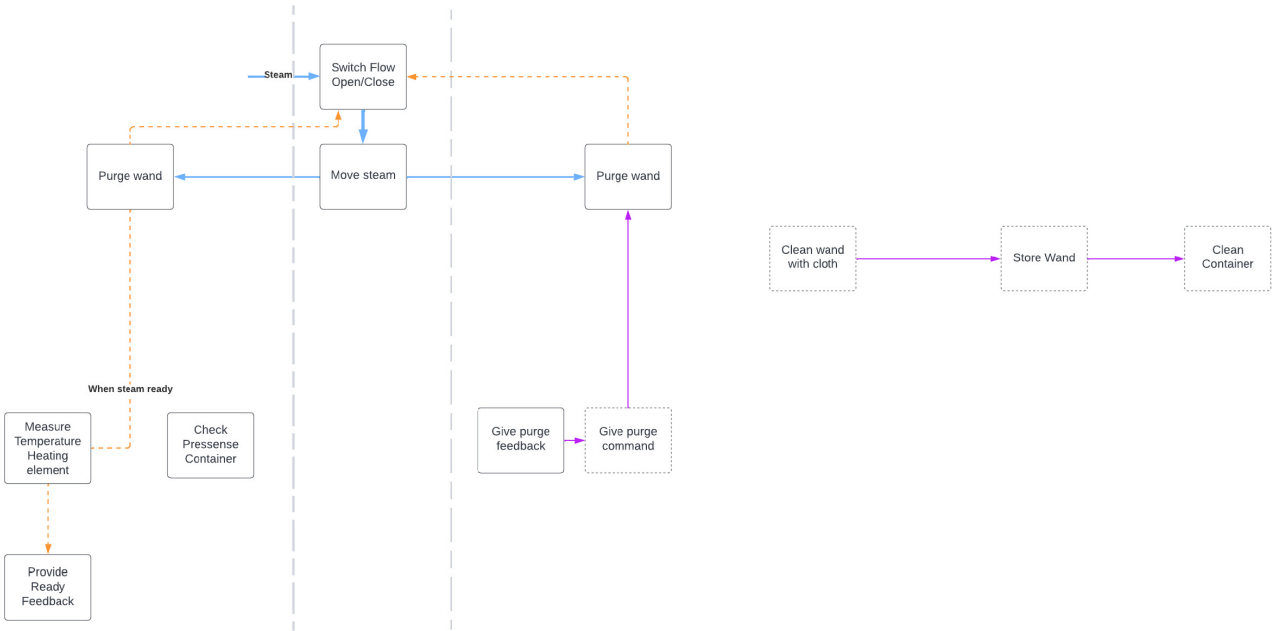


Figure 57 : Cleaning Sub System

10.5. Information system

Figure 58 shows the information transfers. Throughout the system information is transferred from all the functions, making sure the system operates safe and correct. Two feedback loops are in place to manage the temperatures in the system. One is keeping the steam heated to a set amount and one feedback loop makes sure that the milk is not heated to a temperature in which it denaturizes the proteins. Both systems are measuring the temperature with a Negative Temperature Coefficient (NTC) transistor and a maximum setpoint that is depending on the steam settings and user milk type input. A NTC thermistor's electrical resistance is depending on the experienced temperature. The resistance is measured and a temperature value in degrees Celsius can be calculated.

How this information is logically used to perform the tasks can be seen in the state machine chapter 11.3.

In the prototype every block of the diagram is specified to a manufactured or purchased part, most of the parts are chosen based on their availability and being familiar to myself and Quookers employees. Optimisation of the required specifications need to be further conducted as well as sourcing the parts from suppliers. If needed few parts can be manufactured inhouse, or with partners when not available on the market

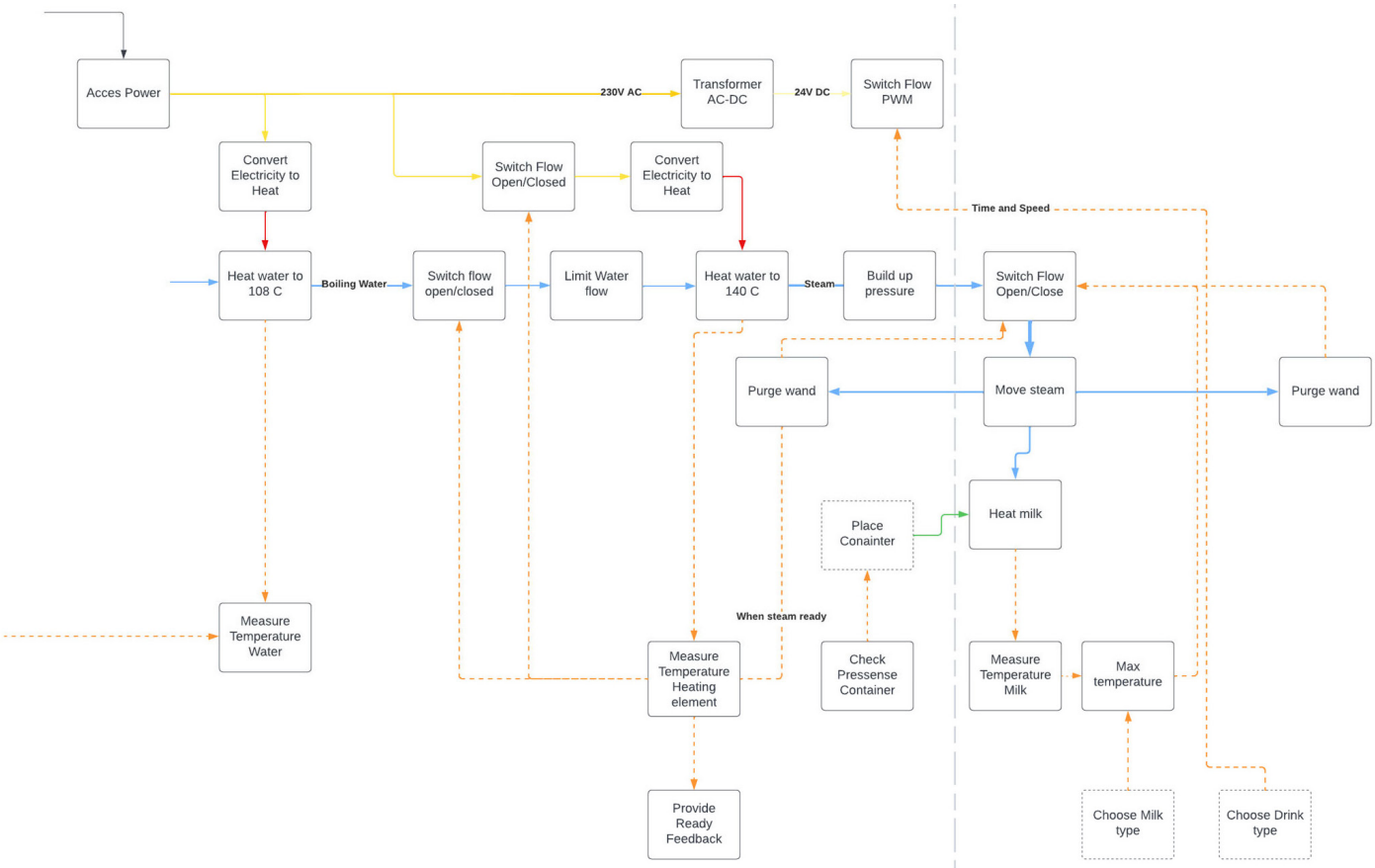


Figure 58 : Data Transfers in the system

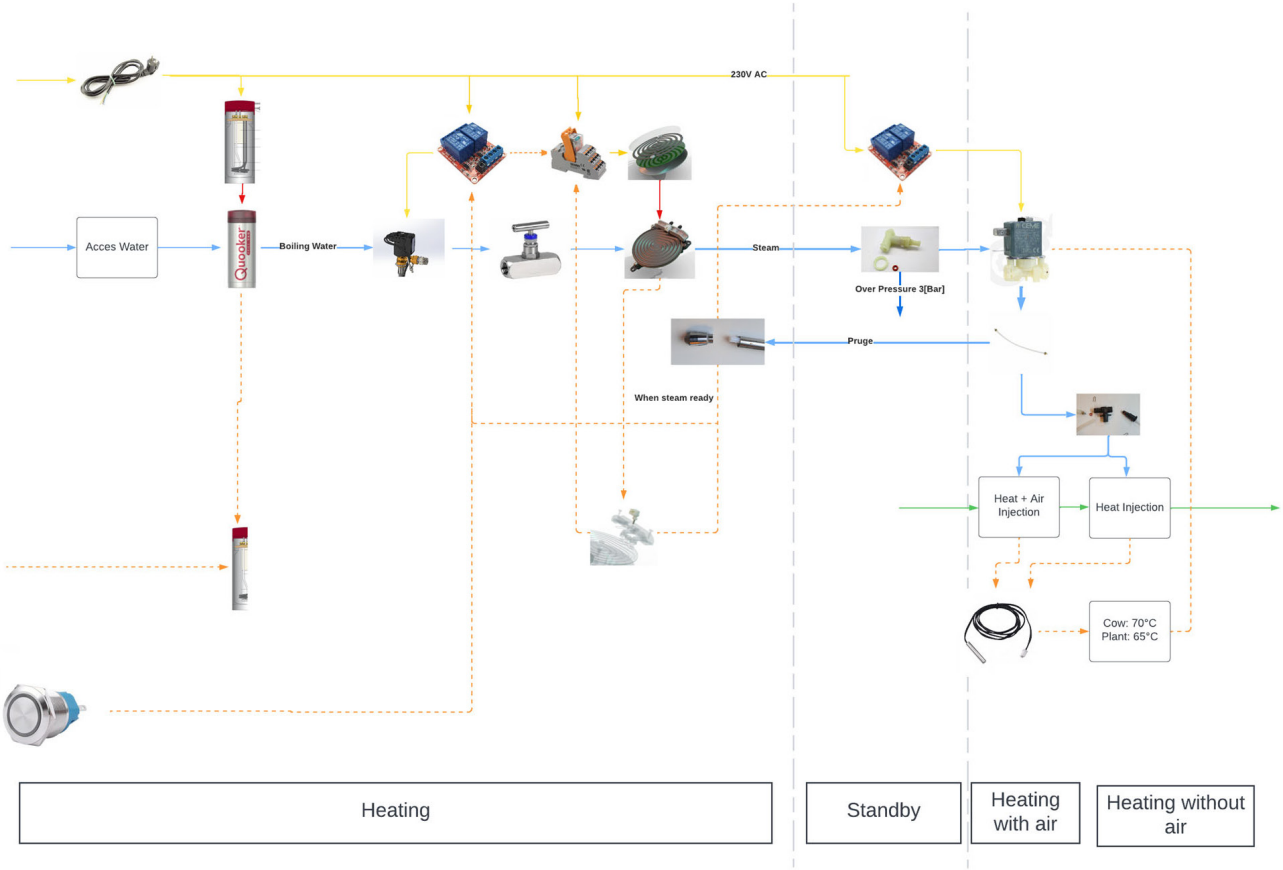


Figure 59 : Emodiment of the steam producing setup

The figure 59 above shows the emodiement steam production part of the function tree discussed above. The parts were picked from existing coffee machines and do not need to be redesigned at this point in th project. The electronics part of the system is explained in chapter 11.2

11. Steam Generator

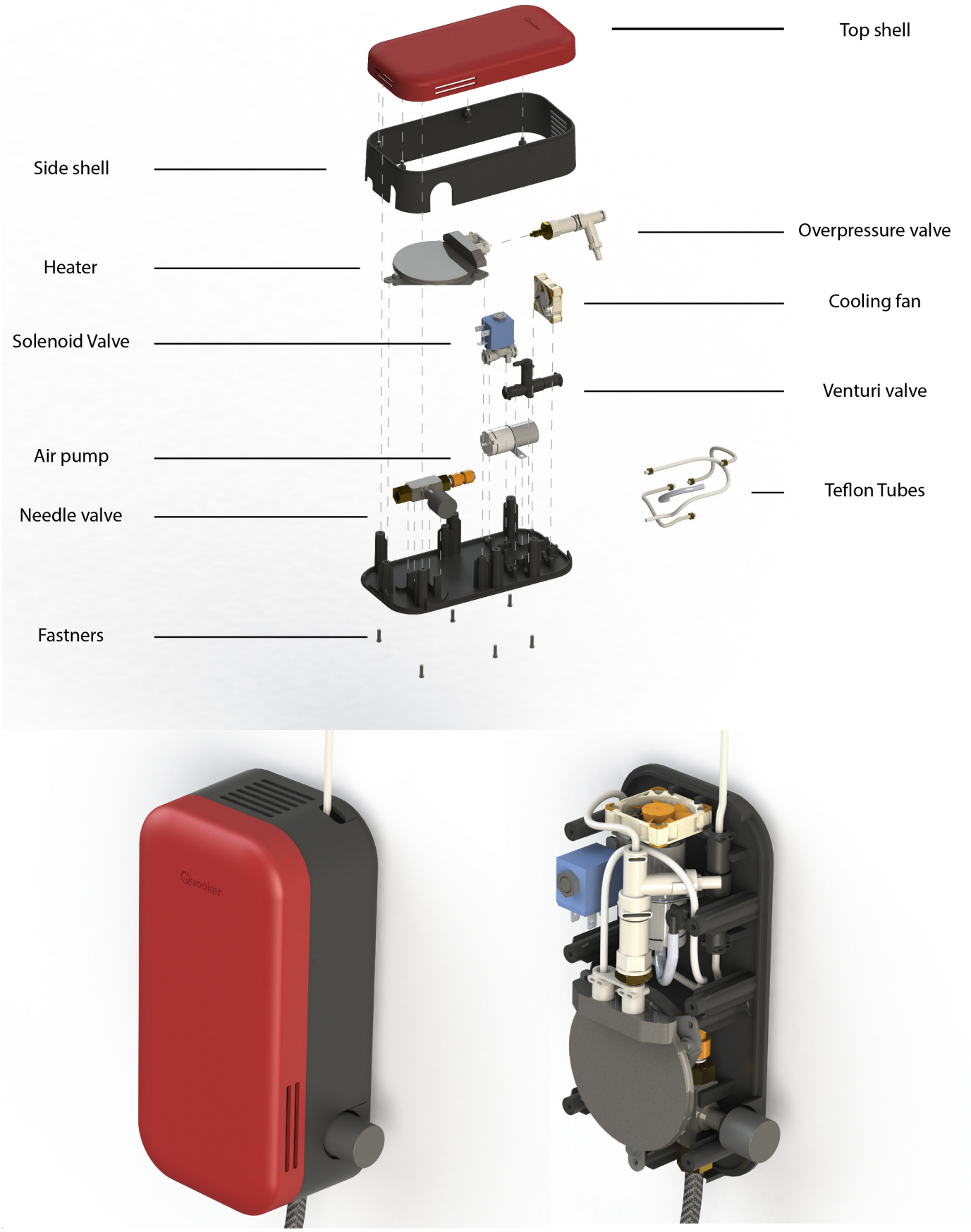


Figure 60 : Render of the housing with internal components

11.1. Water and Steam connections

For the integrated prototype, a safe, reliable and controllable steam source is developed. With knowledge gathered form the heat block experiments in chapter 7, the system's functions described in chapter 10. In figure 60 the final design can be seen. Figure 61 shows the schematic overview of the functions the device must fulfil. The embodiment of the function and the placement in the final design is discussed in this chapter.

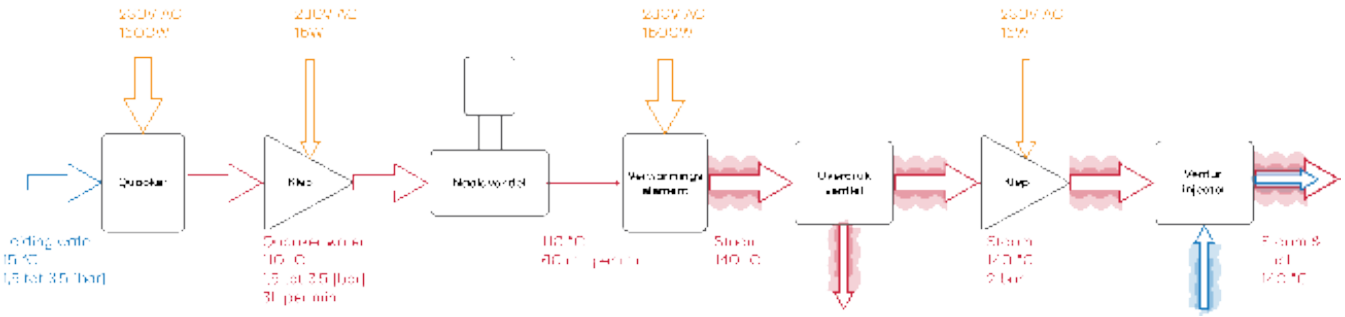


Figure 61 : Flow schematic of steam generator

The first stage of parts is regulating the incoming boiling water to an optimal flow for steam generation and the correct connector pieces. Figure 62 shows these parts. A Quooker EQ3 PRO VAQ kettle is used as the boiling water source. The needle valve of the type NDV DN6 from the manufacturer MHA (MHA Zentgraf, 2023) is used to limit the flow to the thermocoil. The thermocoil is manufactured by Ferrotechniek (2022) and has a laminated heating film with the water channels close to the heating element. Their patented laminated heating element does not use a stainless-steel water channel and electric resistor cast together. The heating element is directly laminated on a thin stainless-steel waiver and the water channels are placed on top. The result is a heater that has a low mass and large convection surface for the heat transfer. It claims to be more efficient, and already has experience in the coffee machine industry. The model used in the prototype is a spare part bought for a specific machine from the brand Sage.

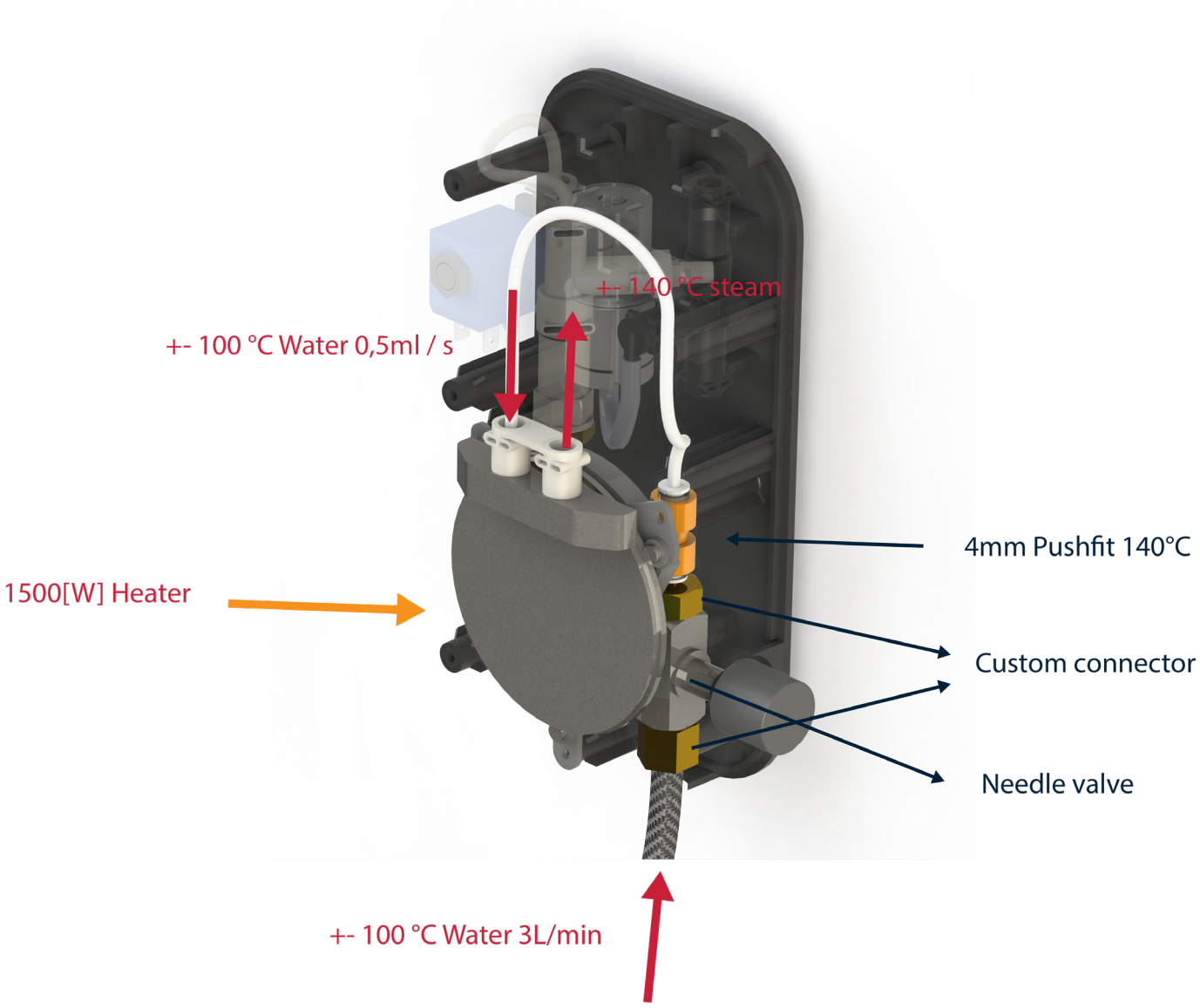


Figure 62 : Render of the needle valve and heater assembly

Two custom brass pieces are machined in the TU Delft IDE faculty workshop to connect the needle valve to the rest of the system. The parts were milled from a hexagonal bar of 17 millimeters. The first connection is from the Quooker's custom outside M12 thread to the internal G1/8" needle valve thread. The second connector is from the needle valve outgoing G1/8" thread to a 4 millimeters tube that is connected with a push-fit connector to a Teflon coffee hose. The finished parts can be seen in figure 63 and the technical drawings used to machine the parts on a lathe in figure 64.

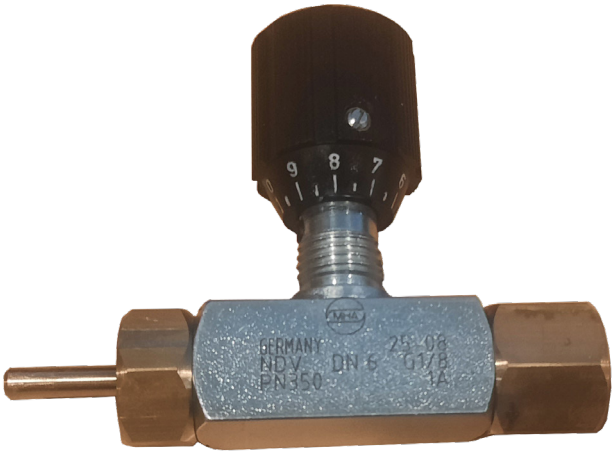


Figure 63 : The needle valve with the brass connector parts

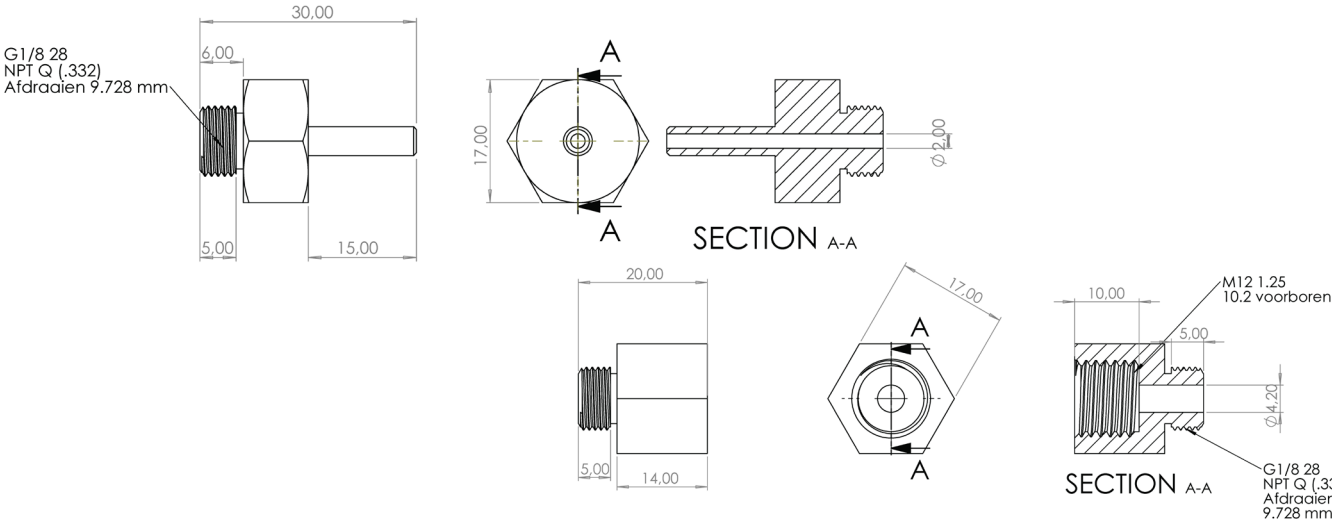


Figure 64 : Technical Drawings of the custom machined parts

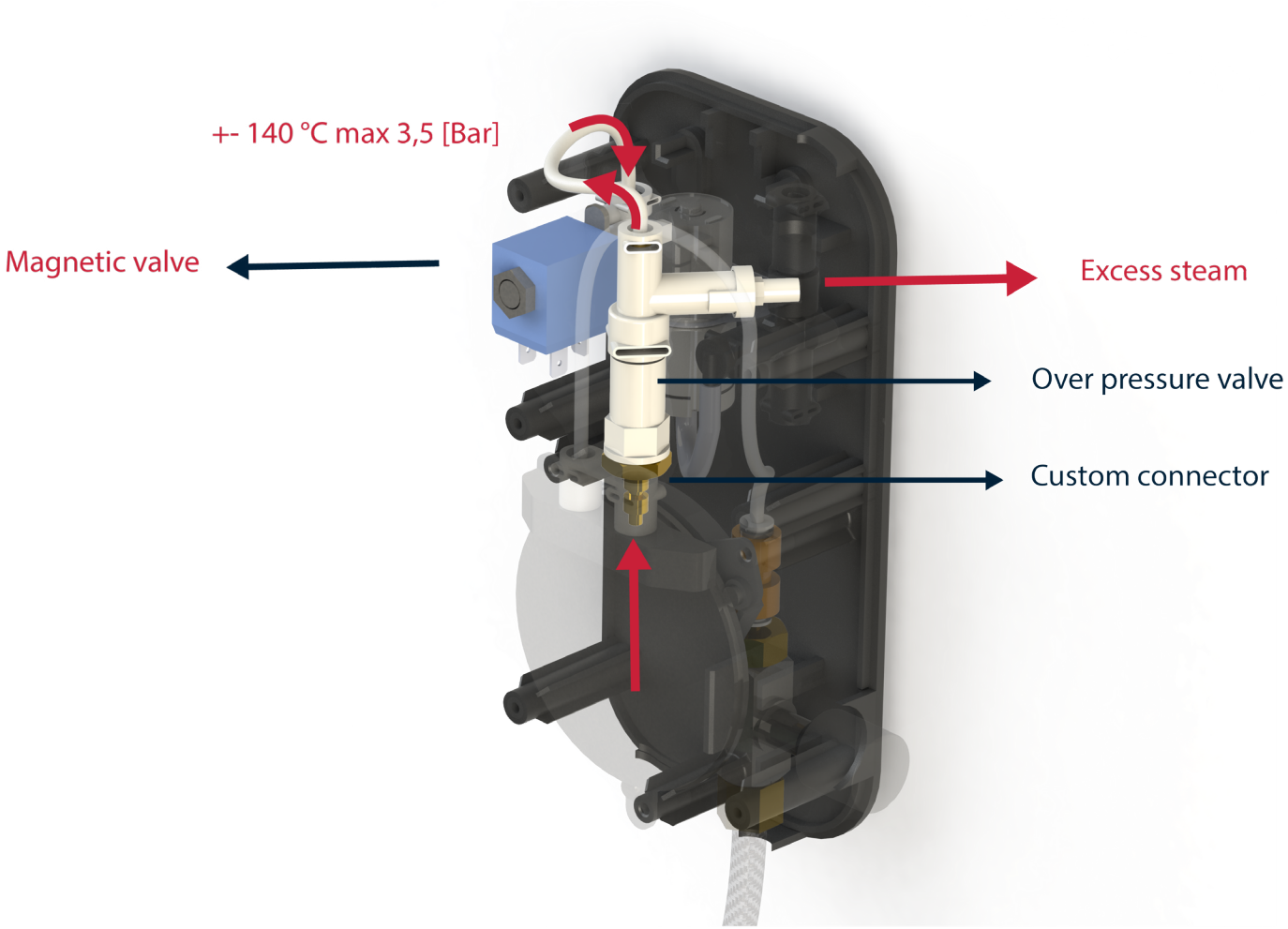


Figure 65 : Render of the overpressure valve and solenoid valve assembly

After the heater is passed and heated the water into steam, the steam passes an overpressure valve which is followed by an electronically controlled solenoid valve, as shown in figure 65. The solenoid valve makes sure that no steam can exit the steam wand when it is not desired. However, in the case of initial heating of the machine the solenoid valve is closed, and the heater is turned on. Water that already is evaporating will expand and exert pressure on all the parts and connections. The overpressure valve keeps the system and its connections safe by keeping the pressure at a reasonable predetermined level. It functions by having a prementioned spring in an auxiliary fluid outlet. When the pressure is higher than the force exerted by the spring the outlet opens and fluid or gasses can escape the system. Figure 66 shows the used over pressure valve in the prototype. To connect the heater to the overpressure, valve the last custom connector needed to be machined, shown in figure 67.

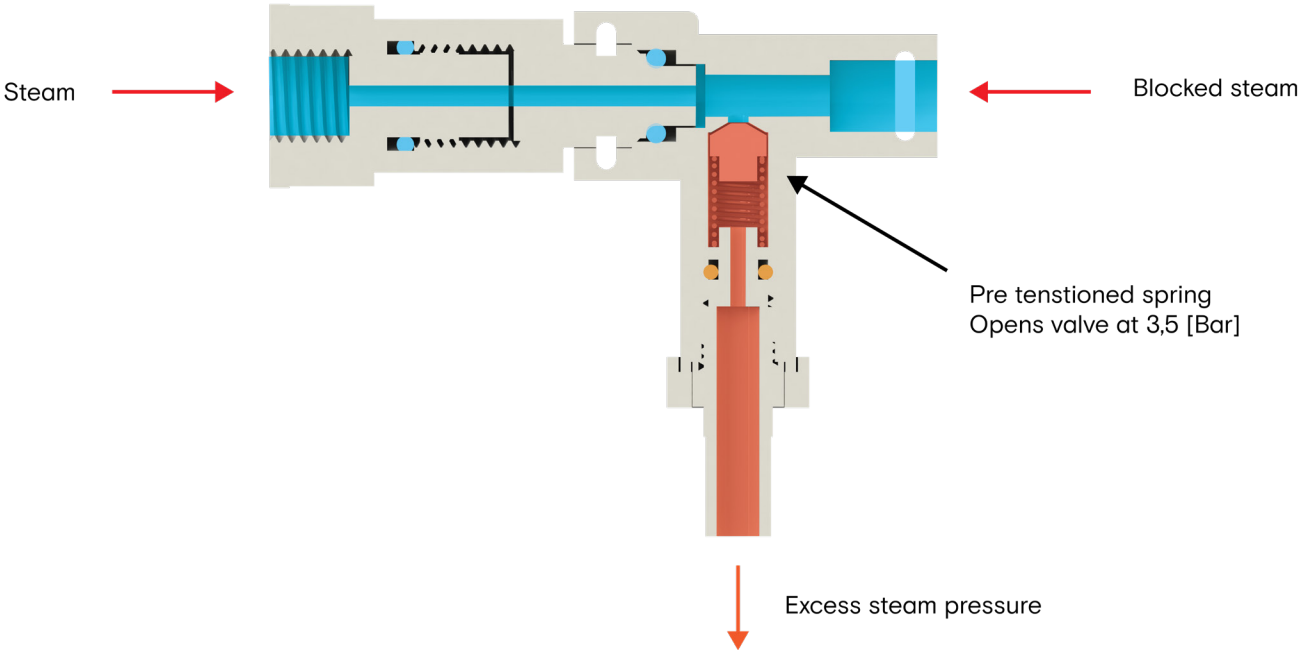


Figure 66 : Explanation of overpressure valve

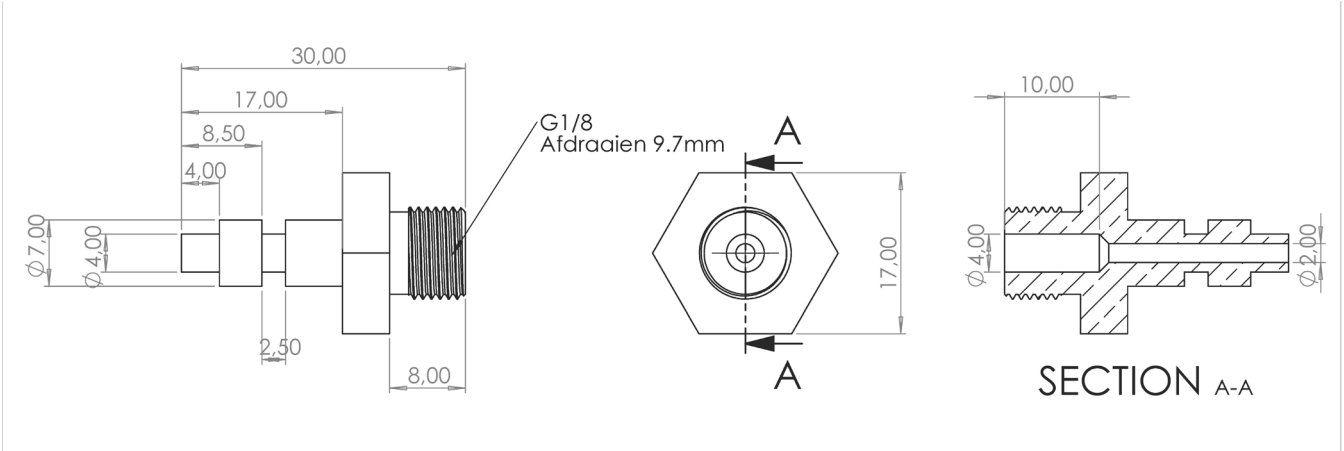


Figure 67 : Technical drawing of last connetor piece

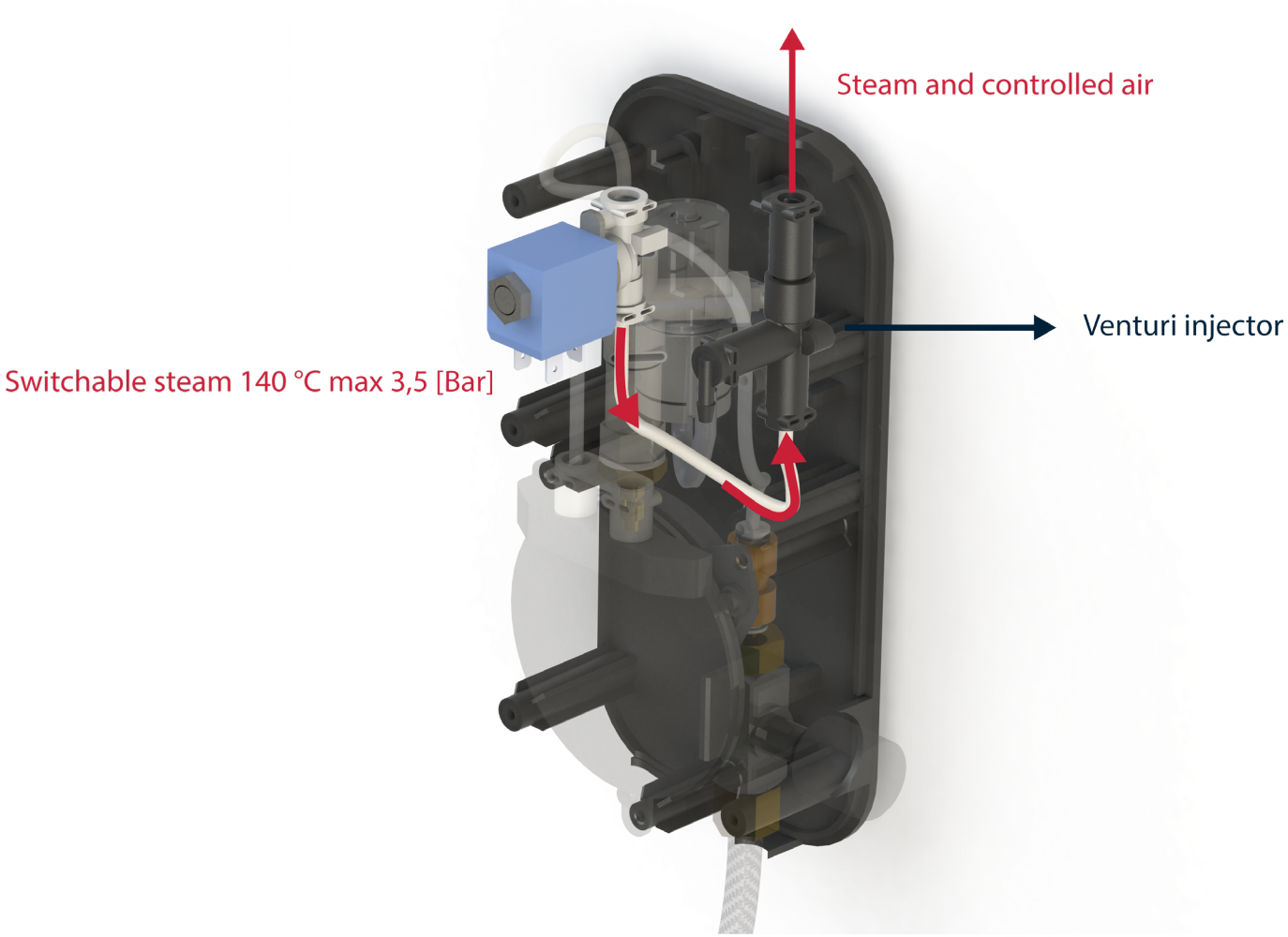


Figure 68 : Render of the solenoid valve and venturi injector assembly

The part that is providing the frothers key feature is the venturi injector. It is placed after the solenoid valve and is the last part in the housing under the counter (figure 68). Its main purpose is to add air to the steam that will aerate the milk, with no skills required by the user. The venturi injector itself is a wel known and used fluid dynamics principle also discussed in chapter 5. A part of the path of the fluid is constricting resulting in a low pressure after the chokepoint.
Figure 69 shows the venturi injector used in the prototype, it is taken from a Sage coffee machine. In blue the air is added to the steam flow, with a check valve preventing the steam from entering the air pump. The air pump is placed next to the injector and air is moved through a silicone hose to the venturi, as shown in figure 70 .

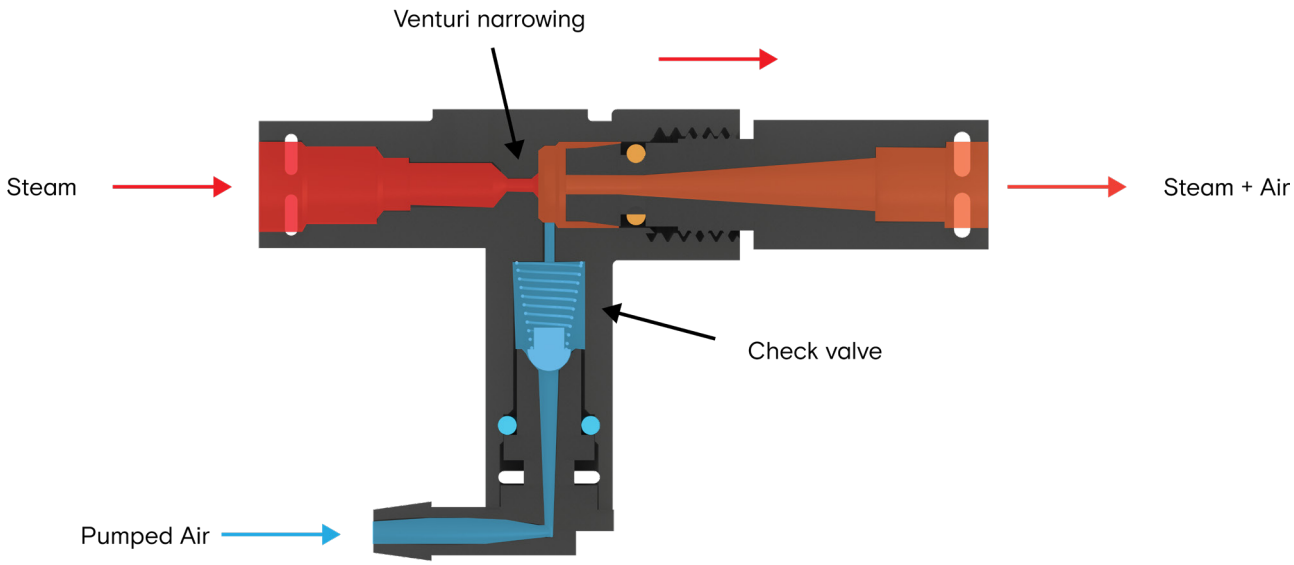


Figure 69 : Explanation of the venturi injector

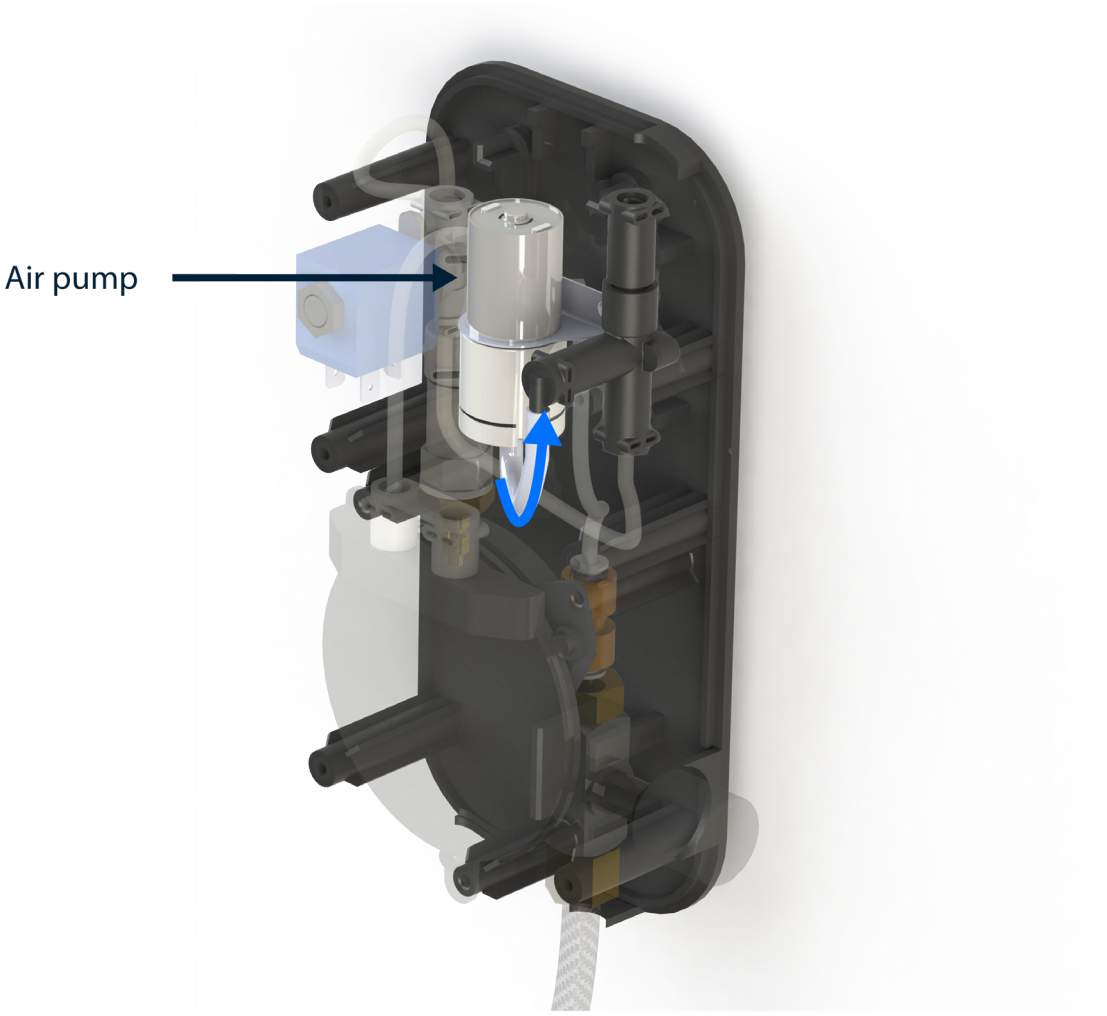


Figure 70 : Render of the venturi injector and air pump assembly

The parts are connected by tubes found often in coffee machines. The tubes are made of PTFE also known as Teflon. It is high resistance to heat makes it suitable for the application. However, a note must be taken that in the production of Teflon and Teflon itself, hazardous materials for the environment are created. The material does not react well with any substance meaning that it will not decompose on its own in the environment. It is advisable to look for a material with similar characteristics without the possible damage done to the planet. The water and gas tight seal is created by a O-ring that is under compression and enclosed in all directions. The brass fitting is clamped around the tube and together with the retention clip the hose is securely fastened. In figure 71 the Teflon hose connection with the over pressure valve can be seen.

The housing consists of three parts that are connected using plastic self-tapping screws. It is possible to make a housing only using two parts, although then the large closing shell could only have one colour. To test if all the parts fit the parts were first printed using a FDM printer. When the conclusion was positive the second iteration is outsourced to a prototyping company that uses a Selective Laser Sintering (SLS) machine to make a more thermally durable prototype.

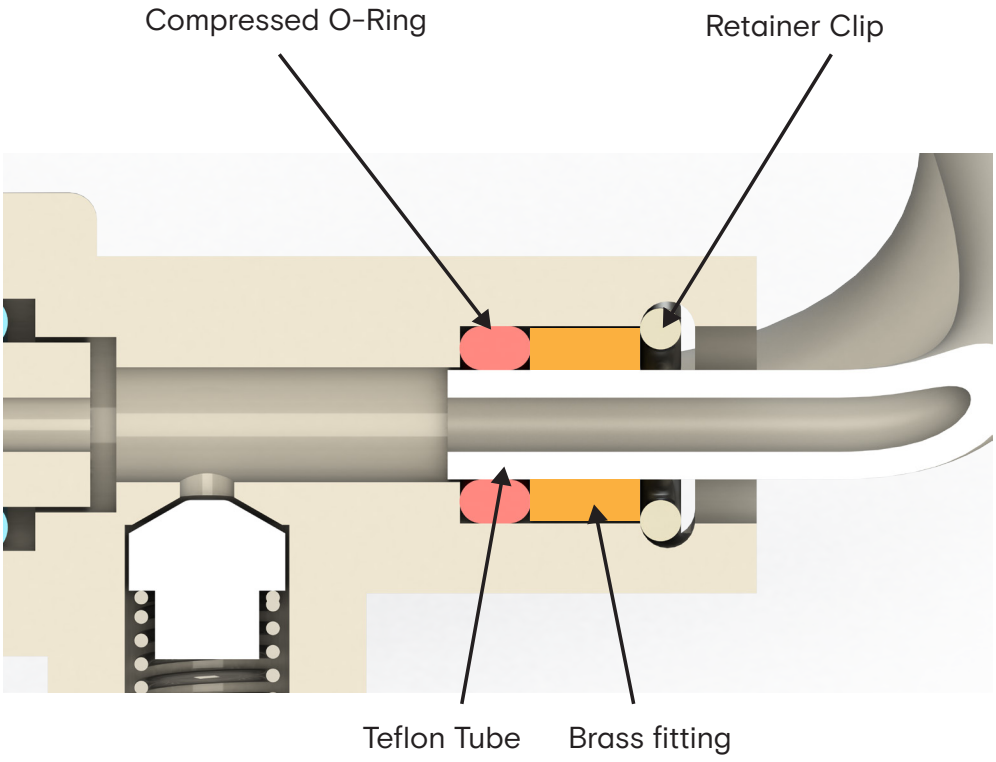


Figure 71 : Explanation of overpressure valve

The used material for the SLS printed prototype is glass filled nylon, that can withstand 120 °C. SLS prints have a higher precision less defects and can be dyed by submerging the print in a colourant creating an even surface finish. The self-tapping screws are optimized to work with plastics and the all the bosses were designed with the EJOT guidelines in mind (EJOT, 2023). Using these optimized screws, the material use can be decreased while maintaining the same mating force of the parts.

The steam generator is controlled by the electronics control box explained in chapter 11.2. In this stage of the project the steam generator housing is embodied, however the electronic circuit is not optimized yet for space to fit inside the housing. The housing parts (figure 72) are now mostly based on the optimal configuration of the components that were used during steam generator tests. It may be possible to alter the connections between the generators parts with a result that is more in line with Quookers current under counter design vision and the overarching coffee project.

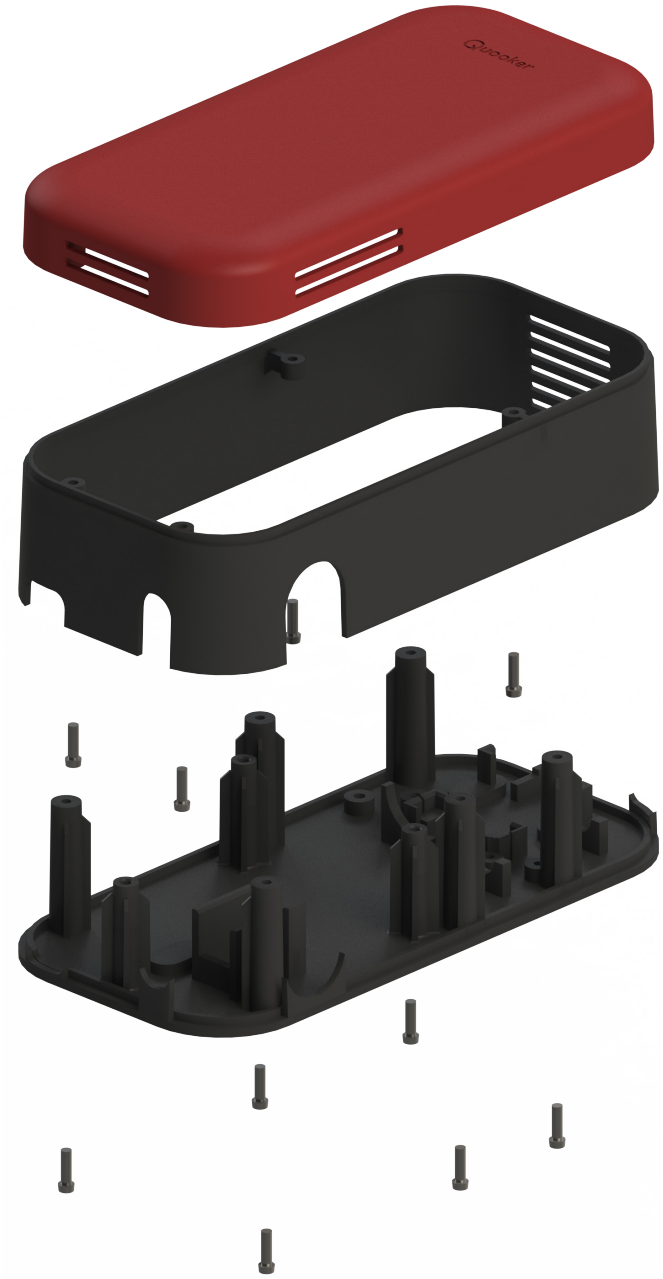


Figure 72 : Explanation of overpressure valve

11.2. Steam control electronics

To control the heater, and valves to create steam electrical junction box was fitted with a micro-controller and relays to control the steam production. The chapter explains the working of the control box which will be used in the definitive proof of concept prototype. The control box main purpose is to switch the high voltage 230V on which the heaters and magnetic valves functions. An additional small development circuit board is soldered to distribute the lower voltages and connections to the NTC thermistors and LCD screen.

Control case

The decision was made to place al the electronics in one Kradex Z95JPH enclosure to safely operate the higher voltage electronics without the risk of spilling any water that could potentially damage the circuitry users, and bystanders. The housing is often used as a junction box for electronics and a DIN rails is used to connect most of the parts. In CAD, a first representation was made to check if all the required parts would fit and can be seen in figure 73.

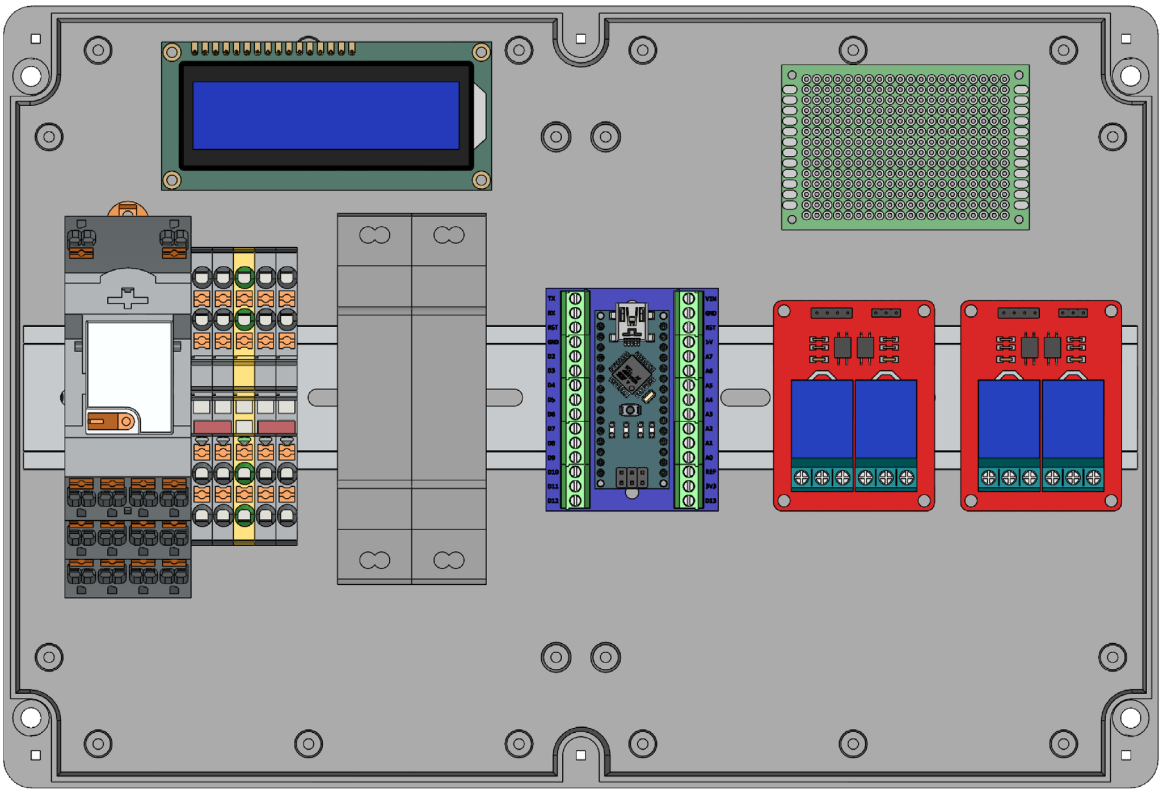


Figure 73 : Kradex control box

High voltage

The system explained in chapter 10, that three relays are necessary to produce steam with the chosen components. The components are that need 230V AC are connected using terminal blocks from Phoenix Contact (2022) (figure 74). The terminals make it easy to connect the wires with a push in connector that is rated for 2.5mm2 wires. The Blue wires are the live wires, the brown the neutral wire and the green lines that have a specifically coloured terminal are the earth. The switches in red with the blue boxes are relays that have the capability to switch 10 ampere current at a maximum of 250v and can be directly switched with a signal voltage of 5V. (Tiny Tronics A. , 2022). An Arduino Nano micro controller (Tiny Tronics B, 2022) is placed in the middle of the control box with a development breakout board that makes swapping the controller possible without too much difficulty. Even though the red relays are rated for the power used in the heater, a phoenix contact relay socket and relay is used (Rs Components , 2022). The brand is more trustworthy and is capable safely handling 30A inrush current that is often seen high power heaters. However, the relays only switch at 12 volts, thus one of the relays in red is controlling the spool of the better one. Lastly two transformers are connected to provide the system with a lower voltage direct current and can specifically designed to be placed on the DIN Rails (Tiny Tronics C., 2022). This is used to power the microcontroller, relay and motor.

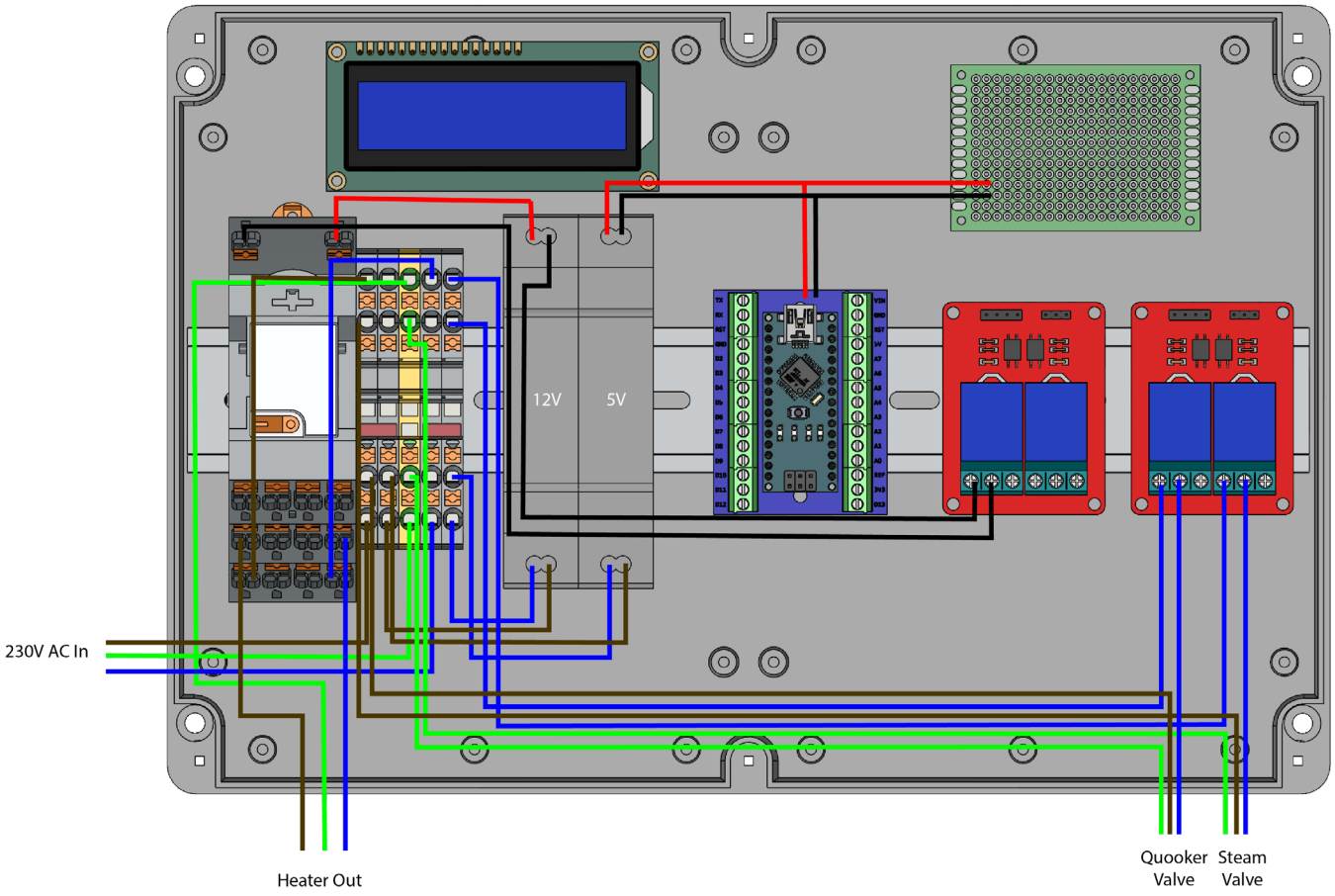


Figure 74 : High voltage AC circuit

Low voltage

The lower voltage part of the control box is shown in figure 75. Starting with power distribution, the small development circuit board is providing power to all the 5V powered components. The LCD screen relay boards and thermocouples are powered from the transformer. The circuit soldered on the development board can be seen in figure 64. Next to the power distribution it also houses four resistors that are required to get a reading from the NTC thermistors and functioning of a switch that also houses a LED. All the signal lines and the type of signal are shown in yellow.

One thermistor comes with the heating element and is a fast response NTC with the following specifications R=50K @25°C, β25/80=3976K. (Ferrotechniek, 2020) The other thermistor is a general R=10K @25°C, β25/80=3950K and is encapsulated in a waterproof container.

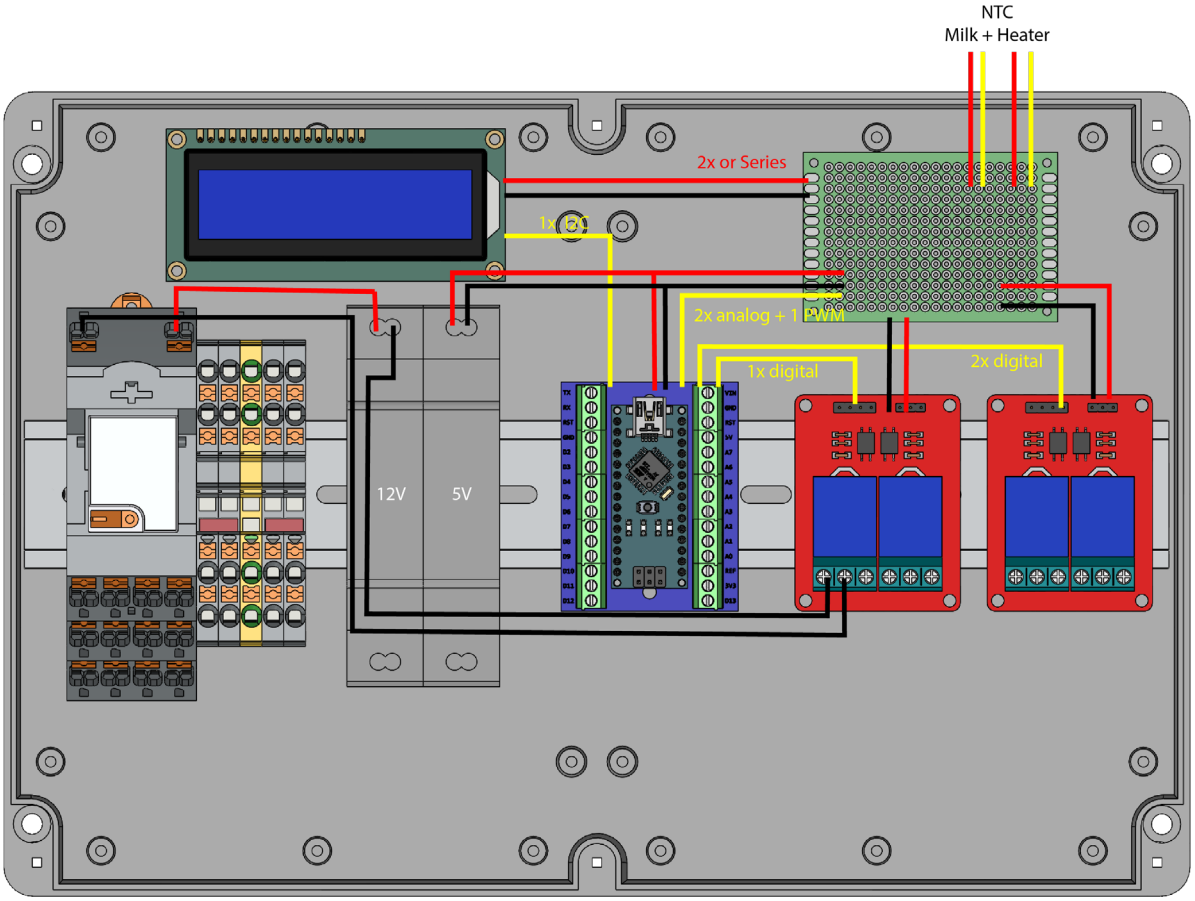


Figure 75 : Low voltage DC circuit

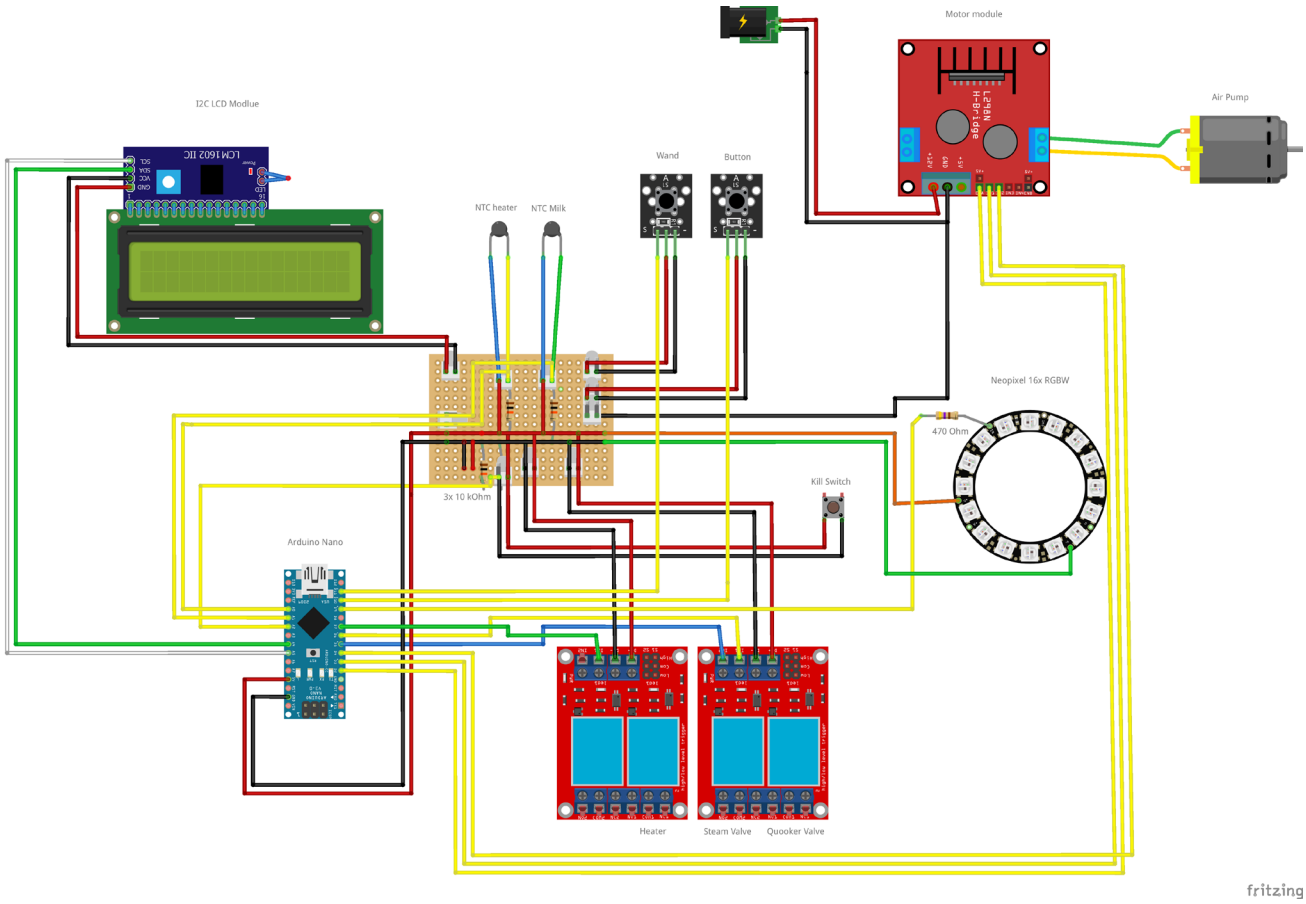


Figure 76 : Arduino controlled circuit

Figure 76 shows the electronics that perform the tasks of the information subs system discussed in chapter 10. The wiring schematic is not to the standards an electrical engineer would like, although it exactly shows how everything is connected to the micro controller. Most signal wires are separately routed to the Arduino while the 5 volt and ground connection for all the sensor and actuating modules are solder to the development board. These power lines are equipped with JST-XH connectors to make separation possible, this is for example necessary when swapping out a module or when reinstalling the protype after shipping it to another kitchen cabinet.

The used computing module is an Arduino Nano, which can handle 13 digital and 7 analog in- or outputs. It was chosen because of its small size and the experience I have with programming these micro controllers and the option to sense analog signals. A feature that is not standard available in for example a Raspberry Pi. To control the steam generator and the device on the kitchen counter almost all if the I/O (inputs / outputs) are used. Even though the only two real analog inputs are used for the NTC readings, the pins on the left side the I2C connection with the LCD screen and the signal coming from the kill switch are also occupying the analog I/O. This was chosen to free up space on the digital I/O side and the I2C function can only be found on the A4 and A5 pins.

On the digital side all the pins can be freely placed except for the pin connecting the LED's. It uses the WS2812 protocol to control the colour behaviour of every individual led connected to the chain. The signal controlling the LED's must be able to provide a Pulse width modulation (PWM) signal even though the WS2812 signal is not PWM. 6 of the 13 digital pins can produce a PWM signal, and in the schematic pin 9 is chosen. All the other signals coming to and from the Arduino are relatively "dumb". For example, the buttons being 5 volts when a button is pushed and 0 volts when it is not.

11.3. State machine & Software

The following simplified version of the state machine diagram is explaining the logical side of the controller. (figure 77) The diagram shows the different “states” in which the program can be, and which conditions are needed to proceed to the next state. The program running on the Arduino checks every pass of the loop in which state the product should be and then executes the commands that are specific for eachw state.

Continuing this chapter three code snippets are shown to explain a few key software examples. First explaining the state machine setup, then the use of functions and at last the non-blocking timers.

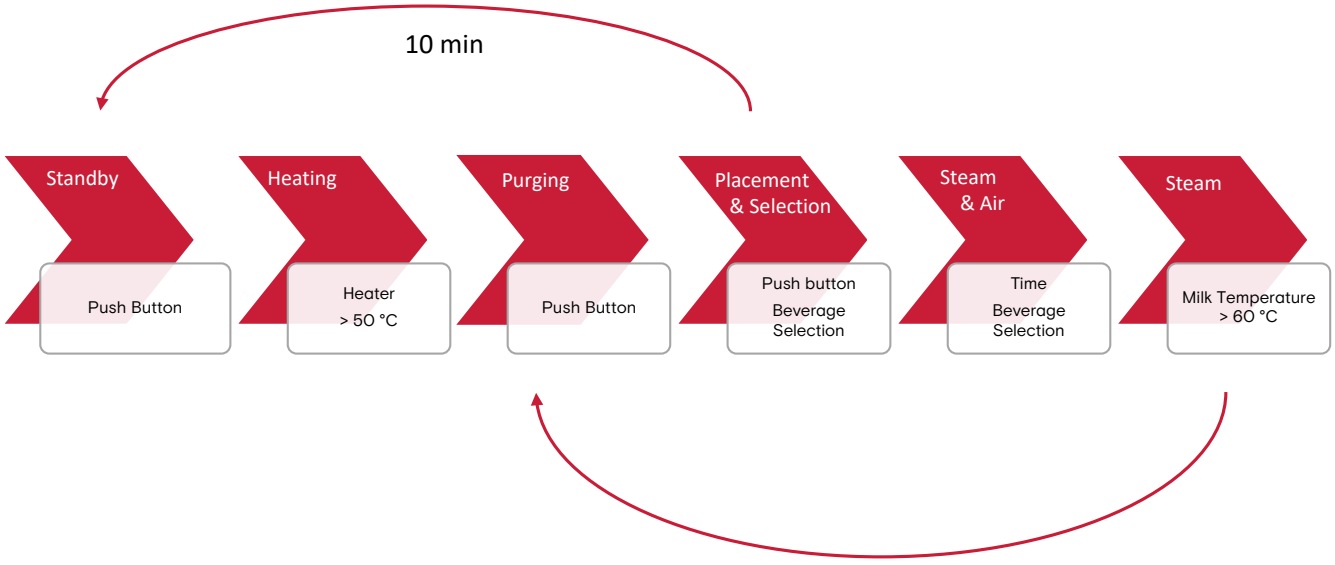


Figure 77 : Simplified state machine diagram of the milkfrother

20221118_Opzetje_Thermostaat § | Display | Klaar | Leds | Opwarmen | Stoom | Stoom_Lucht

```
void loop()
{
  if(digitalRead(killswitch) == LOW){
    current_state = 0;
  }

  temperature_heater = thermistor_heater.read()/10;
  temperature_milk = thermistor_milk.read()/10;

  if(temperature_heater > 180){
    current_state = 0;
  }

  updateStateMachine();

  loopje(temperature_milk, temperature_heater, current_state);
}
```

Figure 78 : main loop of arduino program

The function loop() shown in figure 78 is endlessly executed by the Arduino, however, to minimize the commands in this function it is wise to split the commands in functions when dealing with larger programs. Therefore, the updateStateMachine() function is called to check in which state the program should be and what commands must be executed. Calling a function is means that the program first executes everything in the function before continuing with the loop. In the case of the update state machine no further values are entered in the function, yet in the function loopje() that controls the LCD screen the temperatures and the current state value are sent with the function call, so the temperature does not have to be measured again when changing the LCD information.

Figure 79 : Update state machine function

20221118_Opzetje_Thermostaat § | Display | Klaar | Leds | Opwarmen

```
void opwarmen(){
    Serial.println("Opwarmen");

     digitalWrite(relaisklep_stoom, LOW);
     digitalWrite(relaisklep_quooker, LOW);

     Led_White();
     currentfadeMillis = millis();
     Led_Fade(currentfadeMillis);

  if(temperature_heater > 33){
    digitalWrite(relais_heater, LOW);
        purgestarted = false;
        purgeneeded = false;
        current_state = 2;

  }
  else{
    digitalWrite(relais_heater, HIGH);
        //Serial.println("Heater aan");


  }
}
```

Figure 80 : Heating state code

The updateStateMachine function (figure 79) is just a switch case function that again houses the functions that will later have the commands for the separate states. The switch case works by having a single input and then executing the matching case number with the input. It makes sure that there no other state functions are called as the value current state can only have one value at a given moment. Again, all the state command could be executed from within the case contents, however for clarity reasons all the states are placed in a separate tab to keep a clean and understandable workspace.

When taking the heating program in figure 80 as an example of a state. The water relays are all switched off as is stated in the state machine diagram in appendix I. The led light is told to show a white colour while fading. The temperature measured in the main loop is used to determine if the heater should be turned on. This is the case if the desired pre heat temperature is not met. When the pre heat temperature is reached the heater is turned off and two variables that are needed for the purging function are set. At last, the current state is switched from 1 heating to 2 purging. The next time the main loop is executed the Arduino will not pass the pre-heating commands.

The final scheme is used to make sure that critical measurements of for example the temperature sensors and the actuation of the LEDs and relays are executed quickly. The Arduinos predictable cyclic executive behaviour is now working against the program. The constantly looping program means that only one part of program can be executed at a given time. When it is necessary to wait for a moment, for example to average out the temperature readings the complete program stops and waits before it may continue. To overcome this there is a hard- and software-based solution for this. As many pins are already occupied the software solution is chosen and shown in figure 81. The construction can be found in multiple places in the complete code.

Instead of using a delay, which stops the code and waits, the time of the start of the cycle is recorded. Every time the code passes, which can be tens of times per second the time between start and the present time is calculated. When the waiting time is achieved the desired command is executed and the start time is updated. The example in figure 81 is making sure when the temperature readings are fluctuating at the set point the relay is not triggered to often. This makes a lot of sound and decreases the expected life span of the unit, which often have a set number guaranteed switching actions before breaking down.

```
present_time = millis();
last_relais =  present_time - relaistimer;

if (last_relais > relais_refresh){
    if(temperature_heater < stoomtemp){
      digitalWrite(relais_heater, HIGH);
      }
    if(temperature_heater >stoomtemp){
        digitalWrite(relais_heater, LOW);
        relaistimer = millis();
      }
}
```

Figure 81 : Arduino internal timer

12. Frothing Device

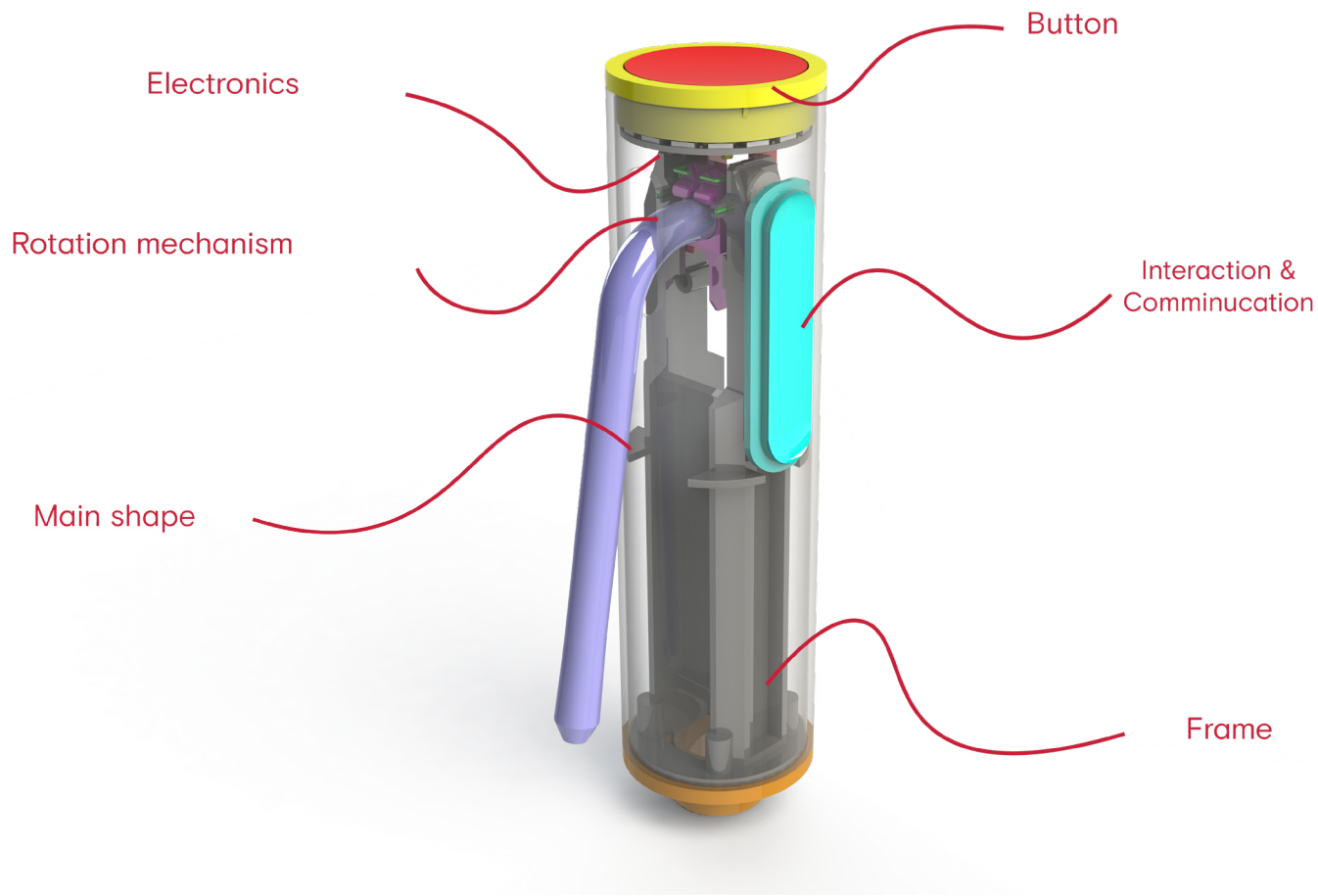


Figure 82 : See through render of the on counter device

Next to the development of the milkfrother system under the kitchen counter the device that interacts with the user is further embodied. This chapter discusses the technical and user aspects of the device shown in figure 82.

12.1. Main shape

The cylindrical shape of the device is achieved by using a grinded stainless-steel tube that it cut to size with two added slots (figure 83). A different approach taken in comparison to the soap dispenser from Quookers portfolio. The soap dispenser is manufactured using the electrical discharge machining, which is time consuming, material inefficient and expensive.

The widely accessible stainless-steel tube is manufactured from a bend sheet that is welded. The weld is grinded down to make it invisible on the outside. When the tube is cut to length two slots are milled. The steam wand is added later and is also made from a bend stainless steel tube of 10 milli meters. The tip is later screwed in a tapped hole and makes the connection to the Teflon tube transporting the steam from the steam producer.

Figure 83 : Stainless steel tube wiht cut slots

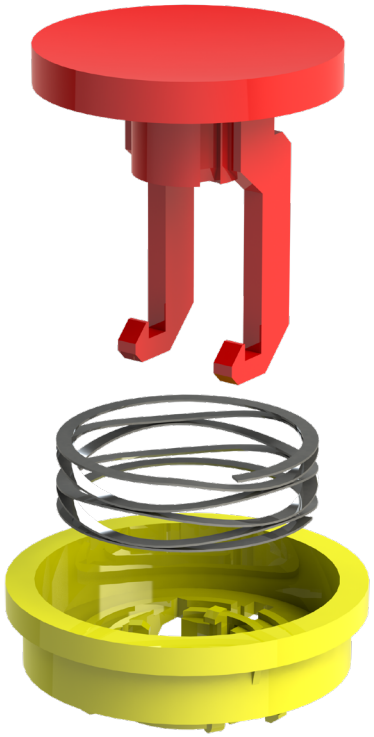


Figure 84 : Button assembly exploded view

12.2. Button

The main point of interaction is a large button placed on top of the device. It fits the current the button's found on a Quooker tap as these buttons also actuates a few millimeters. The moving part of the button is shown in red in figure 84, the yellow part houses the button, and acts as a light guide to transfer the light emitted from multiple led's into one even surface.

The button fits in the lightguide and pushed outwards by a spring. To keep the button inside the housing it is trapped by three hooks that can move in a slot. To prevent the button from sticking

The spring pushing the button back up is a wave spring taken from a Quooker fusion tap. The wave spring has a few advantages in comparison to a normal wire spring. Smally (2023) explains that a wave spring takes up 50% less space while using less materials.

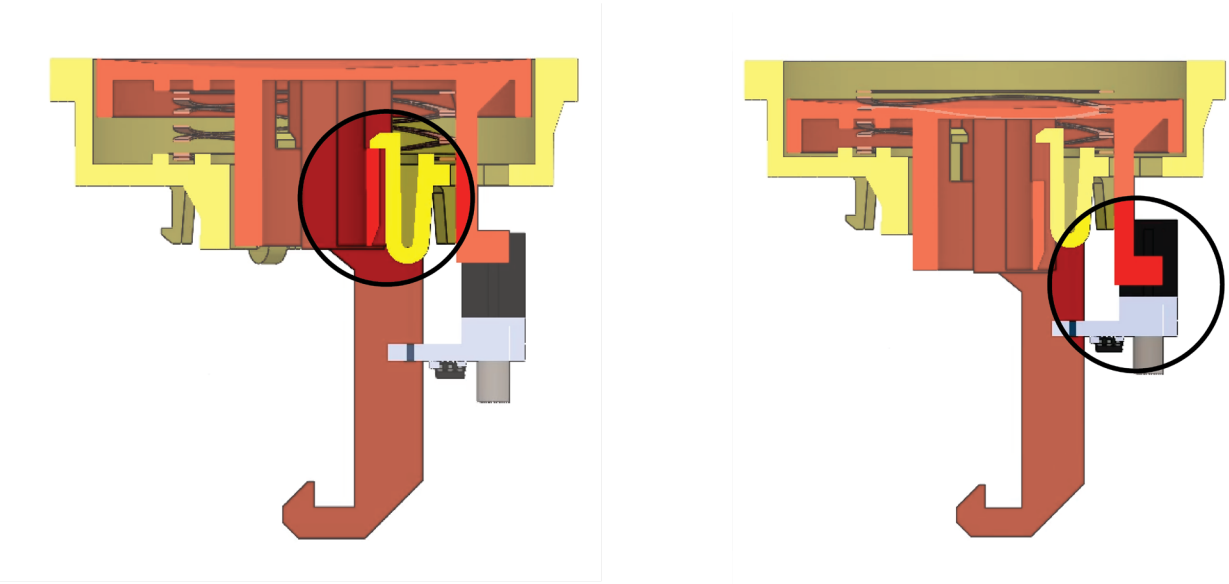


Figure 85 : Button assembly section view

In the right image of figure 85 the slotted optical switch and the pole that blocks its signal can be seen. The button lets the signal pass when it is pressed and blocks it when it is unpressed. It was chosen for its predicted longer lifespan in compression to a mechanical switch, as there is no contact needed to register the push of the button. In the future its placement will also be more flexible depending on the orientation of the circuit board it will be mounted on, while a mechanical switch needs to be in line with the button's movement.

12.3. Rotation Mechanism

To make the placement of the milk jug possible without making a tall device the steam wand can pivot outwards. The decision was made to make the wand partly mechanically actuated, a spring-loaded mechanism moves the wand outwards. The machine turns on by pressing the large button located on the top of the tube and with the downwards motion of the button the wand is also released.

The decision to make the wand partly human actuated as the space inside the tube is small, a solution with an electric motor would be expensive and fragile. The technical solution presented in concept 1, was also not further examined as the solution still required the human interaction, for stowing the wand, only automating the releasing motion.

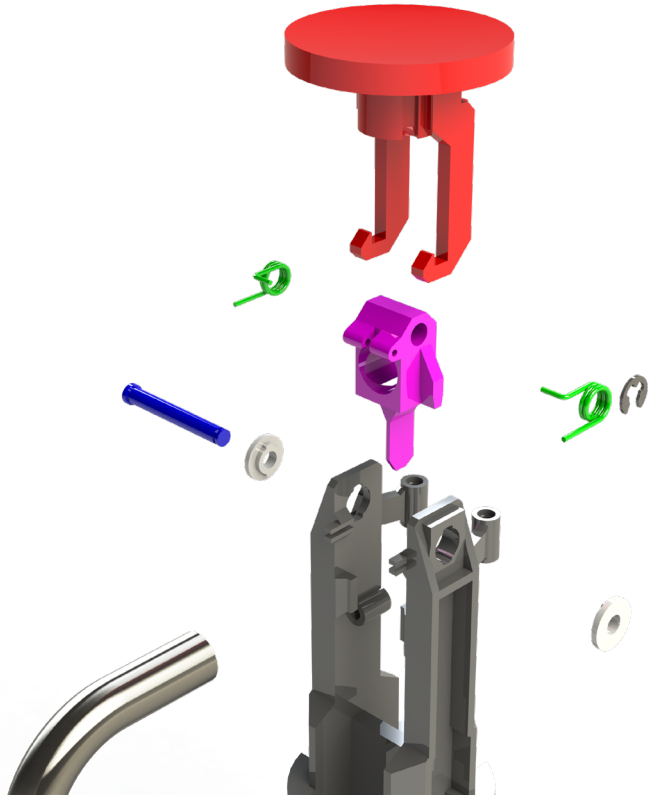


Figure 86 : Rotation assembly exploded view

Figure 86 shows the parts responsible for the rotation mechanism. In blue the 4 milli meter stainless steel axis supported by two sleeve bearings. The pink part grips the steam wand, torsion springs (green) and hooks of the button in red. From a selection of torsion springs suitable for a 4 milli meter axis and the desired range of rotation, the spring with 2,5 windings performed the best. Providing a sufficient moment to lift the wand and not too strong to make stowing the wand impossible. In the prototype two torsion springs are used, one left and one right winded. In a production a custom double winded spring can be bought to minimize the parts used and simplifying the geometry used to tension the springs.

Figure 87 shows how the two hooks on the button trap the finger extending from the hinging part in purple. When the button is pressed the hooks move down releasing the spring-loaded hinge. The wave spring in the button moves the hooks back up. As the wand is stowed the angled surface of the hook moves the button part downwards. At the moment that the fingers are far enough inside the hook the button's spring moves upwards trapping the hinge again.

In the further iteration of the rotation mechanism a guiding surface was added to the black chassis part. The surfaces can be seen in the colour orange in figure 88. Adding the guide surfaces is necessary to prevent misalignment of the red button, due to the forces shown in cyan, resulting in the button being not pressable and potentially mechanically failing. With the new mechanism it is possible to stow the wand without having to push a button, however the longevity of the solution still needs to be validated.

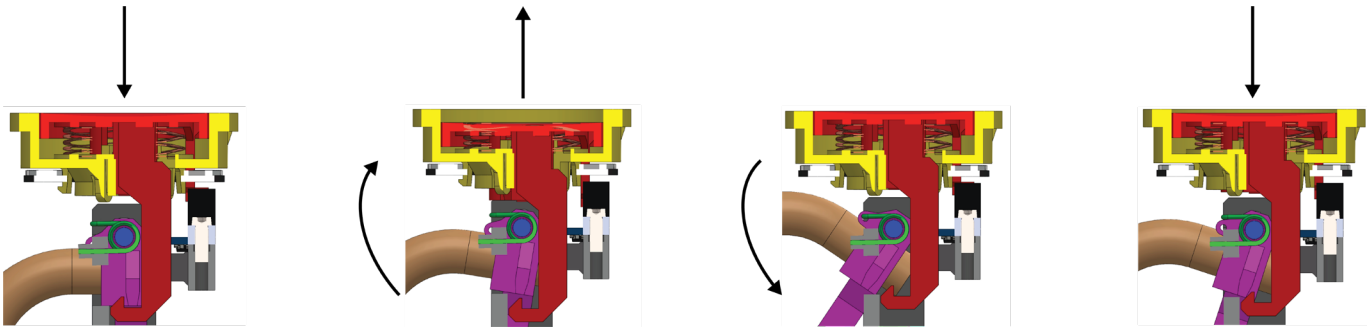
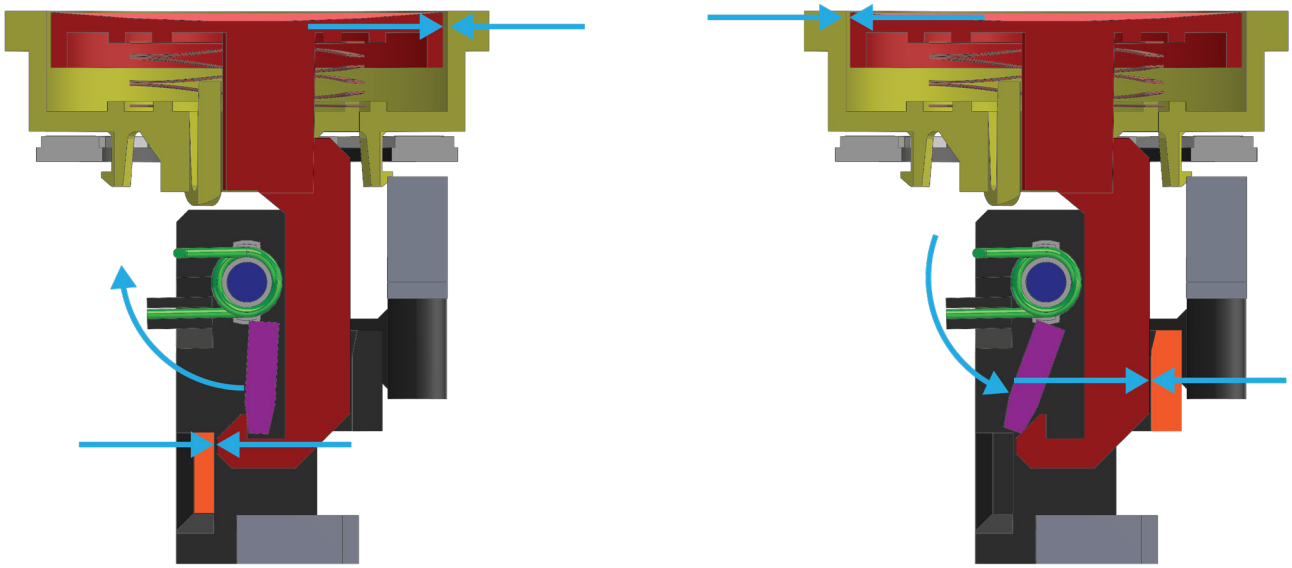


Figure 87 : Rotation assembly section view



Wand stored

Wand stowed

Figure 88 : Rotation assembly section view

12.4. Interaction & Communication

The yellow and cyan parts are communicating with the user (figure 89). The yellow part that houses the button also acts as a diffuser for the led ring located underneath it. Multiple lighting schemes communicate the different phases of the milk frothing process. A hard blinking light will mean that the user must perform an activity to continue, a fading light means the frother is taking control and nothing must be done by the user. A red indication is a warning that steam must be released with caution to clean the system. Figure 90 shows the frothing process and the corresponding light feedback provided by the device.

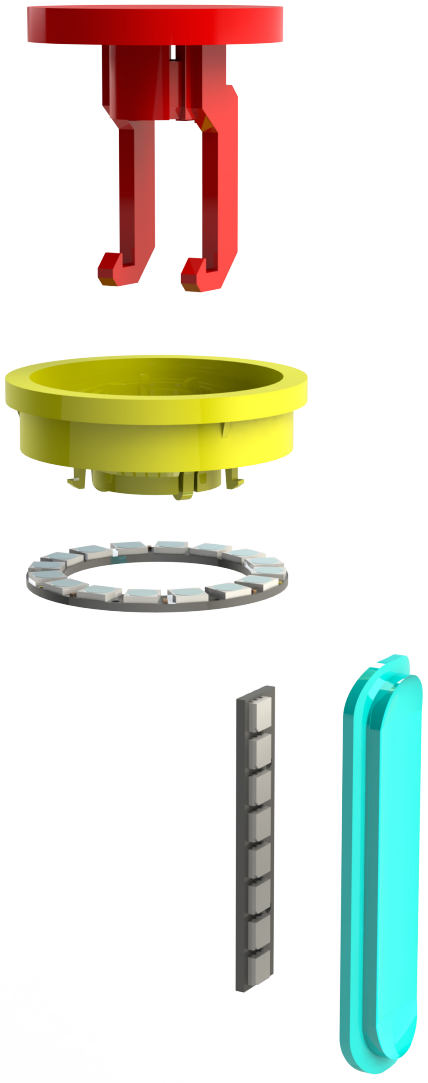


Figure 89 : Interaction assembly exploded view

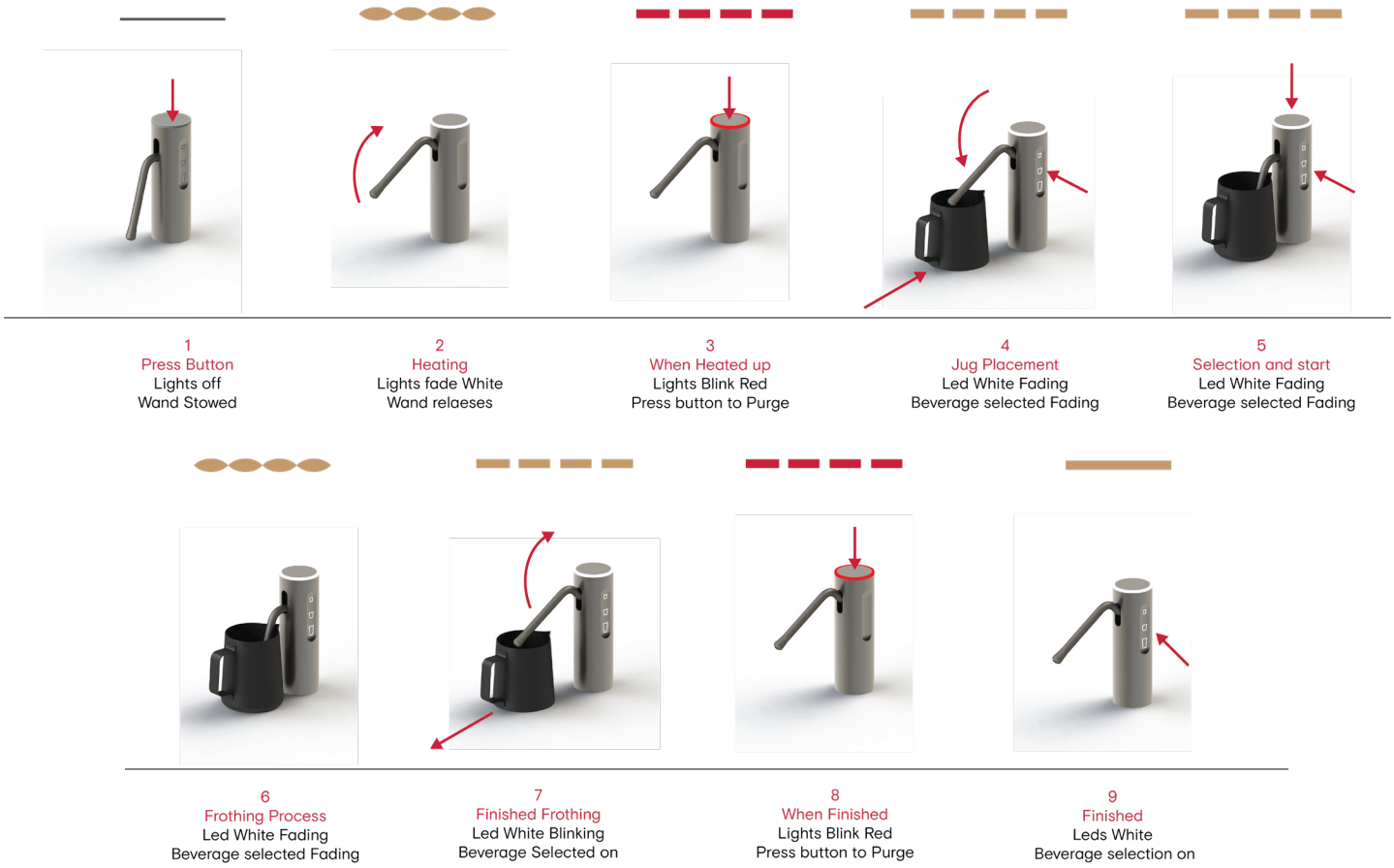


Figure 90 : Ligth beaviour in the frothing process

12.5. Oncounter device electronics

To achieve all the interactions the actions of the user are measured using two slotted optical switches (Figure 91). One is measuring the button and the other one is measuring if the steam wand is stowed. The part that is communicating back are two led strip modules. The circle has sixteen led's and the strip 8 that can be separately controlled in colour and brightness. The led modules house 3 coloured led's, red, blue, green and an extra warm white led. By mixing the different colours a huge amount of colours can be made, however, to make a clean white without any artifacts of the mixing the strips with the extra white led was chosen.

All the electronic modules require a 5-volt power and ground wire and have a separate data line which connects to the Arduino in de control box. All led's are chained together with the data wire starting in the circle and traveling further to the strip.

Figure 91 : Electronics in on counter device

12.6. Assembly Part

Most of the mentioned parts above are assembled in the frame shown in figure 92. The frame is inserted from the top and is screwed down from the bottom with a part that connects to the kitchen counter. The sensors also screwed down and the axis is fixed with the two bearings and a circlip. All the screws are self-tapping and specifically designed for plastics. It is possible use the screw busses a few times, however this amount is not infinite. The button is the closing part and is pressed into the tube fixated by friction.

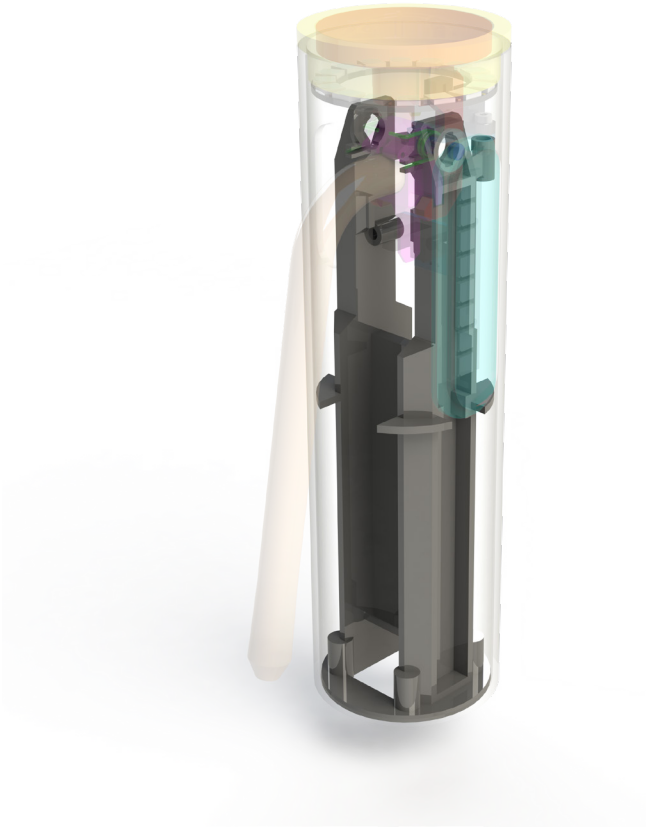


Figure 92 : Frame part in on counter device

13. Cost price estimation

A concise estimation of the expected cost and sales price is drawn up. The buy in items, inhouse parts, assembly and sales price are discussed. Web links to all the parts can be found in a separate paragraph in the references.

This list of items need to be bought as Quooker is not an expert in certain (protected) technologies (table 9), for example the heating element and the wave and torsion springs. The most expensive item is the heating element with €10,00. This estimation is made on the current spare part price of that retails in service stores for €39,00. Placed secondly, the manufacturing of the circuit board managing the steam generator and the frother device is also outsourced. Per circuit board the price is estimated at a price of €2. The remaining bought parts are the second half of the total buy ins at €25,89.

Buy ins	Price/Unit	Amount per order	Used	
Heating element	€ 10,00	1	1	€ **10,00**
PCB	€ 2,00	1	2	€ **4,00**
RVS Tube 48mm	€ 35,12	3000	160	€ **1,87**
RVS Tube 10mm	€ 13,22	3000	100	€ **0,44**
Teflon tubes	€ 9,00	1000	300	€ **2,70**
Air pump	€ 3,00	1	1	€ **3,00**
Leds	€ 0,05	1	6	€ **0,30**
Optical light switch	€ 0,30	1	2	€ **0,60**
Relays	€ 0,40	1	2	€ **0,80**
NTC	€ 0,08	1	1	€ **0,08**
AC DC converter	€ 1,20	1	1	€ **1,20**
Smalley Spring	€ 0,50	1	1	€ **0,50**
Torsion Spring	€ 0,40	1	1	€ **0,40**
				€ **25,89**

Table 9 : Buy in price estimations

Most plastic parts will be manufactured at the site of Quookers injection moulding partner, yet the investments and manufacturing are still financed by Quooker. Three investment calculations were conducted using the web base injection moulding calculator from CustomPartNet (2023) and are shown in table 10. A small, medium and large part are estimated with altering amount of part complexity. The parts used and the result from the estimation tool can be found in appendix L. The material price is also provided, however these numbers are les than 10 percent of the total investments.

Looking at required machine hours the most expensive rework needs to be done in the stainless-steel tube (table 11). It requires a few milling operations, that are the quickest to execute with the use of a CNC machine. Operating these expensive machines is a costly process and results in a cost of €13,89. It may be possible that for larger order the price will decrease a bit, yet it still is a large cost per part.

Machine Hour costs	Price per hour	Hours	Seconds	
Injection Molding Large	€ 50,00	1	60	€ **0,83**
Injection Molding Small	€ 30,00	1	300	€ **2,50**
CNC Mill	€ 200,00	1	250	€ **13,89**
				€ **17,22**

Table 11 : Machine hour estimation

Investments	Mold price	Amount	
Parts L	€ 50.000,00	4	€ **4,00**
Parts M	€ 20.000,00	6	€ **2,40**
Parts S	€ 8.000,00	3	€ **0,48**
			€ **6,88**

Material costs	Price per kilo	grams	grams used	
PSS	€ 12,00	1000	20	€ **0,24**
ABS-GF	€ 3,00	1000	100	€ **0,30**
				€ **0,54**

Table 10 : Injection moulding investment estimations

Smaller and simple sub-assemblies are delivered by Quooker from social workshops, however the regular assembly workers are getting paid to our western norms as can be seen in table 12, making every minute count the assembly time should be minimized and is expected to be 8 minutes per frother. Like the tap assembly lines one worker will start with an empty tray and walks passed a buffet of parts, finishing with a complete frother which is then automatically tested and packaged.

When totalling all the cost to manufacture a milk frother the final cost price is €60.54 (table 13). The main category piece to this number is the amount of parts that must be bought. The last table 14 shows the expected sales price of the milkfrother. These margins are taking up the most part of the final sales price, and the exact percentages are not communicated openly with interns. The profit margin is known to be high for Quooker therefore the number of 60% is chosen. The number is relative as the milkfrother is an addition to the coffee machine that will be the main source of profits.

Assembly	Price per Hour	Assembly Time in minutes	
Assembly Worker	€ 50,00	8	**€ 6,67**
Assembly Station	€ 25,00	8	**€ 3,33**
			€ 10,00

Table 12 : Assembly price estimation

Cost price Total	Price	Percentage
Buy Ins	€ 25,89	43%
Tooling investments	€ 6,88	11%
Material costs	€ 0,54	1%
Machine hours	€ 17,22	28%
Assembly	€ 10,00	17%
	€ 60,54	**100%**

Table 13 : Cost price totals

Sales price	Percentage		
Costprice		**€**	**60,54**
Overhead	20%		
Sales	15%		
Profit margin	60%		
		€	**133,66**
Retail margin	100%		
		€	**267,33**
BTW	21%		
		€	**323,47**

Table 14 : Sales price margins

Evaluation

14. Prototype evaluation
15. Integrated prototype evaluation
16. Requirements check
17. Conclusions
18. Recomandations
19. Personal evaluation

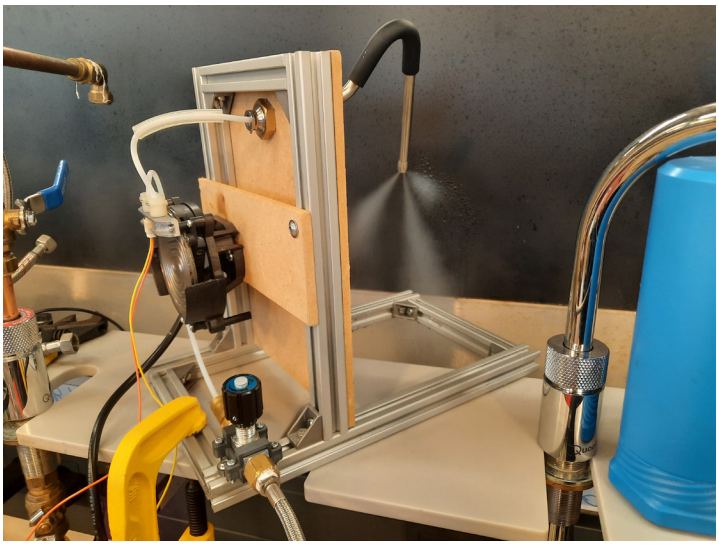
In this phase the prototyping of the design, is first discussed. Ending with a concluding evaluation of these prototypes and recomandations for future developments

14. Prototype evaluation

14.1. Steam prototype test

The under the counter prototype is manufactured from aluminium extrusion profiles with a cross section of 20 by 20 millimeters. A few connections needed to be manufactured on a lathe, which was done in the workshop at the IDE faculty.

It was possible to control steady steam generation, while not exceeding to unsafe temperatures. It was possible to make milk froth by placing the steamwand in the jug and follow the steps described in chapter 3



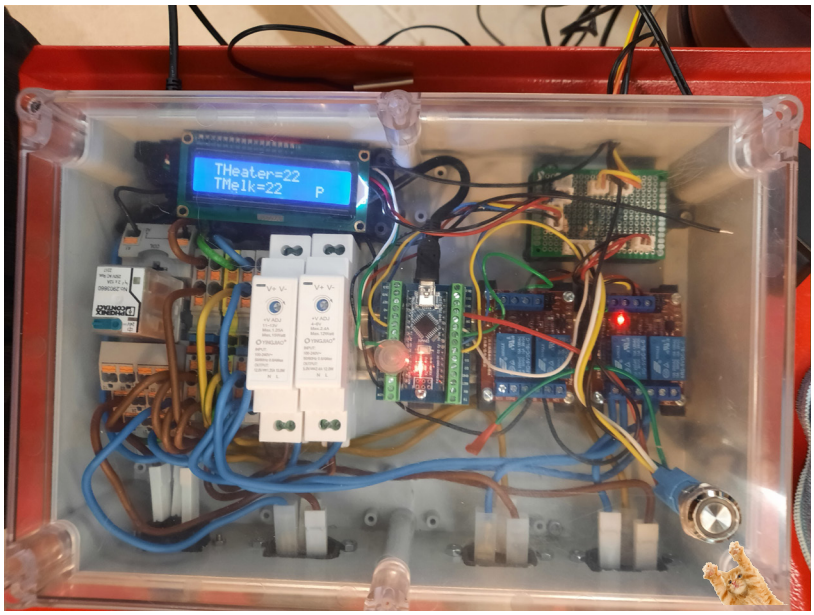


Figure 93 : Pictures of the steam producing prototype

14.2. On counter prototype

The on-counter prototype was designed with an iterative process using many parts manufactured using a 3D printer. The first models were printed using an Ultimaker FDM printer (fused deposition modelling) and the parts further in the process with a Form labs SLA (Stereolithography) printer. These parts were needed to produce more detailed and stiffer parts. The metallic parts were manufactured in the workshop, with stainless steel tubes as a start. A few pictures of the prototype can be seen in figure 94

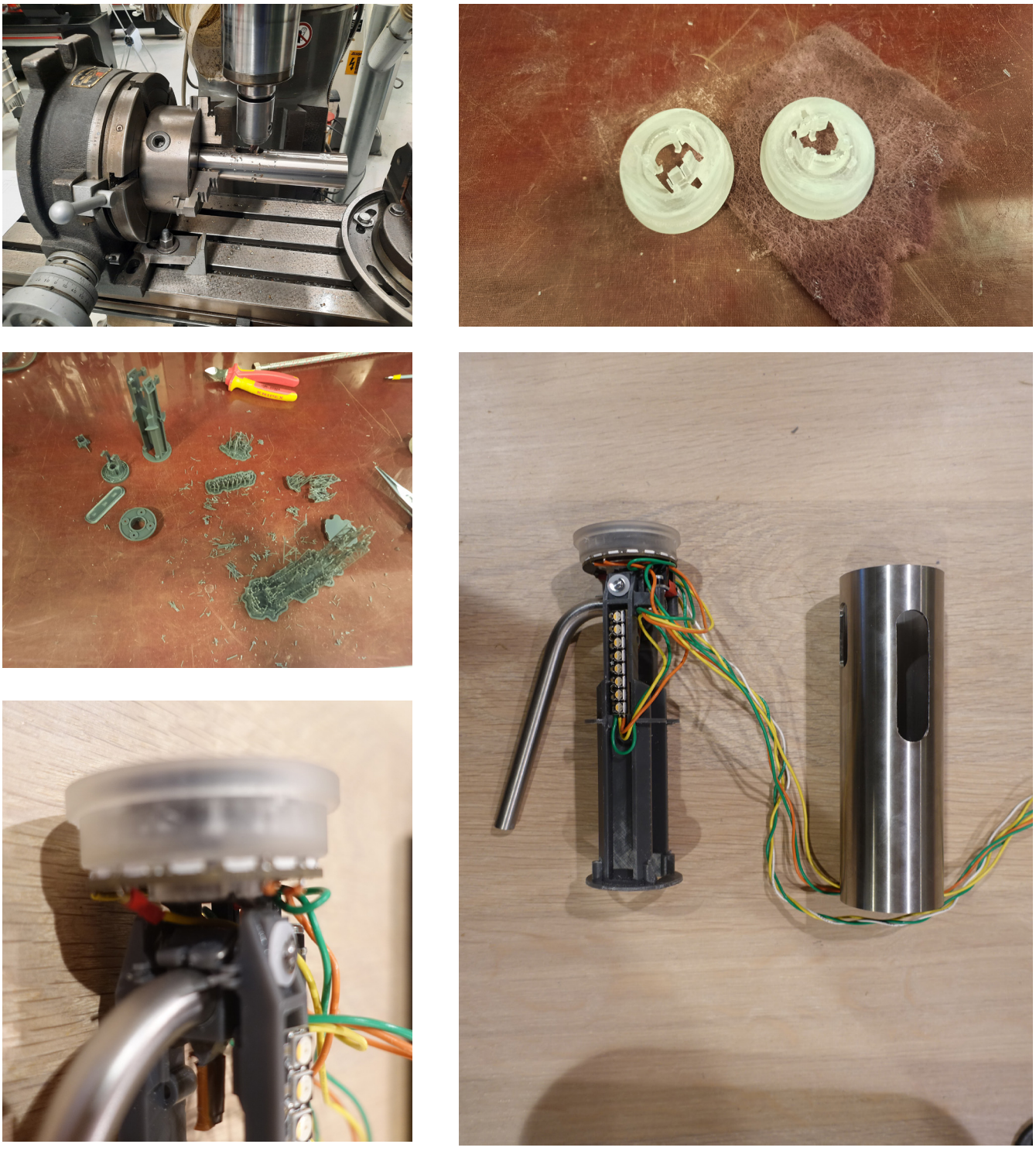


Figure 94 : Pictures of the on counter prototype

14.3. On Counter Prototype User Test

With the on-counter iteration completed new users test are conducted. The goal of the test is to gain proof that the optimized concept is better than the three concepts shown in chapter 8.3. Next to that the envisioned interaction explained in chapter 9.6 is tested. When does the user needs to perform a certain task to continue and when it the product taking control. It is necessary to get the interaction cleared up before testing with the steam generator connected to the system. To make test safer when using steam, the interaction must be better than sufficient and prior to the test the frothers interaction will explained to the participants to achieve a safer situation.

Method

The working prototype of the on-counter device is used in a kitchen setting to let participants make a cappuccino. It is a similar setup as the test in chapter 9.5, however now only one device is tested instead of four. A small kitchen counter was made to also have a Quooker tap present, and to provide a more realistic use situation. A camera is used to record the actions and thoughts of the test participants. A picture showing the setup can be seen in figure 78. To get knowledge on the first goal, the concept, the same assessment form will be used to compare the difference. There must be noted that tests are now conducted with students instead of Quooker owners, thus the value of the results must be discussed. At the same time insights in the interaction the taken. In the form of written feedback and video captured of the tests.

Figure 95 : User evaluation test setup.

Results

One pilot and 6 user tests were conducted in. The users were Students in a rage of age between at 23 to 26. Pictures of the tests can be seen in figure 79.

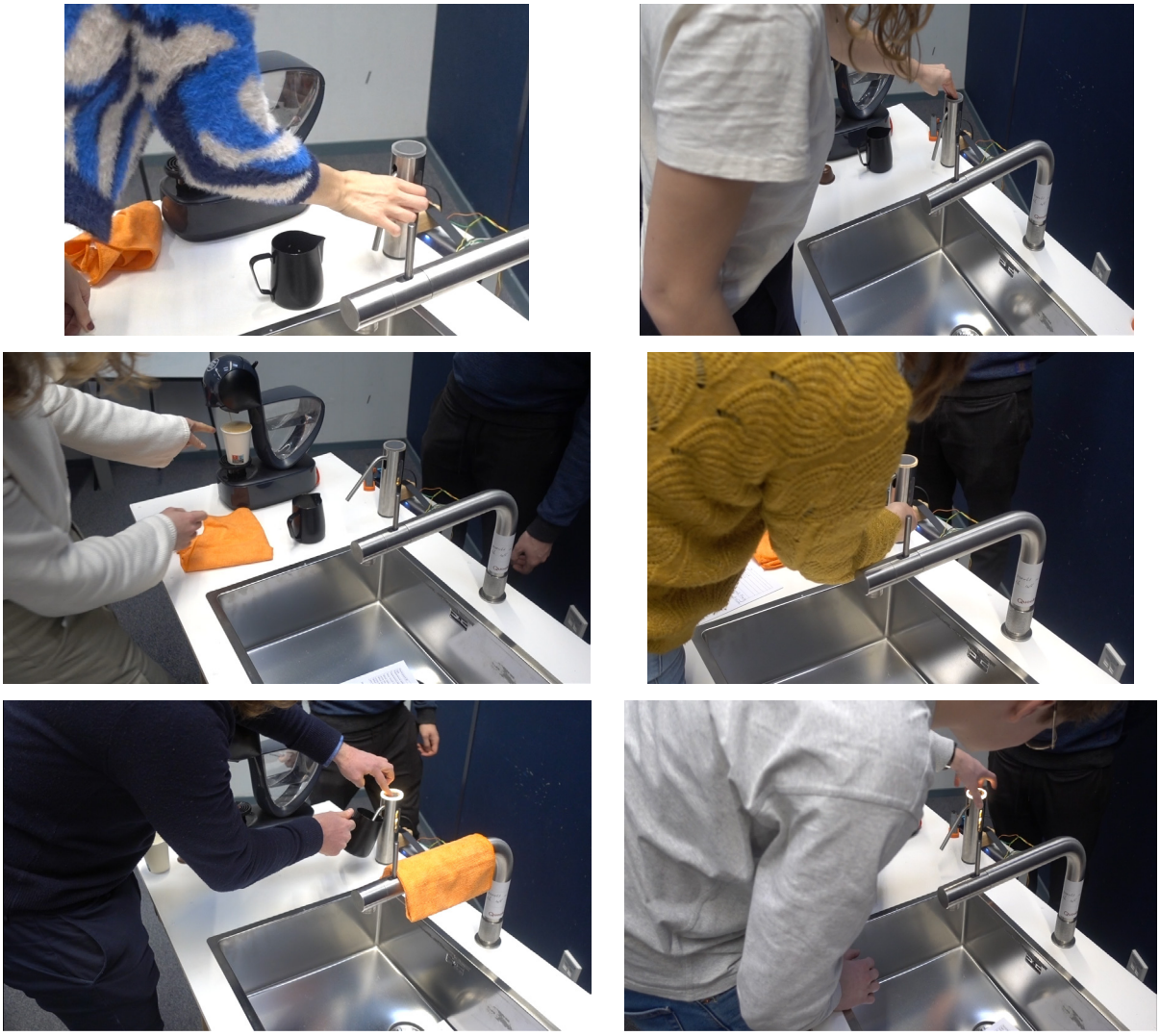


Figure 96 : Pictures of User Tests

All the filled-out forms can be seen in appendix K. Overall, the test participants graded the interaction of the device with a score of 5,9 out of 7. It is an improvement in comparison to the highest score in the previous concept test with a 5,5 out of 7. The comfortability (6,1 out of 7) aesthetics in participants kitchen (5,0 out of 7) and fit with Quookers design (6,4 out of 7). Figure 80 shows the graph of the average grades given by the test participants, the on-counter device is shown in the red line and the best performing concept from the previous test is shown in green.

Next to the grades the participants also answered a few open questions to elaborate on their grade. The thing liked the most from the device is the large lit button that guide the user through the milk froth process, and that coffee making is possible at the same time when the device is doing its job. It shows that the concept with the large button on top was the right direction to follow. Yet there were still a few points that require an improvement, the most mentioned was

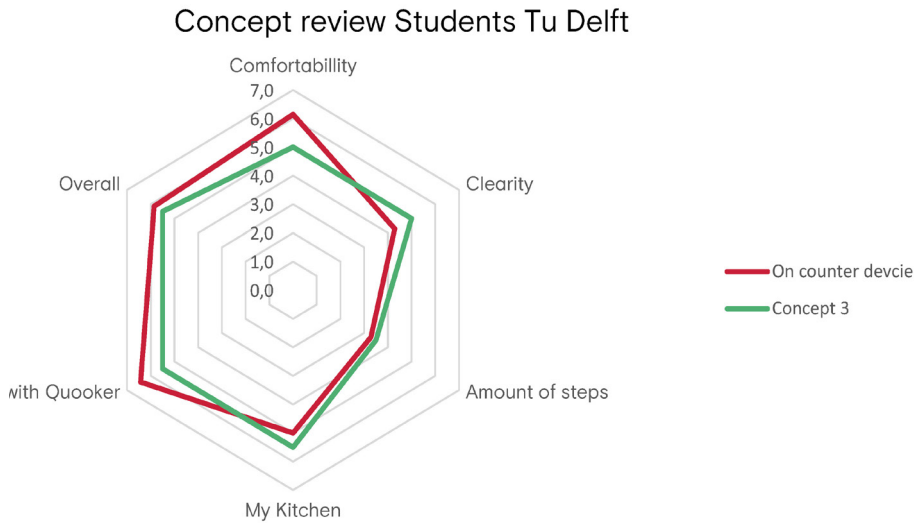


Figure 97 : Graph with Assesment On Counter prototype & Concept 3

the device did not really communicate the cleaning step. Especially the first step as the users did not know that cleaning before frothing is necessary. Next to that the wand still did not reach too far out to make the placement of the jug easy.

Conclusions & Discussion

Even though the test participants assessed that the optimized concept is a successful direction it cannot be fully answered due to the choice of the participants group. The direction is proven to perform better with the students, but it may be possible that the older target group of Quookers clients tell differently. Yet the results are now gathered from a larger amount of test participants, with the notion that the fit with the company is almost unanimously a fit with Quookers design. The major interaction difficulties that became known when testing with Quookers clients, will now also be found. More user testing with the final prototype will be with Quooker employees and (potential) clients to assure the final frother iteration will be desirable and a fit with the company

The results that are gathered are leading to extra improvements for the next design iteration, the light interactions need to be revised, and the steam wand swivel needs to be optimized. The difference between blinking and the fading light was not always noticed, thus it was unclear what was required. After heating up the fading light from that state will be continuously on. The continuous light will not draw as many attention as the blinking, the static image will mean that something is finished, and the next step needs to be taken. The blinking beverage selection on the side will remain blinking to draw attention that a choice needs to be made.

The steam wand position did not seem to be too frustrating, however when looking at the video footage, the wand was pulled upwards to make an opening for the jug. The hinging mechanism was designed to be closed, not extra opened. Over tensioning the spring system will likely lead to parts failing, thus the wand must be opened enough for easy placement, and possibly an extra stop needs to be provided to prevent misuse.

14.4. Prototype optimization

After the green light meeting both the interaction and steam generator prototype shown in figure 98 were combined to one finished model. It serves as a prove that it is technically feasible to make a small new type of milk frother device, and how potential target customers view it.

The integration of both prototypes the three major challenges that needed to be faced were the addition of the venturi injector, the safe housing of the steam generating parts and the steam must be transported though the frothers counter device to the steam wand tip.

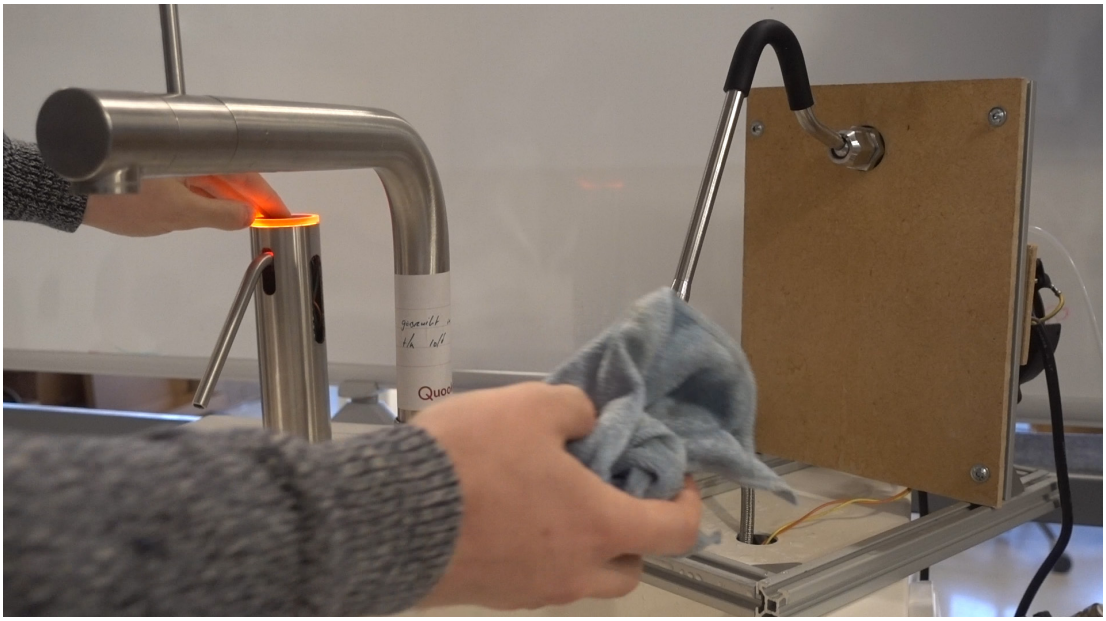


Figure 98 : Interaction and Steam generator prototypes

Figure 99 : Integrated prototype

Venturi Injector

Adding the venturi injector was easier than expected. Tests with the air pump were already conducted and adding the injector to the steams path was easy with the existing coffee connections. In figure 100 the jug when frothing started is shown on the left and the milk after frothing has completed. The jug is remaining still, and no tasks are needed to be performed by the user to make a reasonable quality milk froth. It is not yet the desired quality, however it proves that the venturi principle is also working outside of the Sage machine. On the figure the hand was present to sense the milk temperature, the pictures are taken from a movie in which can be seen the jug does not move.

Steam generator housing

The second optimization, a safe way of working with the steam generator was desired. Aluminum extrusion with lasercut plates could have been the fastest and easiest option, however most of the components were already in CAD. Thus, a bit nicer looking housing was design to not only finish the countertop part of the frother. It provides a more realistic image of how much space the steam generator below the counter claims, and how a certain housing would aesthetically looks. All parts had to be placed together in one file and fitted into the three housing shells. As can be seen in figures 101, the FDM print is test fitted, minor changes to the how the shell parts connect were added and the SLS print is ordered.

Figure 100 : Volume increase in the milk by using the venturi injector

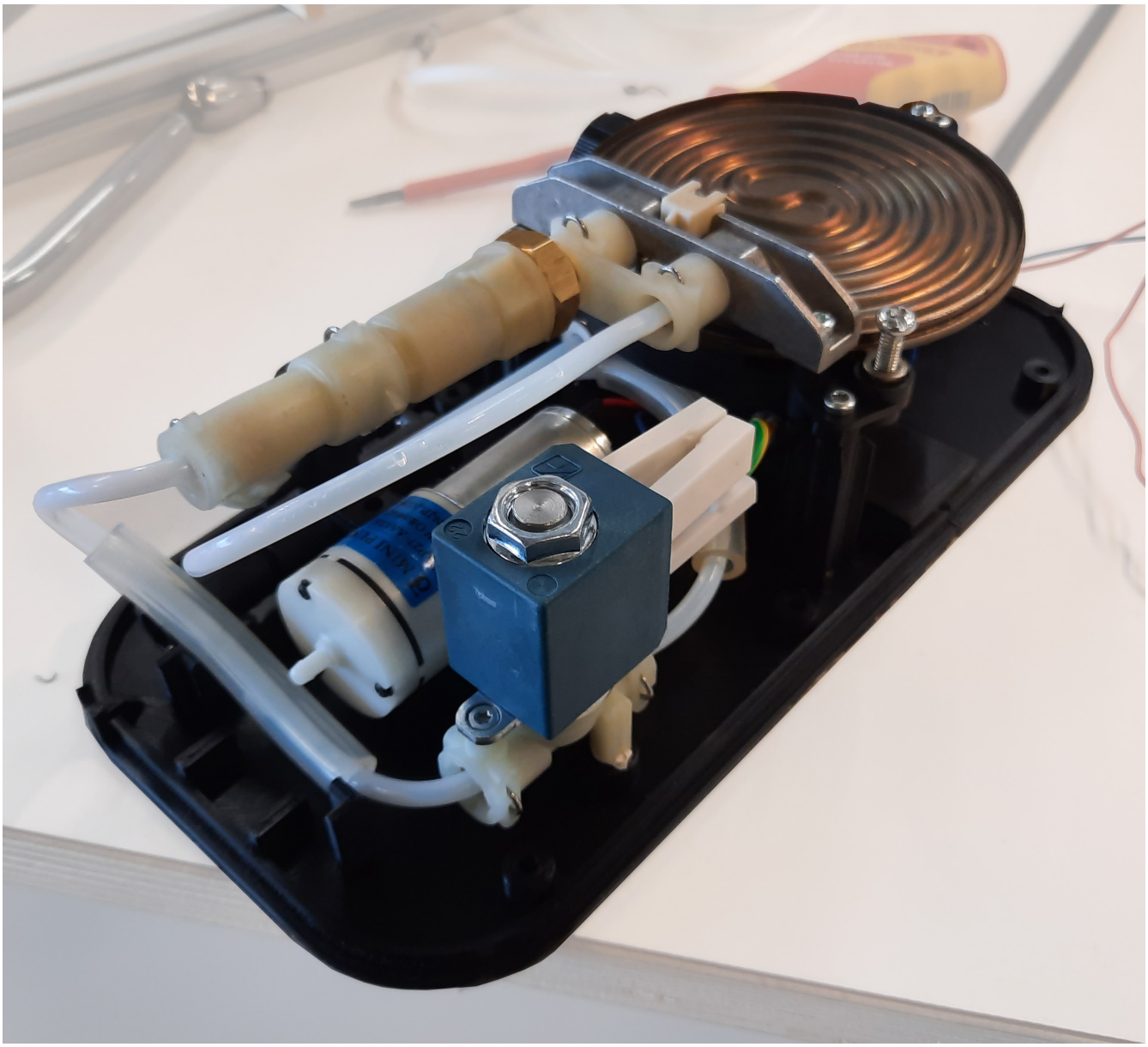


Figure 101 : Test fit parts on FDM 3D print

Figure 102 : Decent wand tip

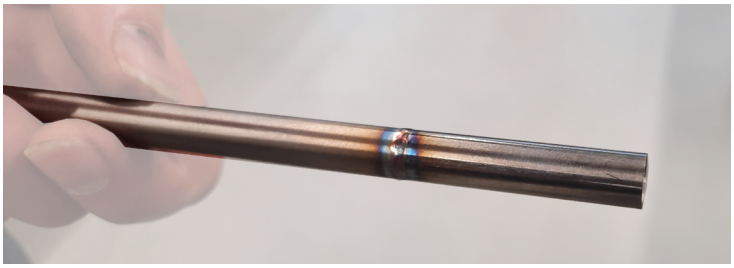


Figure 103 : Welded tubes

Steam transportation

The third integration challenge was using the self-bend stainless steel tube with the steam wand tip from the Decent Coffee machine (figure 104). The tip's design is influencing the frothing performance and is therefore the existing tip used. Although it looks fairly straight forward, tap a screw thread into the 10 millimeters tube with a thickness of 1 millimeters and start frothing, the thread is a custom one of which a tap is not easily purchasable. (M8,3x 0,75)
The custom thread is not only chosen to prevent the tip to be used in other frothing machines, it's abnormal thread size also has a feasibility reason. To make a nicely looking steam wand the wall thickness of the tube should not be too thick, as this will result in a larger bend radius and will leave more marks on the bend. When the wall thickness is to thin, no thread can be tapped into it as there is no wall left. Tapping M8 or M9 x 0,75 with a wall thickness of 1 millimeters will result in an incomplete thread with M8 and M9 will only have a 0,5mm in wall thickness left over. With M8,3 x 0,75 the thread can be fully tapped and will leave a wall thickness of 0,85 millimeters.

In the prototype the problem is solved by cutting a piece form the purchased steam wand and fixating it to a piece of unbend tube. The precision mechanics at the Quooker workshop were happy to help. Their approach was a bit more radical than the solution found by a discussing with the department's colleagues. The two tubes were welded together and in a lathe the weld was sanded down, so it is barely noticeable. A picture of the welded tubes can be seen in figure 103.

Figure 104 : Prototype with loose tip

The Decent steam wand tip is fed by a 5 millimeters teflon tube, while the steam generator tubes have an outside diameter of 4 millimeters. Therefore, a 30 centimeters teflon tube was machined to fit a 4 millimeters push-fit. Before the tube could be machined a weld wire with the same inner diameter had to be inserted. A picture of the lathe with the machine teflon tube can be seen in figure 106.

Logo engraving

To finish the integrated prototype the Quooker logo is engraved in the stainless-steel tube. The device was disassembled, and the tube is clamped in a rotary chuck powered by a stepper motor. The laser pulses evaporate a piece of stainless steel on the surface of the tube. The evaporated gasses prevent the laser from penetrating deeper in te material and evaporating more. The figure 105 below shows the clamped tube and the spark from engraving.

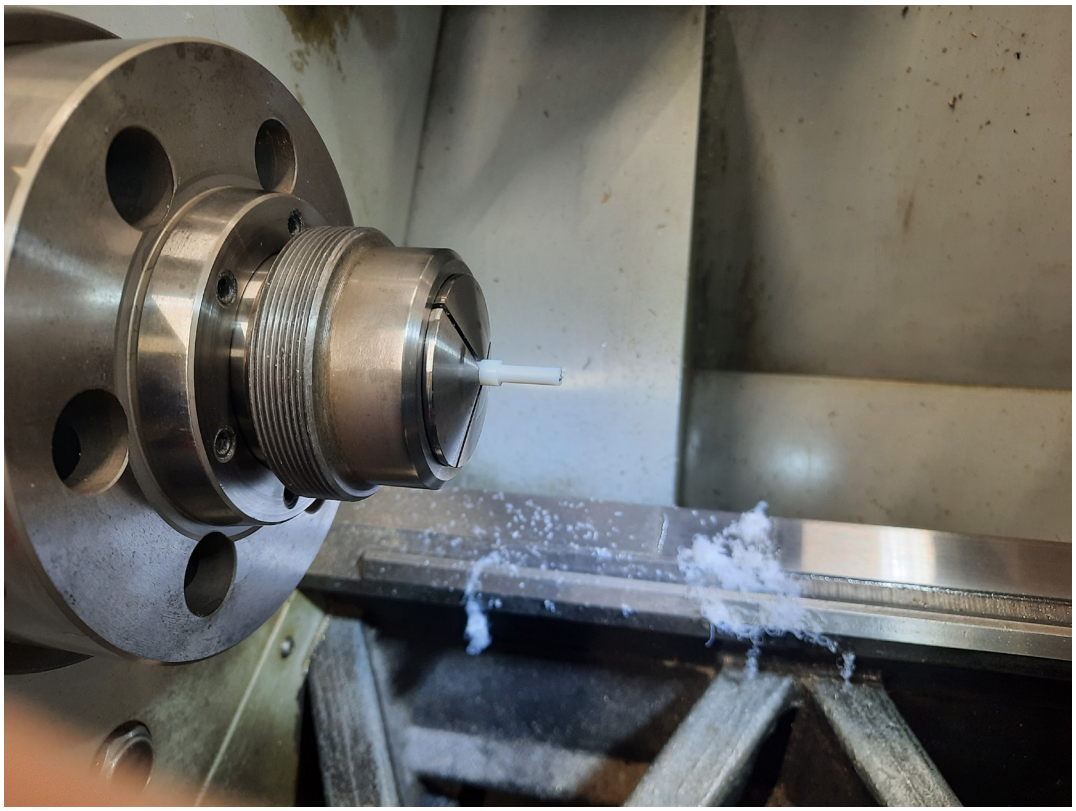


Figure 106 : Teflon tube clamped in lathe

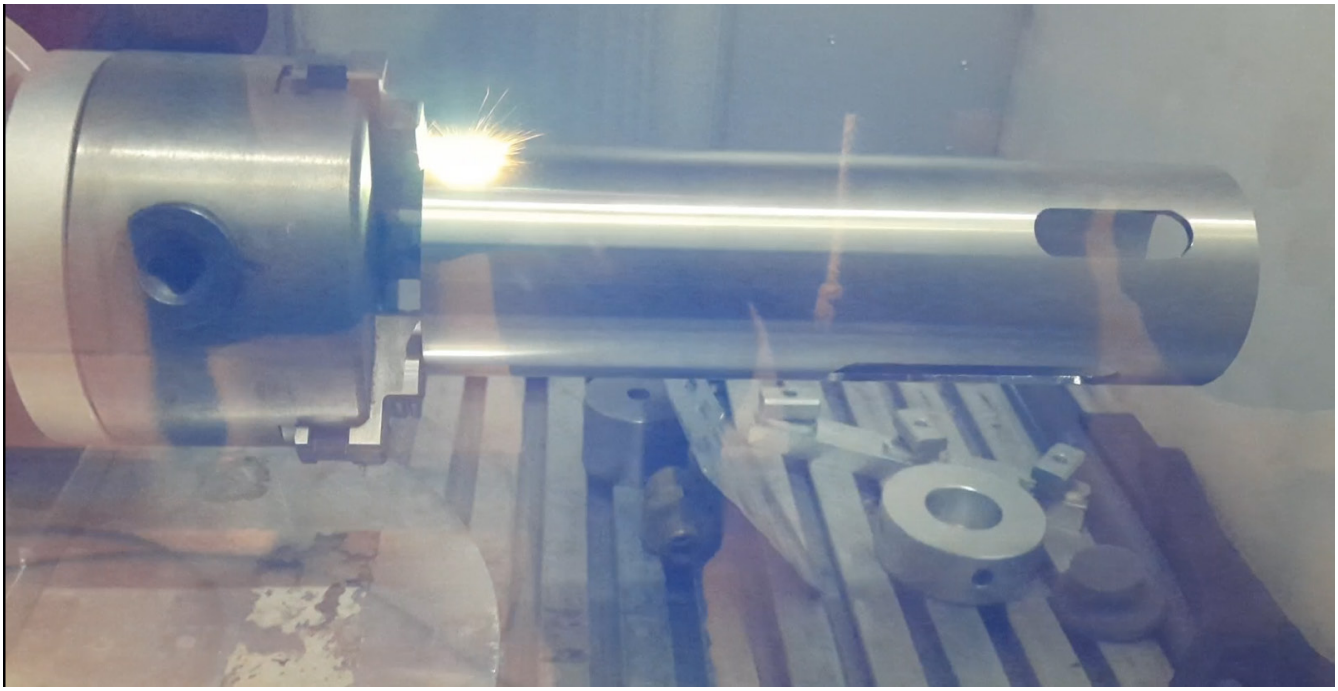


Figure 105 : Engraving process of the stainless steel tube

Jug placement sensing

Next to the improvements of the two separate prototypes a small feasibility test of sensing the jug presence was conducted. An inductive sensor often used in automation and traffic lights can sense the presence of ferrous metals without contact. The milk jug is also made from a ferrous type of stainless steel and thereby making it possible to detect it. The inductive sensor used is a LJ12A3-4-Z/B (Ben's electronics , 2023) and is mostly used in 3D printers. A separate power supply and a PC817 optocoupler circuit as shown in figure 107 needed to be connected to read the sensor data with an Arduino. The sensor was able to successfully detect the jug at around 2 millimeters. Figure 109 shows the detection of the jug. As can be seen the sensor is quite large and will not fit easily in the frothing device, this will not be a problem as figure 108 shows the internal components of the sensor. (Robu, 2020) The piece that senses the metal is only a small portion of the sensor and the rest of the space is taken up by signal processing circuitry that can be located elsewhere. The decision was made to not further integrate the sensor in the integrated prototype due to the time it would take to electronically add the circuit to the already crowded control case.

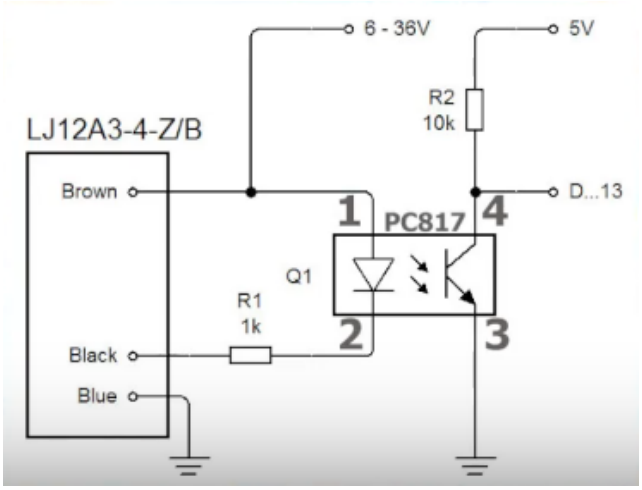


Figure 107 : Inductive sensor wiring schematic

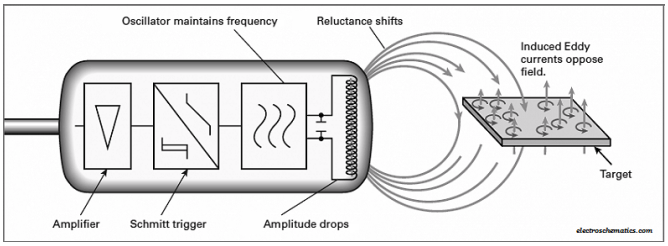


Figure 108 : Inductive sensor working principle

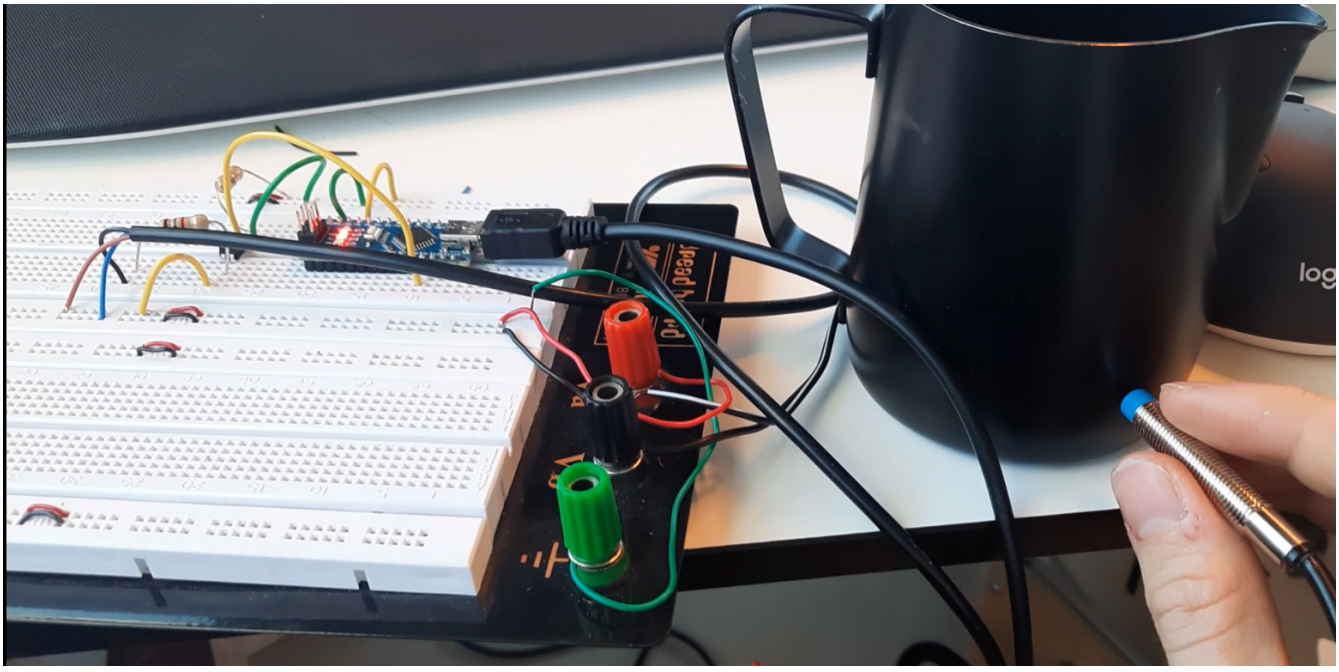


Figure 109 : Inductive sensor test

15. Integrated prototype evaluation

For a final user evaluation, a demonstration video is created to show the new type of frother and its functions. The demonstration takes the watcher step by step through the process of making a frothed jug of milk. The goal is to get their opinion about the product one last time and to discuss what should be better.

The interviewed users are the same contacts from the initial interviews held in chapter 8. First the demonstration video is sent ahead and later a half an hour phone conversation is held to gather the opinions. The decision for this format was made, as the hands-on interaction itself is already tested and evaluated in chapter 14. The integrated prototype is not very transportable in the expo cabinet and even tough the steam the frothing process is predictable, a lot of measurements to test with a potential harmful device must be taken and needs formal approval of the ethics board of the TU Delft (2023).

The following questions were asked to the interviewees.

Can you share your first reactions to the demonstration video?
Is it clear how the milk frothing process works and what the device is doing
Would you see the frother in your own kitchen, together with a Quooker coffee machine. and why?
Do you think the frother fits with Quookers present product portfolio
What feature or improvement do you miss on the frother
Is the wand cleaning step before and after every serving a potential problem?
Even if the device is aiding you through the process. (Bi) Monthly cleaning, soaking the tip in a solvent for 20 min will be necessary to keep the frother in perfect working condition, will this be a problem?
Do you think the product is safe to use for you as a user and your environment.

Interview 1
The first interviewee had restaurant experience with milk frothing with a wand, yet at home the Aerochino type of frother would still be her choice after seeing the video. The Quooker coffee machine would not fit her kitchen and desired coffee experience, as there is enough space in the kitchen to place an espresso machine with separate bean mill. The coffee making process is a zen ritual, while in her view milk frothing is not necessarily zen.

She could relate that when a consumer would purchase a Quooker coffee system the milk froth addition would be a logical step to purchase as well. She could see a clear fit with the Quookers design and portfolio. However, as she explained in chapter 9, the scepticism to the dirty wand, the frother still needs to convince her it will not be as bad as in her experience.

Interview 2
The second interviewee explicitly mentioned that it is really a Quooker product. The light ring on top and the button is familiar and matches the water tap. She liked the minimalistic design and small footprint of the frother. When asked if everything was clear, the answer was that before having the confidence she would have liked to watch the demonstration move a few more times. Especially the cleaning step, the purge of steam she said she deemed a mini barista instruction necessary to safely use the frother. it was mentioned that when the correct cleaning supplies for multiple years of use would be delivered with the product cleaning after every serving and monthly maintenance would not be an issue. A reminder that does not only come from the machine, but for example in the form email or future connected app would be nice. She seemed to be enthusiastic about other

application of steam in food preparation. Fast creation of hot chocolate milk or gluhwein is a welcome addition to kitchen.

Interview 3
The third interviewee liked the aesthetic look of the frother and instantly recognized it as a Quooker product. Quickly in the interview the preference for the Nespresso Aerochino became clear. Its faster use with less steps has her preference over the more authentic and premium way of milk frothing. Even with the fast heating and frothing times. When imagining she owned the product the cleaning steps itself as shown in the movie would not deemed problem, also the 'larger' monthly maintenance would not deemed a lot of work. A dedicated space in the sink cabinet would be made to store the cloth.

Concluding, all three interviewees would see fit with Quooker. The design is small minimalistic and easy to use. When telling the story of the frother as an addition to a future coffee machine the design deemed a logical method of frothing. However, for contradicting reasons the device would not enter the kitchen of the spoken interviewees, the two cleaning steps need more attention when comparing to the Aerochino frother, so the Quooker frother was seen as a more authentic way of frothing milk. While the interviewee that spoke of the coffee brewing method as her moment of zen, the frother she is using is not part of that zen moment.

So, it looks like the current frother's design it will not yet make them throw away their electric milk frother. Now it will appeal a smaller portion of the coffee milk beverage enthusiasts that like to froth with steam in a faster and more convenient way than with a regular espresso machine. However, a clear and relatable link with a Quooker coffee device is found, meaning that when seen next to the future coffee machine the opinion may favour the steam frother.

16. Requirements check

The result of this project performance in checked to the requirements set in chapters 2 to 7. For each requirement an assessment is made in four categories, the requirement is: Met and proven, Not proven no risk, Not proven small risk, Not met with risk, Will not be met.

A1	The product must heat milk to 70 degrees Celsius	Met and proven
A2	The product must aerate milk to create froth	Met and proven
A3	The product must also be able to froth with replacement milk types	Not proven small risk
A5	The serving size must be one serving for every type of coffee beverage	Not proven no risk
D1	After every serving the product must be cleaned easily	Met and proven

With the prototype aerated steam could be created to heat the milk to up to 70 °C. The milk froth quality does need to improve, by iterating on the steam wand geometry and air pump controls. No tests with alternative milks are conducted, the frothing principle is not completely different comparing with cow milk, as discussed in chapter 3. The small risk comes from the fact that aeration needs to be more aggressive with alternative milks, and that this is not yet fully optimized for cow milk. Although requirement A5 is not assessed, the jug used next to the frother is able to make enough frothed milk for one serving. Requirement D1 is met as the purging the machine is enough to clean the device each time a serving is made. Comparing with the Nespresso Aerochino it is faster.

C1	The product must last for at least 10 years	Not proven small risk
C3	The product should at least keep functioning for one kitchen lifespan	Not met with risk
D2	The user must be able to conduct small maintenance	Not proven small risk
D3	The user should be able to conduct large maintenance with the a video	Not proven small risk
D4	A Quooker mechanic must be able to conduct large maintenance during	Not proven small risk

The longevity of the product is depending on the amount and quality of the maintenance performed by the user, and possible mechanics. Like the Sage Oracle touch monthly maintenance to prevent blocking of the wands tip holes. Not only is stuck milk a problem, but lime scale depositions will also form a potential problem. It is not only a problem for the frother, the future coffee machine also must deal with depositions in the internal components. It is partly solved by using the Quooker reservoir which catches a large piece of the lime scale.

The mechanical configuration in the projects final design is not able to withstand 10 years of use. Its lifespan should be longer investigated with the correct materials by means of a duration test that simulates the years of use. A robotic arm can be used to simulate the user and test 24 hours per day, for several weeks to assess if the amount of use cycles can be reached without failing.

B1	The product must remain functional when working with steam at 140 °C	Met and proven
B2	The product should resist cleaning agents commonly used in the kitchen	Not proven no risk
K1	Stainless steel must be used for contact with milk	Met and proven
K2	Plastics that are used must be able to cope with hot temperatures 140°C	Not proven no risk
K3	The use of easily milled brass should be minimized	Not proven no risk

The temperature requirements are met by the prototype. The printed materials can withstand multiple frothing tasks without failing. The plastics that are used are not the envisioned

plastics that are able to withstand even higher temperatures, in the case of PPS or Polyethylene sulfide its application is known for temperature and mechanical resistance with a maximum service temperature of 218 °C.

E1	The milkfrother addition must not cost more than €300	Not met with risk
E2	The addition should not cost more than a separate electric milkfrother	Will not be met
G1	There is expected that the milkfrother is sold to 30.000	Not proven small risk

With the cost price estimation, the expected sales price will be larger than the set amount at the start of the project. The high sales price is mostly affected by the high profit margins Quooker expects from its products. There is a risk that the €300 will be exceeded, yet it is not a significant risk as for example the soap dispenser with one basic feature already retails at €300. The requirement itself should be investigated further if consumers are willing to pay again a premium to be provided with an easy innovative and premium milk frothing experience.

A3	The product should be easily cleaned	Met and proven
J1	The product must look premium with the use of metal	Met and proven
L1	The product must be fast in use	Met and proven
L2	The user must be able to use the product without any skills or training	Not met small risk
L3	The product must be cleaned with regular cleaning supplies	Met and proven & not at all
L4	The product should be cleaned within 10 seconds	Met and proven
M1	The product must not harm the user in any way	Not met small risk
M2	When steam used it must be clear to the user that it is not safe	Not met small risk
M3	The product must communicate that surfaces can be hot	Not met small risk

From the initial user interviews cleaning the device would be the toughest selling point of a frother that uses steam. At certain point the steam must enter the milk, without the milk contaminating the system. With the solution to have the least possible places at which milk could get clogged up the venturi still makes sure no skill is required, in comparison to the steam wand discussed in chapter 6. Training is also not necessary, however as with other Quooker products a short instruction is needed to understand why certain interactions are in place. It is mostly from a safety perspective and eventually aids the user fluently through the frothing process. The safety precautions taken, coloured and flashing lights when steaming are already more than an average espresso machine takes. Yet more can be done to improve the safety of the user, especially when the regular frothing program is interrupted.

17. Recomandations

As this graduation project only has a length of twenty weeks and has the goal to provides a head start when the company decides to further develop a milk frother recommendations are drawn up. As discussed in the previous chapter not all requirements are already met by the proof-of-concept milkfrother. One part of meeting all the requirements is optimizing the frothing and mechanical performance of the device, while a few changes to the concept itself also must be considered.
Optimization and duration tests

The prototype can froth milk, however the performance of device must improve and become more predictable. The performance is affected by multiple variables, steam pressure, wand tip, aeration and wand placement.
The steam production is not very stable as it is depending on the needle valve to manage the varying incoming pressure. The heater should be connected to a known pressure, preferably to the solution created to manage the flow for brewing coffee in the Quooker coffee device. Then the known water pressure and flow can improve the behaviour of the heater, which can be optimized.
During the project no effort was put into the design the steam wands tip. Its design takes many iterations of a hard to machine part, for which there was no time. A part of the tip's behaviour could be digital modelled and simulated, to understand the impact of each variable, but in the end physical testing should be done to improve the geometry of the tip. It is expected that less holes provide more steam pressure, however how the location, size and angle of the nozzle affect frothing performance not verry well known in automatic devices. In home barista setup's it often comes down to personal preference and with skill every wand tip will produce a jug of milk froth.

It is proven that the air pump and venturi can make a jug of milk froth without any required interventions of the consumer, yet the part responsible is not very well studied, and the same recommendation apply as for the wand tip design. How is the venturi injector geometry affecting the aeration of the milk. As an addition to the geometry the behaviour of the air pump also has an influence on the amount of air added to the steam, which should also be examined further.

Lastly the wand and jug placement also influence the milk frothing process. When the wand is placed to close to the jugs walls or bottom the steam is not able to travel far into the milk, creating unnecessary hot zones and extra turbulence. The wand length and angle it enters the milk, both must be make it possible for the user the place the jug easily and to provide the most optimal injection point for steam.

The jug placement itself is also an aspect of the frother that should be examined more thoroughly. A drip tray that collects wastewater from the steam wand is not necessary, however a platter on which the jug can be placed was a mentioned desirable addition in the user tests in chapter 9. Not only to communicate at which position the jug is expected to be placed, also to protect some kitchen counters that are vulnerable for heat, such as wooden and acrylic counters. Next to the placement the thermistor sensing the milk temperature is not yet embodied due to time limitations. In other types of coffee machines exist that have the probe integrated in the wand or touching the jug. A platter as shown in figure 110 could be helpfully to make a successful contact between the probe and the jug. If

Figure 110 : Frother with positioning cue

the safety system also desires a sensor that determines the presence of the jug before frothing starts as was prototyped in chapter 14, it could also be housed in the platter. To get more confidence in the feasibility of the device, multiple duration tests should be executed. Mechanically the most fragile part, the hinging and button mechanism needs to be tested for a longer period. Next to the mechanical specifications the thermal performance of the frother should also be examined.

As explained in the requirement section, parts will reach high temperatures which should not be able to fail parts or seals and not create hot surfaces that the user or bystanders can harm. During a real scenario use case multiple temperature probes should be added to device to get a measurements of the temperatures in the device. A thermal camera could also be used to find the origin of heat and how the heat is transfer though the parts. Not only should the device on the counter be examined the housing underneath should also be tested, to check if there are no alarming situations. The rotation mechanism itself should also be reviewed. The mechanical solution for stowing and ejecting the wand is simple, however it limits the use of the button. When the wand is stowed, the button cannot be pressed if the jug is present. The wand will then eject again against the jugs wall and the position will not be optimal for frothing. The electromechanical solution proposed in concept 1 on page 45 could be a solution for this. Instead of mechanically actuating the hooks a solenoid plunger can actuate the same motion. The solution will require more space in the bottom of the frother, and add more parts, yet the freedom to press the button without moving the wand could be necessary to provide child protection and interactions which are not envisioned in this stage of the project.

18. Personal Reflection

This assignment was the perfect fit with my experiences gained through the master studies. An open brief with the challenge to start development of a new archetype of an existing product. Requiring, theoretical and desk research and a lot of prototyping to figure out what would be liked by the consumers, while also keeping an eye on the feasibility.

The coffee context except for an occasional well-prepared cappuccino and a lot of filter brewed coffee was really new for me. I am familiar with the crafts and tasting of specialty beer which also turned out to be a movement in the coffee industry. Where I met by the world of specialty coffee which means more tastier and carefully grown and roasted coffee, where every link in the chain profits. It honestly ruined my experience of the commodity Douwe Egberts coffee at the IDE faculty.

I applied at Quooker for a graduation internship to gain more insights at working at a larger company while still being in the comfortable position as a student. Not knowing that the research and development department and Quooker itself still try to function as the times 10 years ago where the department only had 5 employees. (Currently 45). The positively crowded office was the ideal workspace where my design could come to life. The rides to and from Ridderkerk were sometimes a bit frustrating, however the colleagues and my own ‘messy’ office desk aided to come to this result

At multiple moments in the project, I knew more and that the quality of my work was more than I realized myself. For myself it was just part of the project and what was expected. Often a reality check, from my enthusiastic collages and supervisor was necessary to enjoy and appreciate my achievements and look back at what I learned.

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20. Appendix A: List of Requirements

List of Requirements

Nr	Requirement or Wish		Category	Origin
A		**Peformance**		
		What main functions does the product need to fulfill?		
A1	R	The product must heat milk to 70 degrees celsius	Feasible	Coffee Analysis
A2	R	The product must aearte milk to create froth	Feasible	Coffee Analysis
A3	W	The product should be easily cleaned	Desireable	User Interviews
A4	R	The product must not have a higher power draw then 1200W	Feasible	Steam tests
A5	R	The serving size must be enough to one serving of every type of coffee beverage	Feasible	Coffee Analysis
B		**Envriroment**		
		What kind of enriomental influences does the product need to withstand		
B1	R	The product must remain functional when working with steam at 140 °C	Feasible	Steam tests
B2	W	The product should resist cleaning agents commonly used in the kitchen	Feasible	User Interviews
C		**Life in Service**		
		With what intensity will the product be used, and how long should it last		
C1	R	The product must last for at least 10 years	Feasible & Desireable	User Interviews & Quooker
C2	R	Expected use is 4 servings a day for 10 years (4 * 365 * 10 = 14600 servings)	Feasible & Desireable	Coffee Analysis
C3	W	The product should at least keep functioning for one average kitchen lifespan (13,3 years)	Feasible & Viable	Quooker
D		**Maintenance**		
		Is maintenance nessasary and possible?		
D1	R	After every serving the product must be cleaned easily	Feasible & Desireable	Coffee Analysis
D2	R	Small maintenance must be conducted by the user	Feasible & Desireable	Quooker
D3	R	Large maintenaince should be conducted by the user with the help of a video manual	Feasible & Desireable	Quooker
D4	R	A Quooker machic must be albe to condut large maintenance during a Quooker service appointment	Feasible & Desireable	Quooker
E		**Target product costs**		
		What is a realistic price for the product		
E1	R	The milkfrother addition must not cost more than €300	Viabillity	User interviews
E2	W	The milkfrother addition should not cost more than a separate milkfrother	Viabillity	
F		**Transport**		
		What requirements are set by transport of the product		
F1	R	The product must be transportable in bonded cardboard boxes	Feasibillity	Quooker
G		**Quantity**		
		What is the amount of units produced		
G1	E	There is expected that the milkfrother is sold to 50% of the people buying Quookers Coffee machine which is 20 percent of total tap sales. (300.000 * 20% * 50% = 30,000	Feasibillity	Quooker
H		**Product Facilities**		
		Should the product be designed for existing production facilities		
H1	R	New production facilities can be aranged	Feasibillity	Quooker
H2	R	The product must be assembled in the factory in Ridderkerk	Feasibillity	Quooker
H3	W	Sub assemblys should be outsourced to external parties	Feasibillity	Quooker
I		**Size and Weight**		
		Are there bounderies for the size and weight of the product		
I1	R	The product must be smaller than the exising Nespresso Aerochino	Feasilibllity & Desireabilli	User Interviews & Quooker
I2	W	The product should not use any valuable kithcen counter space	Feasilibllity & Desireabilli	User Interviews & Quooker
J		**Aestetic aperance and finish**		
		Which preferences do buyers and users have		
J1	R	The product must look premium with preferably the use of metal instead of plastics	Desireabillity	User Interviews & Quooker
J2	R	The product's aestatics must fit Quookers current portfolio	Desireabillity	User Interviews & Quooker
J3	R	Metal must be used for the products exterior	Desireabillity	User Interviews & Quooker
	W	The use of visible plastics should be minimized	Desireabillity	User Interviews & Quooker
K		**Materials**		
		Should certain materials be used?		
K1	E	Stainless steel must be used for contact with milk	Feasibillity	
K2	E	Plastics that are used and come into contact with hot steam must be able to cope with high temperatures	Feasibillity	
K3	W	The use of easily milled brass should be minimized	Feasibillity	
L		**Ergonomics**		
		What requirements result from observing and understanding handeling of the product		
L1	E	The product must be fast in use	Desireabillity	User Interviews
L2	E	The user must be able to use the product without any skills or training	Desireabillity	User Interviews
L3	E	The product must be cleaned with regular cleaning supplies	Desireabillity	User Interviews
L4	W	The product shoulb be cleaned within 10 seconds	Desireabillity	User Interviews
M		**Safety**		
		Should specific precoutions be taken with regard to the safety of users and bystanders?		
M1	E	The product must not harm the user in any way	Desireabillity	User Interviews & Quooker
M2	E	When steam used it must be clear to the user that it is not safe to come near the steam exit	Desireabillity	User Interviews & Quooker
M3	W	The product should communicate that surfaces can be hot	Desireabillity	User Interviews & Quooker

21. Appendix B: Giraffe Coffee Visits

One of the partners in the larger coffee project Is the specialty coffee company Giraffe Coffee roaster. Next to roasting high quality and exotic coffee's the companies' experts teach professionals and consumers in the ways of coffee. The coffee roasting site is in an industrial park on the edge of Rotterdam and the cafe with training facilities resides in the centre of Rotterdam
During the first phase of the project me and the designers working on the coffee maker visited the roasting site to learn more about the coffee market, held a milk frothing workshop to get an expert's opinion about the beverage and held a coffee tasting session to become familiar

discussing the quality of brewed coffee and expand our vocabulary to distinct different taste found in the drink.

Roasting visit Insights

At the roasting site one of the owners Mark took us through the whole process of roasting a coffee bean. From what happens at the farm to how they pack and ship their freshly roasted coffee beans.
Mark explained the shift happening in the new century specialty coffee niche rose from the market dominated by a few large firms that focus on bulk and efficiency. Coffee was previously seen as a commodity of which there Is no Incentive In the whole chain to provide a quality product. Farmers that can only harvest once, while not all beans ripe at the same time, to roasters that try to maintain a general flavour, mixing different coffee species together.

Specialty Coffee takes a different approach. Working together with Individual famers that are rewarded for a better-quality coffee bean. Taking more time to harvest the beans when they are ripe, experiment with different and more exotic species. The roasting process Is then tailored for the specific coffee bean and brewing method, to provide the best tasting product.

Milk workshop Insights

After the visit to the roasting plant, an informative workshop was held with Tilly, a professional barista and coffee teacher of a varying level of 'students'. Next to her professional barista opinion, the training workshops provide her a wide view the skills of the consumer. The whole process of frothing milk was discussed trying out a lot of different types of milk. After the session, a few main takeaways for the project were discussed.

The main question we discussed what makes a quality coffee beverage with milk. How do professionals objectify the quality, and are there certain rules that need to be met?

The conclusion was that the milk beverages harder to objectively assess. For coffee, a standardized process to taste the coffee Is created to grade quality of the bean and the roasting process. For milk beverages there does not exist a certain standard. Tilly also jurying in (inter)national barista championships, focuses more If she can match the story of the barista with what she tastes in the drink. Grading is done with a grading sheet that looks similar as the coffee cupping form. She must rate certain aspects In Intensity such as fragrance, flavour, acidity, and body. These Intensities are then evaluated to her expectations of the drink presentation which results in a more subjective score.

Next to the subjective assessment, the quantities and proportions of coffee and milk are not set in stone. Tilly explained that the beverage should fill the cup, or glass in which it is served. Most of the time, the coffee machine produces a standardised shot of coffee in the cup which then should be filled with milk froth. The volume increase of the milk Is depending on the desired beverage type and can be controlled by managing the aeration or stretching time of the milk. Good baristas are using their experience to predict the milk needed for the drink type and glass size. While at her certification assignment, using pen and paper to calculate the exact amounts as she had to fully empty one pack of milk for a certain order of different types of beverages.

The Dutch like hot coffee, not only does It look like the Dutch have a higher tolerance for warm drinks, but the automatic coffee machines at the offices also often use milk powder to create cappuccino. To quickly dissolve milk powder high temperature water Is needed, resulting in a high temperature cappuccino. When these consumers go to a cafe for a coffee they expect these high temperatures, which Is not possible when frothing normal milk. Which sometimes results in unsatisfied customers when they get a drink of only 55 °C served.

Next to that Tilly, found that her students often bought a piston espresso machine to drink a tastier coffee when working at home. However, the unskilled home baristas could only make coffee's that tasted worse than their old machines. Desperately looking to Improve their skills they joined Tilly's classes to learn how to use their newly bought machines.
She could also confirm that the naïve users often have trouble maintaining their machines. Even though a quick wipe and a purge to empty the steam wand. Should be enough she found multiple machines broken because poor maintenance, with one machine that had to be scrapped because of growing bacteria in the steam boiler.

22. Appendix C: Coffee market research

Coffee market

In 2020 the International Coffee Organisation published Its most recent report, discussing the current market and Its development over the years. In the commodity coffee market, a lot of chains are Involved, to get the bitter drink to the consumers. Figure 1 shows the general chain in which producers (farmers) sell their product to processing plants or exporters. Ending with the coffee beans need to be roasted and sold via a retailer to the consumer. This whole process from harvest to coffee can take up to one year, as harvests activities are annual.

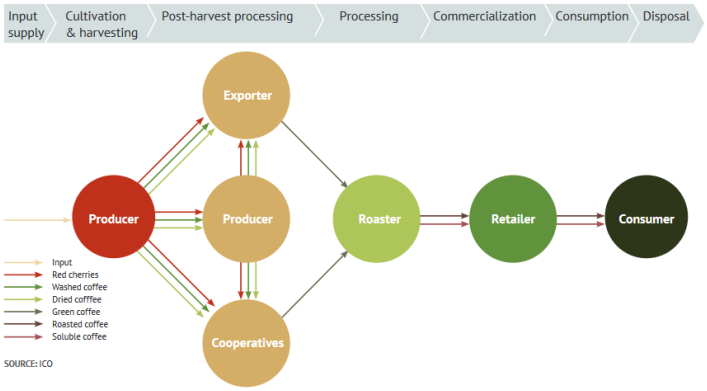


Figure 1: Coffee market chain

To provide a few numbers in the chain the International Coffee Organisation published the production numbers in the year 2018/19. It shows in figure 2 that since 1991 the production has increased from 90 million bags of 60 kilogram to 160 million bags. Totalling a production of 9,6 billion kilograms of green coffee beans.

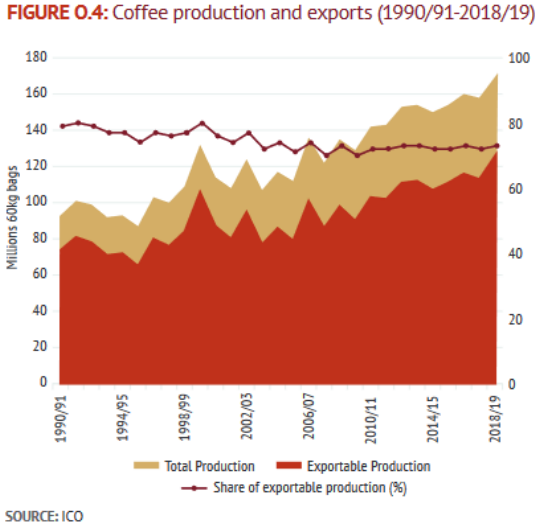


Figure 2: Coffee production & exports

The ICO also concluded in figure 8 that countries that do not have any domestic production have Increased their exports since 2005. This development Is not only caused by moving the bags of unprocessed beans, but that the market Is focusing more on providing value with the coffee. In the form of roasting and the overall experience, outside of the producing countries.

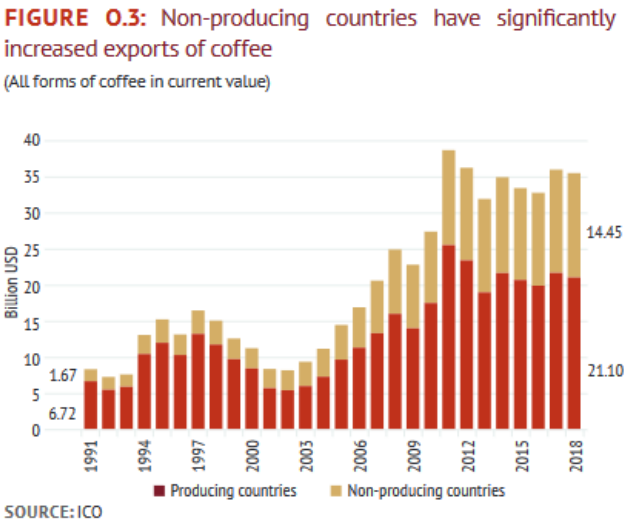


Figure 3: Coffee revenue (non)producing countries

Between different countries and cultures, a difference in coffee consumption can be found. The ICO publishes an annual table found in appendix A with coffee consumption in a selection of countries. Showing that from the total of 410.262.000 bags consumed by Europe in 2019, The Netherlands consumed 2.030.000 In comparison to Spain with 3.253.000 bags. The coffee consumed per capita for the Netherlands Is almost two times as high with 0.11 bags and 0,069 for Spain.

Nationaal Koffieonderzoek

When diving deeper into the coffee consumption In the Netherlands the national association for coffee and thee conducts reports Insights of the market with an annual survey (Koffie & Thee Nederland, 2022). The survey conducted with 1520 participants in a variety of ages to provide a representative view of the average Dutch citizen. The following graphs are taken from their report of 2022)

Since the year 2018 the amount of daily coffee drinkers Is declining, with a shift towards people that quit coffee drinking or drinking less than one cup a day (figure 4). In total the daily drinkers is still quite high making coffee the mostly drank beverage next to tap water. On a day when coffee Is drank the average amount of cups is 3,8. A clear difference between male and female could also be seen with female's drinking 3,3 and male is 4,3 in figure 5 .

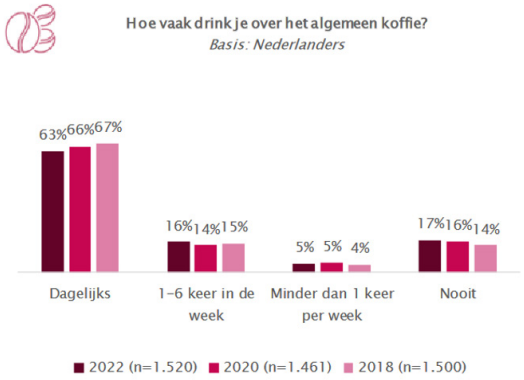


Figure 4: How much coffee is drank weekly in the Netherlands

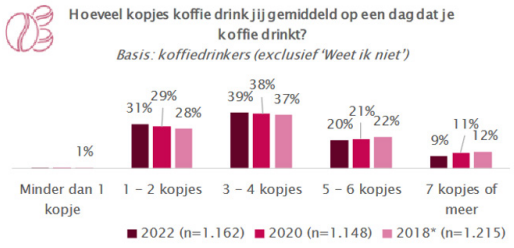


Figure 5: How many cups on a coffee drinking day

Figure 6 shows the beverage types drank most in the Netherlands. The 'black coffee' is drank the most with 66%, it is also the most desired beverage type with 45% of the drinkers having it as their favourite drink. Cappuccino comes second with 47% of drinkers sometimes consuming a cappuccino and the favourite of 25% of the coffee drinkers. The difference between sometimes consuming a cappuccino and the amount of drinker having it as their favourite is quite large with 20% which raises the question why it is more consumed than favourited. Is this because a good tasting cappuccino is not available to every drinker or does the difference come from drinkers sometimes switching up their beverage. The other types of coffee are less popular with an espresso being third with only 8% and a latte macchiato fourth with 6%.

Looking at the most common brewing method machine that use a filter (37%) and filter pads (17%) are still the major source of the drank coffee in the Netherlands (figure 7). The use of capsule-based machines has increased with 6% within 2 years, this is at the cost of the filter and filter pad machines that both decreased with 4%. Fully automatic machines also has a slight increase of 3% in comparison to 2020.

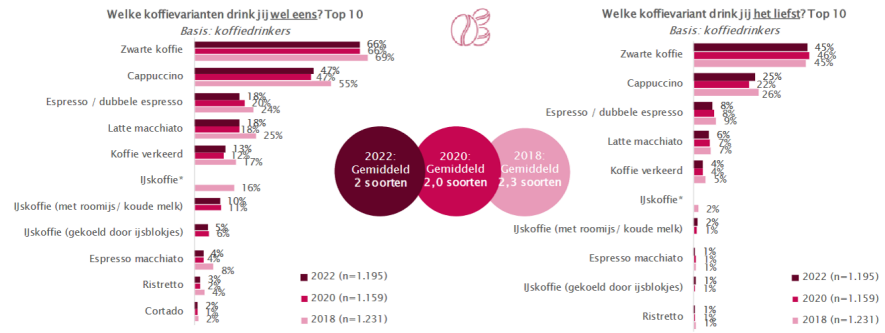


Figure 6: Beverage types consumption and favorites

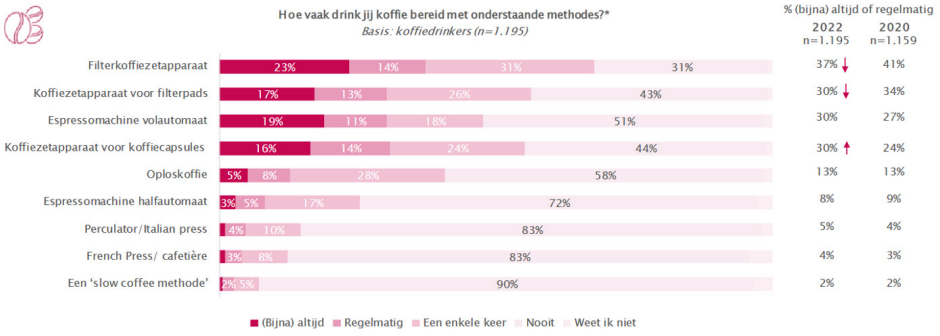


Figure 7: Brewing methods

Quooker Internal

Before the start of this project Quooker also conducted a survey under Its customers. The survey consisted of 147 participants that owned a Quooker. Under the Quooker owners the coffee statistics looked a bit different than the average Dutch citizen. The most used coffee machine Is a fully automatic machine with the cup-based machine placed second. The ratio of filter-based machines has a slightly higher than the remaining type of machines.

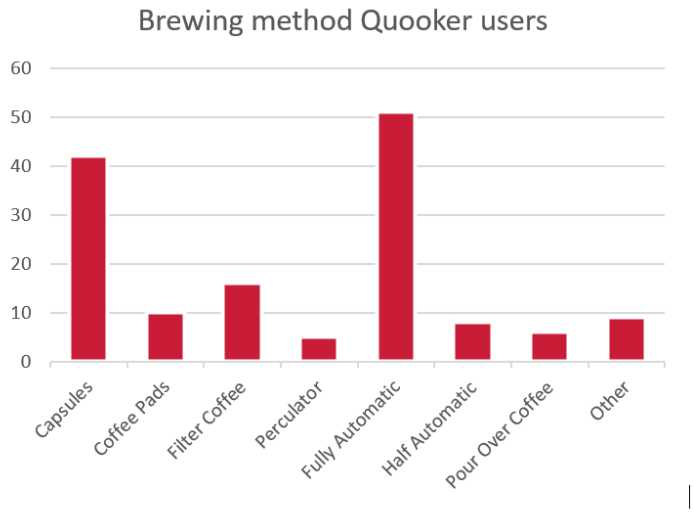


Figure 8: Brewing methods Quooker users

There can be concluded that the coffee market Is a well-established market that Is still growing each year. The whole value chain is diversifying, with non-producing countries Increasing their export value. The development of cup based, and fully automatic systems Is shifting the market to a better coffee taste and experience. While the established brewing methods are still having a large share. In particularly Quooker owners that enjoy the instant boiling tap water and do not mind the investment, can afford, and use the new technologies to get 'better' coffee with ease.

23. Appendix D: User interviews

Introduction

To get a better understanding of who is a typical Quooker owner three Interviews were conducted. The main goal Is to get a better understanding of why they bought their Quooker and what their relationship with coffee (machines) Is. In the relation with coffee, a discussion Is held to see what the Quooker customers perceive as quality, so later a better benchmark milk beverage could be determined. Also, the relation with their coffee machine is discussed. What moved them to the machines they use and what do they expect from their machines. Lastly discussing what they expect from a possible Quooker coffee machine.

Method

The decision was made to conduct the Interviews over the phone, since conducting physical interviews is time consuming, and not necessary to reach the desired results. The participants were asked If they wanted to conduct the Interview with video, so a more personal conversation was possible, it was not mandatory. During the interview notes were taken for documentation, and afterwards the participants were asked If they want to share a picture of their kitchens to also get a better visual understanding.

The Interviewees where acquaintances since the cooperation Is easier to arrange and the confidentiality. Their age was between 45-60, and their household situation were that children that already have left the house and the Interviewees and partners shared the house with the two of them.

Relationship with Quooker

The participants were a huge fan of the boiling water tap and chose to purchase Quooker for Its speed and convenience in the kitchen. The tap was used every day for tea and cooking. They were happy that the product provides a premium experience without any unnecessary bells and whistles.

“I often end up buying the premium product with a lot of unnecessary functions, because I want a high-quality basic functionality”

Service wise they expect also have a premium experience, while this was sometimes turned out to not be always the case, having to call a mechanic to switch the clogged filter as one of the participants was not possible to do it herself. And one other Interview had a rubber O-ring come loose of the tap handle, it does not affect the core function, thus she was hesitant to call service to fix a minor defect.

“Without the nice experience of the handle, the product feels less premium”

Relationship with Coffee

All Interviewees were daily coffee consumers, with a variety of coffee machines. Two of the Interviewees liked drinking cappuccino’s the most, while the third enjoyed the tastes found in a lungo better.

Knowledge wises they would not name themselves an expert in coffee, however they all had a personal preference for a type of coffee. The drinking of coffee Is not seen as a necessity to fill up the caffeine dose, but to have a small moment of peace with a hot and tasteful drink.

'Call me stupid, but I do not drink coffee where It tastes bad'

The interviewees described their perfect cappuccino as, having the correct proportions of milk and foamed milk. However, they could not quantify the proportions. They were happy with the cappuccino’s they could make themselves at home. One participant Is now drinking less cappuccinos because of a milk Intolerance, still has milk in storage to provide milk-based coffees for visiting friends. She tried milk replacements in cappuccino’s but did not like the taste that came with them. Only on Holliday’s where good coffee can be found as a bonus.

'I am allergic to Cappuccino’s with two brown dots''

Relationship with Coffee machines

The Interviewees all used a different machine to make coffee but had the same type of milk frother for cappuccinos. The machines were in line with the survey Quooker conducted, under Its customers. One participant had a Jura fully automatic coffee maker, one a Nespresso capsule-based machine and the last used an espresso piston machine.

The reason they chose their machines Is mostly based on taste and the brewing method.

- The reason the capsule-based machine was chosen was the convenience of not having to maintain a large fully automatic machine while having the possibility to try a lot of different flavours with ease.

- The participant with the fully automatic machine had received their first as a gift and were happy enough to buy a new one after the first was decommissioned after 10 years of use. The perception of still using 'fresh' beans that are not milled, without having to go through all the brewing steps was the main reason for the purchase.

- The piston machine was bought as the participant had experience with the piston espresso brewing method from a student working in a café and liked to consciously brew a coffee from bean to coffee to add value to the better tasting coffee.

Milk wise the all the participants had experimented with different products, all ending up with a version of Nespresso's Aerochino shown in figure 1. It's no skill needed and not much hassle to operate the participants were happy with a decent quality milk foam. The participant with the machine that had a steam wand did not use It anymore as the cleaning process was too much effort. One Aerochino was always stationed next to the coffee machine while the other two were stored out of sight in a nearby cabinet.

"I do not use the steam wand anymore after I had to chip off milk leftovers"

For milk, the small portioned sterilised semi skimmed milk was favourite to make cappuccino's as it could be stored for a longer time. None of the participants had any alternative milks at home.

Figure 1: Nespresso Aerochino

Figure 2: Kitchens of the interviewees

The kitchens

The style of the kitchens of the participants are quite similar with the modern 'clean' look with black, white, and metal colours (figure 2). The coffee maker Is prominently visible on the kitchen counter having Its own dedicated zone. Even though the kitchens are large the coffee zone still takes up a huge amount of workspace on the counter. The large, black, or metallic boxes are drawing quite some attention, the colours are matching the kitchen, but the designs are not that minimalistic as the rest of the kitchen. In the case of the piston machine, it could be possible that the attention Is wanted.

Conclusion

It became clear that the users put ease of use and cleaning as a higher priority than quality. They are familiar with cappuccino's made by baristas in cafés but are satisfied by the milk froth created by the Aerochino's. They were sceptical about the use of steam wands and the hygiene involved with venturi based frother. Thus, a Quooker milk frother that enters their homes should not only be easy to clean and maintain It should convince them that It Is easier than their current product as the milk quality Is less of Importance.

24. Apppendix E: Lavazza LM7000 Test

One of the coffee machines capable of making milk froth with steam was further examined from a technical point of view. The machine a Lavazza LM7000 (figure 24) designed and manufactured by AEG. First the machine was disassembled to learn how the machine creates and controls steam for frothing and afterwards the machines milk froth function was deeper researched by measuring the time and temperature power draw of the machine during frothing.

Figure 1: Lavazza LM7000

The coffee maker is a capsule-based machine with the frothing performed by a rotary mixer with steam injection. A separable cannister is filled with milk, closed, and placed in the machine. The type of milk forth and beverage is selected, and the machine starts heating. When heating is completed, the mixer spins the milk for aeration and the steam pipe heat the milk.

Disassembly was a painful process as the whole machine was ‘clicked’ together with snap fits. When all the housing parts were removed. the internals were easily accessible.

The machine heats the water using a custom designed heating block. Water is moved with the use of a vibration pump, which uses an electromagnetic plunger to push water forwards. The water flow is sent to multiple parts of the machine and is managed by 2 solenoid valves which are placed after the heating element. The

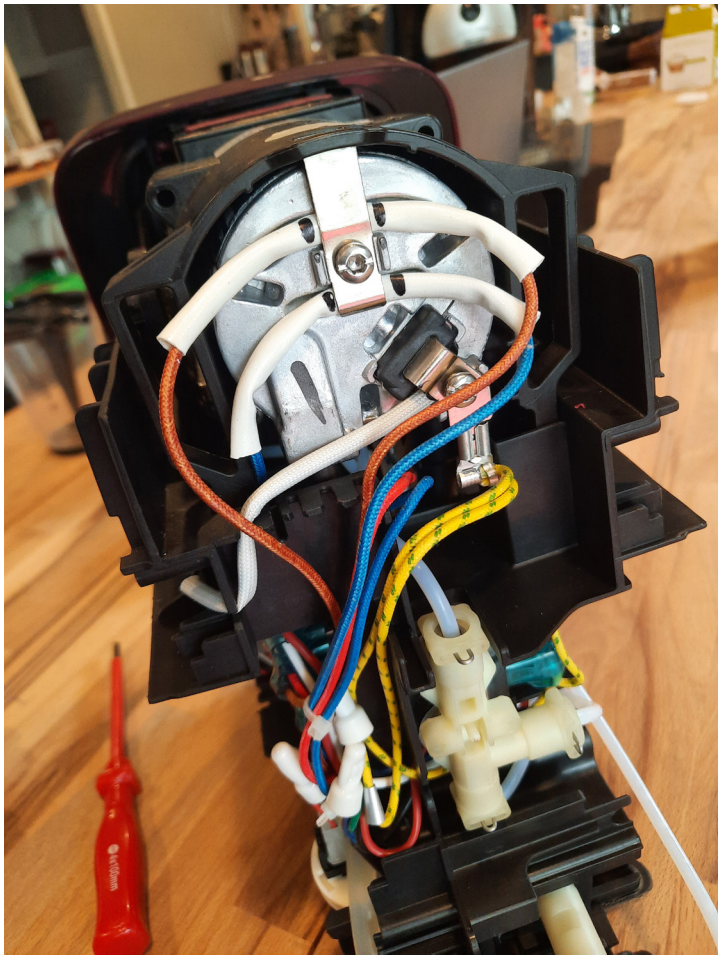


Figure 2: Thermocoil

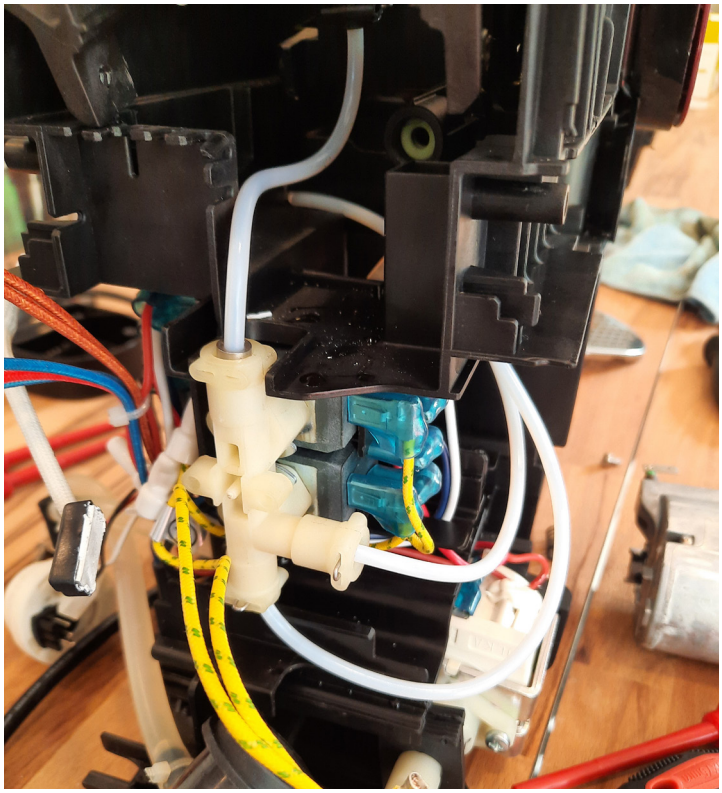


Figure 3: Solenoid Valves & Spliter

presence of the milk frother container is checked by a mechanical switch and the mixer is rotated by an electric motor.

To get a clear overview of the machine's parts and their connections a schematic diagram (figure 4) was made following the water flow and electrical connections.

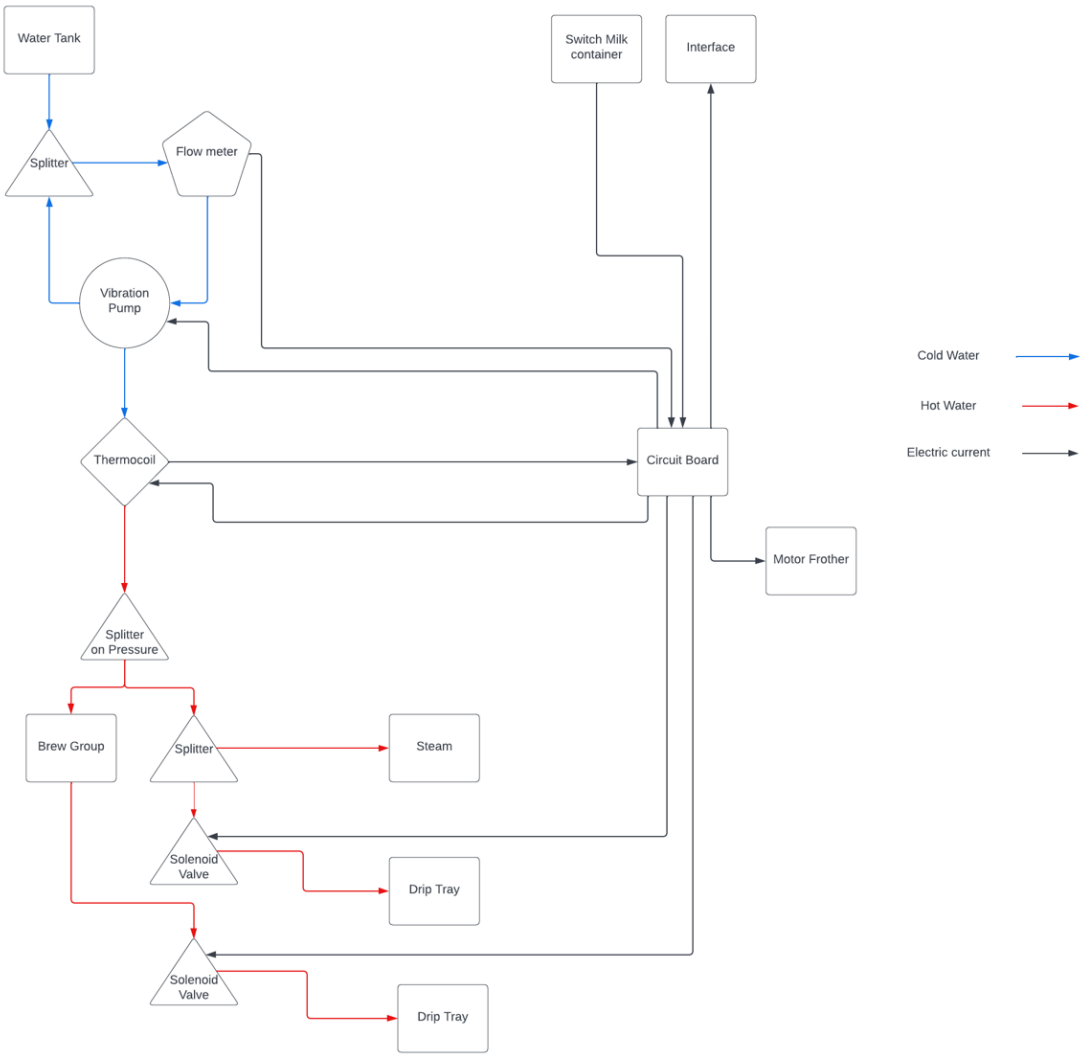


Figure 4: Lavazza LM7000 Schematic

Lavazza LM7000 performance

After the disassembly the machine's coffee functions were restored, and some measurements of the machine could be taken. The goal was to learn what is happening in an existing machine during the milk frothing. A thermocouple was placed on the thermoblock, and milk container. The power draw of the machine is measured to check the behaviour of the circuit and heating element.

The used materials were:

- Lavazza LM7000
- Lavazza Lungo Coffee Cup (Blue model)
- Full fat long shelf-life cow milk
- Digital Thermometer Voltcraft K260 (4CH)
- Brennenstuhl Power meter PM231
- Camera on Tripod

Measured parameters during a coffee and milk froth serving:

- Heating time
- Time Serving
- Temperature Thermoblock Start
- Temperature Thermoblock Min
- Temperature Thermoblock Max
- Temperature Thermoblock End
- Temperature Milk Start
- Temperature Milk End
- Power Draw

Figure 111 : LM7000 Peformance Test

Method

A cappuccino was brewed using the most standard settings of the machine. The results were gathered by filming the machine and displays of the sensors during the serving. The values were later taken by watching the footage. As the sensors did not have any data logging capabilities. In figure 28 the setup can be seen.

Results

Heating from Cold			
Time	49	S	
Temperature	128,7	°C	
Power	1220	W	
Coffee			
Time	17	S	
Temperature Thermoblock	119,9	°C	
Temperature Coffee	61,4	°C	
Power	1200	W	Turns on after serving
Milk			
Heating time	17	S	
Time Frothing	60	S	
Temperature Thermoblock Start	138,8	°C	
Temperature Thermoblock Min	117,2	°C	
Temperature Thermoblock Max	164,7	°C	
Temperature Thermoblock End	145,7	°C	
Temperature Milk Start	9,6	°C	
Temperature Milk End	99,2	°C	
Power	1200	W	Switches off after 15 seconds, after 30 seconds on again.
Water			
Heating up	0	S	
Time	60	S	
Temperature Thermoblock Start	158,8	°C	
Temperature Thermoblock Min	116,7	°C	
Temperature Thermoblock Max	136,6	°C	
Temperature Thermoblock End	145,7	°C	
Temperature Water	82	°C	
Power	1200	W	Switches of after 40s and 152 °C

Conclusions

The machine switches the heating element on and off, no variable power drawn was measured. The thermoblock is used as a buffer for hot water. During the coffee serving it only switched on after the serving was completed. For steaming the milk, the heating element to a higher temperature and the motor was pulsing slower.

The milk froth time was exactly 60s and when measuring the milk, it became too hot. Which was caused by not pouring enough milk in the container.

25. Appendix G: Quookers empolyees concept evaluation sheets

Naam	Jesse
Functie bij Quooker	BIM proces Digitale proces
Ervaring met melkschuim	- ●●○○○ +
Toestemming foto verslag & begeleiders	Ja/annoniem/nee

	Uitleg	Beoordeling 1-5
Gebruik Ervaring	Hoe makkelijk is er met het concept een cappuccino te maken, op basis van de modellen en renders, mag uitproberen	- ○○○●○ +
Fit met Quooker	Past dit concept bij Quooker's portfolio en visie	- ○○●○○ +
Complexiteit	Wat vind je van de complexiteit van het product en hoe verhoudt zich dit tot de levensduur van het product.	- ○●○○○ +
Melkschuim Kwalteit	Ondanks dat het moeilijk te beoordelen is: Hoe goed denk je dat de methode kwalitatief melkschuim kan leveren	- ○○○○○ +

Concept 1 (A)

	Beoordeling 1-5
Gebruik	- ○○●●○ +
Fit met Quooker	- ○●○○○ +
Complexiteit	- ○●○○○ +
Melkschuim Kwalteit	- ○○○○○ +

Concept 2 (B)

	Beoordeling 1-5
Gebruik	- ○○●○○ +
Fit met Quooker	- ○○○●○ +
Complexiteit	- ○○●○○ +
Melkschuim Kwalteit	- ○○○○○ +

Concept 3 (C)

	Beoordeling 1-5
Gebruik	- ○○○●○ +
Fit met Quooker	- ○●○○○ +
Complexiteit	- ○●○○○ +
Melkschuim Kwalteit	- ○○○○○ +

Opmerkingen
- Prijs Kop dan beter - Dat ze niet denken een Quooker product 1-2 Vormgeving past bij Quooker 2 Door knopje past het bij Bedrijf gebruik ik kan nu niet realistisch testen 3 Makkelijk gebruik knoppen niet Quooker algemeen Complex als Gebruik bestand Melk kwaliteit niet te beoordelen

Naam	Mariette
Functie bij Quooker	R&D Koffie
Ervaring met melkschuim	- ○●○○○ +
Toestemming foto verslag & begeleiders	Ja/annoniem/nee

	Uitleg	Beoordeling 1-5
Gebruik Ervaring	Hoe makkelijk is er met het concept een cappuccino te maken, op basis van de modellen en renders, mag uitproberen	- ○○●○○ +
Fit met Quooker	Past dit concept bij Quooker's portfolio en visie	- ●○○○○ +
Complexiteit	Wat vind je van de complexiteit van het product en hoe verhoudt zich dit tot de levensduur van het product.	- ○○○●○ +
Melkschuim Kwalteit	Ondanks dat het moeilijk te beoordelen is: Hoe goed denk je dat de methode kwalitatief melkschuim kan leveren	- ○○●○○ + Mits skills

Concept 1 (A) gebruik = los van reinigen

	Beoordeling 1-5
Gebruik	- ○●○○○ +
Fit met Quooker	- ○●○○○ +
Complexiteit	- ○○○●○ +
Melkschuim Kwalteit	- ○○○○○ + ?

Opmerkingen
○ twijfels bij hoe te reinigen ● draaien linkshandig tevredenheid Kop Zou nog gezien los ding kiezen waarom niet beide? Wat als niet schoongemaakt dan moet je echt boven vooral door vergeten

Concept 2 (B)

	Beoordeling 1-5
Gebruik	- ○○○●○ +
Fit met Quooker	- ○○●○○ +
Complexiteit	- ○○○●○ +
Melkschuim Kwalteit	- ○○○○○ +

Concept 3 (C)

	Beoordeling 1-5
Gebruik	- ●○○○○ +
Fit met Quooker	- ○●○○○ +
Complexiteit	- ○○●○○ +
Melkschuim Kwalteit	- ○○○○○ +

Pilot

Naam	Rik
Functie bij Quooker	R&D lead
Ervaring met melkschuim	- ○○○●○ +
Toestemming foto verslag & begeleiders	Ja/annoniem/nee

	Uitleg	Beoordeling 1-5
Gebruik Ervaring	Hoe makkelijk is er met het concept een cappuccino te maken, op basis van de modellen en renders, mag uitproberen	- ○○○○● +
Fit met Quooker	Past dit concept bij Quooker's portfolio en visie	- ○●○○○ +
Complexiteit	Wat vind je van de complexiteit van het product en hoe verhoudt zich dit tot de levensduur van het product.	- ○○●○○ +
Melkschuim Kwalteit	Ondanks dat het moeilijk te beoordelen is: Hoe goed denk je dat de methode kwalitatief melkschuim kan leveren	- ○○○●○ +

Concept 1 (A)

	Beoordeling 1-5
Gebruik	- ○○○●○ +
Fit met Quooker	- ○○○●○ +
Complexiteit	- ○○●○○ +
Melkschuim Kwalteit	- ○○○●○ +

Concept 2 (B)

	Beoordeling 1-5
Gebruik	- ●○○○○ +
Fit met Quooker	- ○●○○○ +
Complexiteit	- ○●○○○ +
Melkschuim Kwalteit	- ○●○○○ +

Concept 3 (C)

	Beoordeling 1-5
Gebruik	- ○○●○○ +
Fit met Quooker	- ○○●○○ +
Complexiteit	- ●○○○○ +
Melkschuim Kwalteit	- ○○○○● +

Opmerkingen

1- Vet handig op deze manier of kleine schuim
Technisch en product innovatief

2- Onhandig niet Quooker waardig/kwaliteit. Niet meerdere keren afwassen

3- Mogelijk perfect schuim, wel complex ~~[illegible]~~ groot lomp niet helemaal Quooker afneembaar interessant wel onhandig

Naam	Dion
Functie bij Quooker	R&D
Ervaring met melkschuim	- ●○○○○ +
Toestemming foto verslag & begeleiders	(Ja)/annoniem/nee

	Uitleg	Beoordeling 1-5
Gebruik Ervaring	Hoe makkelijk is er met het concept een cappuccino te maken, op basis van de modellen en renders, mag uitproberen	- ○○○○● +
Fit met Quooker	Past dit concept bij Quooker's portfolio en visie	- ○○●○○ +
Complexiteit	Wat vind je van de complexiteit van het product en hoe verhoudt zich dit tot de levensduur van het product.	- ○○○○● +
Melkschuim Kwalteit	Ondanks dat het moeilijk te beoordelen is: Hoe goed denk je dat de methode kwalitatief melkschuim kan leveren	- ●○○○○ +

Concept 1 (A)

	Beoordeling 1-5
Gebruik	- ○○●●○ +
Fit met Quooker	- ○○○●○ +
Complexiteit	- ○●○○○ +
Melkschuim Kwalteit	~~- ○○○○○ +~~

Concept 2 (B)

	Beoordeling 1-5
Gebruik	- ○○○●○ +
Fit met Quooker	- ○●○○○ +
Complexiteit	- ○○●○○ +
Melkschuim Kwalteit	~~- ○○○○○ +~~

Concept 3 (C)

	Beoordeling 1-5
Gebruik	- ○○○●○ +
Fit met Quooker	- ●●○○○ +
Complexiteit	- ○○●○○ +
Melkschuim Kwalteit	~~- ○○○○○ +~~

Opmerkingen

1- Schoonmaken bekend dramatisch Alles wordt zichtbaar wel
Minimalistisch vorm in Pandus

2- Logisch in gebruik kan je goed rammelen
Fit niet des Quookers niet helemaal helder

1- Gebruik duidelijk
Fit met Qu in kast niet des Quooker
Afschappen Pen
kan veel onder het concept

Naam	Rahid
Functie bij Quooker	[illegible] coördinator
Ervaring met melkschuim	- ○○○●○ + Hobby barista
Toestemming foto verslag & begeleiders	(Ja)/annoniem/nee

	Uitleg	Beoordeling 1-5
Gebruik Ervaring	Hoe makkelijk is er met het concept een cappuccino te maken, op basis van de modellen en renders, mag uitproberen	- ○○○○● +
Fit met Quooker	Past dit concept bij Quooker's portfolio en visie	- ○○○○● +
Complexiteit	Wat vind je van de complexiteit van het product en hoe verhoudt zich dit tot de levensduur van het product.	- ○○○○○ +
Melkschuim Kwalteit	Ondanks dat het moeilijk te beoordelen is: Hoe goed denk je dat de methode kwalitatief melkschuim kan leveren	- ○○○○○ +

Concept 1 (A)

	Beoordeling 1-5
Gebruik	- ○○●○○ +
Fit met Quooker	- ●○○○○ +
Complexiteit	- ○●○○○ +
Melkschuim Kwalteit	- ○○○●○ +

Concept 2 (B)

	Beoordeling 1-5
Gebruik	- ○○○●○ +
Fit met Quooker	- ○○○○● +
Complexiteit	- ○○○●○ +
Melkschuim Kwalteit	- ○○○○● +

Concept 3 (C)

	Beoordeling 1-5
Gebruik	- ○○○●○ +
Fit met Quooker	- ○○○●○ +
Complexiteit	- ○○●○○ +
Melkschuim Kwalteit	- ○○○●○ +

Opmerkingen

1 Gebruik liever nog een knop liefst ook graag regelen
niet concreet niks
waarom losse kan niet staan
mogelijk werkbaar

2- Fijn auto start, zelf in de hand
knop lijkt op kraan

3- Dingen laten staan mooi design, koffie machine
ook laten staan

26. Appendix H: User test concept evaluation sheets

Concept: A / B / C Siniz?

ID: 1....

Denk je dat het gelukt is een cappuccino te maken?	(Ja)/Nee
Welke stappen heb je afgerond?	1-2-3-4-5-6-7-8-9-10-11-12-13
Welke stap met het product was het makkelijkst	1-5-6-7-(8)-10-11
Welke stap was het ingewikkeldst	1-5-6-7-8-10-(11)
Hoe beoordeel je de interactie met de melkschuimer	Niet comfortabel o o o o o o (X) Erg comfortabel Niet duidelijk o o o o o o (X) Erg duidelijk Weinig stappen (X) o o o o o o o Veel stappen
Waarom heb je deze beoordeling gegeven?	Weinig handelingen waarbij je niet hoeft na te denken, automatisch gebruiksvriendelijk
Hoe beoordeel deze melkschuimer qua vormgeving	Past niet bij mijn keuken o o o o o o (X) Past bij mijn keuken Past niet bij mijn Quooker o o o o o o (X) Past bij mijn Quooker
Waarom heb je deze beoordeling gegeven?	moderne, stoere vormgeving net als mijn keuken en quooker klein formaat, neemt weinig ruimte in.
Algehele beoordeling	- o o o o o (X) +

Concept: (A) / B / C

ID: 1...

Denk je dat het gelukt is een cappuccino te maken?	Ja/Nee
Welke stappen heb je afgerond?	1-2-3-4-5-6-7-8-9-10-11-12-13
Welke stap met het product was het makkelijkst	1-(5)-6-7-8-10-11
Welke stap was het ingewikkeldst	(1)-5-6-7-8-10-11
Hoe beoordeel je de interactie met de melkschuimer	Niet comfortabel o o o (X) o o o Erg comfortabel Niet duidelijk (X) o o o o o o o Erg duidelijk Weinig stappen o o (X) o o o o Veel stappen
Waarom heb je deze beoordeling gegeven?	Niet duidelijk hoe het werkt Als dat eenmaal duidelijk is vind ik het een mooi project Wel twijfels of het goed schoon te houden is
Hoe beoordeel deze melkschuimer qua vormgeving	Past niet bij mijn keuken o o o o o o (X) Past bij mijn keuken Past niet bij mijn Quooker o o o o o o (X) Past bij mijn Quooker
Waarom heb je deze beoordeling gegeven?	Mooi dat het wegvalt in het aanrecht weinig ruimte inneemt
Algehele beoordeling	- o o o o (X) o +

Concept: A / (B) / C

ID: 1...

Denk je dat het gelukt is een cappuccino te maken?	(Ja)/Nee
Welke stappen heb je afgerond?	1-2-3-4-5-6-7-8-9-10-11-12-13
Welke stap met het product was het makkelijkst	1-(5)-6-7-8-10-11
Welke stap was het ingewikkeldst	1-(5)-6-7-8-10-11
Hoe beoordeel je de interactie met de melkschuimer	Niet comfortabel o (X) o o o o o Erg comfortabel Niet duidelijk o (X) o o o o o Erg duidelijk Weinig stappen o o o o (X) o o Veel stappen
Waarom heb je deze beoordeling gegeven?	niet duidelijk bij start en ik vind ~~ik vind het niet duidelijk bij het~~ de stappen onhandig, het mixer stukje losmaken vind ik lastig.
Hoe beoordeel deze melkschuimer qua vormgeving	Past niet bij mijn keuken o (X) o o o o o Past bij mijn keuken Past niet bij mijn Quooker o (X) o o o o o Past bij mijn Quooker
Waarom heb je deze beoordeling gegeven?	Ik vind het design niet mooi door het mixer gedeelte.
Algehele beoordeling	- o o (X) o o o o +

Concept: A / B / (C)

ID: 1...

Denk je dat het gelukt is een cappuccino te maken?	(Ja)/Nee
Welke stappen heb je afgerond?	1-2-3-4-5-6-7-8-9-10-11-12-(13)
Welke stap met het product was het makkelijkst	1-5-6-7-8-10-11
Welke stap was het ingewikkeldst	1-(5)-6-7-8-10-11
Hoe beoordeel je de interactie met de melkschuimer	Niet comfortabel o o o o (X) o o Erg comfortabel Niet duidelijk o o o o (X) o o Erg duidelijk Weinig stappen o o o o o o (X) Veel stappen
Waarom heb je deze beoordeling gegeven?	Veel stappen maar dat is juist het eigene van dit project en ze zijn duidelijk. leuk om zoveel keuze te hebben! Apparaat is comfortabel in gebruik, bij mij zal hij standaard opstaan omdat altijd melk, maar anders handig dat hij weg te zetten is. Belangrijk: het pijpje komt niet hoog genoeg.
Hoe beoordeel deze melkschuimer qua vormgeving	Past niet bij mijn keuken o o o o o (X) Past bij mijn keuken Past niet bij mijn Quooker o o o o o (X) Past bij mijn Quooker
Waarom heb je deze beoordeling gegeven?	Design is mooi, strak, in lijn met design quooker
Algehele beoordeling	- o o o o o (X) o +

Concept: A / B / C / D

ID: 2

Denk je dat het gelukt is een cappuccino te maken?	Ja/Nee
Welke stappen heb je afgerond?	1-2-3-4-5-6-7-8-9-10-11-12-13
Welke stap met het product was het makkelijkst	1-5-6-7-8-10-11
Welke stap was het ingewikkeldst	1-5-6-7-8-10-11
Hoe beoordeel je de interactie met de melkschuimer	Niet comfortabel ○ ○ ○ ○ ○ ○ ● Erg comfortabel Niet duidelijk ○ ○ ○ ○ ○ ○ ● Erg duidelijk Weinig stappen ● ○ ○ ○ ○ ○ ● Veel stappen
Waarom heb je deze beoordeling gegeven?	- ervaring - duidelijk, 1 ingang, 1 knop, kan los - verse melk uit boerderij - hoeveelheid, in controle - variëren van product
Hoe beoordeel deze melkschuimer qua vormgeving	Past niet bij mijn keuken ○ ○ ○ ○ ○ ○ ● Past bij mijn keuken Past niet bij mijn Quooker ○ ○ ○ ○ ○ ○ ● Past bij mijn Quooker
Waarom heb je deze beoordeling gegeven?	makkelijk op te nuimen en te reinigen
Algehele beoordeling	- ○ ○ ○ ○ ○ ○ ● +

Concept: A / B / C

ID: 2

Denk je dat het gelukt is een cappuccino te maken?	Ja/Nee ontbreekt knop hoe?
Welke stappen heb je afgerond?	1-2-3-4-5-6-7-8-9-10-11-12-13 aanduiding mist
Welke stap met het product was het makkelijkst	1-5-6-7-8-10-11
Welke stap was het ingewikkeldst	1-5-6-7-8-10-11
Hoe beoordeel je de interactie met de melkschuimer	Niet comfortabel ○ ○ ● ○ ○ ○ ○ Erg comfortabel Niet duidelijk ● ○ ○ ○ ○ ○ ○ Erg duidelijk Weinig stappen ○ ○ ● ○ ○ ○ ○ Veel stappen
Waarom heb je deze beoordeling gegeven?	- zoekende - nieuwe manier - spannender
Hoe beoordeel deze melkschuimer qua vormgeving	Past niet bij mijn keuken ○ ○ ○ ● ○ ○ ○ Past bij mijn keuken Past niet bij mijn Quooker ○ ○ ○ ○ ● ○ ○ Past bij mijn Quooker
Waarom heb je deze beoordeling gegeven?	nieuwe methode, wel krachtbaar als inbouw
Algehele beoordeling	- ○ ○ ○ ● ○ ○ ○ +

Concept: A / B / C

ID: 2

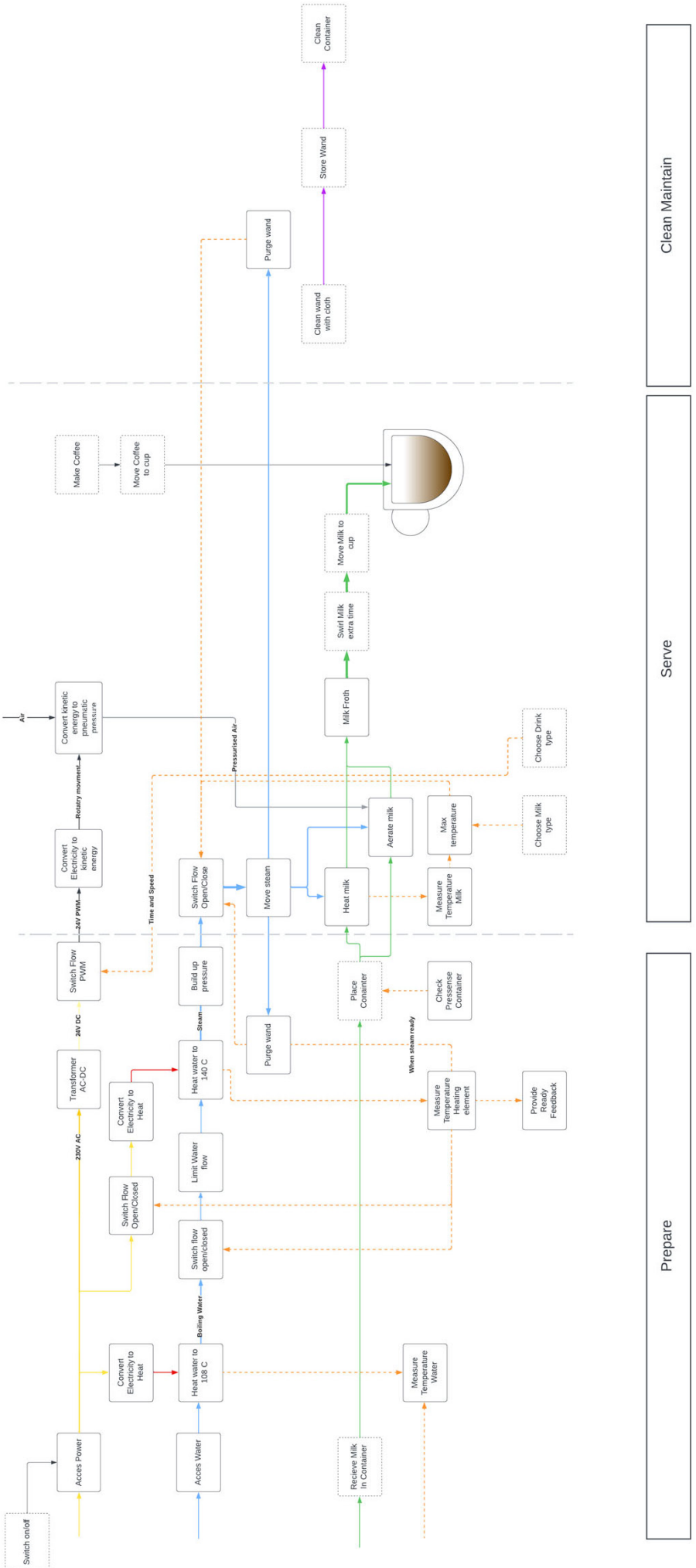
Denk je dat het gelukt is een cappuccino te maken?	Ja/Nee 2e (A)
Welke stappen heb je afgerond?	1-2-3-4-5-6-7-8-9-10-11-12-13
Welke stap met het product was het makkelijkst	1-5-6-7-8-10-11
Welke stap was het ingewikkeldst	1-5-6-7-8-10-11
Hoe beoordeel je de interactie met de melkschuimer	Niet comfortabel ○ ● ○ ○ ○ ○ ○ Erg comfortabel Niet duidelijk ○ ✕ ● ○ ○ ○ ○ Erg duidelijk Weinig stappen ○ ○ ○ ● ○ ○ ○ Veel stappen
Waarom heb je deze beoordeling gegeven?	visueel duidelijker nodigt uit
Hoe beoordeel deze melkschuimer qua vormgeving	Past niet bij mijn keuken ○ ○ ○ ● ○ ○ ○ Past bij mijn keuken Past niet bij mijn Quooker ○ ● ○ ○ ○ ○ ○ Past bij mijn Quooker
Waarom heb je deze beoordeling gegeven?	keuken "voorwerp" (gewenst) duidelijker, wel met losse onderdelen, leuzeketjker...
Algehele beoordeling	- ○ ○ ○ ● ○ ○ ○ +

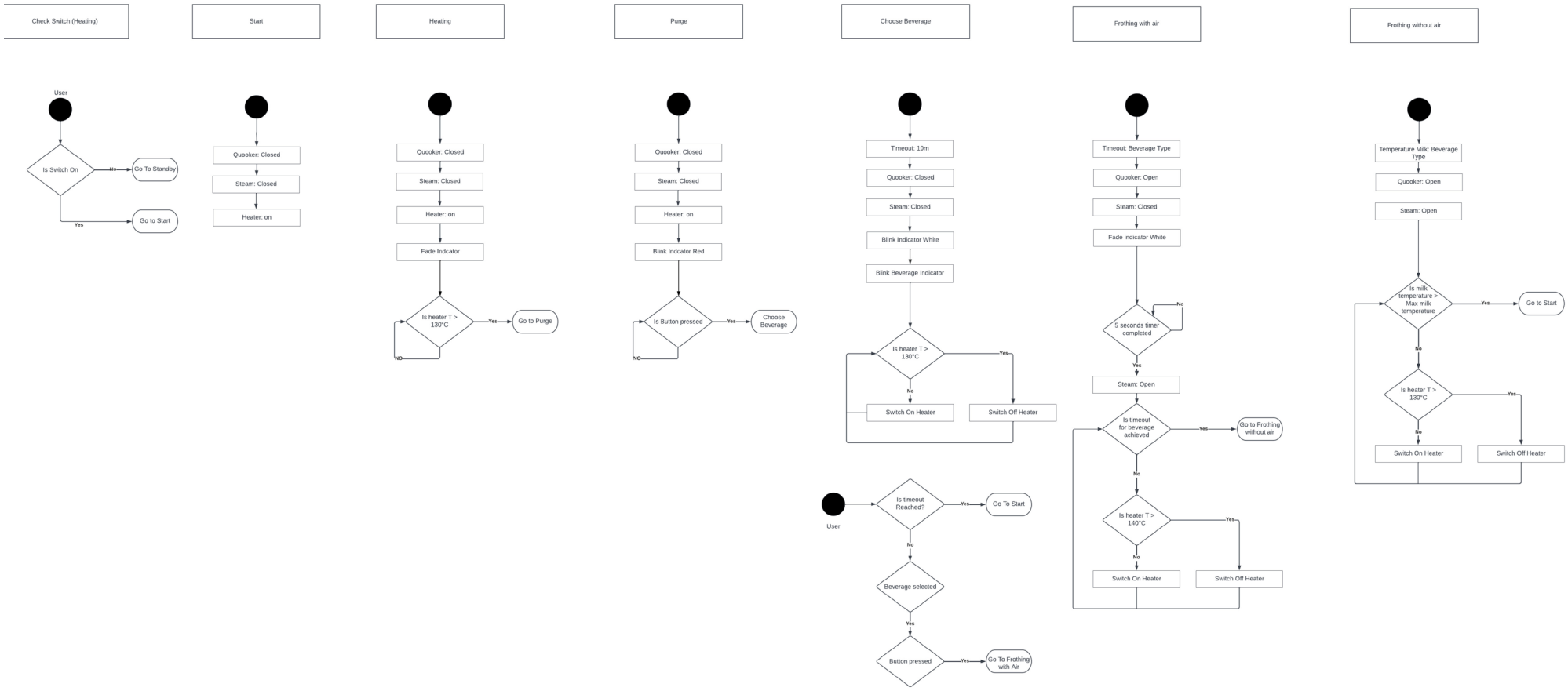
Concept: A / B / C

ID: 2

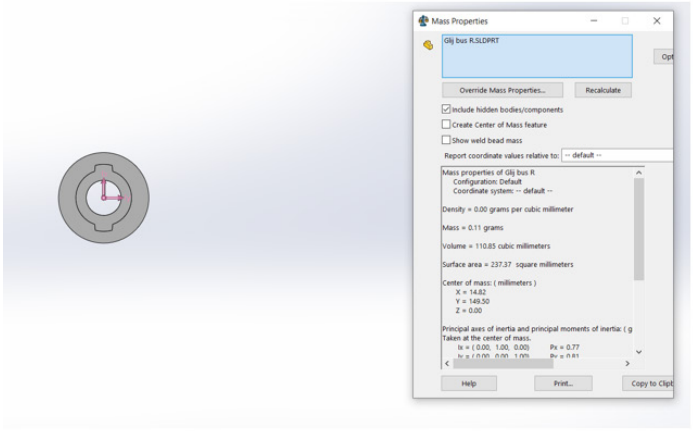
Denk je dat het gelukt is een cappuccino te maken?	Ja/Nee
Welke stappen heb je afgerond?	1-2-3-4-5-6-7-8-9-10-11-12-13 als laatste
Welke stap met het product was het makkelijkst	1-5-6-7-8-10-11
Welke stap was het ingewikkeldst	1-5-6-7-8-10-11
Hoe beoordeel je de interactie met de melkschuimer	Niet comfortabel ○ ○ ○ ○ ● ○ ○ Erg comfortabel Niet duidelijk ○ ○ ○ ○ ● ○ ○ Erg duidelijk Weinig stappen ○ ● ○ ○ ○ ○ ○ Veel stappen
Waarom heb je deze beoordeling gegeven?	stappen helder, je wordt meegenomen in het proces
Hoe beoordeel deze melkschuimer qua vormgeving	Past niet bij mijn keuken ○ ○ ○ ● ○ ○ ○ Past bij mijn keuken Past niet bij mijn Quooker ○ ○ ○ ● ○ ○ ○ Past bij mijn Quooker
Waarom heb je deze beoordeling gegeven?	uitstraling meer kans
Algehele beoordeling	- ○ ○ ○ ○ ● ○ ○ +

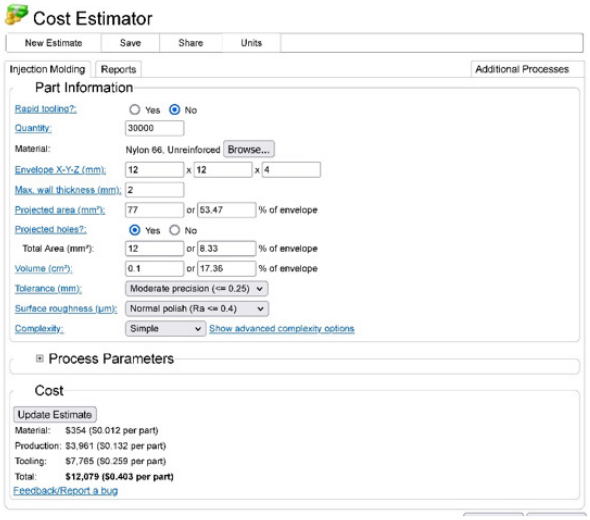
27. Appendix I: Functional Block Diagram

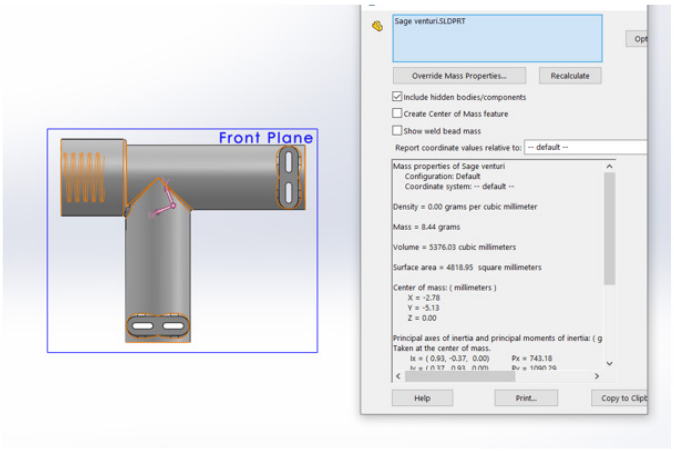


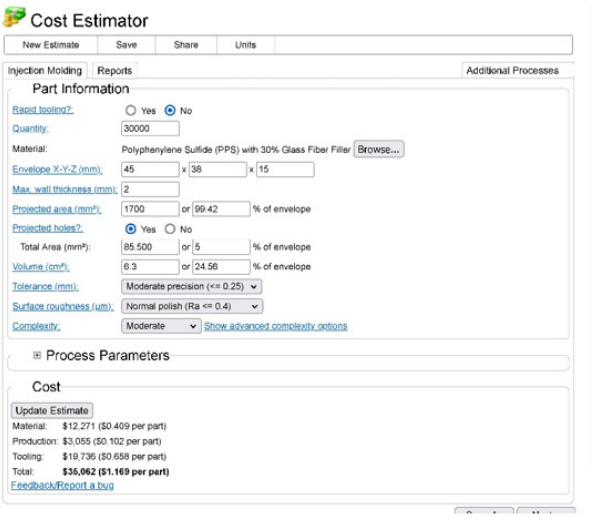

Check Switch (Heating)
User
Is Switch On
No
Go To Standby
Yes
Go to Start
Start
Quooker: Closed
Steam: Closed
Heater: on
Heating
Quooker: Closed
Steam: Closed
Heater: on
Fade Indcator
Is heater T > 130°C
Yes
Go to Purge
NO
Purge
Quooker: Closed
Steam: Closed
Heater: on
Blink Indcator Red
Is Button pressed
Yes
Choose Beverage
NO
Choose Beverage
Timeout: 10m
Quooker: Closed
Steam: Closed
Blink Indicator White
Blink Beverage Indicator
Is heater T > 130°C
Yes
No
Switch On Heater
Switch Off Heater
User
Is timeout Reached?
Yes
Go To Start
No
Beverage selected
Yes
Button pressed
Yes
Go To Frothing with Air
Frothing with air
Timeout: Beverage Type
Quooker: Open
Steam: Closed
Fade indicator White
5 seconds timer completed
No
Yes
Steam: Open
Is timeout for beverage achieved
Yes
Go to Frothing without air
No
Is heater T > 140°C
Yes
No
Switch On Heater
Switch Off Heater
Frothing without air
Temperature Milk: Beverage Type
Quooker: Open
Steam: Open
Is milk temperature > Max milk temperature
Yes
Go to Start
No
Is heater T > 130°C
Yes
No
Switch On Heater
Switch Off Heater

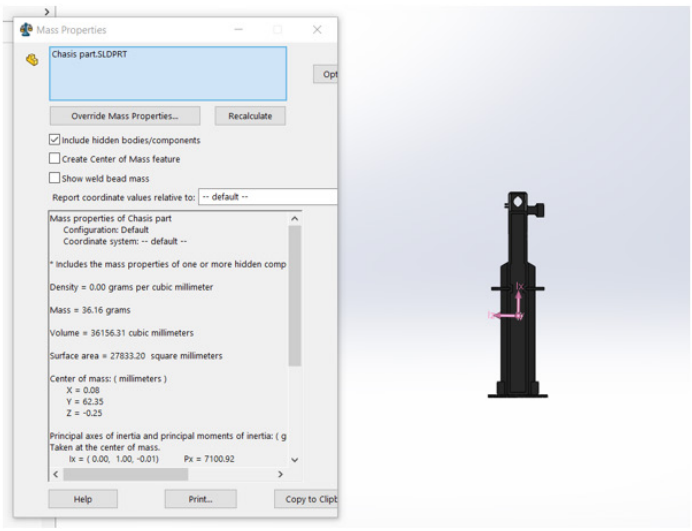
28. Appendix J: Injection Mould Investments

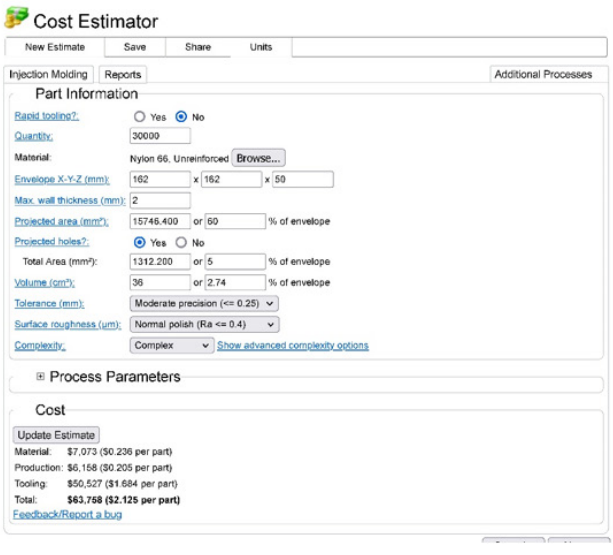












29. Appendix J: Arduino Code

```
#include <Wire.h>
#include <LiquidCrystal_I2C.h>
#include “thermistor.h”
#include “HardwareSerial.h”

LiquidCrystal_I2C lcd(0x27,20,4);

//Thermokoppel
#include <math.h>
#define NTC_Heater A3
#define NTC_Milk A2
THERMISTOR thermistor_heater(NTC_Heater,        // Analog pin
                  50000,          // Nominal resistance at 25 ºC
                  3976,           // thermistor’s beta coefficient
                  10000);         // Value of the series resistor

THERMISTOR thermistor_milk(NTC_Milk,        // Analog pin
                  10000,          // Nominal resistance at 25 ºC
                  3950,           // thermistor’s beta coefficient
                  10000);         // Value of the series resistor

uint16_t temperature_heater;
uint16_t temperature_milk;

//Killswitch
const int killswitch = 7;
int buttonState;
unsigned long lastDebounceTime = 0;
unsigned long debounceDelay = 100;


//Relais
const int relais_heater =  6;
const int relaisklep_quooker =  4;
const int relaisklep_stoom = 5;
unsigned long relais_refresh = 1000;
unsigned long last_relais;
int relais_aan = 0;

//Timers
const long tempinterval = 500;
unsigned long temppreviousMillis = 0;
unsigned long tempcurrentMillis = 0;
unsigned long present_time;
unsigned long relaistimer;


unsigned long interval_time_stoomlucht;
unsigned long starttijd;
long stoomlucht_time = 15000;

int current_state;

//LED
const byte pwmLED = 9;
int fadeInterval = 1;
#define UP 0
#define DOWN 1
const int minPWM = 0;
const int maxPWM = 150;

byte fadeDirection = UP;
int fadeValue = 0;
byte fadeIncrement = 5;
unsigned long previousFadeMillis;


int stoomtemp = 135;
```

```
void setup()
{
pinMode(relais_heater, OUTPUT);
pinMode(relaisklep_quooker, OUTPUT);
pinMode(relaisklep_stoom, OUTPUT);
pinMode(pwmLED, OUTPUT);
pinMode(killswitch, INPUT);
analogWrite(pwmLED, fadeValue);
Serial.begin(9600);
current_state = 0;

  lcd.init();
  lcd.backlight();
  lcd.setCursor(1,0);
  lcd.print(“Setup Done”);

  Serial.println(“Setup done”);
}

void loop()
{
  if(digitalRead(killswitch) == LOW){
    current_state = 0;
  }
  updateStateMachine();
  temperature_heater = thermistor_heater.read();
  temperature_milk = thermistor_milk.read();
    tempcurrentMillis = millis();

  if (tempcurrentMillis - temppreviousMillis >= tempinterval) {
  temppreviousMillis = tempcurrentMillis;
  }

}

const int Standby = 0;
const int Opwarmen = 1;
const int Stoom_lucht = 2;
const int Stoom = 3;
const int Melk_klaar = 4;

void updateStateMachine(){
  switch(current_state){
    case Standby:
      standby();
    break;

    case Opwarmen:
      opwarmen();
    break;

    case Stoom_lucht:
      Stoomlucht();
    break;

    case Stoom:
    Stomen();
    break;


    case Melk_klaar:
    Klaar();
    break;
  }
}
```

```
void loopje(int nummer, int nummer2, int state){
 lcd.setCursor(1,0);
 lcd.print("THeater= ");
 lcd.setCursor(9,0);
 lcd.print(nummer2);
 lcd.setCursor(1,1);
 lcd.print("TMelk= ");
 lcd.setCursor(7,1);
 lcd.print(nummer);
 lcd.setCursor(13,1);

  if (state == 0){
  lcd.print("P  ");
 }
 if (state == 1){
  lcd.print("H");
 }
  if (state == 2){
  lcd.print("S+A");
 }
  if (state == 3){
  lcd.print("S  ");
 }
   if (state == 4){
  lcd.print("F  ");
 }
}

void doTheFade(unsigned long thisMillis) {
   // is it time to update yet?
   // if not, nothing happens
   if (thisMillis - previousFadeMillis >= fadeInterval) {
      // yup, it's time!
      if (fadeDirection == UP) {
         fadeValue = fadeValue + fadeIncrement;
                  //Serial.println(fadeValue);
         if (fadeValue >= maxPWM) {
            // At max, limit and change direction
            fadeValue = maxPWM;
            fadeDirection = DOWN;
            //Serial.println("Change Direction");
         }
      } else {
         //if we aren't going up, we're going down
         fadeValue = fadeValue - fadeIncrement;
         //Serial.println(fadeValue);
         if (fadeValue <= minPWM) {
            // At min, limit and change direction
            fadeValue = minPWM;
            fadeDirection = UP;
         }
      }
      analogWrite(pwmLED, fadeValue);
      previousFadeMillis = thisMillis;
   }
}

void standby(){
    if (digitalRead(killswitch) == HIGH) {
      current_state = 1;
     // Serial.print("wissel  ");
     //Serial.println(current_state);
    }
     digitalWrite(relais_heater, LOW);
     digitalWrite(relaisklep_stoom, HIGH);
     analogWrite(pwmLED,0);

}

void Klaar(){
   digitalWrite(relais_heater, LOW);
   digitalWrite(relaisklep_quooker, LOW);
   if (digitalRead(killswitch) == LOW){
    current_state = 0;
   }
}

void opwarmen(){
  if(temperature_heater > stoomtemp){
    digitalWrite(relais_heater, LOW);
        current_state = 2;
    starttijd = millis();
  }
  else{
    digitalWrite(relais_heater, HIGH);
  }
     unsigned long currentfadeMillis = millis();
     doTheFade(currentfadeMillis);
}


void Stomen(){
    last_relais =  millis() - relaistimer;
    Serial.println(last_relais);

    if (last_relais > relais_refresh){
       if(temperature_heater < stoomtemp){
       digitalWrite(relais_heater, HIGH);
       Serial.println("aan");
    }
       if(temperature_heater >stoomtemp){
       digitalWrite(relais_heater, LOW);
       relaistimer = millis();
       Serial.println("uit");
      }
    }

    digitalWrite(relaisklep_stoom, HIGH);

  if(temperature_milk > 50){
    Serial.println("Melk Klaar");
    current_state = 4;
  }

   analogWrite(pwmLED,255);
}

void Stoomlucht(){
  //Serial.println("Stoom+lucht");
  present_time = millis();
  interval_time_stoomlucht = present_time - starttijd;



  digitalWrite(relaisklep_quooker, HIGH);
  digitalWrite(relaisklep_stoom, HIGH);

    last_relais =  millis() - relaistimer;

    Serial.println(last_relais);

    if (last_relais > relais_refresh){
       if(temperature_heater < stoomtemp){
       digitalWrite(relais_heater, HIGH);
       Serial.println("aan");
    }
       if(temperature_heater >stoomtemp){
       digitalWrite(relais_heater, LOW);
       relaistimer = millis();
       Serial.println("uit");
      }
    }

    if (interval_time_stoomlucht >= stoomlucht_time){
      //Serial.println("Lucht done");
      current_state = 3;
}

  if(temperature_milk > 50){
    //Serial.println("Melk Klaar");
    current_state = 4;
  }
   analogWrite(pwmLED,255);
}
```

30. Appendix L: On counter prototype evaluation sheets

ID: .....

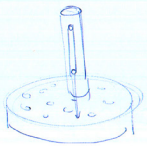
Do you think you were able to make a cappuccino?	Yes/No
Which steps did you complete successfully?	1-2-3-4-5-6-7-8-9-10
How do you asses the interaction with the milk frother?	Not comfortable O O O O O ☒ O Very comfortable Not clear O O ☒ O O O O Very clear Not many steps O O O O O ☒ O A lot of steps
Why did you give this assessment?	Without explanation the steps are a bit confusing the first time. After that its pretty clear
How do you asses the design of the milk frother?	It would not fit in my kitchen O O O O O O O It fit's in my kitchen It would not fit with Quooker O O O O O O ☒ It would not fit with Quooker
Why did you give this assessment?	I would expect something of a dripping tray for the cleaning.
Overall grade	- O O O O O ☒ O +

Aditional Questions ID: pilot

How would you describe your overall experience with the product?	The first time is a bit unclear. The position of the tube is a bit unhandy.
What did you like the most about using this product?	It looks good and nice lighting ring
What did you like the least?	a lot of button presses
What, if anything, caused you frustration?	Fitting the can under the tube
What did you think about the colour and behaviour of the Lights? Did you understand what the device needed and what it was doing?	When cleaning the Red light could stay on. Heating before second clean is bit confusing.
Did you find the placement on the counter sufficient? Were the buttons on the side still reachable?	place on counter is fine. selection button is a bit hard to see and touch. Maybe change for a turning ring, same as Quooker.

ID: ...1

Do you think you were able to make a cappuccino?	Yes/No
Which steps did you complete successfully?	1-2-3-4-5-6-7-8-9-10
How do you asses the interaction with the milk frother?	Not comfortable O O O O O ☒ O Very comfortable Not clear O O O ☒ O O O Very clear Not many steps O O O O ☒ O O A lot of steps
Why did you give this assessment?	• Heer zetten of vasthoud by Stoompypje • uitklappen duidelyk Warm → was ik niet zeker ↳ knippert nog steeds, ik zou verwachten een kleur Schoonmaken vooraf was niet duidelyk keuze menu wel
How do you asses the design of the milk frother?	It would not fit in my kitchen O O O O O O ☒ It fit's in my kitchen It would not fit with Quooker O O O O O O ☒ It would not fit with Quooker
Why did you give this assessment?	Strak, weinig poespas Mooie materialen
Overall grade	- O O O O ☒ O O +



Aditional Questions ID: 1

How would you describe your overall experience with the product?	over algemeen mooi in geheel, mooi uit 2 strakke delen, de vorm is goed → duidelyk een stoompypje. Lichten zyn fyn, het begeleid je er doorheen.
What did you like the most about using this product?	de vorm & begeleiding door stappen
What did you like the least?	redelyk veel stappen. niet elk lichtje was me duidelyk wat myn handeling moest zyn
What, if anything, caused you frustration?	de lampjes, wat myn handeling zou moeten zyn. soms iets minder knipperen als er niks van my verwacht wordt.
What did you think about the colour and behaviour of the Lights? Did you understand what the device needed and what it was doing?	veel knipper soms meer contrast tussen licht : dus, wel knipperen of niet knipperen
Did you find the placement on the counter sufficient? Were the buttons on the side still reachable?	ja, eerst waren my die niet opgevallen, toen lichtjes aangingen wel.

ID: 2

Do you think you were able to make a cappuccino?	~~Yes~~/No
Which steps did you complete successfully?	~~1-2-3-4-5-6-7-8-9-10~~
How do you asses the interaction with the milk frother?	Not comfortable ○ ○ ○ ○ ○ ~~●~~ ● Very comfortable Not clear ○ ○ ○ ● ○ ○ ○ Very clear Not many steps ○ ○ ● ○ ○ ○ ○ A lot of steps
Why did you give this assessment?	Comfortable: design & shape, Clearly: Cleaning step required some additional info Steps are logical. ~~Cleaning steps~~ First cleaning step is maybe redundant, but this depends on the user. Perhaps instead add a separate cleaning button/ function key.
How do you asses the design of the milk frother?	It would not fit in my kitchen ○ ○ ○ ○ ○ ○ ● It fit's in my kitchen It would not fit with Quooker ○ ○ ○ ○ ○ ○ ● It would ~~not~~ fit with Quooker
Why did you give this assessment?	Design & compact, does not take up much space on kitchen counter, especially compared to other milk frothers. Design/style is very compatible with the Quooker design, I could immediately tell it's a Quooker product, style & shape.
Overall grade	- ○ ○ ○ ○ ○ ● ○ +

Aditional Questions ID: 2

How would you describe your overall experience with the product?	Good. If I had had a user manual, I would not have problems; without user manual, some steps took or few seconds to figure out.
What did you like the most about using this product?	~~Style~~ Compactness. Premium style. (shape, ~~design~~ Lights) ~~Light~~
What did you like the least?	~~Use~~ First cleaning step. It should be optional
What, if anything, caused you frustration?	That the first cleaning step is mandatory.
What did you think about the colour and behaviour of the Lights? Did you understand what the device needed and what it was doing?	Cleaning lights are a bit unclear. Also wasn't sure when device was finished heating
Did you find the placement on the counter sufficient? Were the buttons on the side still reachable?	Placement is good, buttons are easily reachable.

ID: 3

Do you think you were able to make a cappuccino?	Yes/No
Which steps did you complete successfully?	1-2-3-4-5-6-7-8-9-10
How do you asses the interaction with the milk frother?	Not comfortable ○ ○ ○ ○ ○ ● ○ Very comfortable Not clear ○ ○ ○ ○ ● ~~●~~ ○ Very clear Not many steps ○ ● ○ ○ ○ ○ ○ A lot of steps
Why did you give this assessment?	~~His~~ 3. I was looking for 100ml line in jug 5. I did not see the buttons 6. I think if i heard psssssh it would be more clear now i needed to guess if i did it correct
How do you asses the design of the milk frother?	It would not fit in my kitchen ○ ○ ○ ○ ○ ● ○ It fit's in my kitchen It would not fit with Quooker ○ ○ ○ ○ ○ ○ ● It would ~~not~~ fit with Quooker
Why did you give this assessment?	it cleans up the kitchen blad and the look & feel fits well
Overall grade	- ○ ○ ○ ○ ○ ● ○ +

Aditional Questions ID: 3

How would you describe your overall experience with the product?	there is a learning curve but I did feel like a real barista
What did you like the most about using this product?	It guids you well thaug the steps and makes you dennit you can make coffee at the same time
What did you like the least?	
What, if anything, caused you frustration?	if my smooth cappuccino does not fit the ~~not~~ quooker cappucino → verschillende types melk
What did you think about the colour and behaviour of the Lights? Did you understand what the device needed and what it was doing?	i did not fully understand the cleaning part
Did you find the placement on the counter sufficient? Were the buttons on the side still reachable?	I would not put this on my heaten blad, never met een lekbak of een onder-zet

ID: Yamila

Do you think you were able to make a cappuccino?	Yes/No — wist wel hoe aan, maar niet hoe start
Which steps did you complete successfully?	1-2-3-4-5-6-7-8-9-10 — niet: 4, 6, 9 — waarschijnlijk wel, moetje even doorhebben → dat voorkom
How do you asses the interaction with the milk frother?	Not comfortable ○ ○ ○ ○ ○ ● ○ Very comfortable Not clear ○ ○ ● ○ ○ ○ ○ Very clear Not many steps ● ○ ○ ○ ○ ○ ○ A lot of steps
Why did you give this assessment?	– interactie werkt goed – kleuren/knoppen niet in 1x duidelijk – efficiënter proces, niet mijn preference (hou van koffie zetten design erg heel strak en mooi
How do you asses the design of the milk frother?	It would not fit in my kitchen ● ○ ○ ○ ○ ○ ○ It fit's in my kitchen It would not fit with Quooker ○ ○ ○ ○ ○ ○ ● It would not fit with Quooker
Why did you give this assessment?	
Overall grade	– ○ ○ ○ ○ ● ○ ○ + — 7/10

Aditional Questions ID:.....

How would you describe your overall experience with the product?	– knipperen niet gewenst – rood is geen goede kleur voor cleaning
What did you like the most about using this product?	fucking dope fysieke knop bovenaan
What did you like the least?	errors/ warnings/ signs not clear hoe gaat het uit?
What, if anything, caused you frustration?	niet weten wat de lichten betekenen
What did you think about the colour and behaviour of the Lights? Did you understand what the device needed and what it was doing?	
Did you find the placement on the counter sufficient? Were the buttons on the side still reachable?	goede plek ik zou ze voorkant doen

ID: 5

Do you think you were able to make a cappuccino?	Yes/No
Which steps did you complete successfully?	1-2-3-4-5-6-7-8-9-10
How do you asses the interaction with the milk frother?	Not comfortable ○ ○ ○ ○ ○ ○ ● ○ Very comfortable Not clear ○ ○ ○ ○ ○ ○ ● ○ Very clear Not many steps ○ ● ○ ○ ○ ○ ○ A lot of steps
Why did you give this assessment?	– Size. selection was really unclear. – feels fragile & bit fragile person – Design feels natural. -> process is similar to
How do you asses the design of the milk frother?	It would not fit in my kitchen ○ ○ ○ ○ ○ ○ ● It fit's in my kitchen It would not fit with Quooker ○ ○ ○ ○ ○ ○ ⊗ It would not fit with Quooker
Why did you give this assessment?	Rust simplicity / led, much low very colour
Overall grade	– ○ ○ ○ ○ ○ ⊗ ○ +

Aditional Questions ID: 5

How would you describe your overall experience with the product?	interesting, I really like the similarity with frothing milk in a professional environment like it.
What did you like the most about using this product?	the take going on, indicates the process is stopped.
What did you like the least?	selection of the cups was unclear for me, hands out of sight
What, if anything, caused you frustration?	selection of size.
What did you think about the colour and behaviour of the Lights? Did you understand what the device needed and what it was doing?	yes, Red is definitely ~~for steaming~~. Steamy steam is coming out of the guide.
Did you find the placement on the counter sufficient? Were the buttons on the side still reachable?	yes, close to the side & but still adjusting your movements

ID: 6

Do you think you were able to make a cappuccino?	(Yes) / No
Which steps did you complete successfully?	(1) 2 (3) 4 (5) 6 7 (8) 9 (10)
How do you asses the interaction with the milk frother?	Not comfortable ○ ○ ○ ○ ○ ● ○ Very comfortable Not clear ○ ○ ○ ○ ● ○ ○ Very clear Not many steps ○ ○ ○ ● ○ ○ ○ A lot of steps
Why did you give this assessment?	Ik had in principe nergens last van bij het gebruik, het is een mooi, [redacted] duidelijk apparaat. Het is eigenlijk net als bij de Quooker: de eerste keer even kijken hoe, daarna heel duidelijk!
How do you asses the design of the milk frother?	It would not fit in my kitchen ○ ○ ○ ○ ○ ○ ● It fit's in my kitchen It would not fit with Quooker ○ ○ ○ ○ ○ ○ ● It would [redacted] fit with Quooker
Why did you give this assessment?	Hij past perfect bij het design van de Quooker! En hij is erg compact, dus het past denk ik in elke keuken wel!
Overall grade	- ○ ○ ○ ○ ○ ● ○ +

Aditional Questions

ID: 6

How would you describe your overall experience with the product?	Na 1 keer gebruik duidelijk
What did you like the most about using this product?	Niet te veel knoppen.
What did you like the least?	Ik wist niet dat vantevoren schoonmaken nodig was.
What, if anything, caused you frustration?	Waarom knippert hij rood?
What did you think about the colour and behaviour of the Lights? Did you understand what the device needed and what it was doing?	
Did you find the placement on the counter sufficient? Were the buttons on the side still reachable?	yes!