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The Design of a Volume Control System for the Quooker Tap

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Acknowledgments

First of all, I would like to thank all the people that were by my side and helped me throughout this project. The outcome of this Master thesis wouldn't be the same without them.

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This thesis is a testament to the collective support and encouragement of these wonderful individuals. Thank you all for being an integral part of this academic journey.

Abstract

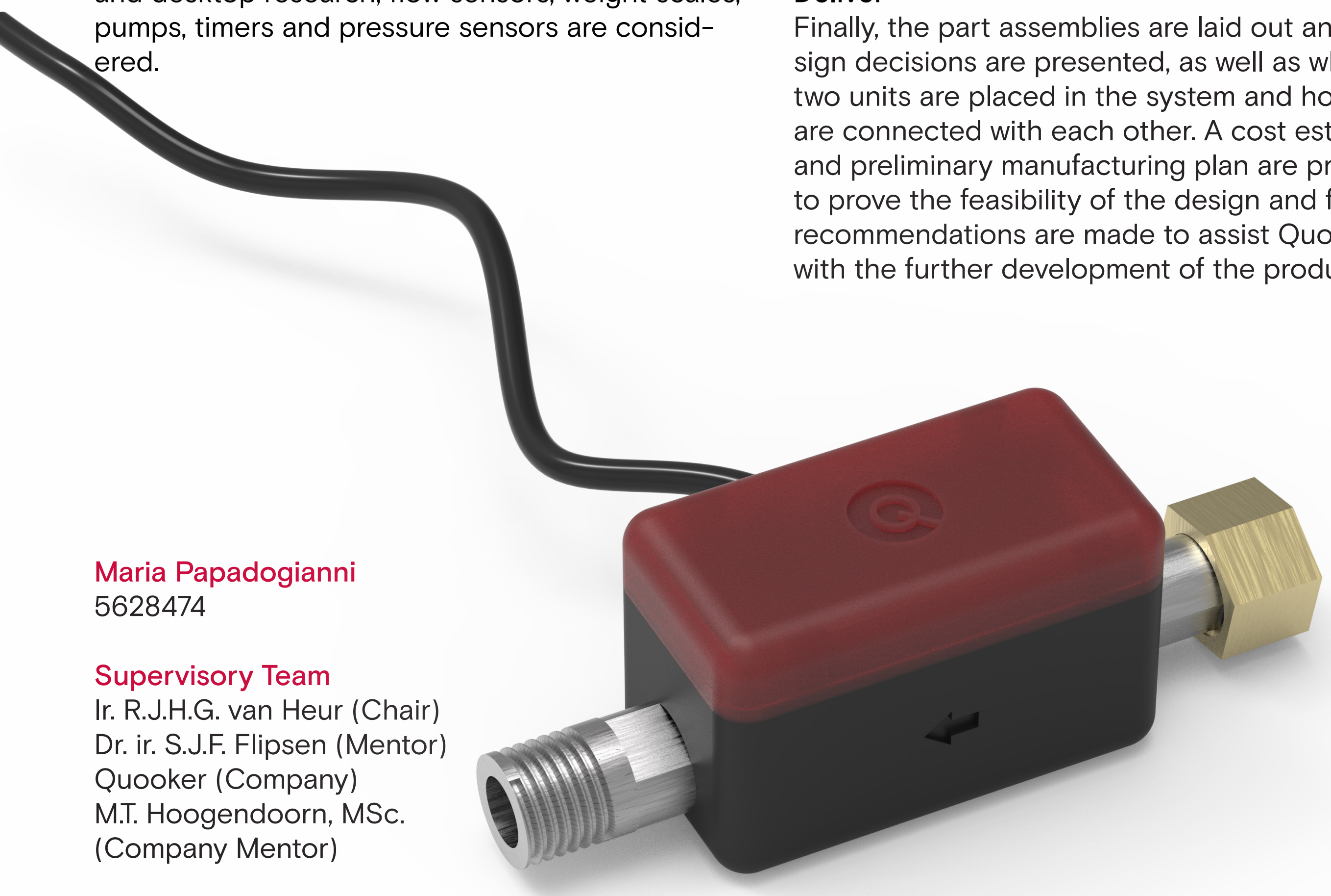
This report presents the process of designing a volume unit as an addition to the current product system, which will allow the user to control boiling, chilled and carbonated water volumes. This assignment tackles both the user interaction that takes place around the tap over the counter, as well as the functionality and technology implemented below the counter to control the water volumes. One of the drivers of this project is backwards compatibility, making the designed system suitable for all existing taps and reservoirs.

Discover
Research is conducted internally at Quooker B.V. to identify the system characteristics when it comes to Quooker reservoirs, as well as the user interface and usability of the taps and accessories. Externally, competitors and other field applications are considered as inspiration for the design of the project. A set of use cases is obtained through exploration and user interviews, which serve as guideline for the design. Interestingly, users don't frequently measure water volumes as they rather fill their pots by feeling based on the relative water level in the container. As for technology, after careful literature and desktop research, flow sensors, weight scales, pumps, timers and pressure sensors are considered.

Define
Based on the user needs and wishes, as well as Quooker system limitations, a list of requirements is created to steer the direction of the design process. These criteria include amongst others; usability, performance, aesthetic and cost price requirements. Some important aspects that are considered are limescale, flow rate, mental strain and the properties of special feature water, such as temperature, pressure and water consistency.

Develop
The next step is to explore different design directions. Several options are considered for both the user interaction and flow measurement, as well as possible placements within the current system to establish compatibility. These options are evaluated by users and R&D engineers and the final concepts were chosen; an external knob for over-the-counter user interaction alongside a turbine flow sensor at the inlet of the water system. These concepts are developed and tested within and outside of Quooker B.V. and iterations are made to improve the design.

Deliver
Finally, the part assemblies are laid out and design decisions are presented, as well as where the two units are placed in the system and how they are connected with each other. A cost estimation and preliminary manufacturing plan are presented to prove the feasibility of the design and future recommendations are made to assist Quooker B.V. with the further development of the product.



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1 Introduction

This chapter serves as an introduction to the report of “The Design of a Volume Control System for the Quooker tap”, an Integrated Product Design Graduation Project in collaboration with Quooker and TU Delft. It presents the assignment and the main design drivers, as well as the compnay and how this assignment was carried out and planned.

1.1 Assignment

Within the Research & Development department, "search fields" are identified which represent research areas within the Quooker-context. These search fields make up the fuzzy front-end and focus on exploring new solutions and products to enrich daily life. This graduation project falls into the search field of "Electronic Mixing". Controlling the water with the aid of electronics leads to a better sense of control and better performance of a tap.

With the current Quooker system, the users have to wait next to their tap when filling larger volumes of water. For example, filling a pot of boiling water of 5 liters takes approximately 1:40 min, a carafe of sparkling water can take 1 minute to fill. Measuring cups are needed to determine the exact quantity of water. Water gets wasted or spilled. The goal of this project is to develop a solution to let the user control the volume of special feature water (boiling, chilled, carbonated, filtered) dispensed by the tap while avoiding the aforementioned points.

Given the limited time scope (20 weeks), the key drivers for the design of a volume dispensing unit for the Quooker tap include, in order of priority:

- **Functionality**

  The volume unit must be able to control the volume of water dispensed accurately and efficiently.

- **Usability**

  The volume unit must be intuitive to use and understand, following the Quooker interaction language.

- **Compatibility**

  The volume unit needs to be backwards compatible with existing tap models and reservoirs.

- **Safety**

  The volume unit must be designed in such a way that is safe for the user.

- **Aesthetics**

  The volume unit should complement the tap design and match the overall aesthetic of Quooker products.

"Design a volume unit as an addition to the current product system, which will allow the user to control boiling, chilled and carbonated water volumes."

1.2 Company

Quooker is a Dutch tap manufacturer, renowned for the innovation of the first instant boiling water tap. The founder of the company Henri Peteri, inspired by instant soup, realized that there's a need for instant boiling water. Driven by this idea, the Quooker ("quick cooker") boiling tap was born, enabling water to be kept at 107°C and dispensed on demand.

Quooker provides other types of special feature water within the same tap as well, such as chilled, carbonated and filtered. Amongst their taps, Quooker offers two other product categories: reservoirs and accessories.

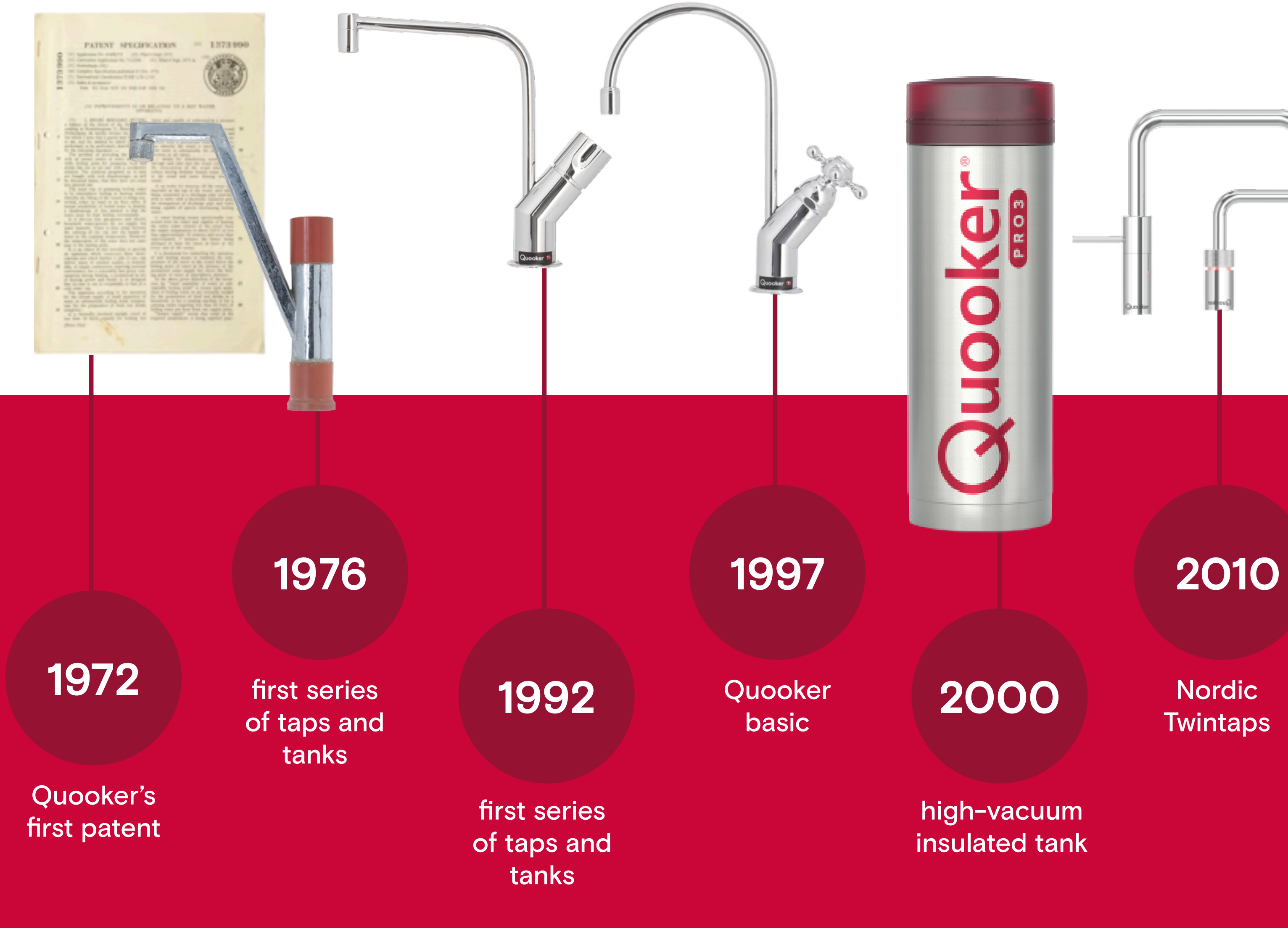
Quooker is continuously working on improving existing products and developing new solutions to supply as many kitchens as possible with boiling water in a smart and responsible way. By combining boiling, chilled, sparkling or filtered water in one tap, Quooker is a sustainable purchase. The company strives to stay true to their innovative character by continuously working on new products and improving the current system. Figure 1 shows a timeline of the company's growing product portfolio.

Quooker's vision

instant boiling water in the kitchen enriches people's lives.

Quooker's mission

ingenious water solutions for residential kitchens that exceed expectations.



Quooker follows these four principles to achieve their vision and mission:

High standards

Quooker strives for quality. The engineers within R&D are constantly working towards a more faultless, more satisfying, more precise and more complete design. The details are important.

Originality

From the very beginning, Quooker has had an entrepreneurial character. After all, Quooker is the original boiling water tap. This means that Quooker strives for originality, looking for the next logical step in the development of the Quooker taps and implementing smart innovations. Innovation is the main part of Quooker's agenda. As innovators in the field of special feature tap water, Quooker strives to stay ahead and provide their customers with the best and newest technology. The offices, workshops and factory are all within the same building, so ideas can be explored, tested and developed on the spot.

Empathy

Quooker's products and services strive to make people's lives a little better. There's an awareness that Quooker products are involved with real people, people with busy lives and all kinds of things on their minds. Quooker is there to simplify daily habits and provide comfort. Quooker's new products and solutions must consider the target user's lifestyle, as well as fit within the Quooker line and aesthetics.

Liveliness

Ultimately, it's about the life in and around your kitchen. To make this tangible on all levels, Quooker adopts an optimistic attitude and an active, positive and energetic point of view.

Figure 1. Timeline of Quooker's product portfolio

1.3 Structure & Planning

This project follows the Basic Design Cycle as presented by Roozenburg et. al. Starting with an Analysis and Synthesis, followed by Simulation, Evaluation, Decisions and Iterations. This design project has a dual character, one side dealing with the user interaction and the other with the below-the-counter functionality. These two aspects are handled separately throughout the project and combined at the end, since they barely affect each other. This structure is also followed throughout this report with each topic consisting of a Discover, Define and Develop Chapter. The Deliver Chapter presents the embodiment of both units into one product. The Discover, Define, Develop, Deliver framework provides a structured approach to product design, ensuring a thorough exploration of the problem space and a well-defined direction for development and delivery. It's important to note that the product design process is often iterative, and these steps may overlap or require revisiting as new insights are gained.

For the project management, a triple diamond is implemented, and the project was divided in three phases (Fig. 2):

Phase 1

The main component of Phase 1 is Research with the goal of getting familiar with the project and Quooker's systems. The context is investigated through desktop and literature research of relevant technologies, applications in different (industrial) fields, flow measurement in household appliances, as well as competitor analysis and lab testing of the Quooker system. Similarly for the user interaction aspect of the project, user interviews and observations are conducted. A deep dive into User Interaction principles and analysis of the product design of volume indications provides useful insights for this project and several directions for ideation. The outcome of Phase 1 is a list of requirements to help navigate and guide the next phases.

Phase 2

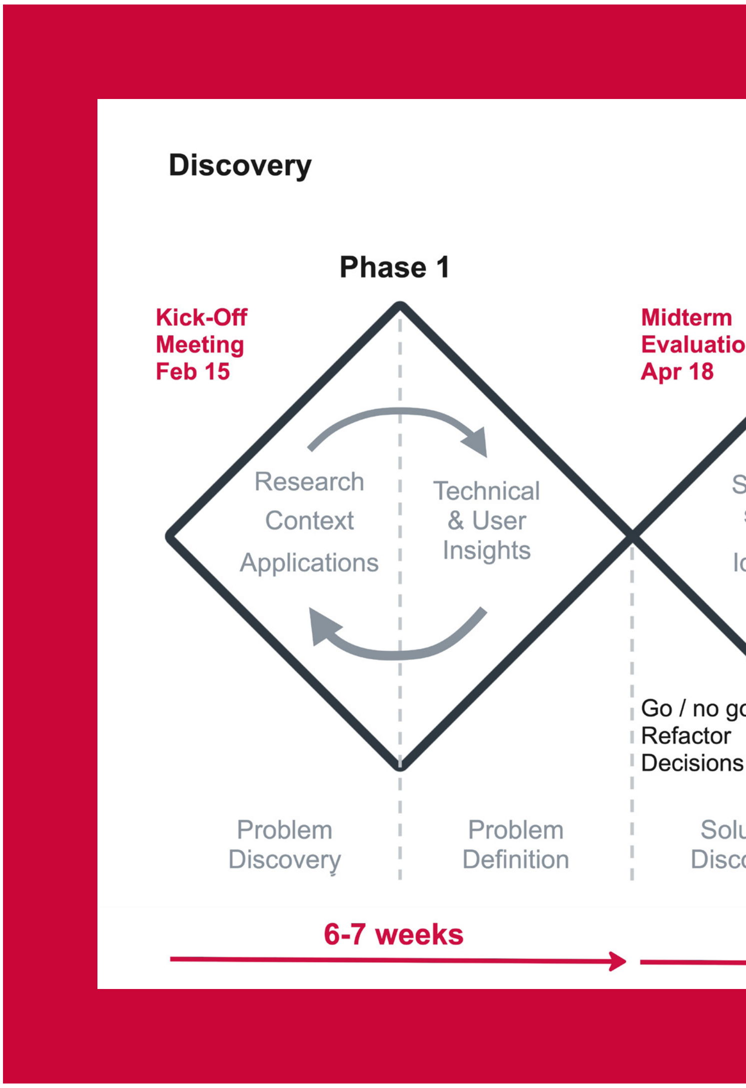
Phase 2 comprises of ideation, concept generation, evaluation, and prioritization. Ideas are generated based on the insights and information of Phase 1. Brainstorming and co-creation sessions are organized within the department and amongst students at university. Ideas are sketched and prototyped for visualization and testing purposes. The ideas are later iterated, combined and filtered to generate 4 concepts. One of them will be chosen based on the list of requirements, user feedback and Nielsen's heuristics.

Phase 3

Phase 3 follows the final concept and consists of prototyping, testing and iterations of the final design. Prototypes' functionality is tested in the testing lab within R&D. In addition to this, user tests are conducted to evaluate the design of the user interface and provide further improvements. Both functionality and usability are validated and combined into one functional prototype.

Communication

Throughout the project, frequent meetings are organized with the university supervisory team



to discuss the progress and collect feedback on how to proceed. Within the company, in addition to weekly mentor meetings, questions and decisions are discussed with experts for validation. External stakeholders such as users (household, commercial) and other companies (eg. flow sensor manufacturers) were consulted to reach informed decisions.

Goal

The goal of this project is to configure a method to efficiently measure water volumes, with existing technology or a custom-made module accustomed to Quooker's system. Simultaneously, a user interaction unit for the counter-top is to be designed, one that enables the user to intuitively select the desired volume without additional mental strain, while also fitting the Quooker system.

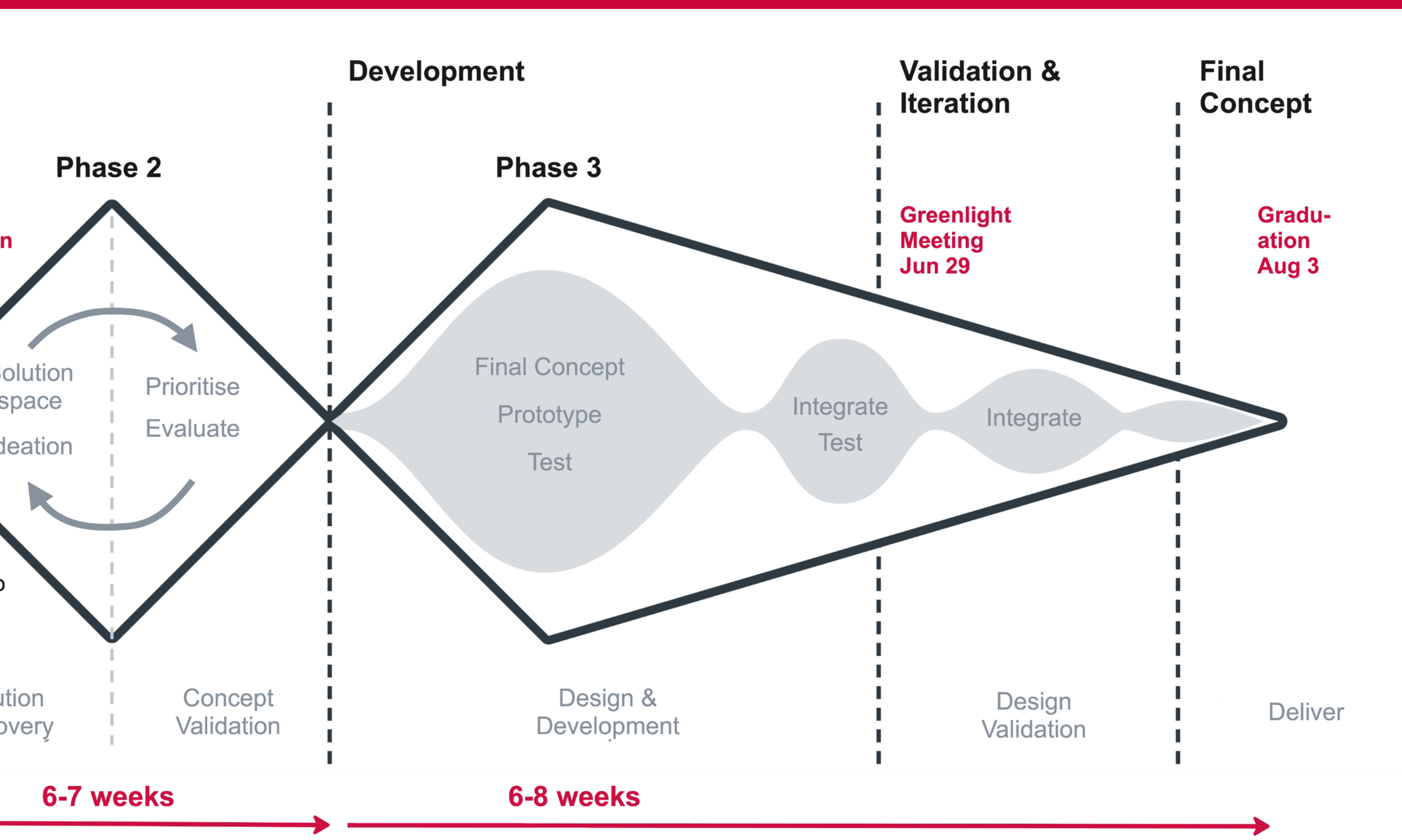


Figure 2. Triple Diamond for Project Management

USER INTERAC-TION

2

Discover
user interaction

This section kicks off the user interaction part of the report with desktop and literature research, as well as user interviews to explore user habits around measuring water in the kitchen and also identify uder needs.

The Quooker system and characteristics are investigated to provide a guideline for the design of the user interaction unit. Furthermore, competitor products with volume control functions are analyzed, as well as other product applications offering volume selection.

2.1 Quooker Exploration

Figure 3. Quooker's 3 product categories; taps, reservoirs, accessories

Quooker's line consists of three product categories; taps, reservoirs and accessories. The Volume Control System belongs to the category accessories, alongside the soap dispenser, water filters, scale control etc. The soap dispenser is the most comparable to the volume control unit, with a price range of 200-395€, depending on the finish.

User Interface

Above the counter is where user interaction takes place. The tap is connected to the lower system in the kitchen cabinet and offers the user the functionalities of a conventional water tap, as well as the special water features. The user can use the lever to control the temperature of the water, and the flow rate of the mixed water being dispensed, similarly to any water tap.

In addition to this, the knurl knob on the faucet operates the special feature water; boiling, filtered, chilled and carbonated. The use sequences are pictured in the figures bellow. The LED on the knob shines red when boiling water is being dispensed, blue for (filtered) chilled and pulsing blue for carbonated.

So far, the user has no control over the dispensing of special feature water, except for turning it on and off. The temperature, flow rate and exact volume dispensed cannot be adjusted through the current tap interface. Some settings are available below the counter to adjust the temperature and carbonation levels of the water.

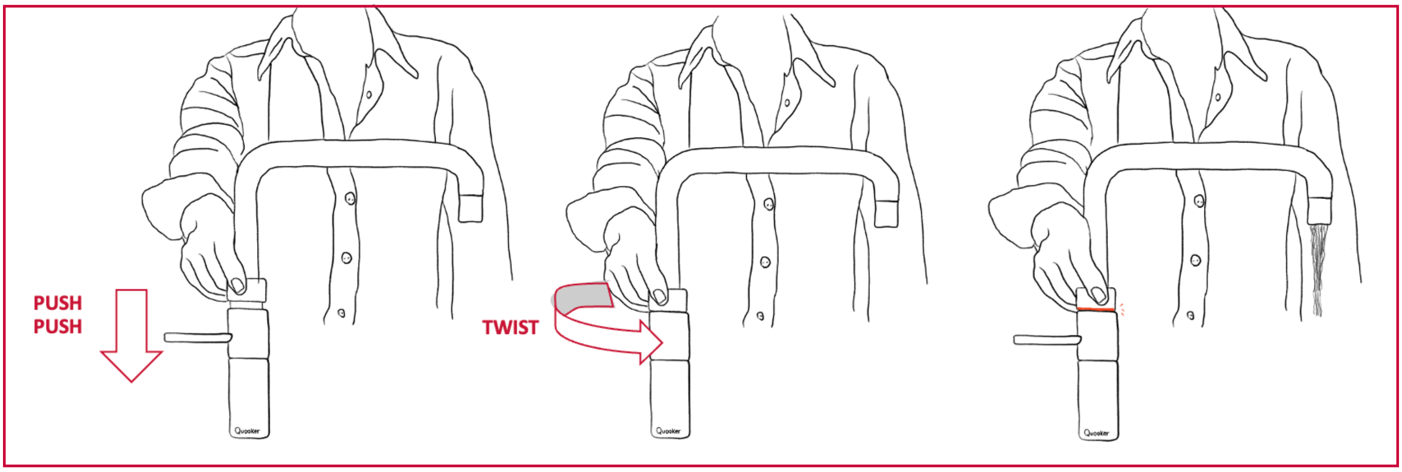


Figure 4. Boiling water sequence; double push & twist, all tap models

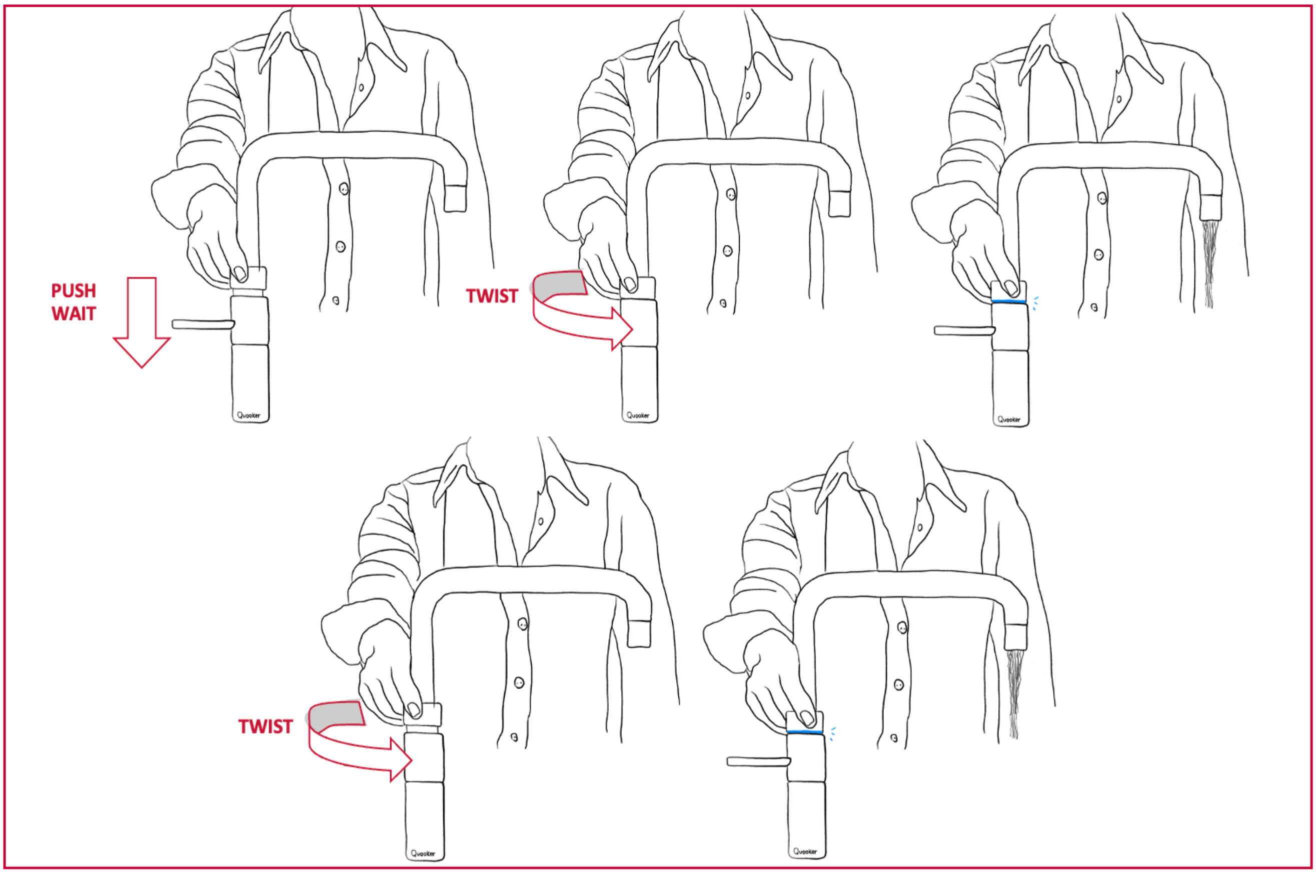


Figure 5. Chilled (filtered) water sequence; push, wait & twist, all tap models except Front | twist, Front

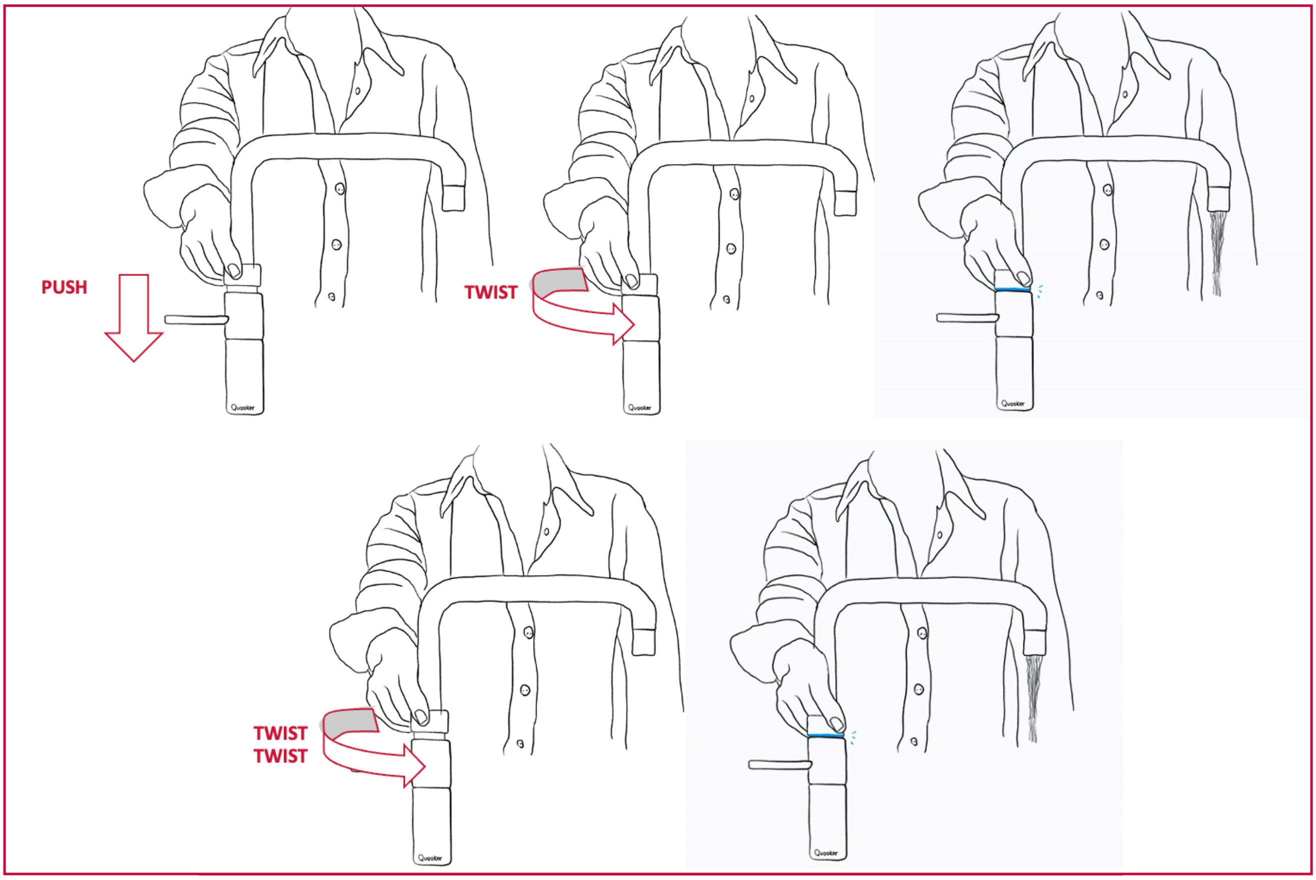


Figure 6. Carbonated water sequence; push & twist, all tap models except Front | double twist, Front

2.2 Quooker Characteristics

Figure 7. Push-and-twist-to-lock Bayonet fitting

The first tap and interaction

During a meeting with the co-founder, Niels Peteri, the Quooker interaction and use sequences were discussed. The first Quooker tap featured a detachable handle that could be stored away from the tap to ensure that the product was childproof and not accidentally used. The next design had an integrated handle that would activate the boiling water function via a “push and twist”. The idea for this feature was inspired by bayonet fittings and the intuitive movement of activating similar types of applications, such as gas stove knobs. The second iteration of the interaction for “double push and twist” derived from user and dealer requests for increased child safety.

Quooker taps have a unique design that sets them apart from traditional taps. They have a single spout that dispenses both hot and cold water, as well as boiling water. There are certain characteristics that distinguish Quooker taps from others.

Knurled knob

The Knurled Knob is a unique feature of the boiling water tap. It is a textured knob that is designed to be easy to grip and turn, providing a tactile and visual cue for the user to open and close the valve. The Knurled Knob is designed to be easy to clean and maintain. It can be wiped clean with a damp cloth to remove any dirt or residue.

LED lights

Quooker taps are equipped with LED lights that indicate the status of the tap. When the tap is turned on, the light ring around the knurled knob turns red or blue providing feedback to the user that the boiling, chilled or carbonated water function is activated.

Auditory feedback

Quooker taps emit an audible click when the boiling water function is activated, providing feedback to the user that the water is ready to dispense. The boiling water in combination with steam makes a rattling noise while being dispensed.

Finishes

Quooker offers different finishes for their taps to fit every kitchen. There are six options in all: chrome, stainless steel, black, gold, patinated brass and polished nickel.

Safety features

Quooker taps have several safety features to prevent accidental use. The tap’s handle is childproof and must be double-pushed and turned to dispense boiling water.

User manual

Quooker provides a detailed user manual with each tap, which includes instructions for use, maintenance, and troubleshooting. Explanatory videos are also available online.

Figure 8. Nordic Twin Taps in stainless steel, Flex tap in black finish

2.3 Competitors

Figure 9. Sedal Digital Shower interface (left) U by Moen Smart Faucet (top) Blanco Evol-S Volume (bottom right)

Quooker has several competitors in the field of boiling water taps like InSinkErator, Qettle and Grohe [3]. For this project, water taps with volume control are considered and examined in terms of functionality and usability. U by Moen (Fig. 9) lets the user control the tap via voice command through a smart assistant (eg. Alexa, Google Home), smartphone application, motion sensor on the top and the conventional knob. For volume control, the user has to ask the smart assistant to dispense a certain amount, like for example “Alexa, dispense a cup of hot water.” [2]. Otherwise, presets set within an app can be chosen either via the app or voice command. The Blanco Evol-S Volume is controlled by a rotary knob, providing the user volume options between 100 ml to 5 liters. After choosing the volume, the user has to touch the side-mounted sensor-based control to activate the tap [4].

The Sedal Mozaic tap, was presented in the ISH 2023 in Frankfurt, provides the user with two presets that they can set themselves. The presets are then activated by one pull (preset 1) and double pull (preset two). The tap handle displays the temperature of the water while it’s being dispensed. The handle shown in Figure 9 is part of Sedal’s digital shower system interface, similar to their tap design.

These competitor applications with volume control range from 630€ to 800€, including other tap functions.

2.4 Use Cases

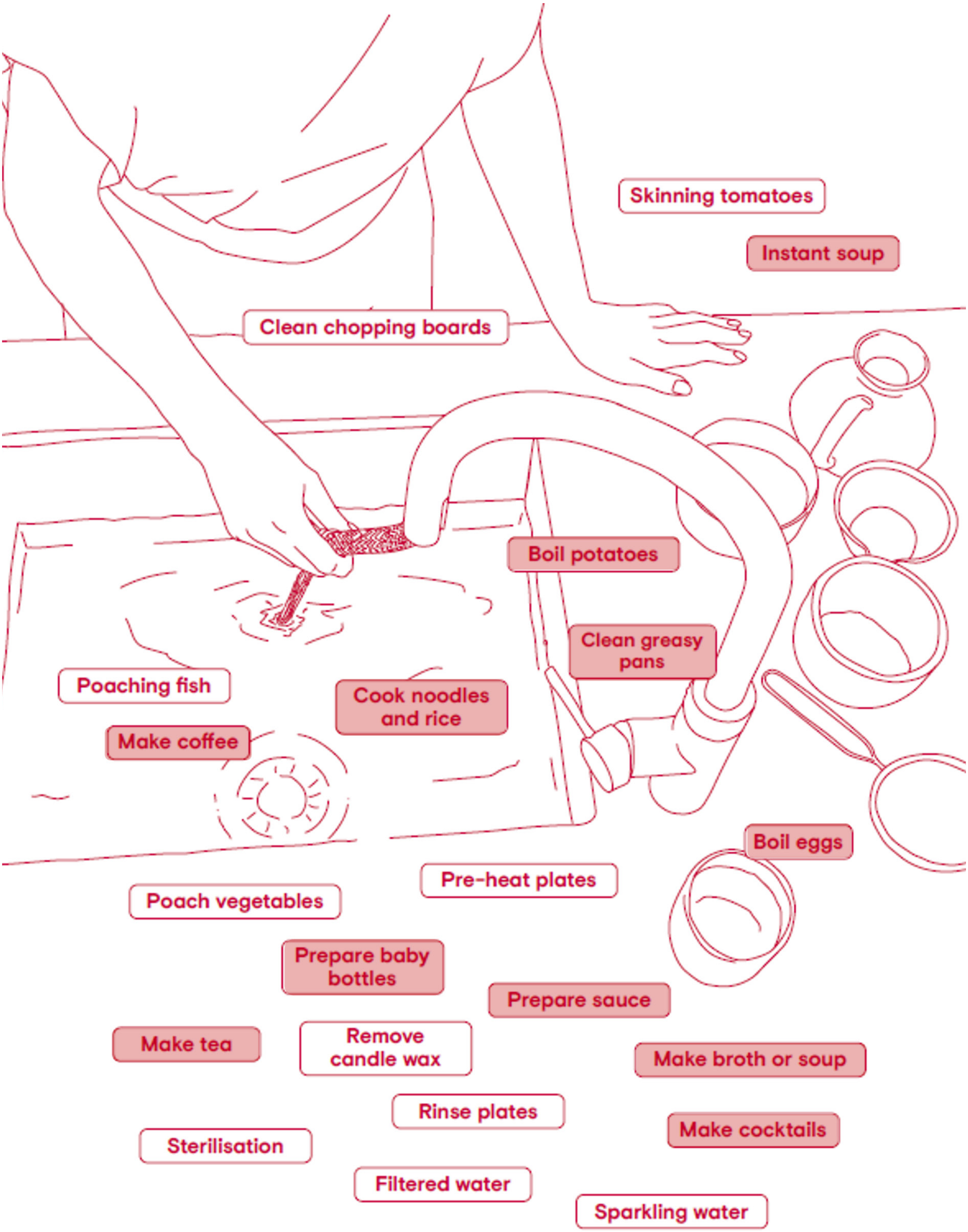


Figure 10. Use Cases, Quooker Dealer Brochure

To gain more insights into the functions needed to be executed by the volume control unit, the Use Cases of the Quooker system were investigated. Figure 10 shows an overview of the uses cases as presented in Quooker's Dealer brochure. The instances when volume control would be needed are highlighted in red.

To investigate user behaviors and activities, a comprehensive analysis was conducted through a combination of interviews and observations. The study participants were interviewed within the confines of their household in the Netherlands, while for participants residing in the United Kingdom and Switzerland, online interviews were conducted. A series of inquiries were posed to the participants during these sessions.

The following list outlines the relevant use cases for this particular application. The use cases presented in black denote the primary activities performed by Quooker users on a daily basis, whereas those presented in gray encompass more sporadic tasks.

Cooking
- Boiling Pasta/Rice (1-5L)
- Broth (250ml-500ml-1L)
- Sauce (250ml-1L)
- Boiling/ Steaming Vegetables (1.5-3L)
- Soup (300ml-2L)
- Boiling Eggs(1L)

Baking
- Dough (100-500ml)

Tea
- Teacup (200-250 ml)
- Teapot (250ml-2L)
- Special tea (70C)

Carafe of water (500ml-1l)
Glass of water (200-300ml)

Parents
- Disinfecting (Bottles, Pacifier)
- Baby formula (225-330ml)

Pet water bowls (200ml-2l)

2.5 User Study

Both qualitative and quantitative user interviews were conducted. The goal of these interviews was to investigate the behavior of the user within the kitchen when tapping water, using pots and measuring volumes.

In the qualitative interviews, the participants were asked to show how they measure water volumes, what containers they use and how they feel about measuring. One of the main takeaways was that the users feel uncertain when measuring the quantity of water.

They either do so with a measuring cup, a scale or any container they find in their vicinity (relative volume). However, they don't have the need to measure exact volumes of water in their daily life, only occasionally when following a recipe.

Figure 11. The user has to bring the measuring cup to eye level to determine the exact quantity

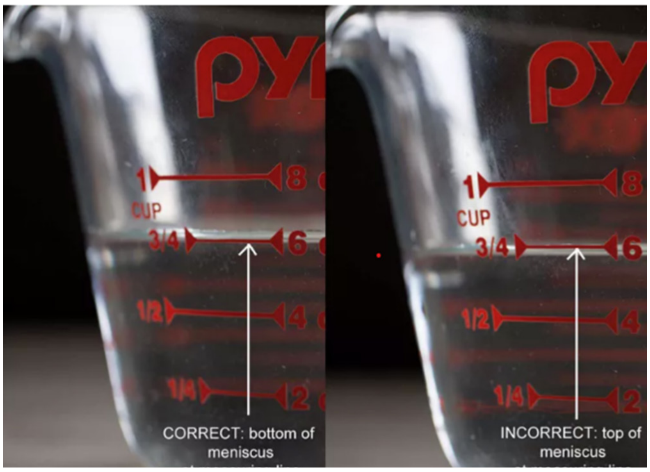


Figure 12. Users don't know the correct indication

When it comes to regular cooking, the water is filled up to a certain level that “feels comfortable” to the user. This specific water level is usually associated with certain pots and pans, as well as time of activity; e.g. cooking broth/pasta/rice, boiling eggs, making tea etc.

Most common pot sizes are 1-3L, while people usually revert to 2-3 pots that they consistently use. Personal daily habits also determine the frequency of measuring water volumes, as well as the quantities.

During the quantitative user study, the participants were asked to fill pots with water and their behavior was observed and documented. Other than the numerical values of these experiments, there were interesting qualitative findings as well. When asked to fill the pots with water, the users associated the water volume with a certain activity. For instance, they said “I would use the big pot for soup or boiling pasta.”. They filled the pots with water, while keeping these specific activities in mind.

Another interesting finding was the pot placement during these experiments. When it came to big water volumes, some participants placed the pot inside the sink, while others next to it. Small pots were usually held under the running water. When asked about the tap placement, some participants pointed out that it’s convenient when the tap can reach the edge of the sink, but this is not always the case. The bottom of the sink is considered dirty and messy by others.

Quooker users also mentioned that sometimes they don’t use Quooker’s boiling water to fill big volumes of water, as the flow rate is too low and it takes longer to fill up the pot. Some even pointed out a way to accelerate it by opening the mixing water lever. This increases the flow rate, but the water isn’t boiling anymore. This method doesn’t accelerate the cooking, since the water needs more time on the stove to reach the boiling point. The conclusion of this is that the users don’t like to wait above the tap while holding big pots in their hands.

The results of the quantitative tests can be found in the section “Accuracy”.

Figure 13. Participants with their cooking pots, demonstrating how they fill them with water

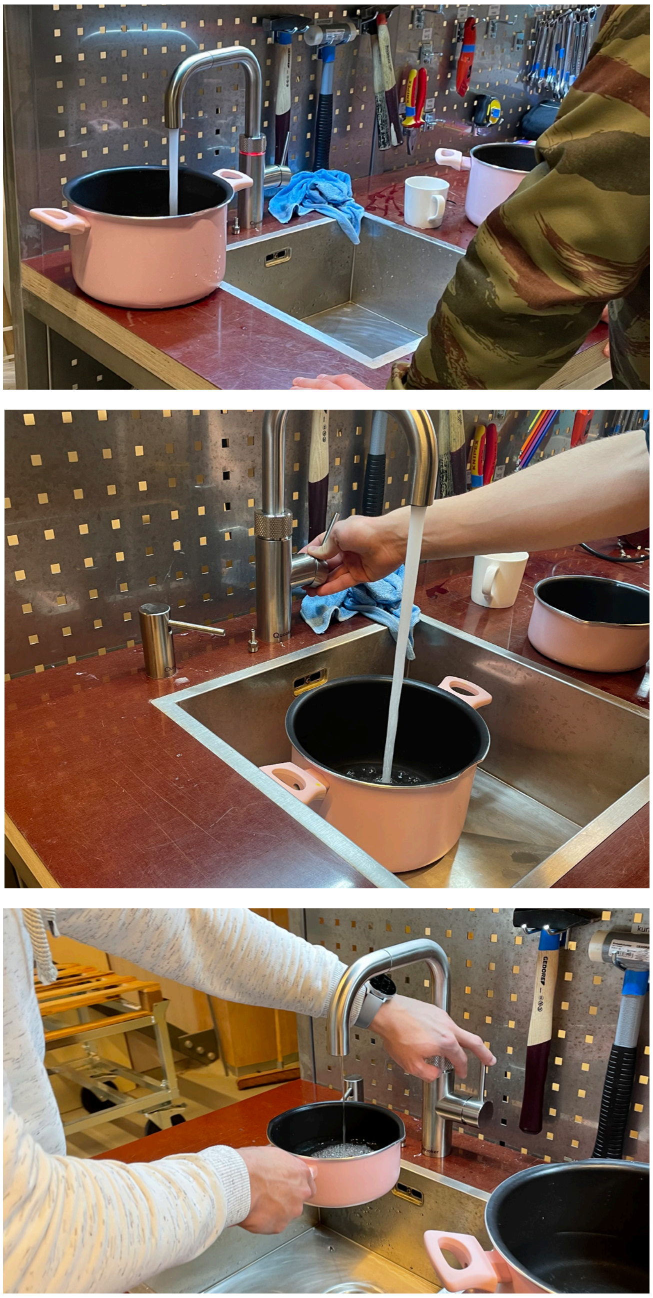


Figure 14. Pot placement while filling water

2.6 Product Applications

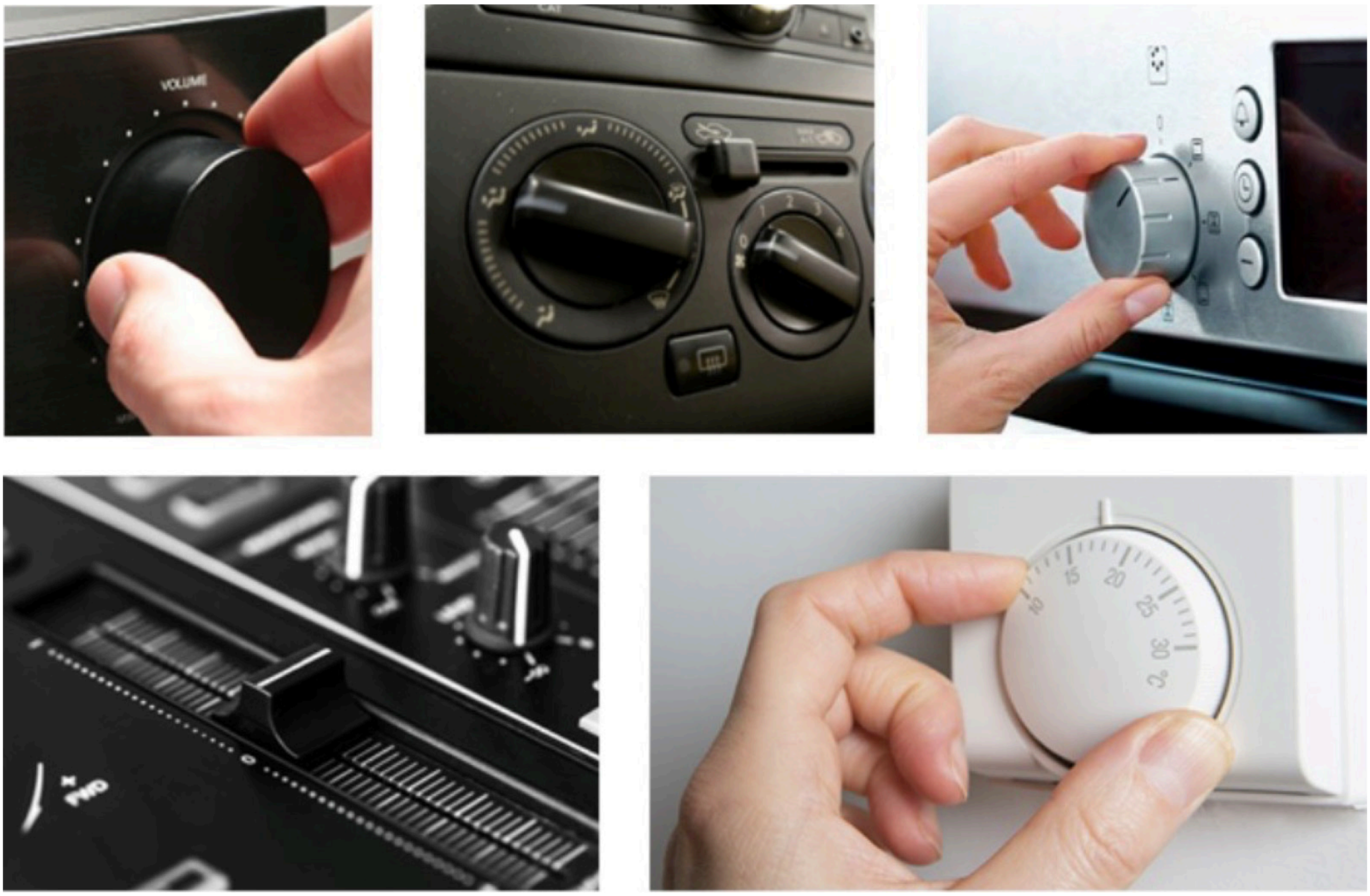


Figure 15. Knobs and sliders for volume control

In order to deepen our understanding of the requisite user interaction functions, an investigation was conducted into the design of various product applications. This approach enabled the collection of valuable information pointing to the necessary design considerations for creating cohesive products that facilitate user-friendly volume selection.

Volume Indication in Products

Various products with different types of volume indications were evaluated. The analysis and exploration of the UI design for selecting specific volumes or a range of volumes were conducted to gain valuable insights for enhancing the usability of the volume unit design. These products are commonly encountered in everyday life and form part of people's daily routines. Some examples of such products include:

- Sound volume in stereos
- Air-conditioning settings in the car
- Time setting in microwaves and kitchen timers
- Temperature setting on the thermostat
- Sound levels as a slider on a DJ booth

These applications usually feature rotary knobs and sliders, with markings or engravings such as numbers, symbols, and weighted lines.
Adopting certain features of these volume indications will ensure that the user recognizes the volume selection use cue and can intuitively operate the system. This follows Nielsen's second heuristic, match between system and the real world [17] and enables the product to speak the user's language and follow real-world conventions.

Communication volumes and system status

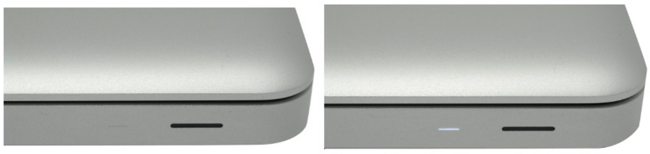
Another one of Nielsen's heuristics states that the system should provide recognition rather than recall. The product should reduce user's cognitive load, not rely on their memory capacity and include information to assist users in navigating the design. In this case, we are interested in the way products communicate volume indications to the user, without becoming overbearing or overcomplicated.

Such means of communication entail screens as seen on the “Morning” Coffee Machine, matrix displays like the one integrated in older models of the VanMoof Bike, as well as light indications. These light indications include single lights and light rings, communicating through light intensity, patterns and colours.

This is a feature applied in the Quooker taps, with the indication light in the knob glowing and flashing in blue and red to indicate the system status (e.g. tapping) or errors within certain components.

“Morning” Coffee Machine

MacBook Invisible Light-transmissive Display

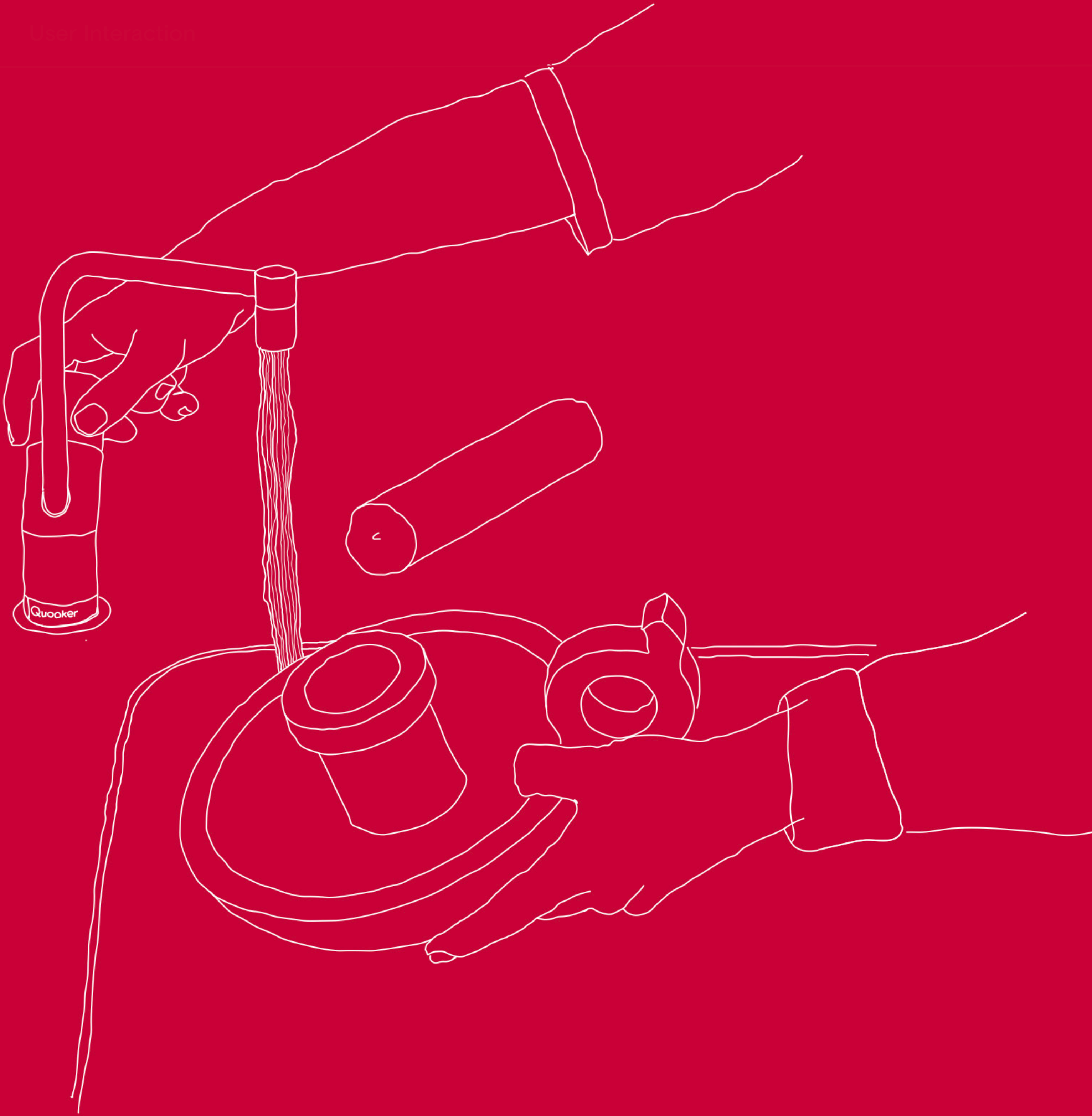


“VanMoof” Matrix Display & Halo rings

“Miniot” Wheel

“Joseph Joseph” Pie Kitchen Timer

Figure 16. Volume indications on consumer products



USER INTERAC-TION

3

Define
user interaction

The Define stage of the user interaction unit draws conclusions from the research (Discover) and identifies the core challenges and opportunities that the product should address. Some questions that arise include:

• How can the Quooker mechanical functions be retained while also incorporating electronic aspects?
• What is the available space above and below the counter that can be used by the system?
• What is the Unique Selling Point of this design that adds value for the company and the customer, making it unique and appealing?

This section is completed with a Product Life Cycle Analysis to identify the activities and situations the design will turn up in and generate a list of requirements for all these cases.

3.1 Mechanical to Electronic

Since the project is part of E-Mixing as explained in the Chapter "Assignment", it already aims to incorporate electronic features for a better sense of control and better performance. This mainly refers to the product's functionality. To explore how this direction could be applied in the usability of the volume unit, products were inspected, whose inherent functionality is mechanical, but has turned electronic as the product has evolved with time. These products are shown in Table 1. These products combine mechanical features with electronic components.

In the example of the kitchen timer, the twisting motion has remained the same, while the display has turned digital. Same goes for the thermometer and the kitchen scale. A common trend among all these products is the consistency of the use cues and haptic feedback. The electronic handbrake still incorporates the pulling motion of its predecessor. In addition to this, the keyboard and camera offer haptic and auditory feedback, in the form of clicking and button resistance, that indicate the activity status.

When it comes to Quooker and the volume unit design, some of these features can be adopted in order to combine mechanical and electronic components in a way that makes sense to the user, and still fits within the Quooker line and ecosystem. This could include features such as the push and twist motions, dials for volume control and aesthetic features such as the knurled knob and chamfers.

This way, the Quooker functions maintain consistency throughout the entirety of the system to prevent confusion and complex usage. The design should exploit natural relationships that couple function and control as seen in everyday products as well as the Quooker system, and make intelligent use of constraints [22].

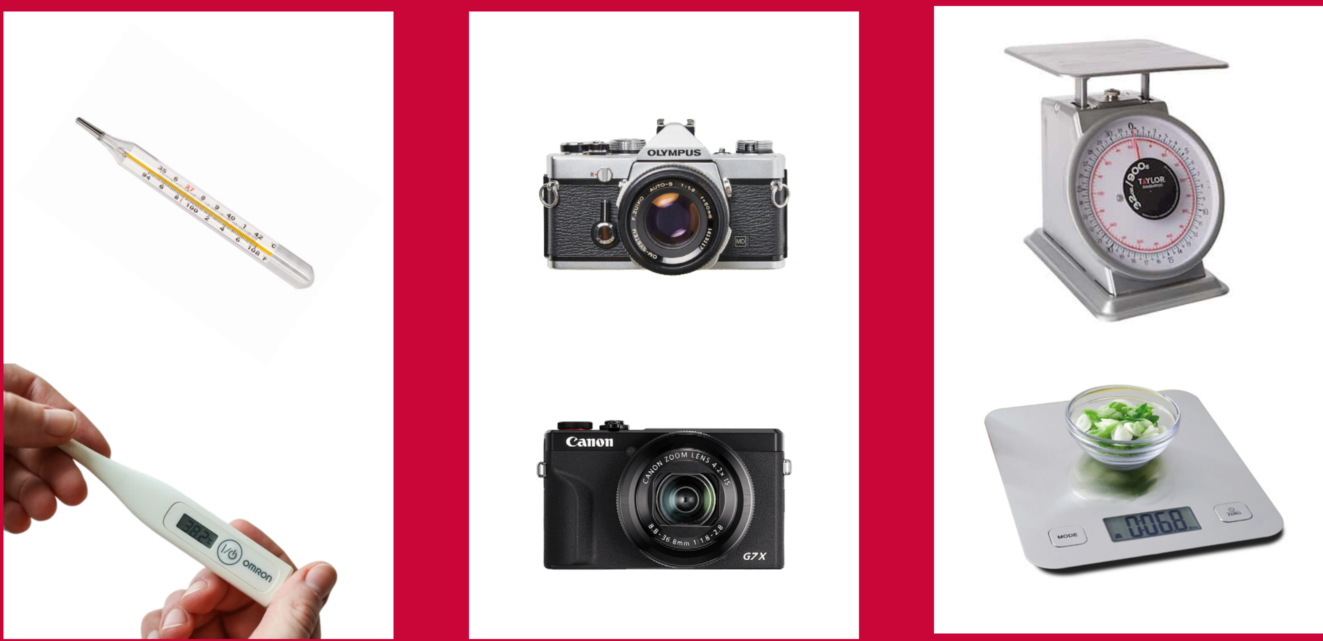


Table 1. Examples Electronic Iterations of Mechanical Designs , retaining interaction qualities

3.2 Added Value

Unique Selling Point

One of the main advantages of the volume control unit, as an addition to an existing system, is that it allows previous customers to come back and purchase it. This unique selling point is valuable because it helps to retain customers and take advantage of an established customer base.

By offering a way for past customers to return and get the new product as an upgrade to their current system, this feature promotes customer loyalty, builds trust, and strengthens long-term relationships. It gives the product a competitive edge, boosts profitability, and supports business growth by tapping into the existing customer base and long-term success in the market.

New opportunities

The envisioned product embodies a range of novel features that hold the potential to attract new customers. It offers users with a heightened sense of freedom by being able to control the tap. By introducing streamlined functionalities and simplified processes, the product endeavors to optimize daily activities, ultimately resulting in time-saving benefits.

Moreover, the integration of electronic components in this design not only enhances its capabilities but also opens up a realm of future possibilities for further advancements and implementation opportunities. This forward-looking approach paves the way for expanded horizons in terms of design versatility and technological innovation.

Through these distinct attributes, the product not only aims to entice new customers but also envisions a future marked by continuous refinement and progressive enhancements.

3.3 Space Claim

Figure 17. Available space below the sink

Figure 18. Kitchen cabinet usage, Quooker technician during maintenance

In the beginning of the project, one day was spent with service, driving from house to house to repair and maintain Quooker systems around the Netherlands. One important observation from this day was the realization that the counter space below and around the sink is extremely limited. In addition to this, during the user interviews the participants mentioned that they use the cabinet space below the sink for various purposes, usually to store cleaning supplies, trash cans and accessories, as well as other kitchen equipment.

In order to estimate the available space, all Quooker system components were placed in the cabinet, alongside carton boxes to represent storage elements such as cleaning supplies, trash cans etc., as shown in Fig. 17.

During the process of repairing or replacing components, the Quooker technician encountered difficulties in accessing specific areas of the sink, as illustrated in Figure 18. This aspect should also be considered in the design, particularly regarding the installation of the unit.

Fig 19. shows the possible placements of the below-counter volume unit and the available space in each area.

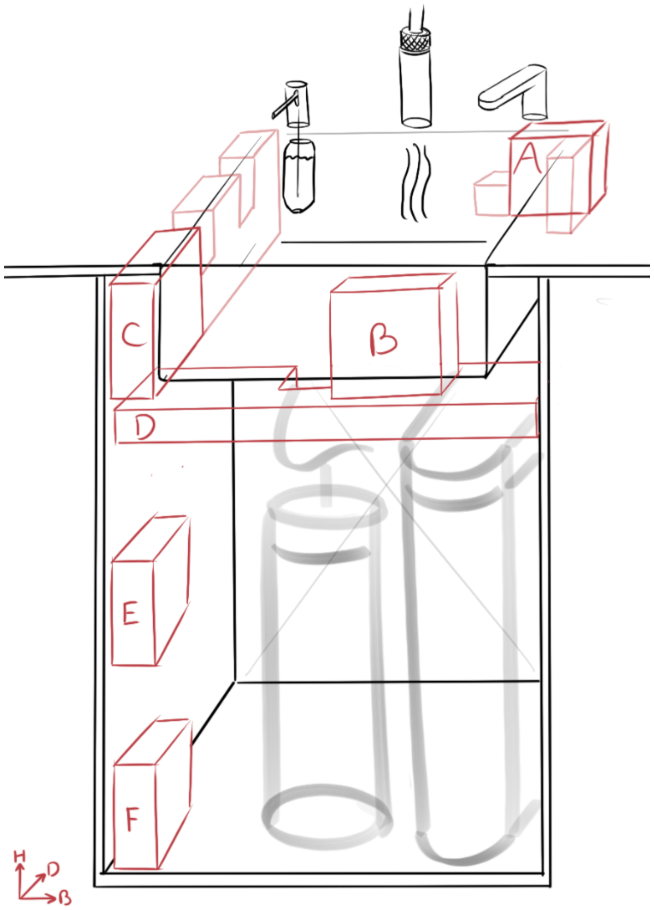


Figure 19. Illustration of possible unit placements and available space

A. Rear sink
170 x 90 x 130 (B x D x H)
+ Close to the above-counter unit
- Limited depth
- Difficult to reach

B. Front sink
600 x 50 x 130 (B x D x H)
+ Easily accessible

C. Side sink
(only at 40x40 tray!)
50 x 70 x 130 (B x D x H)
- Limited width and depth
- Load of doorstop, hinges, sink mount

D. Bottom sink
600 x ~150 x 90 (B x D x H)
+Freedom in width
- Limited height
- Tied to one size cabinet

E. Side wall cabinet
200 x 270 x 250? (B x D x H)
+ Flexible placement
+ Lots of space
- Wall panel can resonate

F. Bottom cabinet
200 x 270 x 450 (B x D x H)
+ Flexible placement
+ Lots of space
- Far from the above-counter unit
- Space useful for other things (combi, cube, trash

In conclusion, there's usually space above the Quooker and Cube, however it could be limited if they are directly under the sink. Setup flexibility with extra tubes could prevent this issue.

In addition to this, there is available space between sink and wall (back of the cabinet), similarly to the placement of the soap dispenser. This are however would be difficult to reach during installation and maintenance.

3.4 List of Requirements

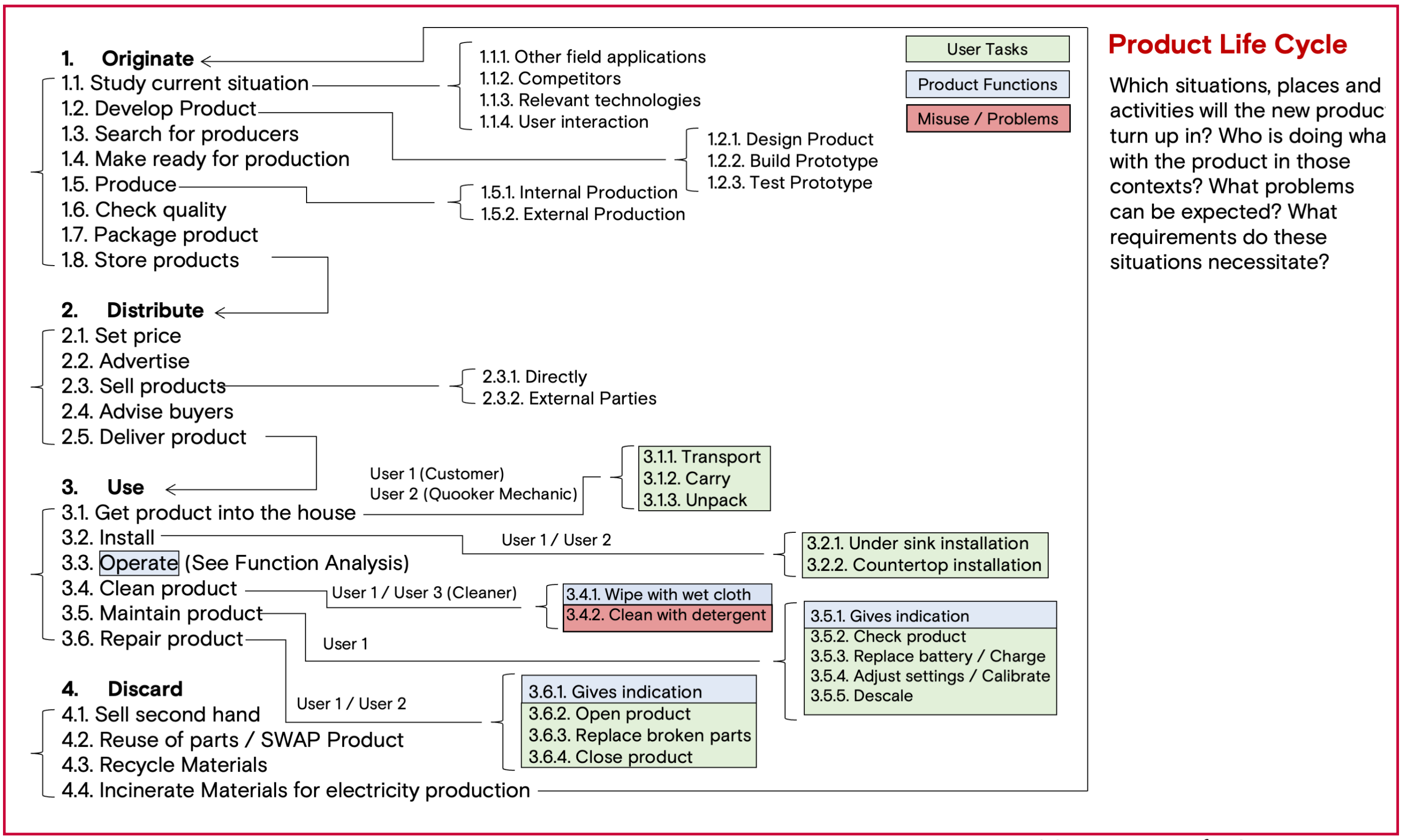


Figure 20. Product Life Cycle Analysis

The list of requirements has been a living document throughout the entirety of the project. Through the interviews, tests and desktop research, criteria would show up that were deemed as important for the final result. In order to create a structure to reach completeness, tools such as the Product Life Cycle (PLC) and Product Function Analysis (PFA) were used.

The PLC offers a guideline of the activities and steps the product will follow during its lifetime. This ensures that all relevant situations are taken into account and all different types of users are considered during the design of the product.

Due to the limited time, the focus of the project is set on the third stage of the product's life cycle, namely the Use. As the name suggests, the user interaction unit handles signifiers and affordances, as presented by D. Norman, to enable correct handling and intuitive usage. Other secondary functions include installation, cleaning and maintenance.

The following list of requirements serves as a summary of the aforementioned points and a guideline to the design of the volume control unit.

The product should:

Usability

- Relieve the user from **mindful volume measurement** (e.g. measuring cups, "eye-balling", weighing scale etc.)
- Be **intuitive** to use and require minimal explanation to users, no more complex interaction than current Quooker products.

Aesthetics

- Fit the Quooker house style.

Size

- Fit easily:
  - Below the counter (ca. 200 x 270 x 250mm (BxDxH))
  - Next to the tap on the countertop (ca. Ø35-60mm, H80mm)

Cost Price

- 200-300 € (consumer price)

The functionality aspects of the list can be found in Section 6.5.

3.5 UI Scope

Figure 21. Interactive Unit Applications

To conclude this section and define the scope for the user interaction unit, the possible applications of volume selection are examined. Inspired by the research conducted including volume selection products (Section 2.6), competitor applications (Section 2.3), as well as Quooker's ecosystem and vision, five alternatives arise:

- **Integrated into Quooker's knob/ extra knob**
  As presented earlier, the knurled knob on the tap is where all special feature water interactions take place. Quooker users are accustomed to the push and twist functionalities for selecting and tapping boiling, chilled and sparkling water through the knob. Volume selection could be integrated within the existing knob, or within an additional one devoted to the new function. This method fits Quooker's current interactions and house style, however it could increase interaction complexity and mental effort.
- **Side feature**
  Similar to Quooker's soap dispenser, an external side feature could be implemented next to the tap, dedicated to volume selection. This is an easy way to implement a new functionality without complicating the current interaction. However, this side feature contradicts Quooker's vision of including everything within one system.
- **Aerator**
  Another interesting application is at the end of the tap, integrated in the aerator. This is a way to incorporate volume selection within the tap, in an unobtrusive way by replacing an existing feature with an upgraded version of it. In addition to this, the aerator is an accessible interaction location on the tap, limited however in terms of space and backwards compatibility for all tap models.
- **Voice control**
  Voice controlled volume selection offers a hands-free alternative, without any additional features within the system, while the user can choose from a wide range of volumes. An external device like a smart assistant is needed to operate the system, which is outside of Quooker's scope.
- **App control**
  Likewise, a smartphone app can be implemented to control volumes. Similar pros and cons as the voice control arise within this application, while an external device needs to be used, consequently reducing ease of use and safety.

USER INTERAC- TION

4

Develop
user interaction

Following the list of requirements and preliminary choices made in the previous section, ideation is kicked off. Methods such as sketching, mind-mapping, brainstorming and morphological charts provide interesting directions for further exploration.

Ideation is concluded with concept generation, concept screening and selection by consulting Quooker engineers, users and employing quantitative methods like weighted criteria tables and decisions matrices.

The final concept is developed through experimental prototyping [25] to offer a proof of concept through usability testing. The insights are collected and formed into conclusions & iterations.

4.1 Ideation

Initial ideas were conceived throughout research based on the findings. These ideas were further explored and developed during the Ideation phase. In addition to this, new directions were explored using various methods, such as brainstorming in groups, morphological charts, sketching, as well as analogies from other fields with similar functionalities.

Mind map

Throughout Ideation, the ideas were visualized in a mind map (Fig. 22). This made it easier to see the big picture and understand how different elements fit together when brainstorming in groups. The non-linear format encouraged free association and creative exploration by sparking new insights through the map's interconnections. Lastly, the structure provided by the map broke down the complexity of the project and offered categories and prioritization to be explored further and turned into concepts later.

Morphological Chart

Both the functionality and the usability were deconstructed into sub-functions and placed into separate morphological charts. For usability these included; volume indication, type of user interaction, unit mounting, current state indication, and activation. Possible principal solutions were explored for each sub-function. The combination of the sub-functions provided design directions for ideation, which were later sketched, developed and tested. (Fig. 23)

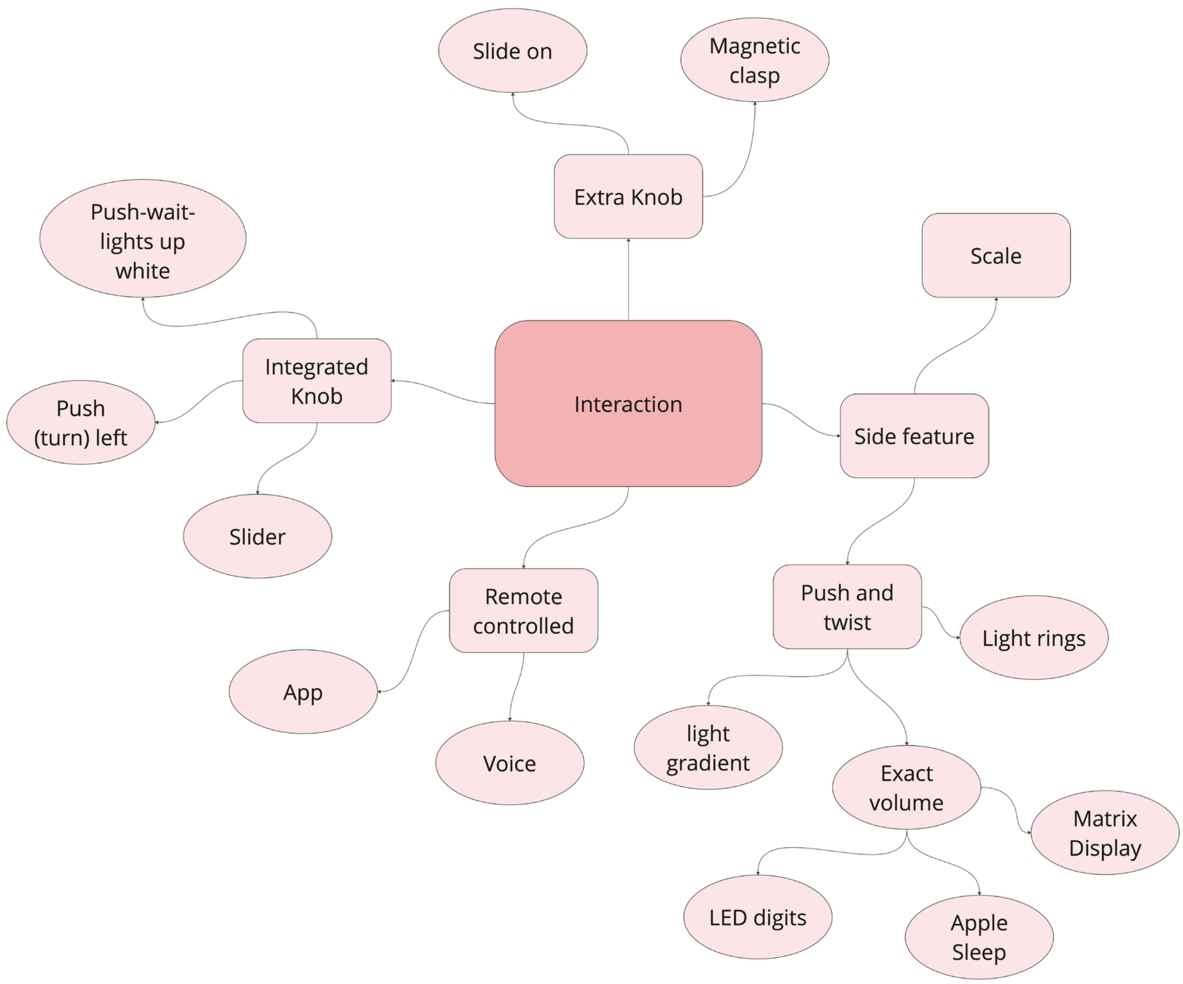
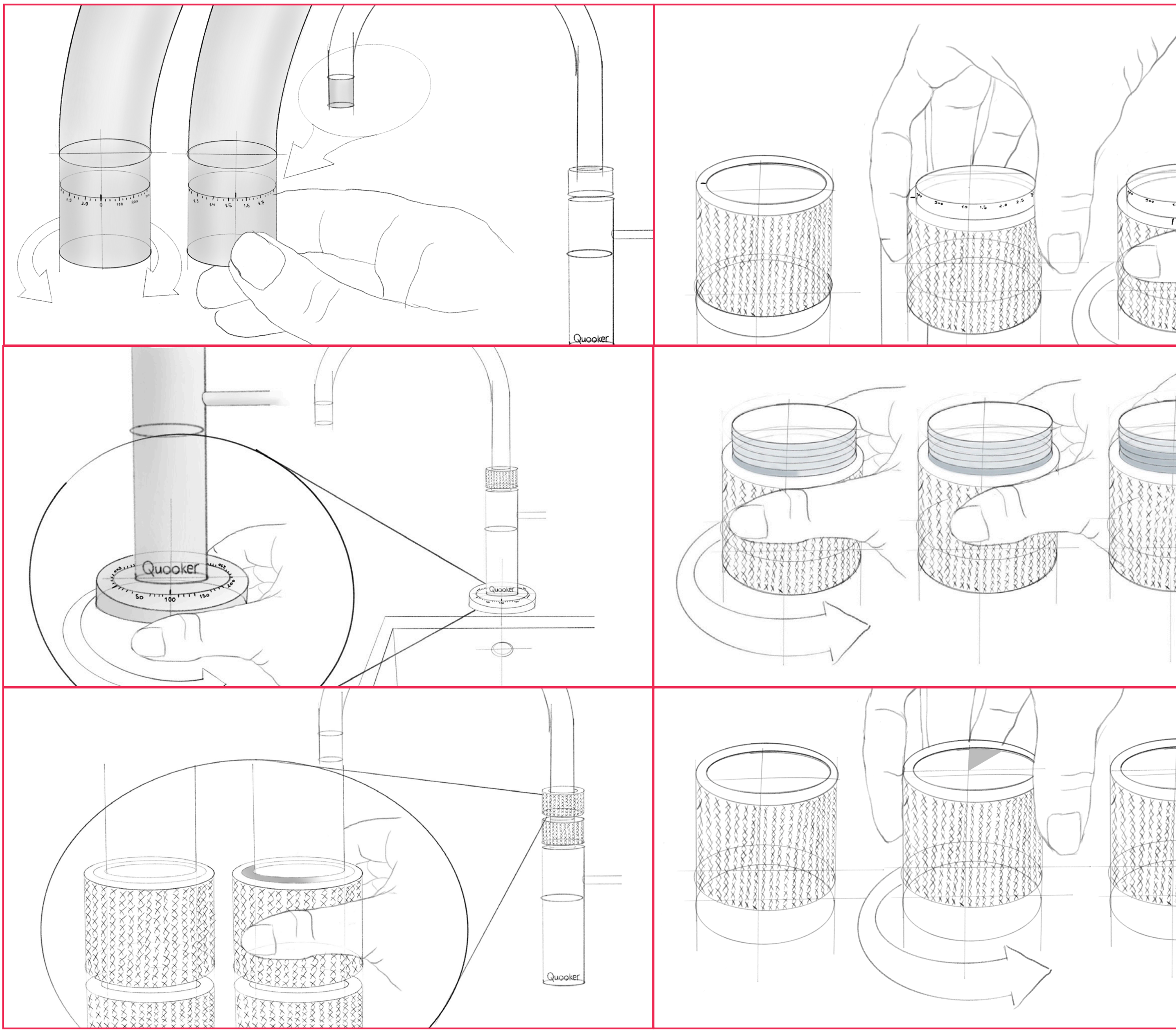
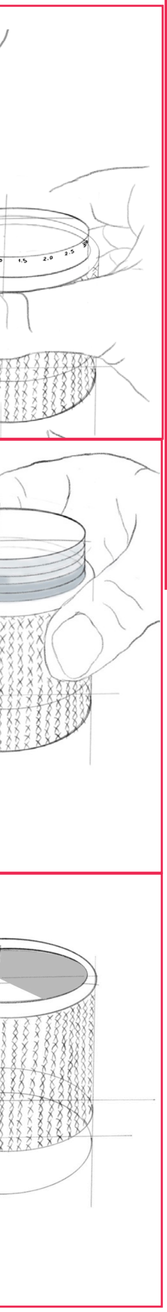


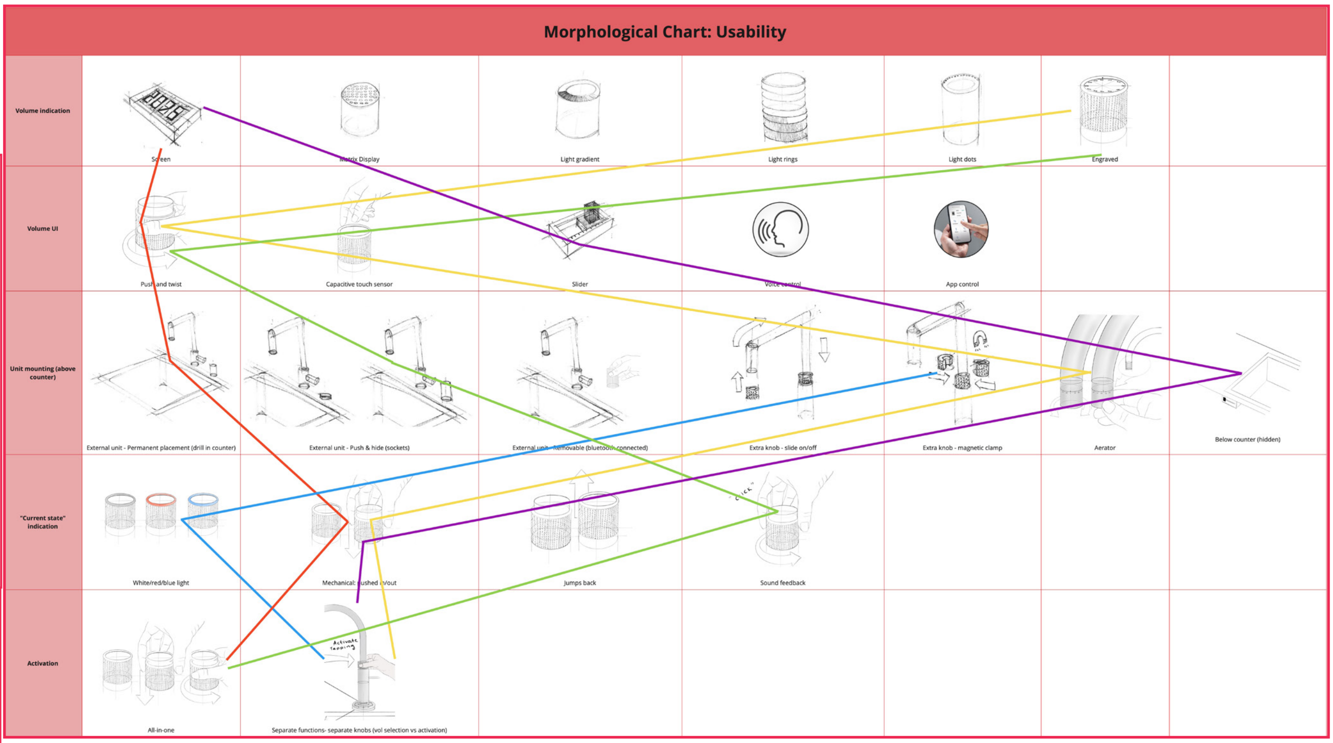
Figure 22. User Interaction Mind Map

Morphological Chart: Usability							
Volume indication	Screen	Matrix Display	Light gradient	Light rings	Light dots	Engraved	
Volume UI	Push and twist	Capacitive touch sensor	Slider	Voice control	App control		
Unit mounting (above counter)	External unit - Permanent placement (drill in counter)	External unit - Push & hide (sockets)	External unit - Removable (bluetooth connected)	Extra knob - slide on/off	clamp	Aerator	Below counter (hidden)
"Current state" indication	White/red/blue light	Mechanical: pushed in/out	Jumps back	Sound feedback			
Activation	All-in-one	Separate functions- separate knobs (vol selection vs activation)					

Table 2. Morphological chart of UI functions and sub-functions


Quooker
Quooker
50
100
150
Quooker





- Ideas were sketched, discussed and iterated in focus groups with Quooker engineers and with users one-on one. The concepts stemming from this ideation are presented in the next section.
- The ideation sketches are presented in Appendix I.
- The morphological chart helped generate possible combinations of different components within the design problem as a form of efficient problem solving as shown in Table 2.
- These combinations are shown in the sketches.

4.2 Concept Generation

Rosette

The rosette concept integrates the user interaction unit in the tap by replacing the rosette, the ring around the base of the tap, with a volume engraved ring. It consists of an inner and an outer ring. The user twists the outer ring to select the desired volume.
This concept provides a clear and intuitive way of selecting a volume with a dial similar to the kitchen timer. It offers an added feature on the existing tap in a backwards compatible manner, while the user can choose a volume from the increments on the ring.

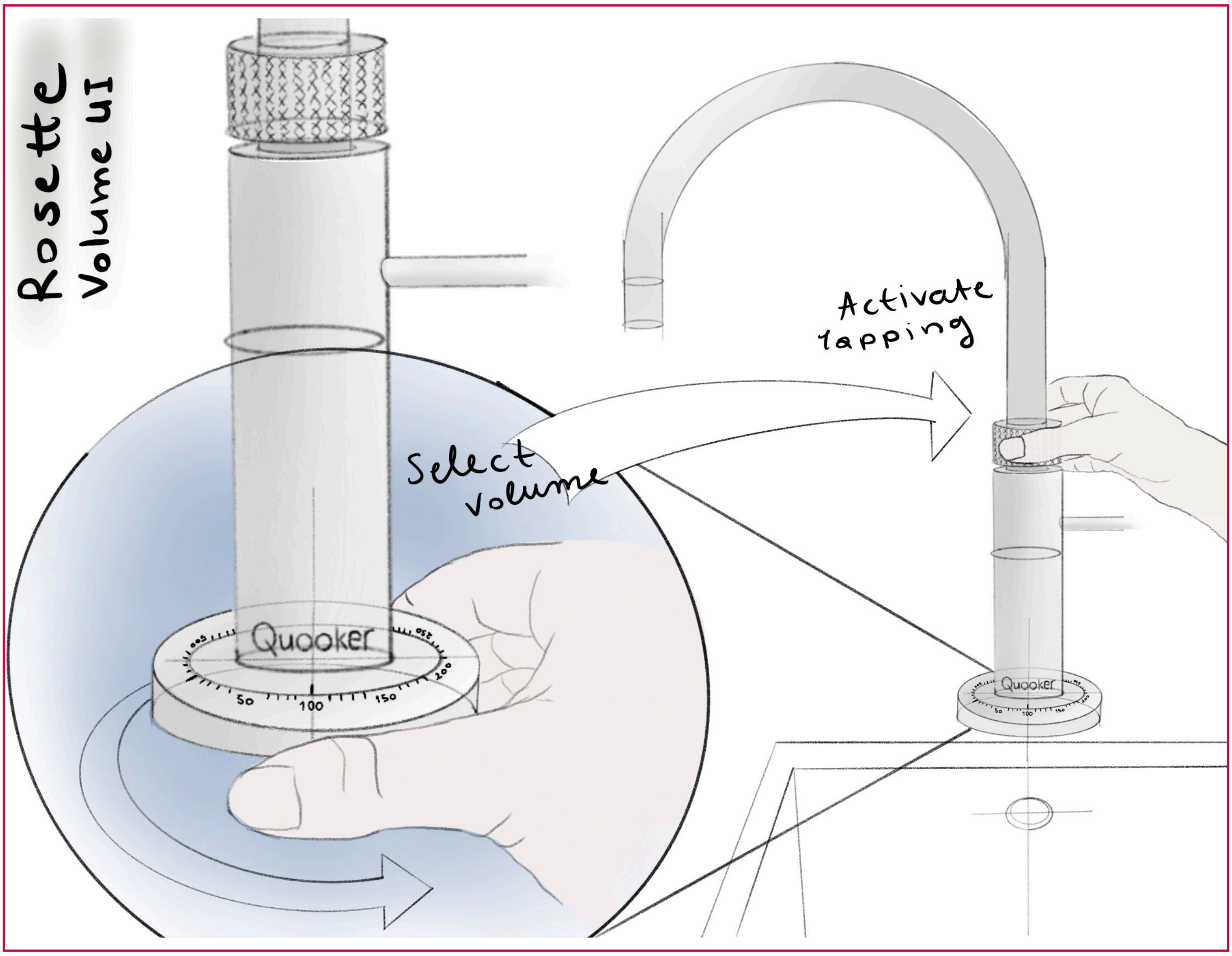


Figure 23. Rosette Concept

Scale Pad

The scale pad is a fully automated concept for volume selection including presets calibrated based on the cooking pots and pans.
The user places the pot on the pad and it detects which one it is based on its weight. Then the user twists the head of the tap and runs the special feature water with the knurled knob. The scale pad detects the amount of water dispensed and stops the tap the desired volume is reached.

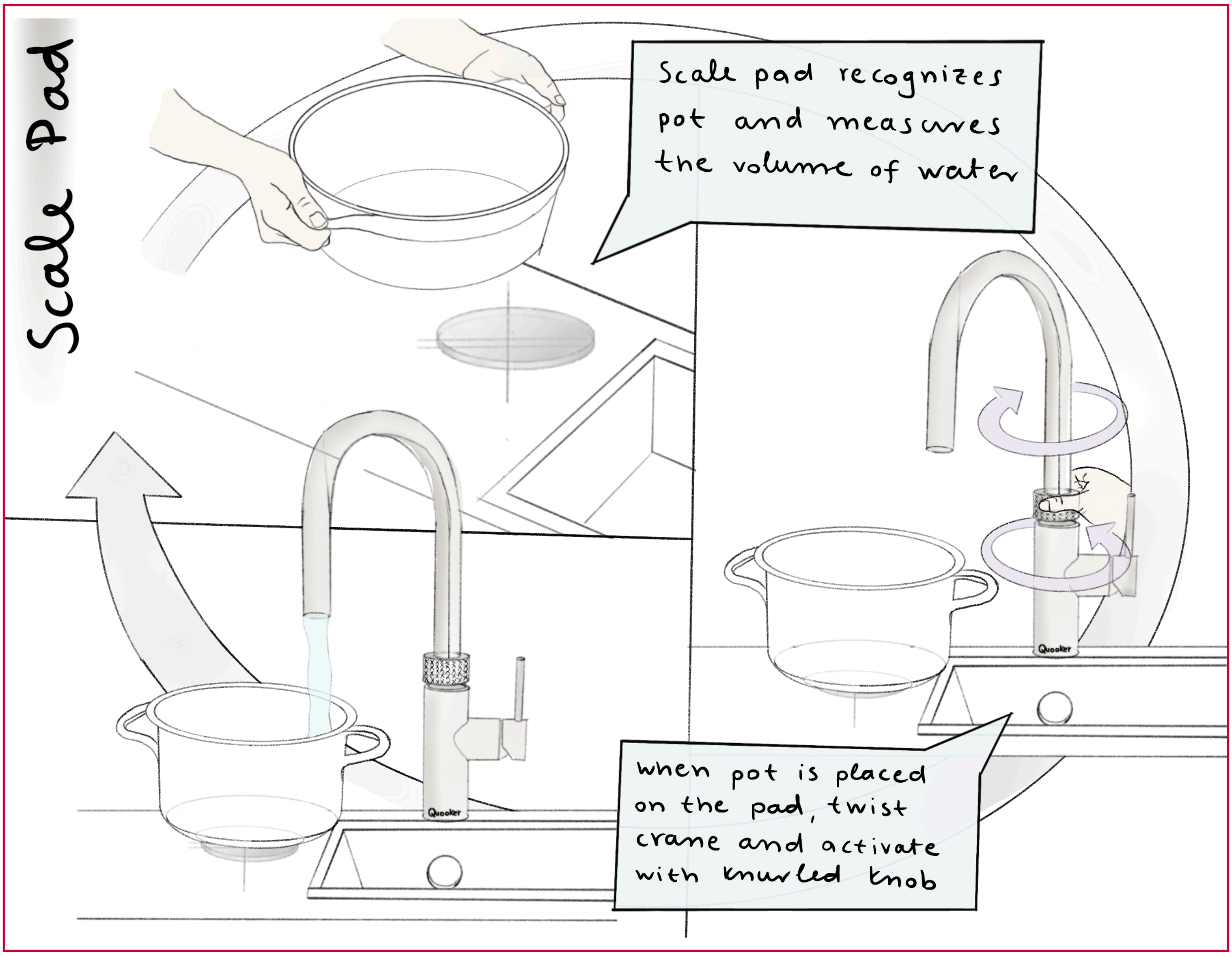


Figure 24. Scale Pad Concept

Below Counter Unit

The Below-Counter is a Unit inspired by the standing desk usability. It features a control handle with an LCD screen to display the selected amount of water. The user pulls up the handle to increase the volume and pushes down to decrease.
This concept incorporates the intuitive use cue of up = increase, down = decrease, while it offers a solution off the counter and out of the way.

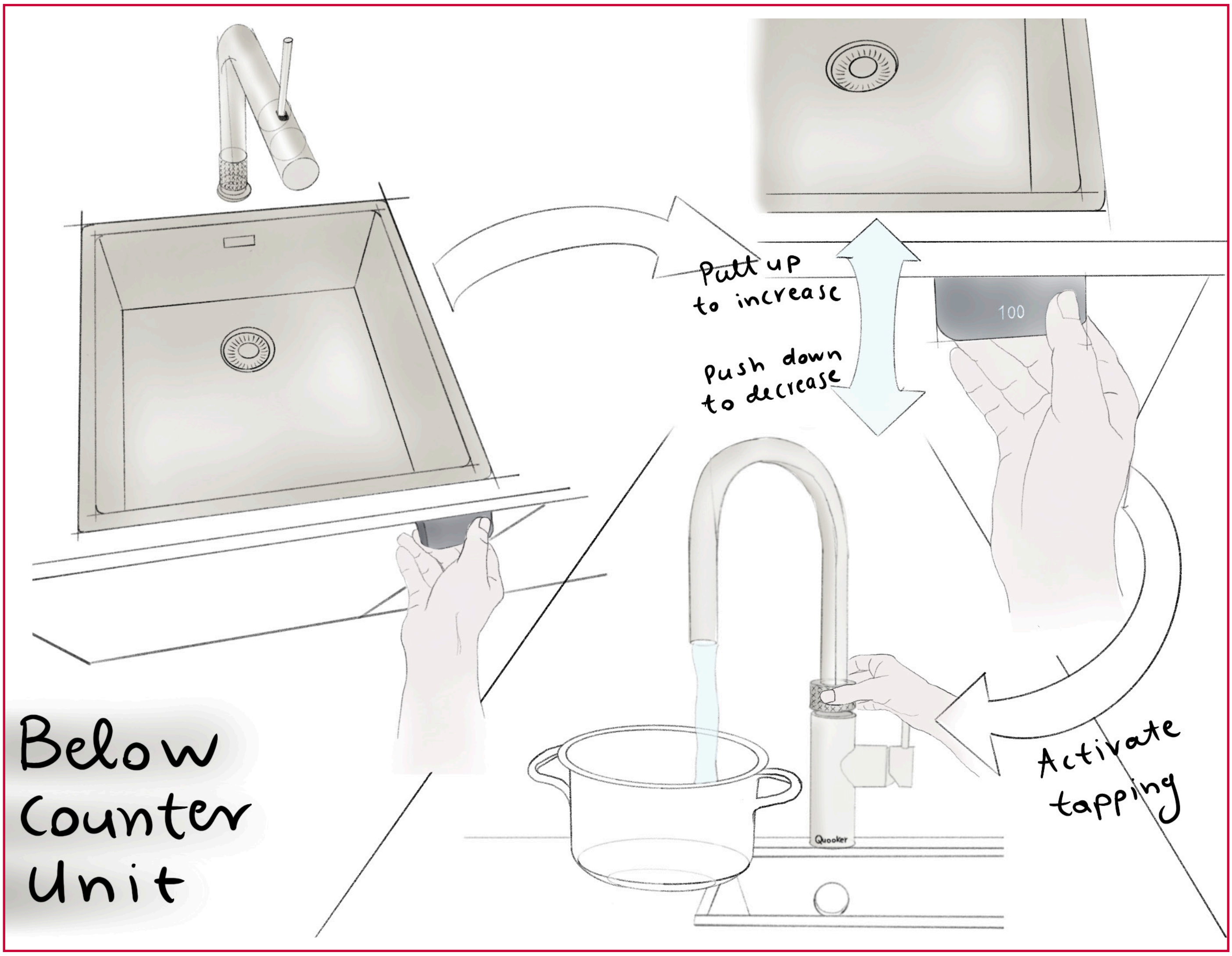


Figure 25. Below Counter Unit Concept

Pie Light

The pie light is the concept that combines presets and specific volumes in the form of an external knob next to the tap. The user twists the knurled knob clockwise to increase the volume. This volume is displayed as segments of a "pie", with the full pie representing 3L. This choice was made based on the smallest Quooker reservoir, as well as the use cases mentioned earlier (Section 2.4 Use Cases). The presets can be chosen by pushing the knob, once for preset one and twice for preset two. The preset volume can still be adjusted by twisting the knob before activating the tap. This links back to the User Research insight that users adapt the water volume based on the type of meal and amount of people eating.

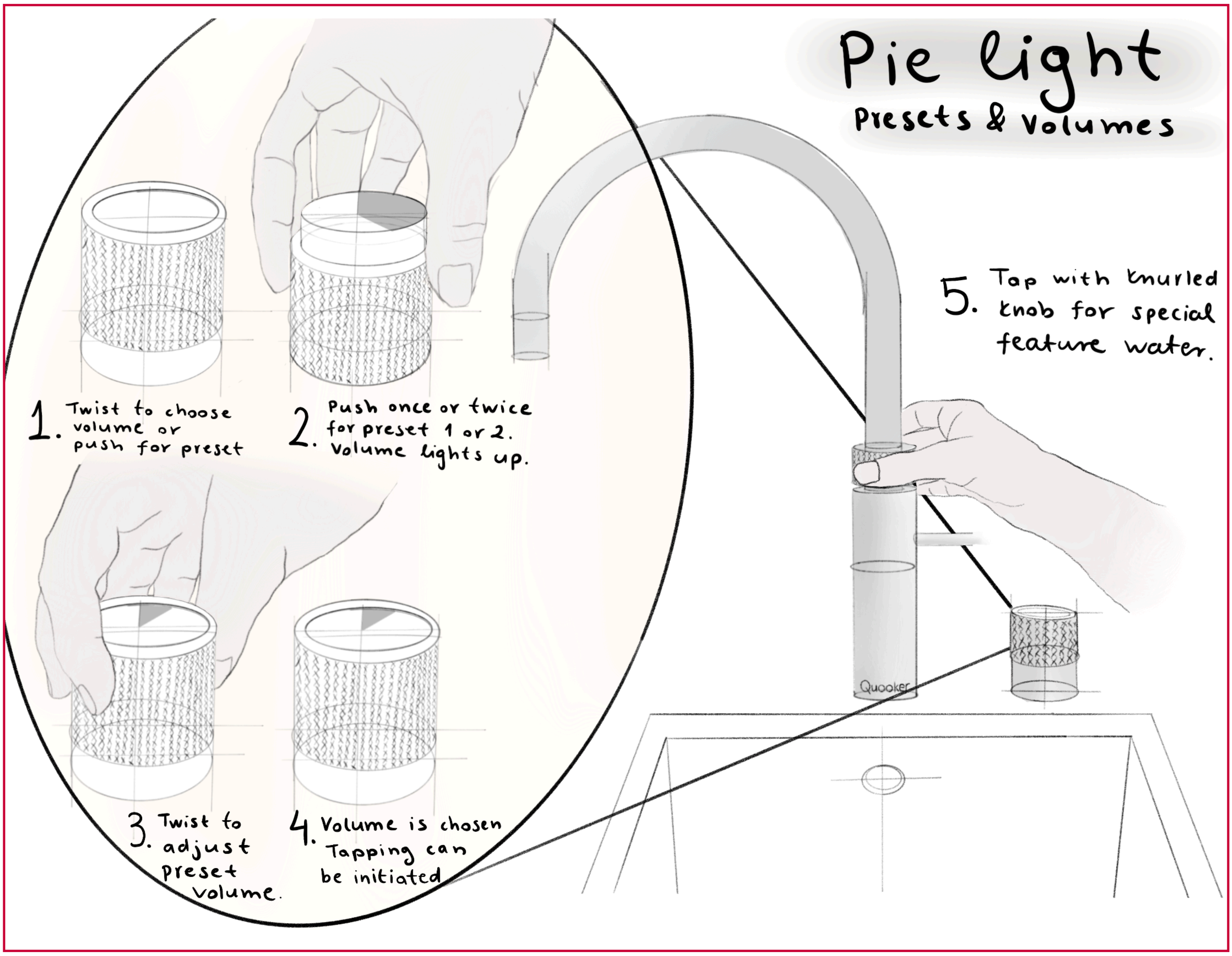


Figure 26. Pie light concept

4.3 Concept Selection

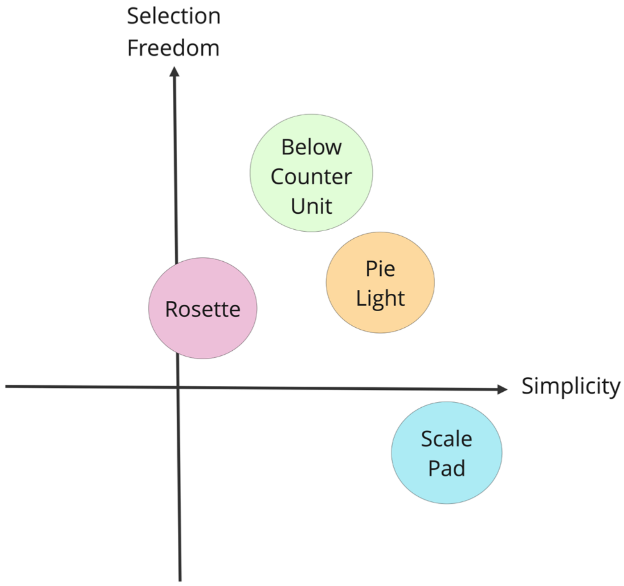
	Rosette	Scale Pad	Below Counter	Pie Light
Disadvantages	Obstructed visibility of volumes	Limited space around tap & sink	Far away from action - mental connection to tap	Limited space around tap
	Dirt/water around tap	Sink size - tap might not reach the pot	Cabinet obstruction/ compatibility	Extra hole
	Far to reach - less ergonomic	Hot pan - temperature limitation	Accidental usage	Learning curve tweaking volumes
	Space limitations	Precise positioning under tap	Mental effort determining volume	Mental effort remembering presets
	Difficult installation	Can't use tall containers		
	Mental effort determining volume	Food in pot affects measurement		
		Extra hole		
		Accidental activation		
Advantages	No extra hole	Simple technology	Freedom in volume selection	Simple usability
	Intuitive usage	Cheap	No extra counter clutter	More freedom (future opportunities)
	Simple design - fits Quooker taps	Convenient	Placement flexibility	Calm design
	Clear/ retro design - connection to kitchen timer	Precise	Ergonomic control	Combination of presets and specific volumes
	Freedom in volume selection	No extra steps - clean interaction		
Possibilities	No progress visible	Twist pad to set volume instead of automatic detection	changing volume while tapping	Progress visibility
Interesting	Integration in tap component	Automated functionality	Hidden - no extra counter clutter	Combination of presets and specific volumes

Table 3. vALUe, IR, and PMI

The concepts were critically discussed in focus groups and one-on-one discussions with users. First, the sketches were given to users, including university students, roommates and other people familiar with Quooker taps, and the concepts were explained. An open discussion was led by the designer, where the positive and negative aspects of each concept were proposed by the interview participant.
The concepts were also discussed in detail with Quooker engineers. The participants were asked to place post-it stickers on each concept sketch with the advantages and disadvantages of each idea (Figure 27). Then, all collected input was discussed in the group.

These techniques offered a new perspective of the concepts from both the point of view of users and engineers. The insights were analyzed based on the method of vALUe, IR, and PMI as presented in the Delft Design Guide [20] to eliminate and screen design ideas in a systematic way. The collected advantages, disadvantages, possibilities (for iteration) and interesting qualities are presented in Table 3.

Figure 27. Quooker Engineers Focus Group



Graph 1. Selection Matrix for the final four concepts

A selection matrix was also used to visually compare the four concepts in terms of “selection freedom and “simplicity” (Graph 1). These two criteria were perceived as most important by users and as they are frequently mutually exclusive, the chosen solution needs to offer as best of a trade-off as possible. Based on the matrix, the Pie Light would be the best candidate.

In addition to this, the concepts were evaluated with the weighted objectives methods based on the overall value of each design concept [20]. The criteria were chosen from the list of requirements in combination with Nielsen’s Heuristics as mentioned in Section 2.6. Weights were assigned according to each criterion’s importance for the evaluation. The weighted selection and results can be see in Table 4. The best concept was deemed to be the Pie light with a score of 235 with the Rosette as a close second at 231 points.

Table 4. Weighted Criteria Table for final concept selection

		Rosette		Scale Pad		Bellow Counter		Pie Light	
Criteria	Weight	Score	Total	Score	Total	Score	Total	Score	Total
Intuitive - Match between system & real world	8	9	72	7	56	5	40	8	64
Quooker house style - Consistency	6	7	42	6	36	5	30	8	48
Space availability/ constraints	5	8	40	4	20	9	45	7	35
Flexibility - User control & Freedom	4	7	28	3	12	8	32	9	36
Recognition rather than recall	4	7	28	8	32	7	28	7	28
Error prevention	3	7	21	4	12	6	18	8	24
			231		168		193		235

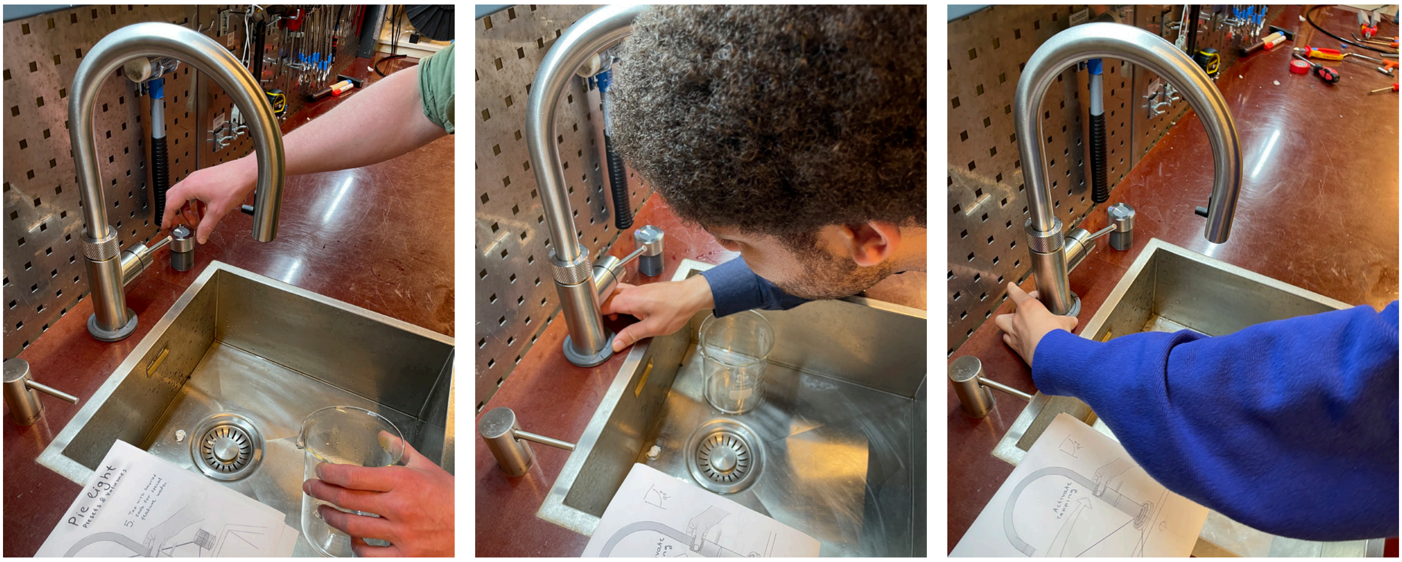


Figure 28. Rosette and Pie Light User Testing with preliminary prototypes

To confirm the final concept, further user testing was conducted with preliminary 3D-printed prototypes next to the Quooker tap. Based on previous feedback, the Pie Light was iterated to include exact volume numbers when needed. The participants were given the sketches and were asked to interact with the prototypes in the vicinity of the tap (Fig. 28).

The user test results and feedback are presented in Fig. 30 with green for the positive and pink for the negative reactions. Other reactions and recommendations for improvements are shown in yellow and white. Since the Pie Light received most positive reactions and showed biggest potential for further improvements, it was deemed as the final concept.

4.4 Final Concept Development

After the final concept selection, the Pie Light prototype was iterated to include feedback and an interface for user interaction and usability testing (Fig. 29).

A round LCD screen was incorporated and coded to display the pie increase with a corresponding volume indication. For the user interaction, a rotary encoder with an integrated push button was used. The rotary encoder had to be placed off-center so that the screen can rigidly connect to the bottom part of the knob. This created a problem for the push button since it was being pushed asymmetrically and thus resulting in a skew motion of the outer ring, also known as “Schubladeneffekt” in German. To fix this issue, the contact area between the outer ring overhang and the gear on the pushbutton was increased and a spring was added to act as a symmetric counterforce.

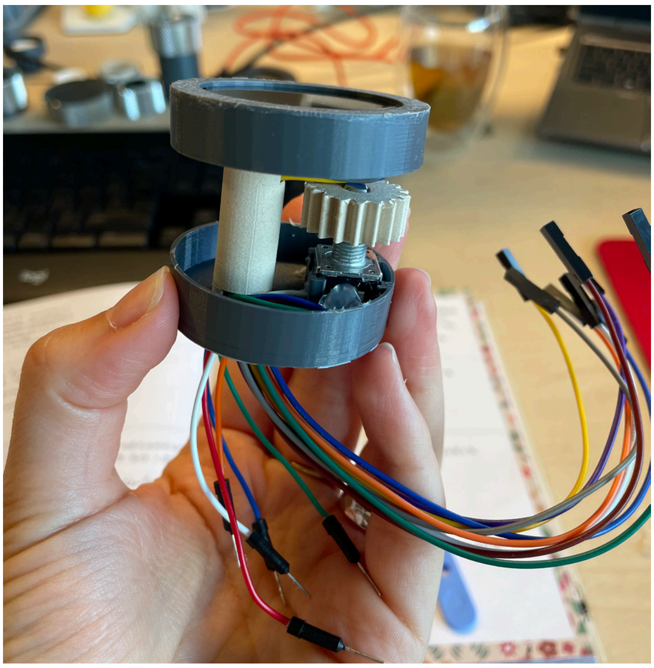


Figure 29. 3D-Printed prototype with electronics

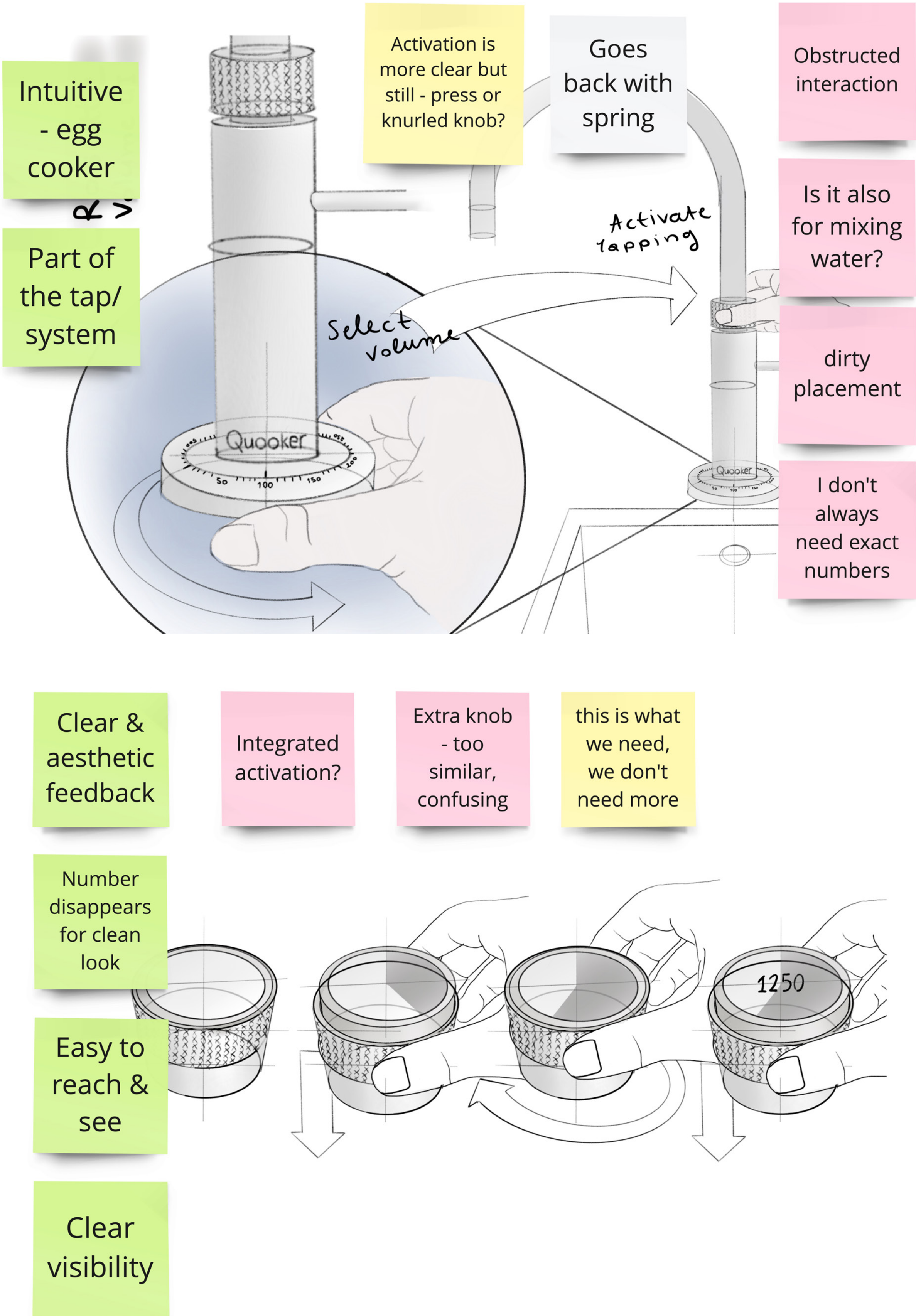


Figure 30. Preliminary User Testing reactions

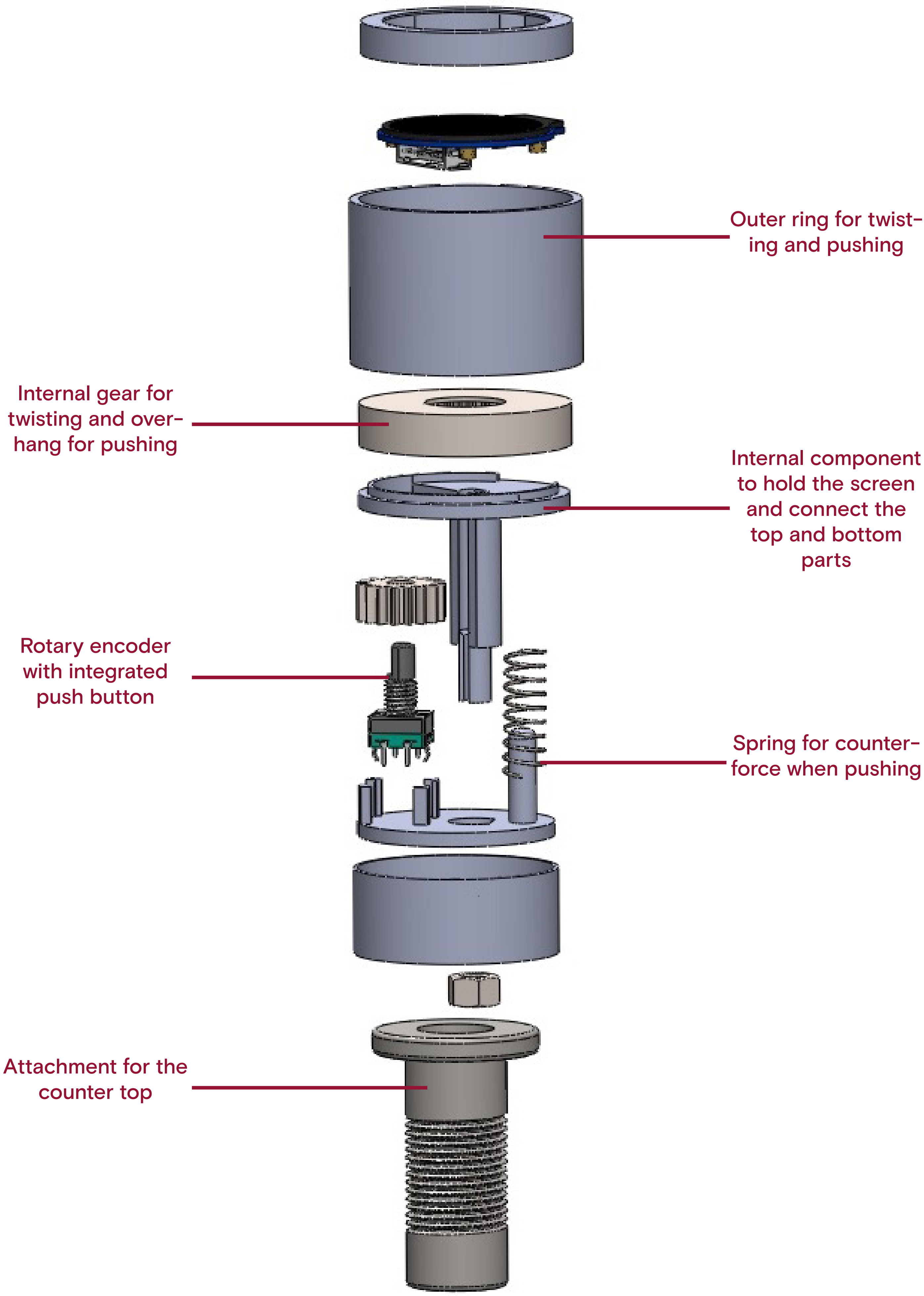


Figure 31. Exploded View of Knob Prototype

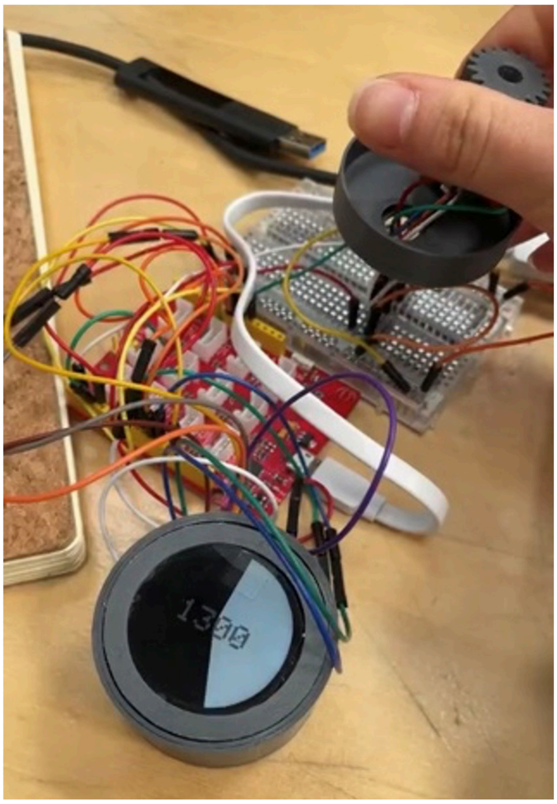


Figure 32. Rotary encoder is twisted; pie segments and volume indications increase incrementally

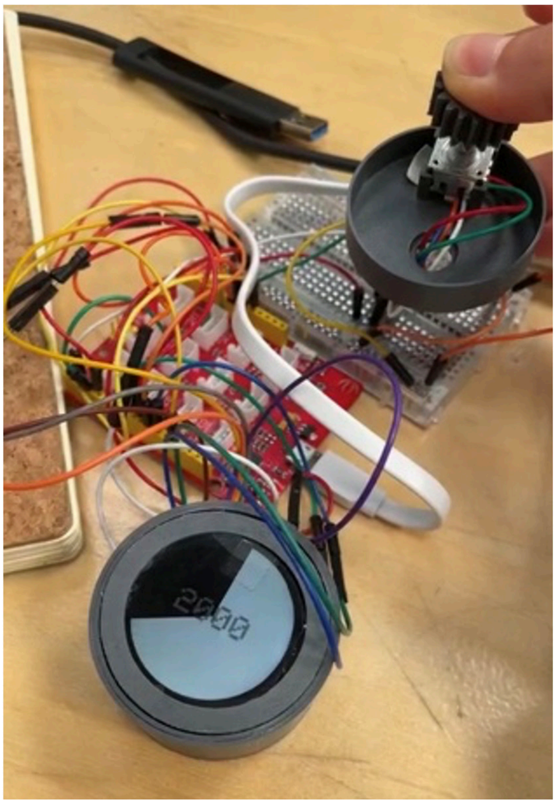


Figure 33. Integrated push button is pushed; volume and pie jumps to preset volume

When the encoder is twisted clockwise, the pie segments and volume indication increase by increments of 50ml. When the push-button is pushed, the volume jumps to a preset quantity, in this case 2L. (Fig. 33). This design is meant for user testing and will be further iterated based on the test results and for manufacturing purposes.

4.5 Usability Testing

The prototype shown in the previous section was used in usability testing. Main purpose of this user testing was to evaluate the product's performance in terms of how intuitive the interaction is and how comfortable the usability. The responses and reactions of the participants were collected through video and analyzed later to obtain the results. The user testing was conducted as follows:

1. The project and product were explained in brief.
2. In case the participant wasn't familiar with the Quooker tap, its functionality was explained, and the participant was asked to try it out.
3. Then, the participant was asked to pick a volume and tap the water without further explanation.
4. After the participant tried it out on their own, the full functionality was explained including the presets.
5. After the explanation, the participant was asked again to pick a volume and tap water.
6. Lastly, a scenario is presented. The participant is asked to pick 1.5l of boiling water to cook pasta. They are asked to repeat the test with this situation in mind.

Figure 34. a) Wizard of Oz prototype with hidden electronics b) Wired button to control the tap

These tests were run in the "Wizard of Oz" manner with all prototype electronics hidden inside a box. After the participant picks the volume and turns the knob, the researcher starts and stops the tapping with a wired button connected to the Quooker reservoir below the counter (Fig. 34). This way the tapping sequence is recreated to induce the feeling that the tap stops when the target volume is reached.

The first participant didn't have any previous experience with a Quooker prior to the testing, so she took some time to get familiar with the tap. Affected by Quooker's counterclockwise turning, she started turning the knob to the left and nothing was happening. Then she tried activating it by pushing the button (Fig. 35a) or using the display as a touch screen (Fig. 35b). During this process she said; "I need a manual". After explanation, she understood how the volumes are chosen and after picking one she tried activating the tapping by pressing the button, using the display as a touch screen, and performing the Quooker's double-push-turn on the external knob. Figure 35c also shows her frustration during this process. After explanation from the researcher, she reverted to using the tap's knob for activation and seemed relieved and satisfied that it finally worked out.

Figure 35. a) Participant is pushing the outer ring to wake up the module b) Participant is using the display as a touch screen c) Participant reverts to pushing and tapping to dispense water d) Participant is satisfied after explanation

Participant number two was familiar with the Quooker system but doesn't own one herself. She tried to wake up the knob by pressing on it (Fig. 36a) and then twisting in the right direction which showed the pie chart increasing (Fig. 36b). She was surprised when she twisted all the way to 3L (maximum volume the users can use) and then the pie chart reset (Fig. 36c). When asked to activate the tapping she pulled the mixing water lever due to unawareness that the function is only connected to special feature water. She seemed pleasantly surprised by the tap starting and stopping automatically.

As shown in Figure 36, the participant leans over the knob to look at the pie chart and animation. After questioning it seemed like this wasn't because of visibility reasons but more so due to curiosity to see what's happening.

Figure 36. a) Participant presses on knob to activate b) Participant twists to set the volumes c) Surprised when the pie chart rests d) Uses mixing water lever to tap water e) Pleasantly surprised when system stops automatically

The third participant is familiar with Quooker and has worked on a project on this tap before, meaning that she has had experience with its design and functionalities. She pushed the knob to activate as well (Fig. 37a) and the immediately started twisting to the right and left (Fig. 37b) and figured out quickly how the system works. When asked to tap water she reverted to the knurled knob on the tap (Fig. 37c).

Both participants two and three are American and they were confused by the numbering on the volume unit, namely the volumes displayed in milliliters. This is because they are not used to measuring water in liters but rather cups, gallons and ounces. It was specifically said: “I am foreign” and “I don't know what the numbers mean” when asked to pick a specific amount of water.

Furthermore, it was mentioned that “If this was mine and I knew it, it would be understandable” when referring to the numbering and the pie chart. This confirms the initial goal of making a system that the user learns to use with time, and correlates to specific actions (e.g. cooking activities, containers). The last participant, having a certain experience with Quooker, thought the system makes sense in combination with Quooker's use cues and functionalities.

It should be noted that the prototype used during these user tests was in its early form and couldn't fully perform some actions. For instance, the pushing of the button failed during the tests and the participants couldn't select presets. In addition to this, the display looks like it's loading with a specific refresh rate which delays the response between encoder and screen animation. This seemed to confuse the participants in certain cases. Both these aspects are improved in the second round of usability testing.

Figure 37. a) Participant initially pushes the knob button to activate b) Participant is twisting the knob to choose the volume c) Participant immediately interacts with the knurled knob when asked to activate the tapping

Second Round

The second round of usability testing was focused on users who already own a Quooker in their house (see Section 3.2, Added Value). These tests were conducted within the Quooker offices and the participants were selected specifically so that they don't have prior knowledge about the project, nor a design engineering background. Six (n=6) users participated in this round.

All users had a positive reaction to the volume control unit and seemed to grasp the functionalities after a quick explanation by the researcher. They seemed to like the two modes between pie and number indications.

Some quotes from the tests include:

"Once you know how it works, it feels clear and natural"

"It's really ideal, I wouldn't need measuring cups anymore"

"But it's not moving back [referring to the pie while the water taps]"

"I expected all interactions to be on the external knob"

Volume selection was intuitive and didn't require much explanation, except for "hidden" features such as the presets and mode switching (from pie to numbers).

Activation of the tapping was split among the users. Several users reverted immediately to the knurled knob, others used the external volume control knob by pushing and turning, pushing or tapping the screen. Even though this was their initial response, after clarification by the researcher, they seemed to grasp the division of the two functions of volume selection and activation between the two knobs. A couple users also pointed out that it makes sense for safety reasons.

Regarding the feedback communicated by the screen. Users showed a preference for the pie to decrease while water is tapping, and the screen to turn a different colour (red, blue, light blue) to indicate the type of chosen special water and show the connection to the tap. One user seemed confused by the simplicity of the screen information and requested either numbers or symbols to confirm the volume of choice.

Figure 38. a) Testing set up b) Participant twisting to choose volumes c) Participant measuring tapped water to compare to the numbers indicated on the screen, surprised by the accuracy

Interestingly, one user (Figure 38.c) tried measuring the water dispensed by the tap once the mode was switched to numbers shown on the screen, in order to confirm that the volume dispensed by the system is correct. This confirms the assumption that numbers evoke feelings of higher accuracy, however this is something that has been taken into account when choosing the flow measuring technology (Chapter 7).

Overall, the usability tests provided great insights for user behavior towards the volume control unit and insights for the further development of the unit, presented in the following section.

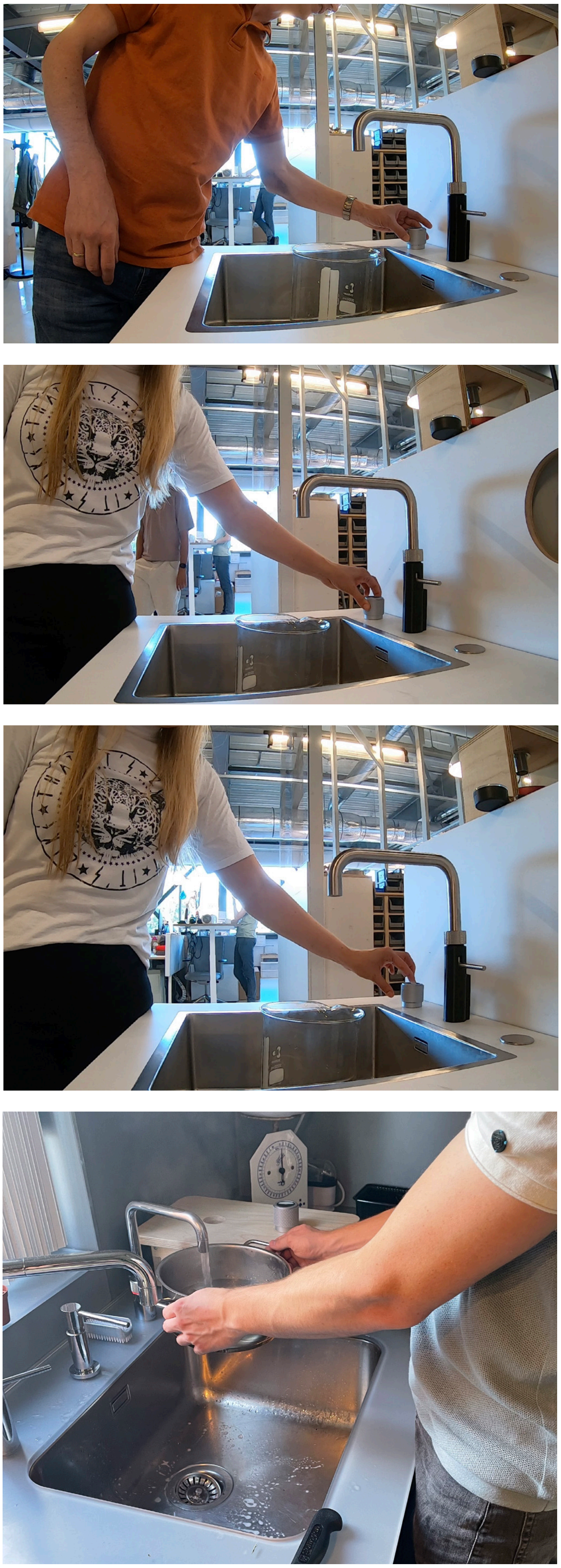


Figure 39. a) Participant pushing the knob to activate tapping b) Participant performing Quooker's double-push-twist to activate tapping c) Participant attempting to tap by tapping and pushing on the display d) Testing within the use environment

4.6 Conclusions & Iterations

Based on the feedback and insights from the user tests there are certain iterations to the design that are taken into account.

Progress visibility

All participants were curious about the remaining time it takes for the water to finish tapping. Even though this module is meant to save time and reduce mental effort, an extra feature that could be added for feedback would be that the pie chart decreases while the water is being tapped (Fig. 40). This way the user will know how much water remains to be tapped.

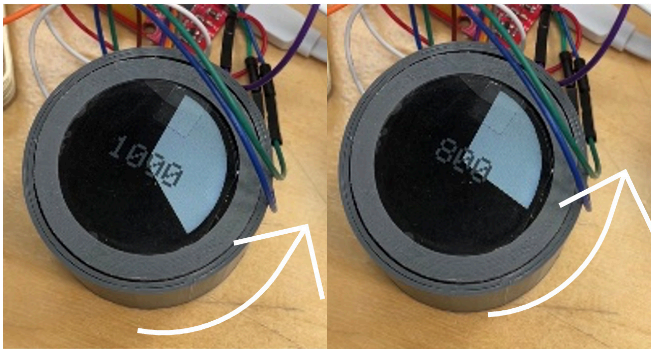


Figure 40. Progress visibility, volumes on display decreasing while tapping

Twisting counterclockwise

For better communication to the user, the pie will start at 3000ml and decrease when twisted counterclockwise from the initial '0' position (Fig. 41). This way, the user will know that they are decreasing the volume and should twist clockwise to start from '0' and increase. This way any possible interaction with the knob provides feedback accordingly to guide the user through volume selection.

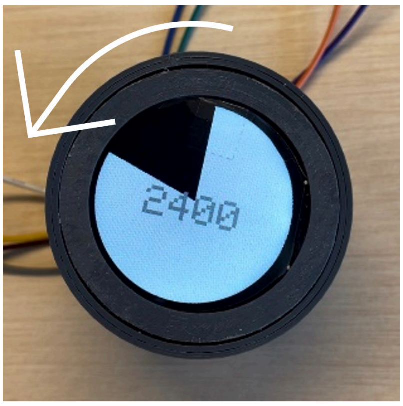


Figure 41. Volumes jump to 3000 and decrease when twisted counterclockwise from 0

Incremental adjustment

In the current prototype, the volumes increase and decrease by 50ml when the encoder is twisted (Fig. 42). This number was chosen based on the use cases, since people usually don't need in-between water volumes. However, the dial for setting the volume can implement a non-linear relationship to allow for more precise time settings. The non-linear relationship means that each increment of the dial does not represent an equal increase in volume. Instead, the dial adjusts the volume setting in a way that allows for finer control over the duration, similarly to some digital oven timers. For example, when the dial is rotated slowly, each small increment might correspond to a few milliliters. However, as the user rotates the dial faster or turns it more vigorously, the increments could change, and each movement might now represent 100ml instead of a couple. This way, the dial achieves a balance between ease of use for quick volume settings and precision for more specific durations.

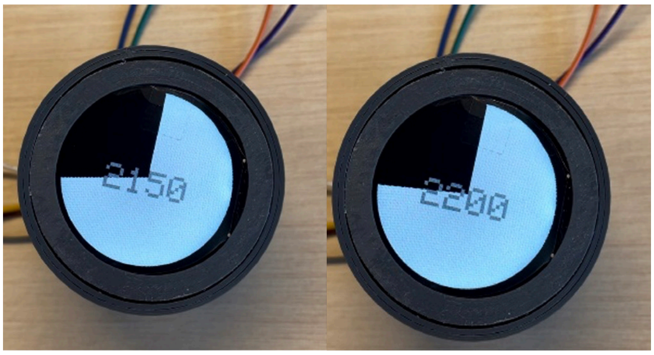


Figure 42. Current incremental increase by 50ml

Knurled knob on the tap

Some participants mentioned: “I assume that it [the knurled knob] would pop back up automatically when it’s done”. After discussion with Quooker interaction experts, it was concluded that users develop a troublesome feeling when having to perform another handling after they already have the result, in this case the handling being twisting back the knurled knob after the water has been dispensed. Due to the project’s “backwards compatible” character, this feature cannot be added since it would have to adjust the mechanism inside the tap.

The knurled knob on the tap has been chosen as the tap activation point for several reasons; the main reason is to adhere to Quooker’s interaction language and not to confuse the user with added functionalities. In this case there’s a clear separation between functions; the external knob is used for volume selection and the tap’s knurled knob for tapping activation. This does, however, add an additional interaction point.

The twisting-back of the knurled knob might add an extra step the next time the tap is used, however, similarly to pushing back the button of roller shutters after they stops or pushing in the oven buttons after usage, it doesn’t increase mental load or system complexity. This needs to be revisited and validated for the final product design.

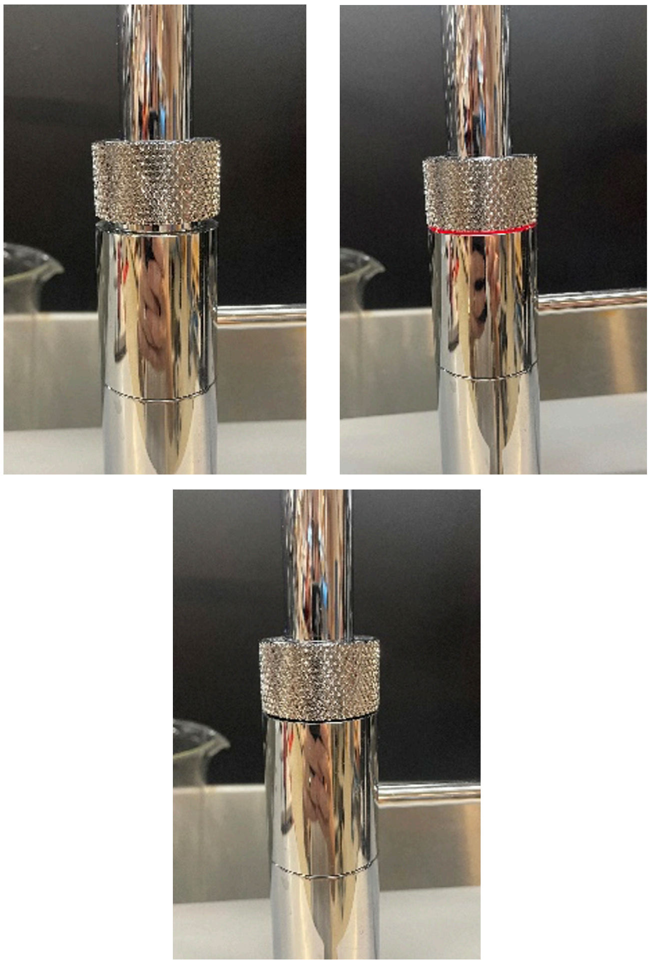


Figure 43. Knurled knob before activation, while tapping, after tapping is complete

Communication

Several users wanted to see more communication between the volume unit and the tap. For instance, when the tapping is activated with the knurled knob, the pie on the display turns red for boiling, blue for chilled and light blue for carbonated water.

In addition to this, some users seemed confused by the unit-less number indication on the display, while others immediately understood that the volumes are displayed in milliliters. This feature wouldn’t pose a problem when the product is used in a household environment. However, in order to prevent confusion and accommodate the liquid measuring system of each country, the unit can be displayed next to the volume in ml for the metric system (Europe, UAE) and in fluid ounces and pints for the imperial system (UK).

FLOW MEASURE-MENT

5

Discover
flow measurement

Similarly to the User Interaction, this sections presents thorough internal and external research in the direction of flow measurement and available technologies in that field.

The Quooker system functionalities are analyzed, as well as flow measuring technologies in competitor taps and water systems, other fields and industrial applications.

5.1 Quooker System

The Quooker system comprises of several elements, both above and below the kitchen counter. This Chapter focuses on the functionality and technology below the counter and all variables affecting it. For the functionality above the counter, refer to Section 2.1.

Below the counter, the main component of the system is the Quooker reservoir (Figure 44). There are several models of this boiler, however, the main function of them all is to prepare and store the boiling water.

An additional reservoir can be found next to the Quooker, the CUBE. The CUBE is used to filtrate, cool down and carbonate water to be dispensed through the same tap. The Quooker system requires the presence of a Quooker reservoir to operate the CUBE, so it cannot be a standalone product. The CUBE is equipped with an Activated Carbon Fiber Filter to prevent bacteria, chloride, chemicals and pesticide from entering the system. Next to the CUBE, the CO_2 cylinder can be found, providing up to 60 liters of sparkling water.

Both the Quooker and the CUBE are connected to the water inlet through a separate reducing valve. Both of these reducing valves serve as regulative devices, to reduce the water pressure supply to the required pressure and prevent damage to the system due to overpressure.

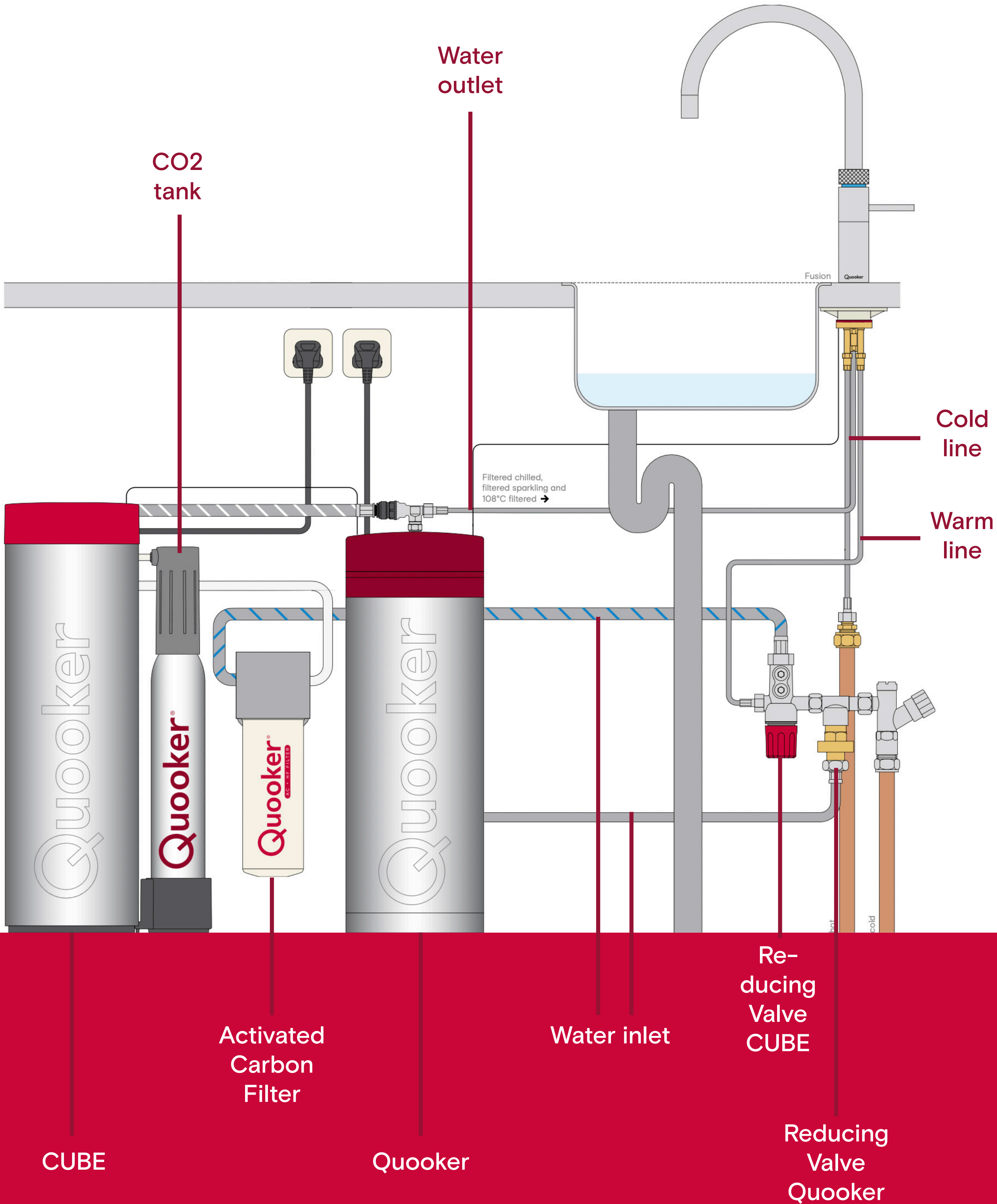


Figure 44. Quooker System and Connections

Quooker

Cold water enters the reservoir through the main water line, it gets heated up and preserved at 107°C in the vacuum sealed container. Due to the overpressure of 1.2 bar within the tank, the water doesn't reach its boiling point and thus starts boiling only when in contact with atmo-spheric pressure. When tapping is actuated by the user, the valve opens and boiling water in combination with steam leaves the reservoir due to the overpressure and is dispensed through the tap. The "dead water" in the water line dries instantly due to the high temperatures, therefore boiling water can be dispensed almost instantly without being affected by colder water residue.

When boiling water is tapped, the tank is imme-diately refilled with cold water form the mains water supply. The hot and cold water don't mix thanks to the difference in density. This ensures that the boiling water is clearly separated at the top of the tank. The boiling water is then fed through the activated carbon filter to the tap to ensure better water quality (Figure 45).

CUBE

The filtered water enters the CUBE through a pump and goes through a cooling mechanism, which uses a refrigeration system to lower the temperature. This ensures that the water is chilled and ready to dispense. When selected, the chilled water passes through this system, where it gets infused with carbon dioxide to create the sparkling effect. Figure 46 shows the components of the CUBE. The pictures on the left and right show cross sections of two differ-ent CUBE models, however the working principle is the same.

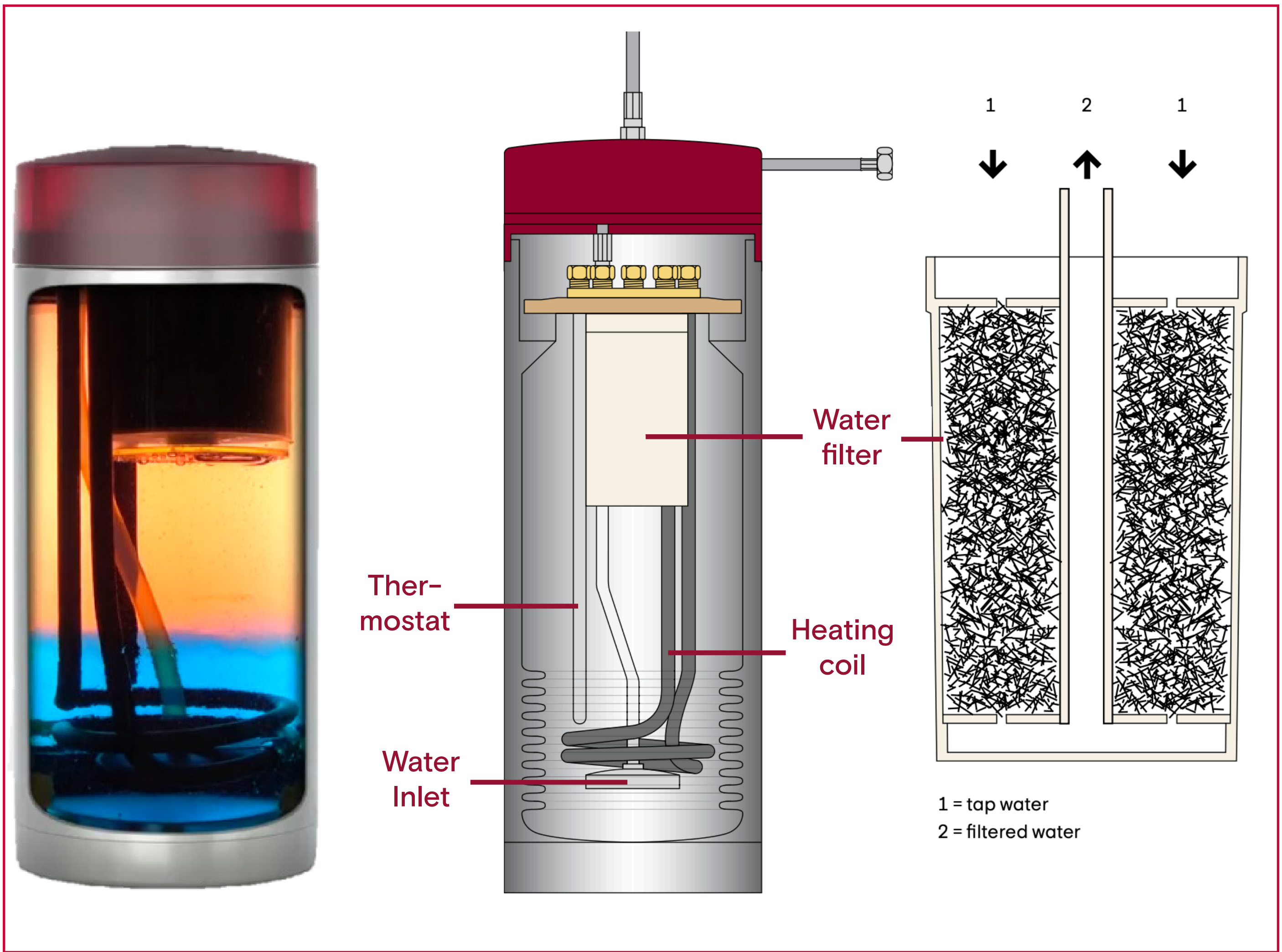


Figure 45. Quooker Reservoir Components

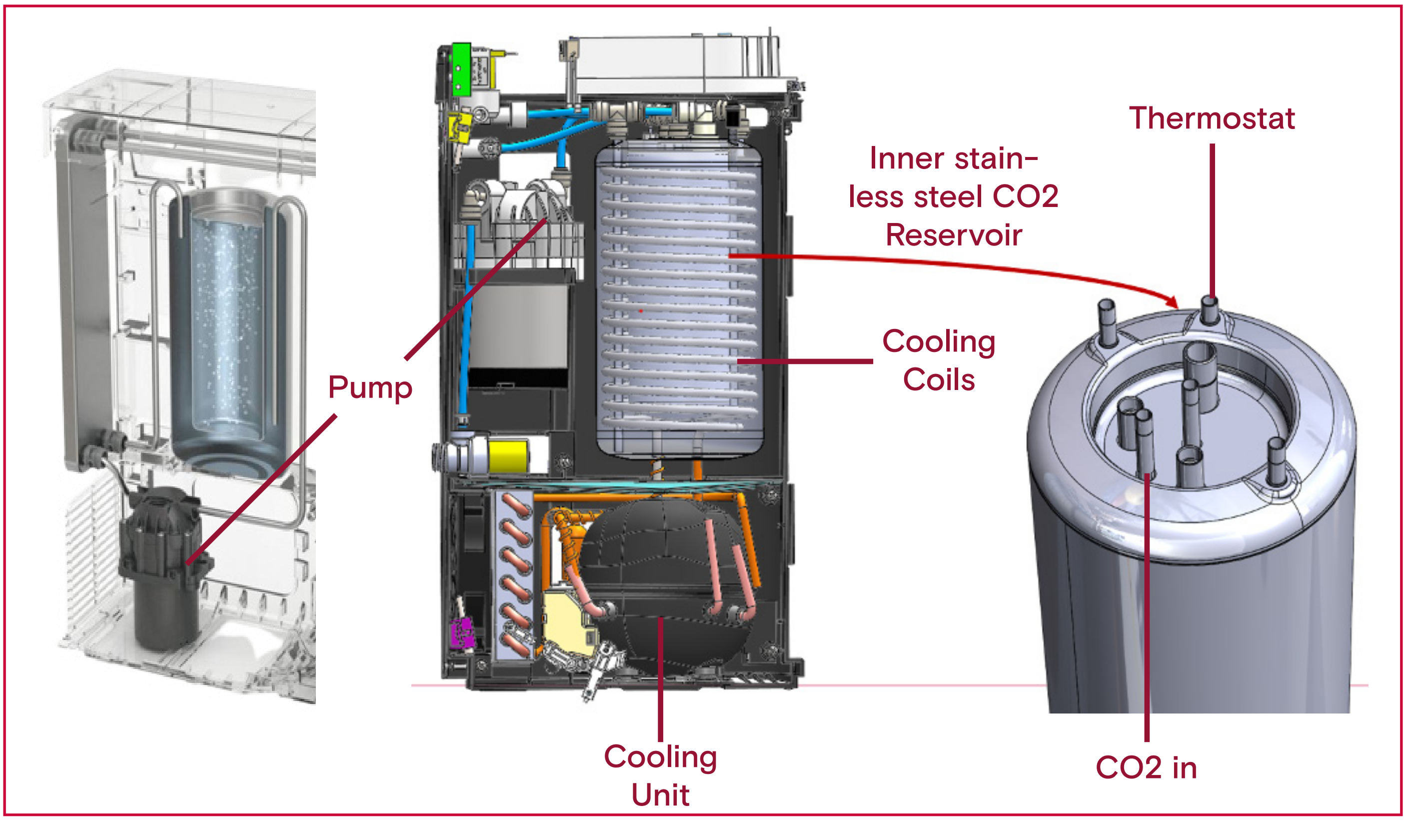


Figure 46. CUBE Reservoir Components

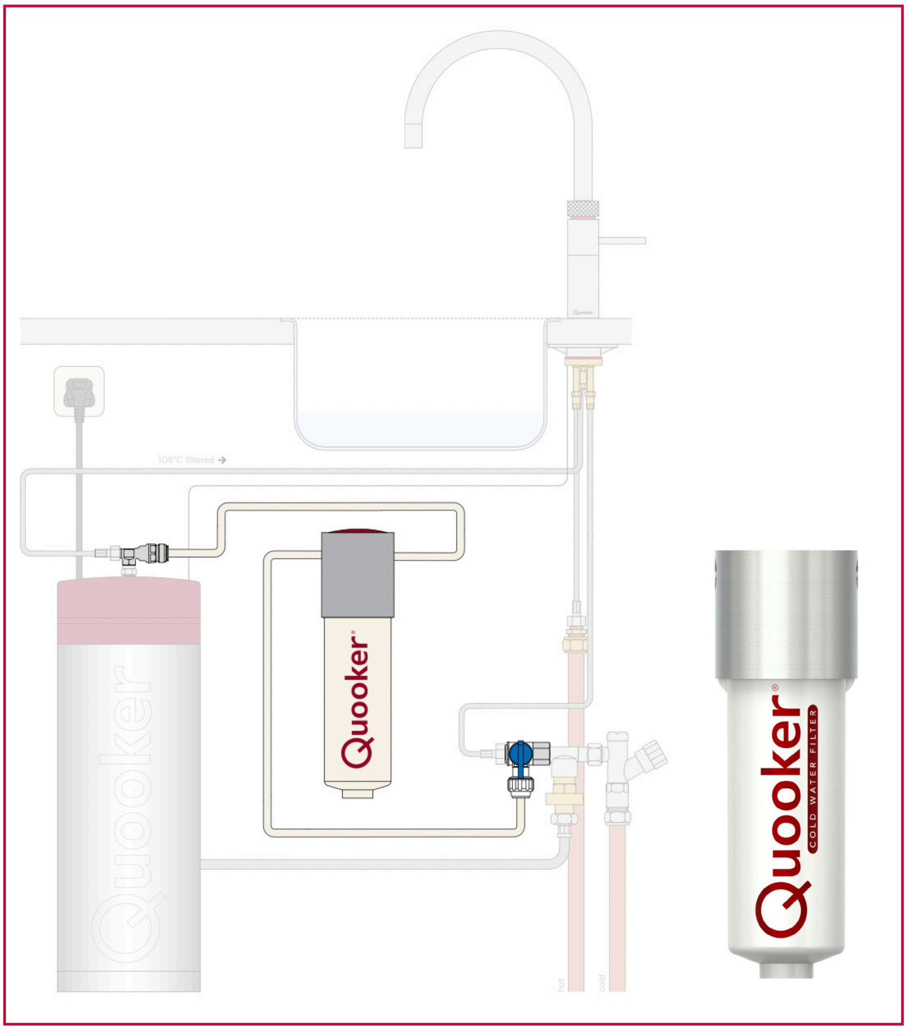


Figure 47. Cold Water Filter

CWF

Similar to the CUBE, Quooker offers a Cold Water Filter (CWF). As the name suggests, this unit filters the cold water before it enters the tap. It is used instead of the CUBE to offer filtered water as another special feature, in case the user does not have or want to purchase a CUBE. The CWF allows to switch from cold to filtered water using the built in knurled knob on the Quooker tap.

The Quooker reservoir, the CUBE and the CWF are the three relevant components of the lower system for this project.

5.2 Field Application

A market analysis was conducted to provide an overview of the current volume measuring applications. Competitor taps, industrial applications and household appliances were investigated in combination with desktop and literature research in the field of flow measuring.

Competitors

For this project, water taps with volume control are considered and examined in terms of functionality and usability. The usability is presented in Section 2.3.

In terms of technology, U by Moen uses an impeller flow sensor in combination with a hall sensor to control the flow. The tap was taken apart to examine the flow sensor and the connection to the system. This type of flow sensor is used for mixed water and not boiling, chilled or carbonated. The Blanco Evol-S volume works similarly but with a timer instead of a sensor.

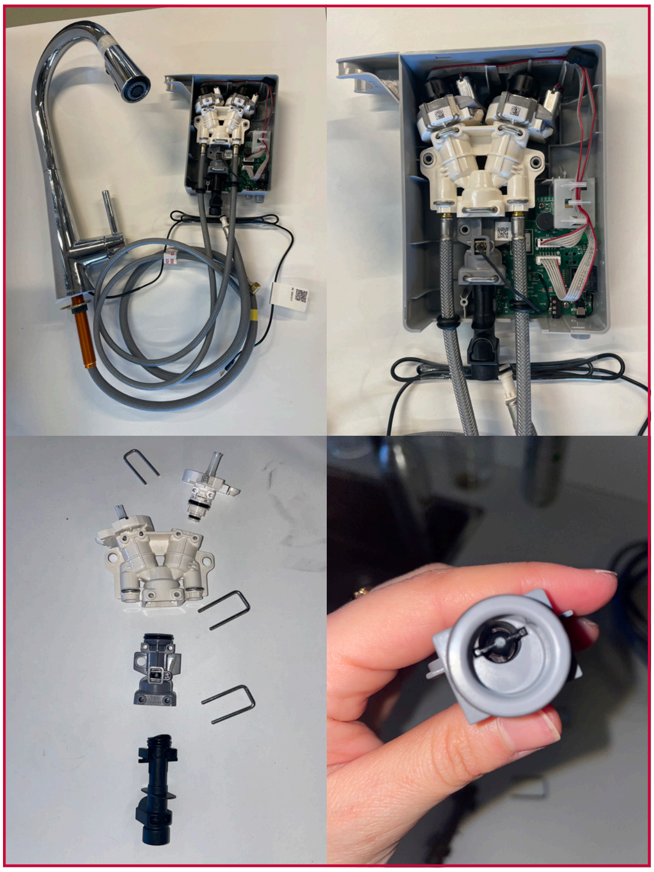


Figure 48. U by Moen Taken Apart

Household Appliances

Flow and volume measurement can be also seen in other household appliances like coffee and washing machines.

Coffee machines use several types of flow measuring, either with a timer, integrated flow sensor or even weight.

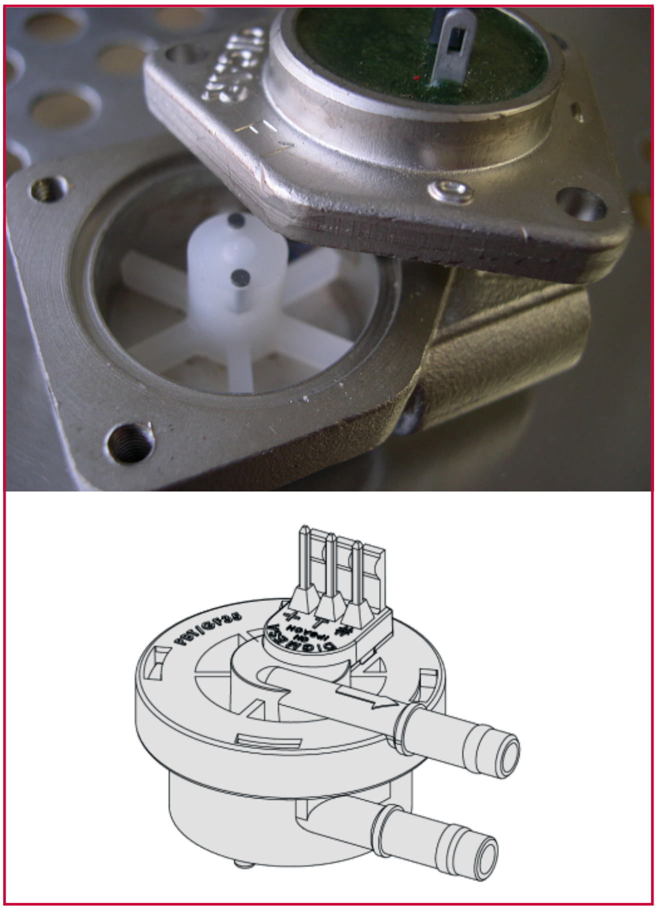


Figure 49. Coffee Machine Turbine Flow sensor

Figure 50. Breville Espresso Machine with integrated scale tray

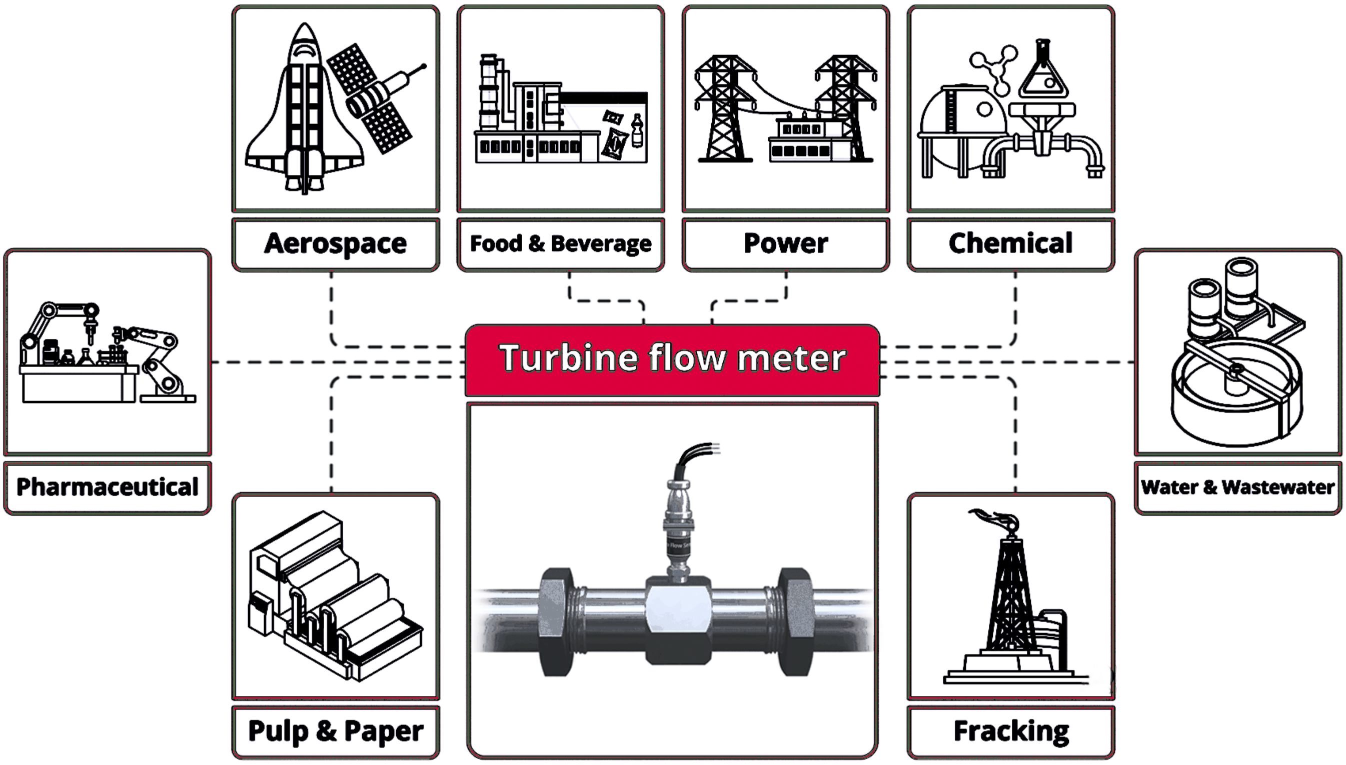


Figure 51. Turbine Flow meter Industrial applications

Relevant Technology & Industrial Applications

Flow measurement is an essential process in many industrial applications as well, to ensure efficient operation and quality control. There are several methods used for flow measurement in an industrial setting. The most common ones are listed below:

Variable area Flow meters

Variable area Flow meters or Rota meters consist of a tapered tube with a float inside that moves up and down based on the flow rate of the fluid. These sensors can be found in the chemical processing, pharmaceutical, and water treatment industry.

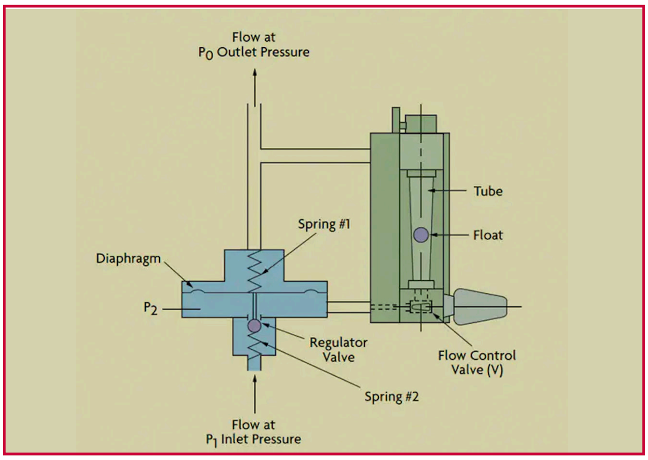


Figure 52. Variable Area Flow Meter

Differential Pressure Flow meters

This type of flow meter uses a constriction in the flow path to create a pressure drop. The pressure difference is measured to determine the flow rate. Some examples of DP flow meters include orifice plates, venturi metes and flow nozzles. They are implemented in industries like HVAC, chemical processing and oil and gas production.

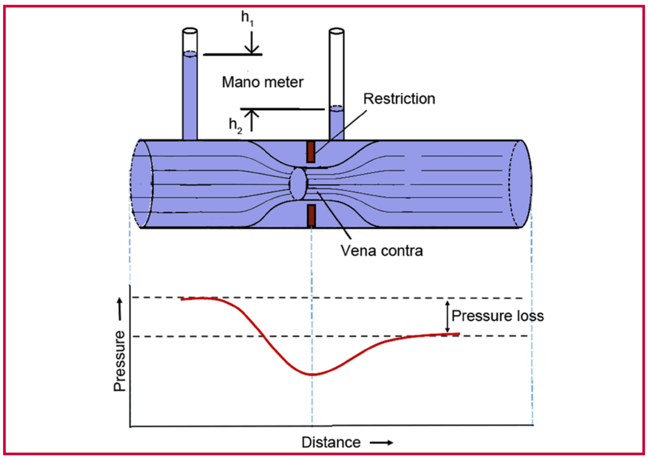


Figure 53. Differential Pressure Flow Meter

Turbine Flow meters

These flow meters consist of an impeller suspended in the stream. The rotational speed of the rotor is proportional to the flow rate of the liquid. The speed is calculated by the voltage generated or by a hall sensor and magnets on the blades of the impeller. This is one of the most common flow sensors found amongst others in the petroleum, chemical and food industry.

Vortex Flow meters

Vortex flow meters consist of a bluff body in the flow stream that causes vortices to the fluid passing through. The frequency of these vortices is proportional to the flow rate of the fluid. This type of flow meter is used for steam flow measurement in power plants and other industrial applications.

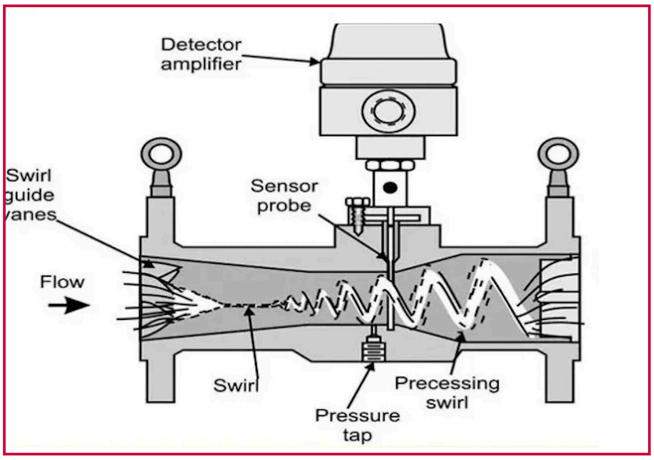


Figure 54. Vortex Flow Meter

Positive Displacement Flow meters

These flow meters measure the flow rate by trapping and measuring the volume of fluid passing through the meter. The principle of PD flow meters is dividing the fluid into known volumes and then counting the number of volumes to determine the flow rate. This includes piston, oval gear and nutating disc meters. They are most frequently found in the petroleum and chemical industry.

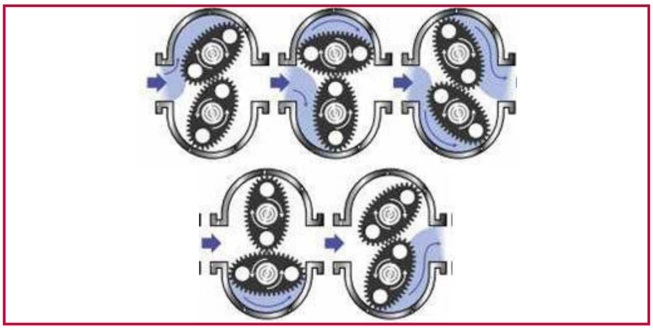


Figure 55. Positive Displacement Flow Meter

Electromagnetic Flow meters

These flow meters apply Faraday's law of electromagnetic induction to measure the flow rate of conductive fluids by measuring the voltage generated by the fluid when it passes through the electromagnetic field created by the sensor. They can be found in the water treatment, mining, and HVAC industry.

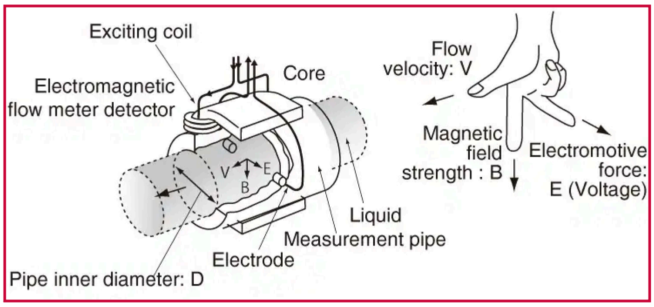


Figure 56. Electromagnetic Flow Meter

Ultrasonic Flow meters

Ultrasonic flow meters use sound waves to calculate the velocity of the fluid to calculate the flow rate. This type of flow meter can be clamped on existing tubes and is usually applied in the food and pharmaceutical industry due to its non-invasive form.

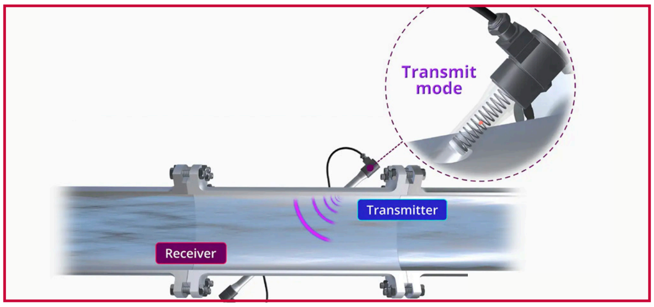


Figure 57. Ultrasonic Flow Meter

Piezoresistive Flow meters

A pressure sensor made of piezoresistive material (e.g. silicon, germanium) is used in these flow meters and detects the change in the resistance of the piezoresistive material when fluid passes through. This change in the resistance is converted into an electrical signal used to determine the flow rate. This type of flow meters is implemented in medical devices, industrial processes, and the automotive industry.

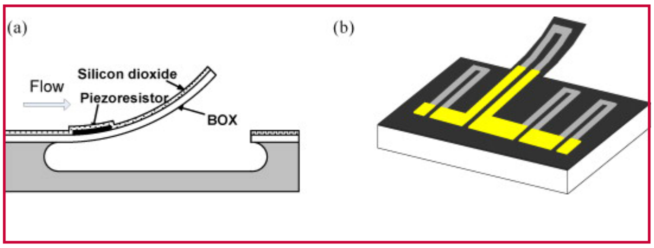


Figure 58. Piezoresistive Flow Meter

Coriolis Mass Flow meters

These flow meters detect the twisting motion induced by the fluid as it flows through the sensor, also known as the Coriolis effect. This type of flow meters is used in the chemical and pharmaceutical industry.

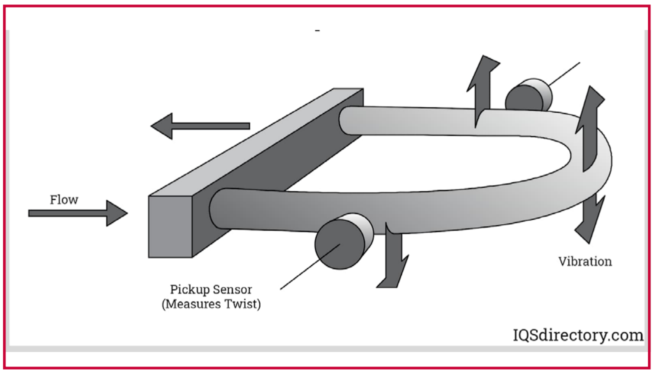


Figure 59. Coriolis Flow Meter

Thermal Mass Flow meters

The mass flow rate of the fluid is calculated by measuring the temperature difference between two points in the fluid as it flows past a heated sensor. Thermal mass flow meters can be found in HVAC Systems, environmental monitoring and biomedical research.

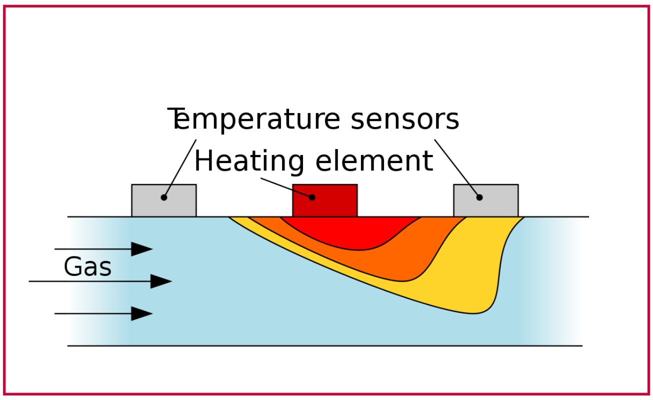
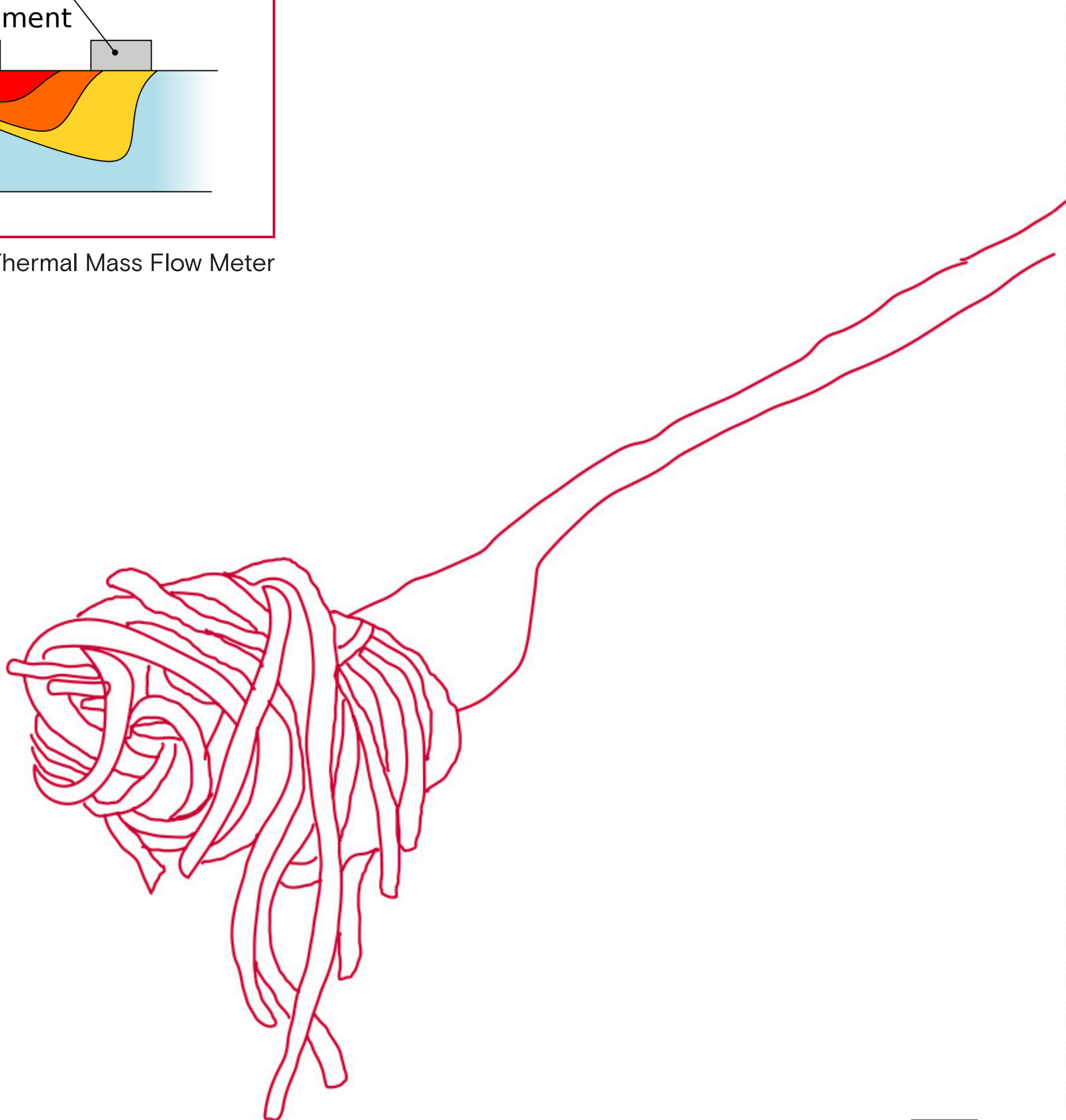


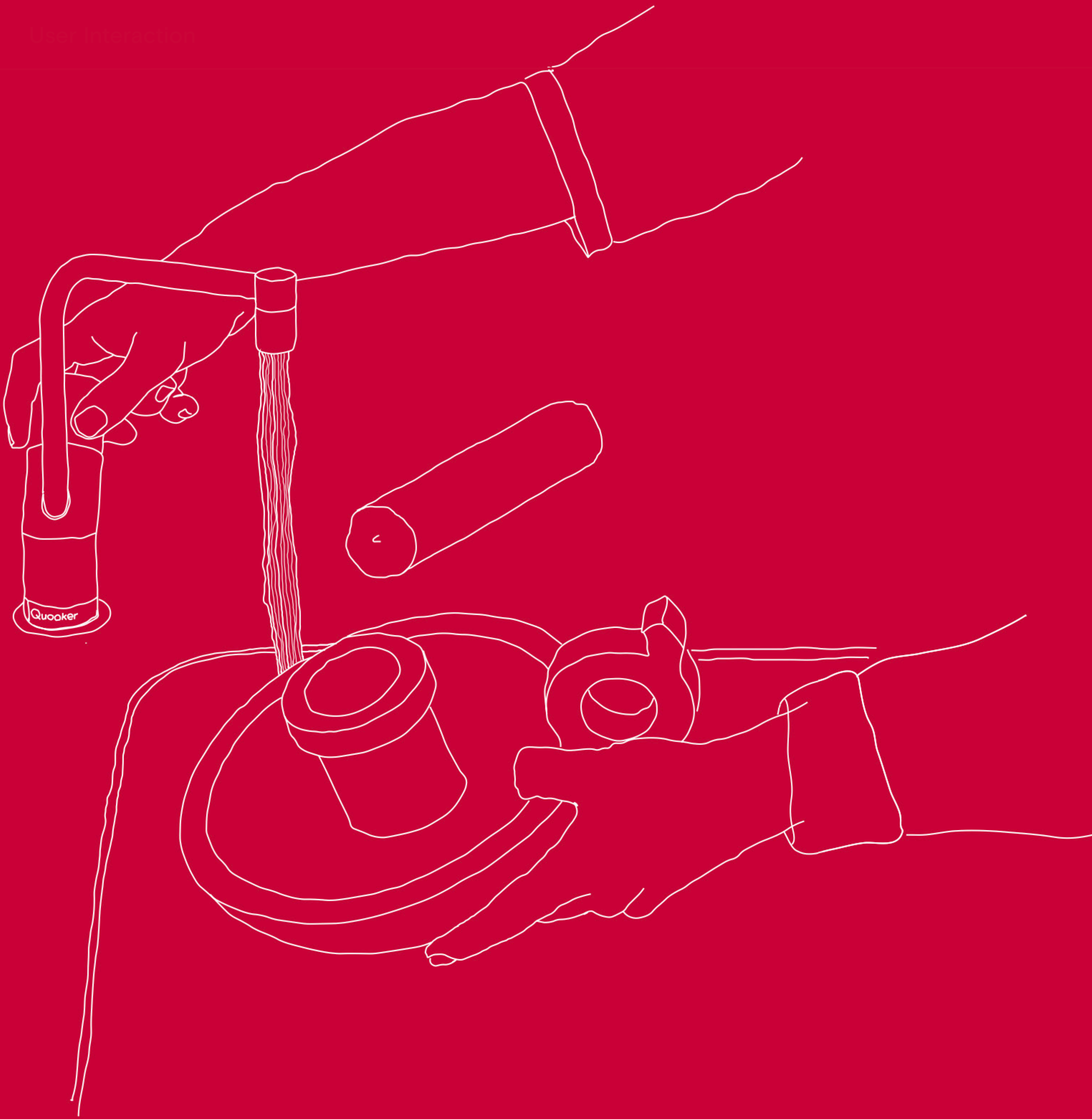
Figure 60. Thermal Mass Flow Meter

Conclusion

The Quooker system consists of many different components that need to be taken into account for the design of the Volume Control System. Given the project's objective of maintaining backward compatibility, it becomes imperative to thoroughly evaluate the complexity and distinctive attributes of each individual component. The specific limitations that the system imposes are explained in detail in the next section.

In addition to the intrinsic components of the system, a diverse array of technological options should be taken into account when contemplating the utilization of this application. The options presented in this chapter are filtered later based on the requirements of the system. Flow measurement finds applications across various industries, as well as within household appliances, and the implemented solutions, such as flow sensors, pumps, scales etc, could present an intriguing avenue for enhancing the functionality of this particular unit.





FLOW MEASURE-MENT

6

Define
flow measurement

Since the Quooker system was explored in the previous section certain questions came up due to the components' specifications:

- What is the effect of limescale on the flow measurement?
- What is the accuracy the system has to reach?
- What is the pressure drop in the house water supply and how does it affect the flow measurement?
- How does the Balg tank in some of the Quooker reservoirs affect the flow measurement?

These four points were identified throughout the research in the previous section and are examined in this section. The findings are later synthesized into the core challenges and opportunities the design has to adhere to and the scope of the project is set through a function analysis and a list of requirements.

6.1 Limescale

Figure 61. Limescale Buildup collected from Quooker reservoirs in different countries.

Figure 62. Limescale flakes within a Quooker reservoir

Limescale is a hard, chalky white deposit that can build up on surfaces that come into regular contact with hard water, such as kettles, pipes, and taps. It is composed primarily of calcium carbonate, which is a naturally occurring mineral found in many water sources. When hard water is heated or evaporates, the calcium carbonate forms a solid mineral deposit that can build up over time.

Limescale can be unsightly and can also affect the performance of appliances and plumbing systems. It can reduce water flow, cause blockages, and increase energy costs. The timespan for limescale buildup can vary depending on hardness of water, operating temperature and frequency of use of the affected surfaces. In general, limescale buildup occurs gradually over time and it takes several months to years to become noticeable [5]. Countries with hard water, such as the UK and Denmark, face problems in their kitchen appliances caused by limescale. Quooker has developed Scale Control R, a descaler meant to treat the water and reduce calcium carbonate before it enters the Quooker.

Limescale could pose a problem in this system as well, depending on the form (eg. Type of flow meter, moving parts) and location of the volume control unit (eg. contact with boiling water). Due to the limited timeframe of the project, it won't be possible to test limescale buildup on the final design. After consultation with experts within Quooker, the conclusion was drawn that, when it comes to limescale buildup, other system functions would fail first (e.g. decrease in flow rate, thermostat obstruction) before limescale causes significant problems in the volume control unit. Nevertheless, if the design allows, a system with limited to no moving parts would restrict the limescale effect on the volume measurement.

6.2 Pressure Drop

There are several variables affecting the flow rate of the water within the pipes, such as temperature, pipe properties and pressure. The first two are usually constant within the Quooker system and cannot be changed. However, pressure is affected by external factors, such as the house main water supply and simultaneous water demand.

According to the American Water Works Association, simultaneous water demand from multiple fixtures, such as a shower and a kitchen faucet, can cause a pressure drop in the system [6]. The actual pressure drop can vary depending on several factors, including the size of the pipes, the length of the plumbing system, and the overall water demand in the building. However, in general, the AWWA notes that a pressure drop of 5 to 10 psi (0.3-0.7 bar) may be noticeable. This pressure drop would result in the decrease of flow rate.

To verify this, tests were run in houses. The flow rate of the tap was calculated with a timer and a scale and the measurement was repeated for

Figure 63. Testing flow rate with simultaneous water demand in the house

Table 5. Results from simultaneous water demand tests in houses

Test	Normal Flow Rate [l/m]	Toilet flushing [l/m]	Shower running [l/m]	Toilet tap running [l/m]
H1	7.1	7.07	-	-
H2/3	6.51	5.22	4.31	-
H4	7.63	6.9	7.5	6.88
H5	11.9	10.5 10.46	10.28	-
H6	8.0	7.59	7.47	7.9

simultaneous demand, such as running the tap and shower in the bathroom and flushing the toilet. The results are listed in Table 1. As it can be seen in the table, some houses were barely affected (e.g. H1), while others show a significant decrease in flow rate (e.g. H2/3). H1 is an industrial building, previously used as a hospital, and nowadays as student accommodation. H2/3 is a terraced house ("rijtjeshuis") commonly found in the Netherlands.

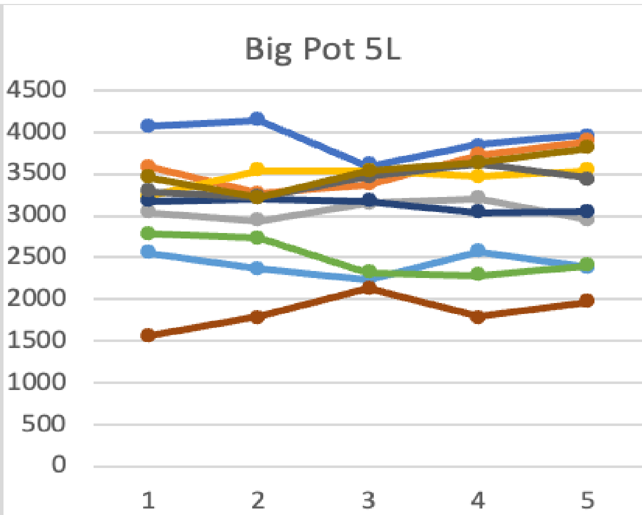
The experiment yielded conclusive results, thus confirming our hypothesis that the pressure drop is hard to predict and varies for different types of households. Consequently, the volume control unit should be able to operate under pressure changes so that it doesn't affect the dispensed volume.

6.3 Accuracy

One of the parameters that dictates certain design choices for the volume unit is the accuracy of the system. In order to determine how accurate the system has to be when dispensing water volumes, user testing was conducted.

Four containers were given to the test participants and they were asked to identify the uses of these containers and fill them with water according to these uses. The filling was repeated 5 times for each container to calculate the accuracy of each participant (standard deviation), shown in Table 6.

The deviation is very different from participant to participant. This can be connected to how accurate the participants were trying to be when filling the containers. Before the experiment, it was expected that the smaller volume containers (e.g. teacup) would show a higher accuracy (lower deviation), however the highest accuracy was performed with the big pot of 5L by participant 7.



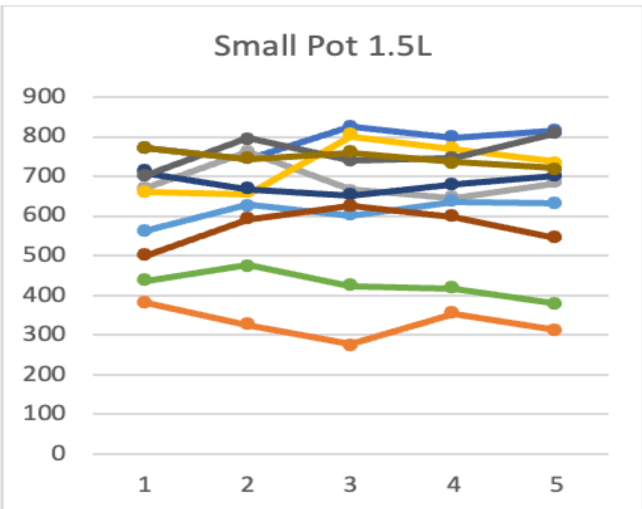
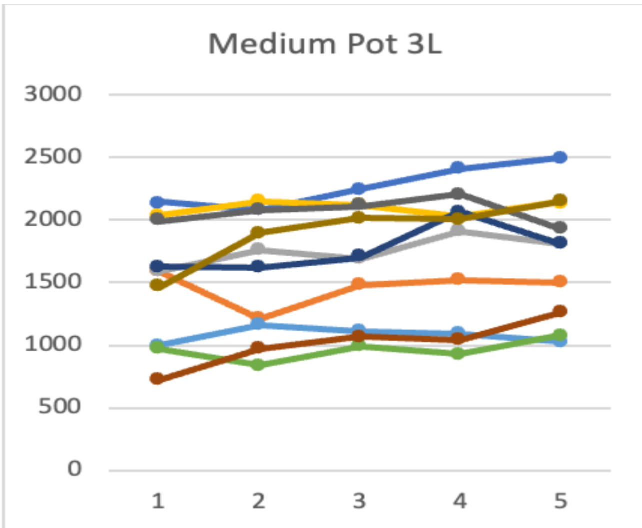
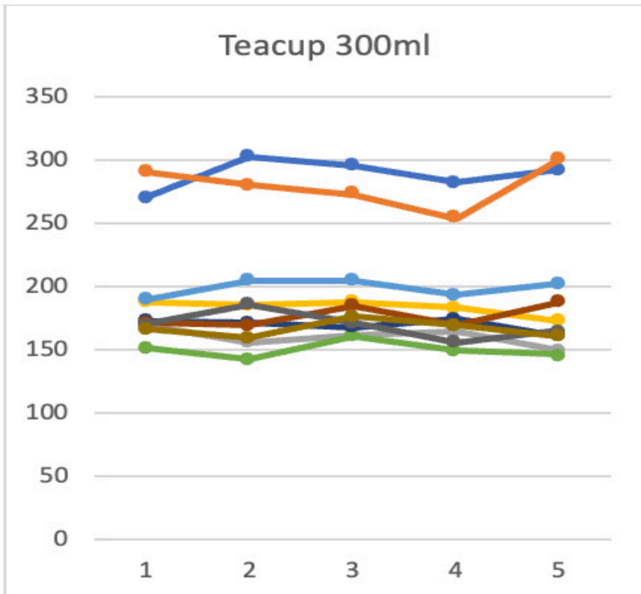


Table 6. Standard Deviation of Volumes for Filling Tests

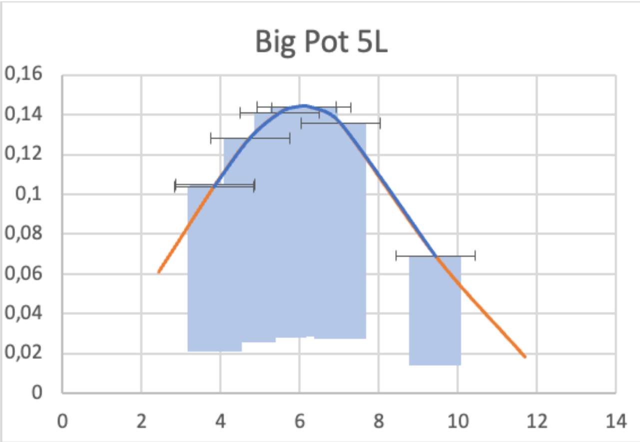
	Standard Deviation [%]			
	Big Pot	Medium Pot	Small Pot	Teacup
F1	5.5	7.83	4.22	4.31
F2	7.02	9.94	12.25	6.41
F3	3.83	6.94	6.49	5.07
F4	3.87	2.7	9.01	3.37
F5	5.91	5.98	5	3.54
F6	9.43	9.2	8.2	4.5
F7	2.44	10.4	3.54	3.42
F8	11.69	19.13	8.65	5.16
F9	4.73	5.21	5.75	6.63
F10	6.29	13.79	2.74	4.41
min.	2.44	2.7	2.74	3.37
max.	11.69	19.13	12.25	6.63

The filling quantities of each participant per container are shown in the graphs below.





Graph 2. Filling Tendencies for different pot sizes per participant



Graph 3. Normal Distribution of volume deviations for the 5L Pot

The normal distribution of the accuracy results was calculated to rule out outliers between participants and determine the desired accuracy of the system. The standard deviation gave intervals of 99.4-99.6% for the pots and 75% for the teacup. The normal distribution curve of the big pot is shown in Graph 2. Based on these results, the final design will aim for an accuracy of 6-9% for big pots (1.5-5L) and 4.5-6% for smaller containers (200-500ml).

6.4 Balg

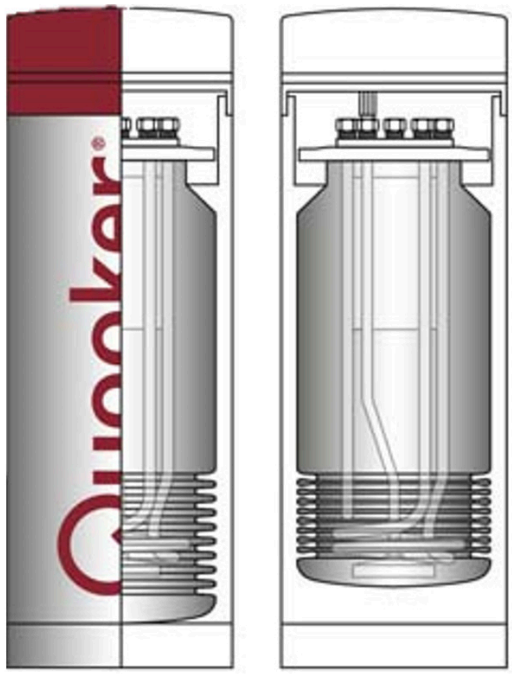
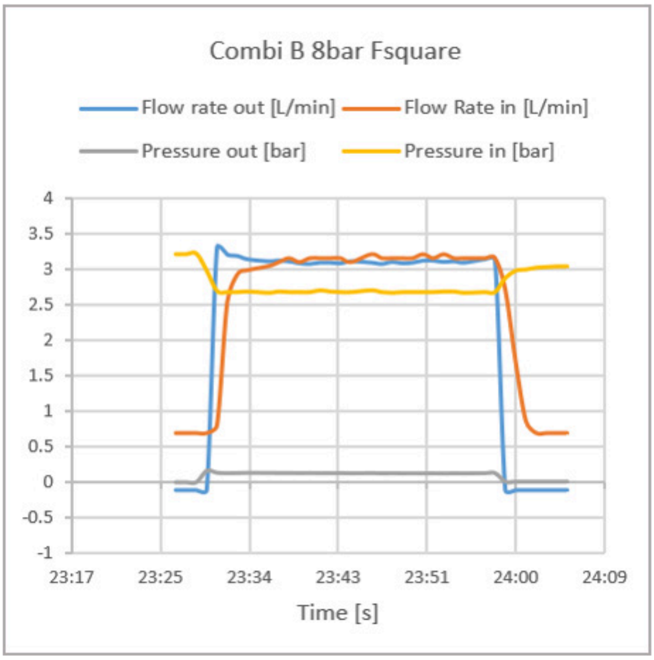


Figure 64. Bellow tank within the Quooker reservoir

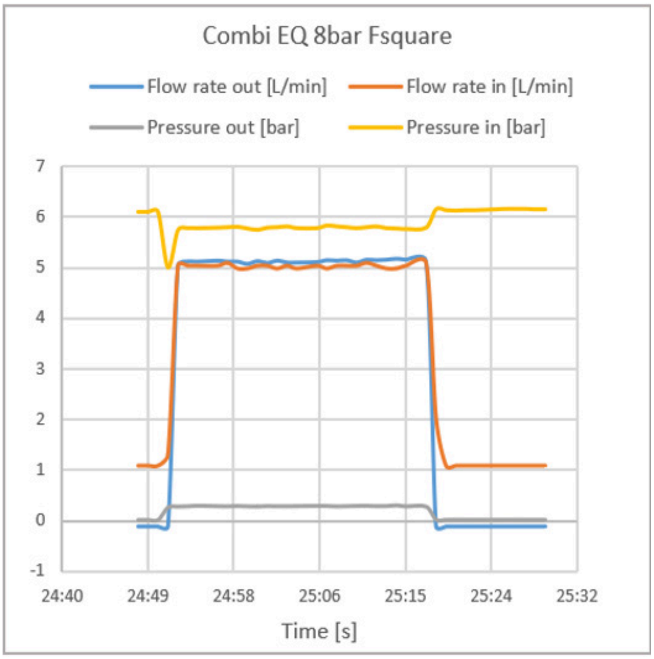
There are three Quooker reservoirs to choose from; the PRO3, PRO7 and COMBI. All new Quooker reservoirs contain a “Bellow” tank. This tank is partly flexible due to the bellow shape, allowing it to expand when water is heated up and retract when boiling water is being tapped and cold water enters the reservoir.

In this manner, when water volume expands when heated up, the extra water doesn’t need to be discarded through the drain anymore, since the tank expands to adapt to the additional volume. The Bellow is surrounded by pressurized gas, providing a counterforce to the increasing hydrostatic pressure within the tank and keeping the Bellow in balance. This counterforce is what causes the tank to retract when water is tapped. The Bellow tank is one of Quooker’s innovations, and its effect on the flow rate had to be investigated.

A test set-up was created with flow and pressure sensors at the inlet and outlet of the Quooker. This way, the influence between pressure and flow rate can be examined, as well as the effect of the Bellow on these parameters. Two reservoirs were implemented, one with the Bellow (Combi B) and one without (Combi EQ). The results are shown in the graphs below.



Graph 4. Flow rate and Pressure Results for Combi B



Graph 5. Flow rate and Pressure Results for Combi EQ

Overall, the Bellow tank doesn't seem to have a significant effect on the flow rate of the boiling water during the dispensing. The blue line (flow rate out) seems to stay constant over the tapping period with slight oscillations from time to time. The oscillations in the orange line (flow rate in) could be caused by the pump of Quooker's water lab.

Worth mentioning is the spike of the blue line in Graph 1 when the tap is turned on. This indicates the effect of the Bellow pushing out the water and retracting the moment the outlet valve is opened. This increased flow rate lasts for 1-4 seconds and the difference in tapped water amounts for up to 200ml. This of course is not constant.

The expansion and retraction of the Bellow depends on the temperature of the water entering and leaving the tank, as well as the water pressure. Thus, it is hard to predict the effect of the Bellow on the outlet flow rate. Looking back at the targeted use cases, the lowest water volume is used when tapping a teacup or glass of water (150-200 ml). The additional 50-200ml of the Bellow fall within the 5% accuracy that was determined in the previous section. In combination with the technology chosen in the next phase of the project, this could eventually affect the accuracy of the system, thus the effect of the Balg needs to be further investigated in later stages and considered in the final design.

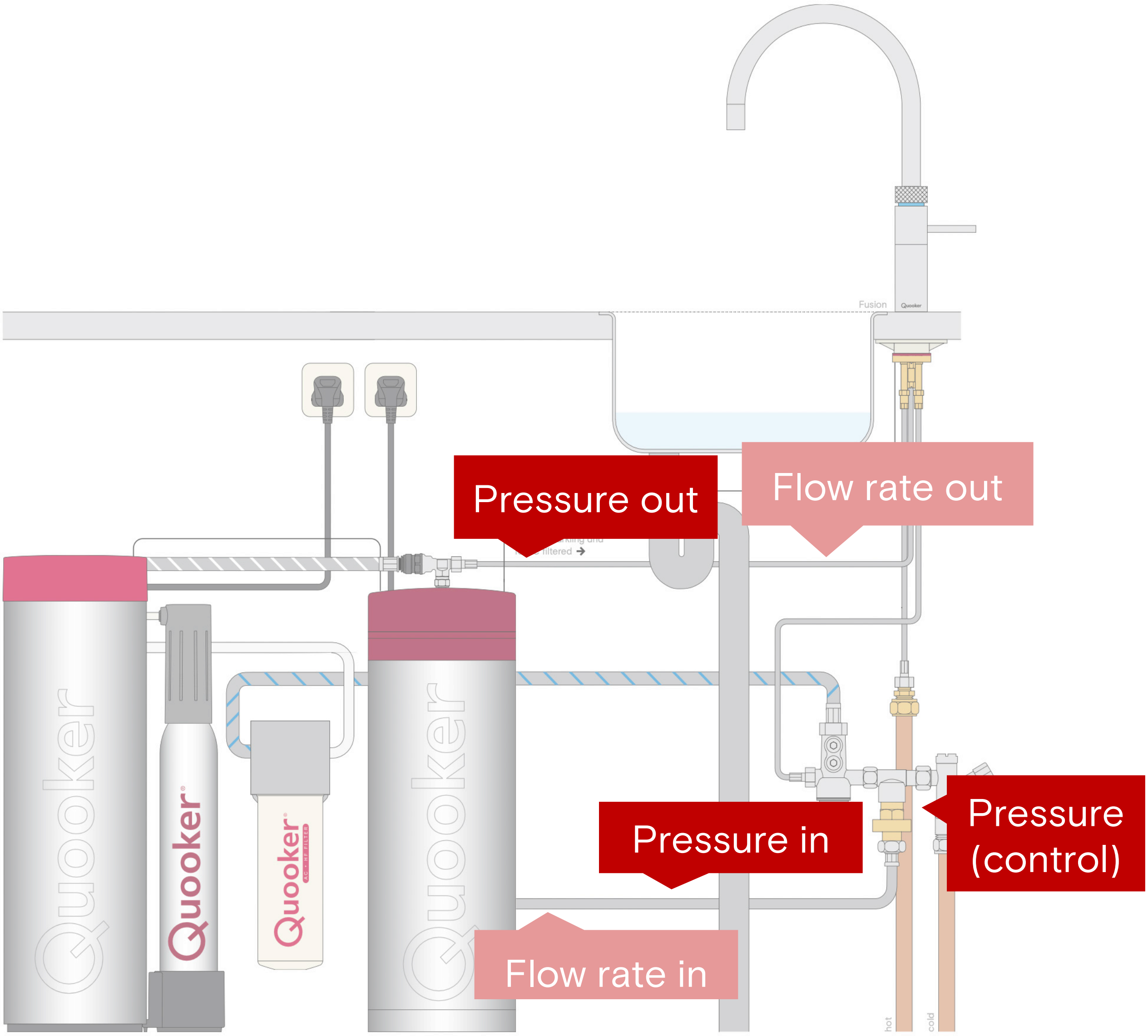


Figure 65. Flow rate and Pressure Measuring Points

6.5 List of Requirements

Similarly to the List of requirements presented in chapter 3.4, a Product Function Analysis (PFA) Diagram was made to align all relevant functions for the flow measurement unit.

The PFA shows each function, their order and how they affect each other. The functions and sub-functions attribute an order of priority to the list of requirements and factor in certain edge cases, or unintended uses of the product.

The list of requirements can be found below as a summary of the criteria concluded from the research.

The product should:

Performance

• Work for all three types of SFW; boiling, chilled/ filtered and sparkling.
  - Operating Temperature: 4-107°C
  - Pressure: 1-5 bar
  - Flow rate: 0.7-5 L/min

• Dispense a predetermined amount of water with accuracy:
  - 4-6% for small quantities (200-500ml)
  - 6-9% for bigger quantities (1.5-5L)

Compatibility

• Be backwards compatible - compatible with previous Quooker system components from 2017 onwards.

Standards, Rules and regulations

• Be watertight (hidden and insulated electronics)
  - Outside IP21, inside to outside double working pressure (max. 10 bar)
  - Made of water-safe materials
  - WRAS approved and 4Metals

Cost Price

• 200-300 € (consumer price)

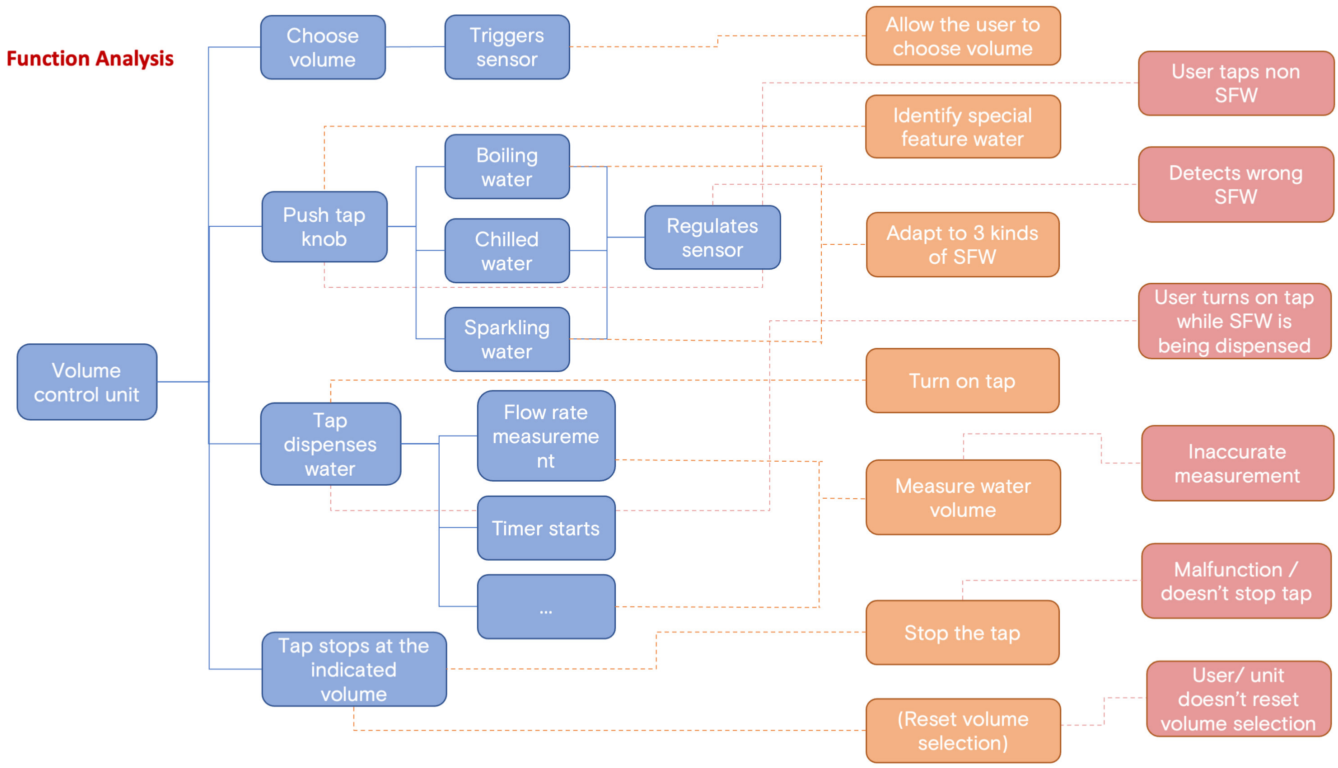


Figure 66. Product Function Analysis incl. functions, sub-functions and unintended uses

6.6 Flow Sensor Matrix

Table 7. Flow sensor types evaluated for the project

	Flow Sensor	No moving parts	Temp. range [C]	Low pressure drop	Flow rate range	Cost price [€]	Turbulence insusceptible	Dimensions	Other
Volume Flow	**Variable Area (eg. Rotameter)**	×	<540	✓	0.2-2 l/min	low	×	6 mm ++	Vertical mounting position
	Differential Pressure (eg. Orifice, pitot)	✓	-270 to 500	×	low to high (<2 l/h)	15-1000	×	15mm-10m	High wear factor
	Turbine	×	-200 to 500	✓	1.6 to 760,000 l/min	low (~2.75 for inserts)	×	6-300mm	Needs periodic maintenance / high wear factor
	Vortex	✓	<300	×	0.9-240 l/m	low (up to 80mm)	×	15-300mm	Needs periodic maintenance
	Positive Displacement PD (eg. Oval gear)	×	up to 200	high (internal wiping seals) low (liquid seal)	0.1-400 l/min	low	×	wide range	Mostly used for viscous fluids and gases
	Electro-magnetic	✓	-40 to 150	✓	0.3 to 10 m/s	50-1000	✓	wide range	Lower conductivity limit 0.05 μS/cm
	Ultrasonic	✓	<200	✓	2-1500 ml/min	low for inserts, high for modules	×	10-1600mm	Not suitable for pipes with inner lining for clamp-on mounting
Volume & Mass Flow	**Piezoresistive**	✓	-40 to 150	✓	wide range	low to high	✓		Consumes relatively more power, small variety
Mass Flow	**Coriolis**	✓	<120	×	few g/h up to 120,000 lbs/min	high	×	2-300mm	
	Thermal	✓	-50 to 120	✓	0-3000 ml/min	30-50	×	15mm-10m	Thermal conductivity of water is higher than steam/ air pockets

The different types of flow sensing technology as presented in the previous Section 5.2 are listed in the table above. These flow sensors are evaluated based on the aforementioned limitations and the Quooker system constraints. The parameters for each category of the table were determined through literature and desktop research, as well as through expert and external company consultations. As dictated by the list of requirements, the flow rate, operating temperature and cost price are the deciding factors for the choice of flow sensor.

The flow sensors to be explored in the next stages of the project are the ones presented in green; turbine, vortex, ultrasonic and thermal flow sensors.

6.7 Solution Space

Table 8. Technologies considered for flow measurement

	Flow sensors	Weight	
Pros	**Accuracy:** Flow sensors can provide highly accurate measurements of liquid flow rates, helping to ensure precision in various industrial and scientific applications.	**Direct measurement:** Weight-based flow measurement directly measures the mass of the liquid, providing a more fundamental and accurate measurement compared to some volumetric flow measurement methods.	**Flow control:** Using a pump precise control over the flow or stroke, you can regulate th requirements.
	Real-time monitoring: Flow sensors offer real-time data, enabling continuous monitoring of liquid flow, which is crucial for process control and optimization.	**High accuracy:** Gravimetric flow measurement can offer high accuracy, especially when used with precise and well-calibrated scales, making it suitable for applications that require precise control.	**Automation:** Pump-based fl easily integrated into automa and consistent flow control w
	Process control: By measuring liquid flow, flow sensors allow for better process control in industrial settings, helping to maintain desired flow rates and detect anomalies promptly.	**Wide range of liquids:** This method is generally applicable to a wide range of liquids, regardless of their viscosity or corrosiveness, as long as the scale material is compatible with the liquid.	**Versatility:** Pumps can hand be used with various liquids, applications across different
	Integration with automation: Flow sensors can be easily integrated into automated systems, making it convenient to control and regulate liquid flow without constant human intervention.	**Minimal influence from environmental factors:** Unlike some flow sensors that can be affected by changes in temperature, pressure, or viscosity, weight-based measurements are less sensitive to these environmental factors.	**Accuracy:** When properly ca measurement can provide re especially in systems with a s
	Non-invasive options: Some flow sensors can be installed externally, without the need to modify the flow path, which minimizes the risk of contamination or disruption to the system.	**No obstruction or clogging:** Since there are no physical obstructions in the flow path, weight-based systems are not susceptible to clogging or fouling due to particles or debris in the liquid.	**Reliability:** Pumps are robus regular maintenance, they ca over extended periods.
		Simple setup: The setup for a weight-based flow measurement system can be relatively simple, consisting of a scale, a container, and a means to control the liquid flow.	
Cons	**Initial cost:** High-quality flow sensors can be expensive, particularly those designed for specialized or high-precision applications, which can pose a barrier to adoption for some users.	**Lag time:** Weight-based flow measurement systems might have some lag time due to the time required to accumulate a measurable change in weight, particularly in applications with low flow rates.	**Limited accuracy at low flo** accurate at very low flow rate or fluctuations that affect the
	Sensitivity to environmental factors: Certain flow sensors can be sensitive to changes in temperature, pressure, or viscosity, which may affect their accuracy and reliability.	**Inertia effects:** Rapid changes in flow rates can lead to inertia effects, affecting the accuracy of the measurements until the system stabilizes.	**Energy consumption:** Runni speeds to achieve specific flo consumption, resulting in hig
	Potential for clogging: In some cases, flow sensors can be susceptible to clogging, especially when used with liquids containing particles or debris, leading to inaccurate readings or system malfunctions.	**Cost and complexity:** High-precision scales and sophisticated systems capable of handling different flow rates can be expensive and complex to implement.	**Calibration and maintenan** require regular calibration ar the overall maintenance expe
	Limited compatibility: Not all flow sensors are suitable for measuring all types of liquids, and some may have limitations based on the liquid's properties (e.g., viscosity, corrosiveness).	**Space requirements:** Gravimetric flow measurement systems may require more space compared to some inline flow sensors, making them less suitable for compact or confined environments.	**Priming and start-up challe** require priming before opera can be a time-consuming pro
	Installation challenges: Proper installation and positioning of flow sensors are critical for accurate readings, and this can be challenging in certain setups, especially in cramped or inaccessible spaces.	**Maintenance challenges:** The scales and associated components require regular calibration and maintenance to ensure accuracy, which can add to the overall costs and system complexity	**Mechanical wear and tear:** pumps can experience wear leading to reduced accuracy
	Electrical requirements: Many flow sensors require electrical power to function, which means additional considerations for power supply and potential safety risks in certain environments.		**Risk of leakage:** Depending there might be a risk of leaka or environmental concerns.
			Space and installation cons measurement systems may r installation compared to som compact environments.

Other than the flow sensors discussed earlier, relevant technologies for flow control include timers and weighing scales as seen in section 5.2. Inspired by the CUBE's system, a pump could provide control over the flow and therefore the dispensed water volume. Similarly, since flow rate is pressure dependent [18], the flow could be measured with a pressure sensor. The table below shows the main advantages and disadvantages of each method.

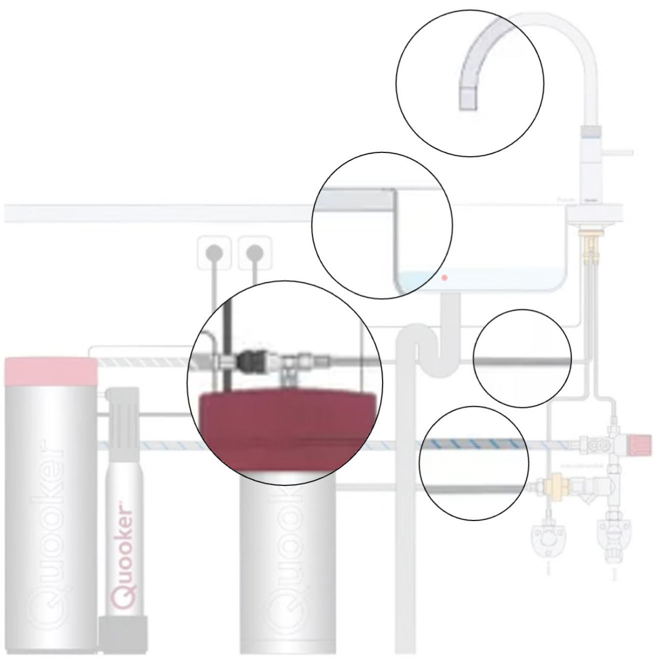
Pump	Timer	Pressure Sensor
to measure liquid flow allows for rate. By adjusting the pump speed he flow to meet specific	**Simplicity:** Timer-based flow measurement systems are relatively simple and cost-effective compared to some other flow measurement methods, such as using flow sensors or pumps.	**Non-invasive:** Pressure-based flow measurement can be non-invasive, as it does not require direct contact with the flowing liquid, reducing the risk of contamination or disruption to the flow.
ow measurement systems can be ated processes, allowing for efficient vithout constant human intervention.	**Low maintenance:** Since timer-based systems do not involve complex mechanical or electronic components, they typically require minimal maintenance.	**Real-time measurement:** Pressure sensors can provide real-time flow measurements, enabling continuous monitoring and control of liquid flow in various processes.
lle a wide range of flow rates and can making them suitable for diverse industries.	**No moving parts:** Timer-based systems do not have any moving parts, reducing the risk of wear and tear or mechanical failure.	**Accuracy:** When properly calibrated and installed, pressure-based flow measurement can offer good accuracy and reliability in a wide range of flow rates.
librated, pump-based flow easonably accurate measurements, stable and consistent flow.	**Suitable for low flow rates:** Timer-based systems can be useful for measuring low flow rates that may not be easily measurable with certain flow sensors or pumps.	**Low maintenance:** Pressure sensors generally have no moving parts, resulting in low maintenance requirements and longer service life.
t and reliable machines, and with n provide consistent performance	**Non-invasive:** Timer-based systems can be non-invasive, not requiring any modification to the flow path, making them suitable for some applications where inline flow sensors might not be practical.	**Compact and versatile:** Pressure sensors are often compact and can be easily integrated into existing systems, making them suitable for various industrial applications.
w rates: Pumps might not be as es, as they can experience pulsations e measurement precision.	**Accuracy:** The accuracy of timer-based flow measurement heavily relies on the consistency of the flow and the precision of the timing mechanism. Variations in flow rate or inaccuracies in timing can lead to significant measurement errors.	**Requires calibration:** To achieve accurate measurements, pressure sensors need to be calibrated for specific flow rates and liquid properties, which may require additional time and effort during setup.
ing pumps continuously or at high w rates can lead to increased energy gher operating costs.	**Limited to constant flow rates:** Timer-based systems are most accurate when the flow rate remains relatively constant during the measurement period. Any fluctuations in flow can result in inaccurate readings.	**Limited accuracy at low flow rates:** Pressure-based flow measurement might not be as accurate at very low flow rates, as the pressure difference might be too small to provide precise readings.
ce: To maintain accuracy, pumps d maintenance, which can add to enses.	**Inability to capture real-time changes:** Since timer-based systems measure the time it takes to accumulate a certain volume, they might not capture real-time changes in flow rates.	**Susceptible to environmental changes:** Changes in temperature, pressure, or viscosity of the liquid can impact pressure-based flow measurements, leading to potential inaccuracies.
enges: Some pump types may ation, and getting the system started ocess.	**Environmental factors:** Timer-based measurements can be influenced by environmental factors such as temperature, pressure, and humidity, affecting the accuracy of the results.	**Flow profile sensitivity:** The accuracy of pressure-based flow measurement can be affected by the flow profile, especially in turbulent flow conditions.
The mechanical components of and tear over time, potentially or system failures.	**Cumulative errors:** In long-duration measurements, small inaccuracies in timing or measurement can accumulate and lead to larger errors.	**Pressure drop concerns:** Pressure sensors introduce a pressure drop in the flow path, which can be a consideration in systems with limited pressure margins.
on the pump type and application, ge, which can lead to safety hazards		**System complexity:** Pressure-based flow measurement systems might require additional components, such as differential pressure transmitters, to convert pressure readings into flow measurements, adding to the overall system complexity and cost.
siderations: Pump-based flow require more space and careful e inline flow sensors, especially in		**Invasive installations:** While some pressure sensors can be non-invasive, others may require insertion into the flow path, which can create potential points of failure or maintenance challenges.

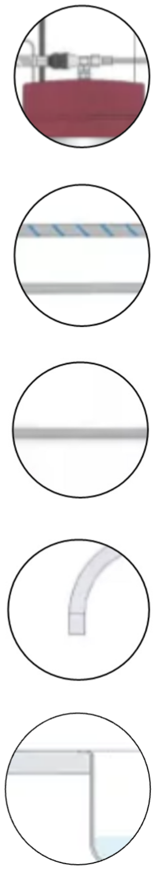
Table 9. Evaluation of flow measurement methods for development

	Flow sensors	Weight	Pump	Timer	Pressure sensor
Accuracy	✓	✓	✓	✗	-
Reliability	✓	✗	✓	✗	-
Cost	-	-	✗	✓	✓
Space claim	✓	✗	✗	✓	✓
System Complexity	✗	✓	✗	✓	✗

All five methods were evaluated based on their pros and cons in accordance with the list of requirements. An overview of this assessment is illustrated in table 9. It needs to be noted that this early evaluation was based on the data obtained by desktop and literature research and a couple of methods could be selected for further exploration and development in consideration of the project's timeframe, namely flow and pressure sensors.

Below-counter Unit Placement





Outlet of Quooker/ T-Point
Pros: Accuracy, easy to mount
Cons: Suitable for different water temperatures

Inlet Water Tube
Pros: Constant temperature (cold), no limescale
Cons: Difference in nlet vs outlet flow rate

(Around) Outlet Water Tuber
Pros: No direct contact with water
Cons: Expensive, inconsistencies with different kinds of water

Aerator
Pros: Easy to mount and maintain
Cons: Electronic connection, limited space, functionality

External / In-around sink
Pros: Avoid system complexities
Cons: Out of Quooker's scope, system integration, accuracy possibly

Figure 67. Flow sensing unit placement pros & cons

Lastly, the Discover section of the Flow measurement unit is concluded with the possible locations to implement the measuring technology. There are five different locations to measure the flow in the system, shown in Figure 67:

- **Outlet of Quooker / T-Point**
  The outlet of the Quooker, also known as T-Point, is the point where all kinds of special feature water are dispensed. The CUBE (and CWF) connect to the Quooker in that point and when the valve opens, water runs through the T-joint. The benefit of this location is that the flow technology measures the flow directly before the water gets dispensed, thus omitting the forenamed complexities of the reservoirs. However, this implies that the technology employed at that juncture must be capable of managing all characteristics associated with the special water, ranging from low to high temperature and the presence of gas bubbles, as well as limescale buildup. Such circumstances could potentially present design challenges and increased costs.

- **Inlet Water Tube**
  An alternative approach for measuring flow is utilizing the water inlet of the system. In this case, the flow is measured prior to the water entering the reservoirs, ensuring consistent water flow conditions in terms of temperature and water composition. The disadvantage of this location lies within the intricate nature of the system, as the flow measurement technology must account for all the limitations mentioned in section XX to guarantee that the measured flow at the inlet corresponds to that at the outlet.

- **(Around) Outlet Water Tube**
  Certain technologies offer alternatives for mounting around/ on the outside of water tubes. This method increases the lifespan of the unit since it doesn't come in direct contact with water and impurities such as particles in the water and limescale. Nevertheless, these technologies can prove to be expensive, necessitating the capability to accommodate all types of special feature water when installed at the outlet, and require the use of specific types of unlined tubes.

- **Aerator**
  A more unconventional location for the flow measurement is the aerator at the end of the tap. This is the exit point of the water when dispensed. This location ensures that the flow measured is the exact one that reaches the user's container. However, this could be a challenging application due to the limited space and obstructed connection to the rest of the system.

- **External / In-around sink**
  A flow measuring application separate from the Quooker system poses another alternative. In this scenario, the water is measured after it exits the system, possibly through weight/ a scale. This is another method to avoid system complexities, but it is out of Quooker's scope since it isn't connected to the system below the counter.

These options, alongside the technology illustrated in the previous table are going to be explored and tested in the Chapter Develop. The technology selection for further testing is shown in Section 7.1, alongside testing in 7.2.

FLOW MEASURE-MENT

7

Develop
flow measurement

After identifying the available technologies for this application, the Develop phase of the flow measuring unit is initiated with ideation. Even though the options are not as many as for user interaction, every possibility is explored and evaluated based on the information gathered.

To accept or reject possible candidates, tests are conducted in the testing lab within the R&D, were the flow sensing technology is tested with the Quooker system and its limitations. Calibrations are made and the choices are investigated leading to a turbine flow sensor, placed at the system's water inlet, as the optimal candidate out of the ones investigated.

7.1 Ideation

Similarly to the other sections, ideation for "User Interaction" and "Flow Measurement" were conducted in parallel, thus they employ the same methods. However, the directions within the Flow Measurement ideation were more limited in comparison to User Interaction. These directions are illustrated in the mind map in Figure 68, following the evaluation presented in Section 6.7. Based on the list of requirements methods like the pump and the timer were eliminated. Using weight as a method for flow measurement was investigated in the "User Interaction" Chapter (Section 4.2) and it was decided not to proceed in that direction.

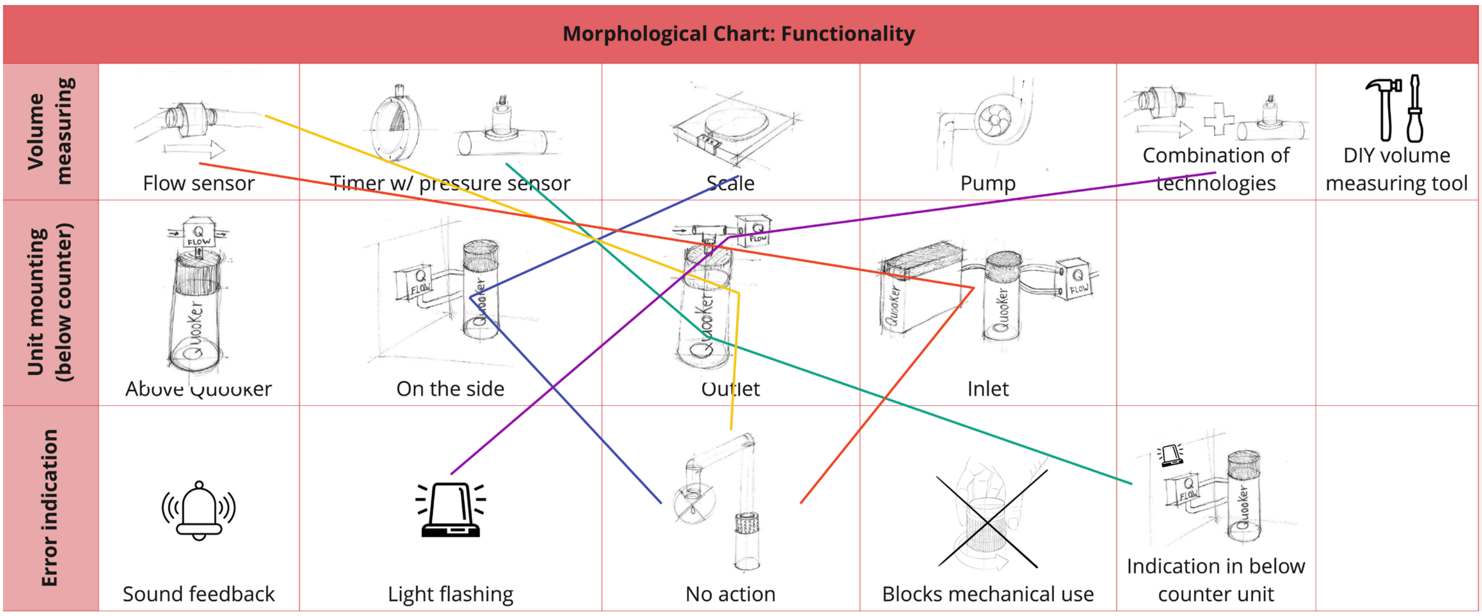
The morphological chart below presents different combinations of functions and sub-functions. Flow measurement and control remain the main functions, with the sub-functions including installation (e.g. unit mounting) and error indication (for maintenance and user communication.

As presented earlier, there are two questions to be answered in this chapter:

- Which is the best suitable technology for flow measurement?
- What is the ideal location of flow measurement within the system?

Table 10. Morphological Chart of possible flow measurement function and sub-function combinations

Morphological Chart: Functionality						
Volume measuring	Flow sensor	Timer w/ pressure sensor	Scale	Pump	Combination of technologies	DIY volume measuring tool
Unit mounting (below counter)	Above Quooker	On the side	Outlet	Inlet		
Error indication	Sound feedback	Light flashing	No action	Blocks mechanical use	Indication in below counter unit	



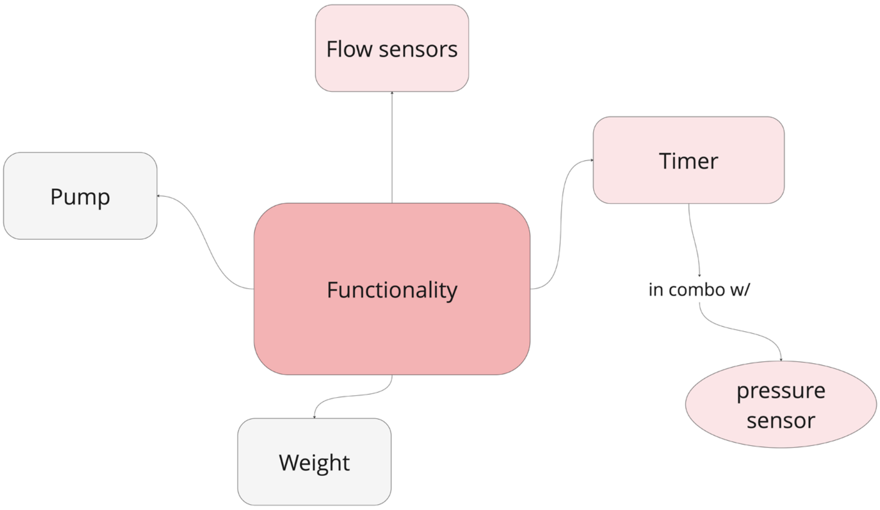


Figure 68. Mind-map for flow measurement

Due to the different types of special water and their distinctive properties, one of the solutions could be using two separate flow or pressure sensors, one for the Quooker and one for the CUBE. This way, each flow sensor would be calibrated based on each reservoirs unique characteristics to achieve the highest possible accuracy. However, incorporating two flow measuring units instead of one would result in increased costs, both in manufacturing and consumer price. For this reason, looking back at the use cases (Section 2.4), the focus was set on the Quooker. The Quooker reservoir is Quooker B.V.'s protagonist alongside the taps, and a standalone feature, in comparison to the CUBE.

Therefore, testing featuring a single sensor was initiated, looking at the type of sensor and its placement. The next section presents these tests and accompanying results.

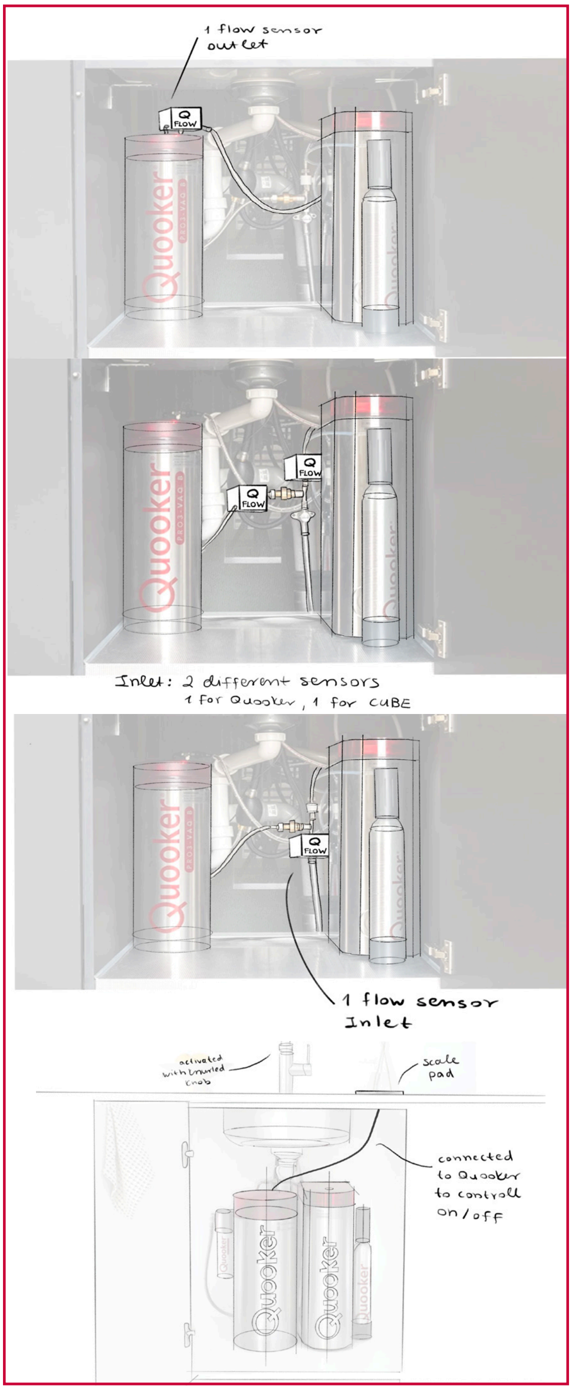


Figure 69. Flow rate and Pressure Measuring Points

7.2 Flow Sensor Testing

Based on the research from Section 6.6, four different types of flow sensors were deemed suitable for this application, namely Turbine, Vortex, Thermal and Ultrasonic flow sensors. Due to the limited time provided for this project, 2 of these flow sensors were tested; the Turbine and Vortex flow sensor.

The tests were conducted in the Water lab within R&D, under controlled circumstances. An inlet pressure of 5 bar was regulated by a pump with small deviations due to its efficiency over time. A bigger variety of inlet pressures was examined for the pressure-flow control. Each test was repeated 10 times for the volumes of 100ml, 250ml, 500ml, 1l, 1.5l and 2l. This way, a big range of volumes, small to large, was explored to evaluate the performance of the sensors and determine calibration, as well as the best candidate for this project. This was repeated for each type of special feature water (3 times).

The test set-up is pictured in Figure 70 and the procedure during the tests was as follows:

1. A flow sensor was placed in the system of the Quooker, outside the reservoir, connected to both the Quooker reservoir and the CUBE.
2. An application on the computer connected to an Arduino and the flow sensor gave the input of the desired volume and turned on manually each type of SFW.
3. The “Kraanprater”, a device to control when the tap starts and stops tapping, connected the computer with the Quooker.

Thermal flow sensor

Due to its interesting nature, a Thermal flow sensor was obtained for experimental testing of the 3 different special waters separate of the system due to its small size (Fig. 71). However, other alternatives were explored further because of time limitations.

Figure 70. Flow Sensor Test Set-up; Quooker system, flow sesnor, laptop with control application, container, precision scale

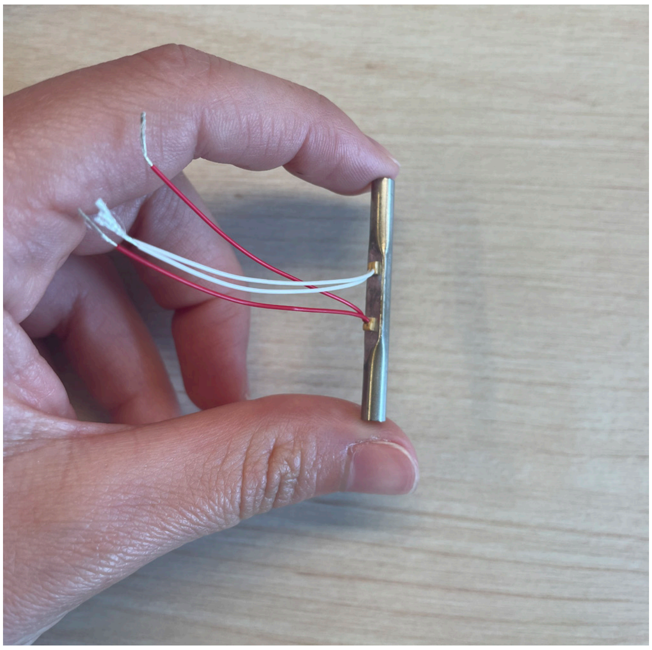


Figure 71. Thermal flow sensor from IST A.G.

Figure 72. Vortex Flow Sensor by HUBA Control AG

Vortex flow sensor

The Vortex flow sensor was tested at the outlet of the Quooker system. This means that 3 different types of water were to flow through this module:

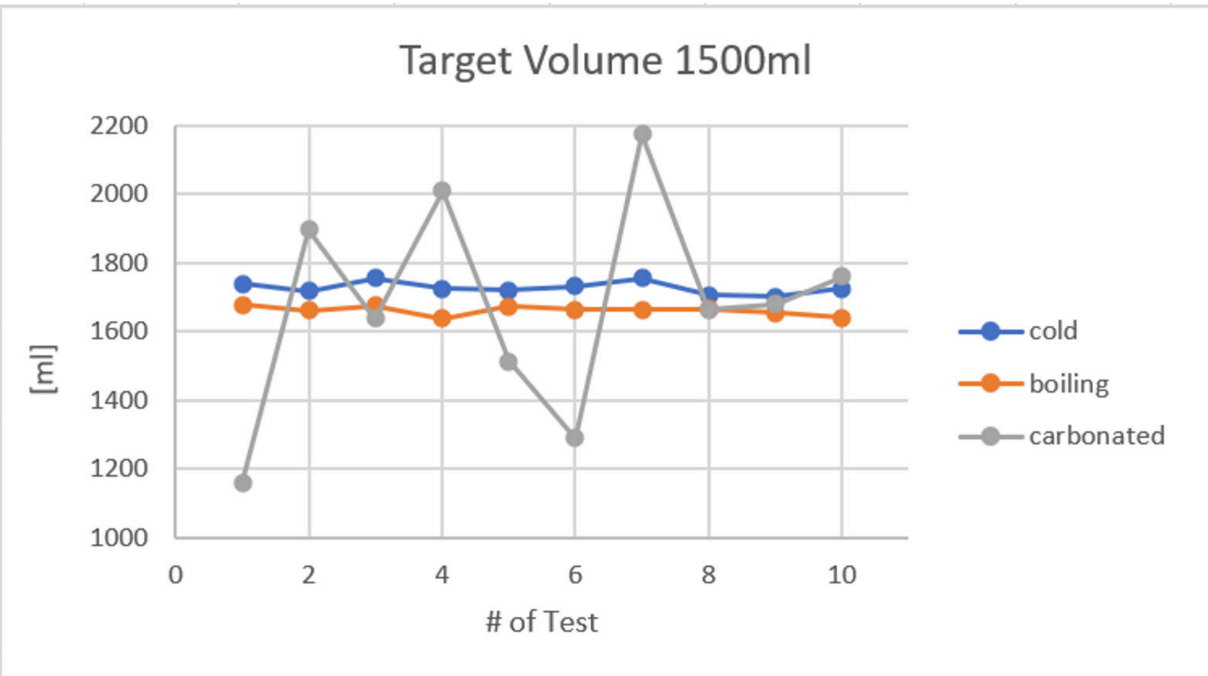
- Boiling water at 100°C including surrounding steam.
- Chilled water at 4°C.
- Carbonated water at 4°C including CO2 bubbles.

This flow sensor was the only one tested at the outlet because it could handle such high temperatures. The reason for testing at the outlet of the Quooker was to avoid any effects that the system may have on the flow of the water, such as the CUBE pump and the Bellow in some Quooker reservoirs. These effects are easily detectable by a flow sensor at the outlet in comparison to one at the inlet.

The results from the vortex inlet tests were more consistent than expected for the cold and boiling water. The overshoot for each targeted volume fluctuated between 15-30% for the cold and 10-30% for the boiling water. Since the deviation was more or less consistent over the experiments, these percentages can be improved by a simple calibration.

However, when it comes to carbonated water, the deviation from the target volume was very inconsistent. This effect is connected to the CO_2 bubbles in the water, which obstruct the signal within the Vortex sensor. This outcome was predicted by HUBA, the company supplying the flow sensor, however, it was interesting to explore if there was a pattern for the percentage of deviation. As illustrated in Graph 6, the deviation behaves very unpredictably (grey line) and thus is hard to calibrate.

Due to these results and the high price of the flow sensor, it was decided to continue in a different direction.



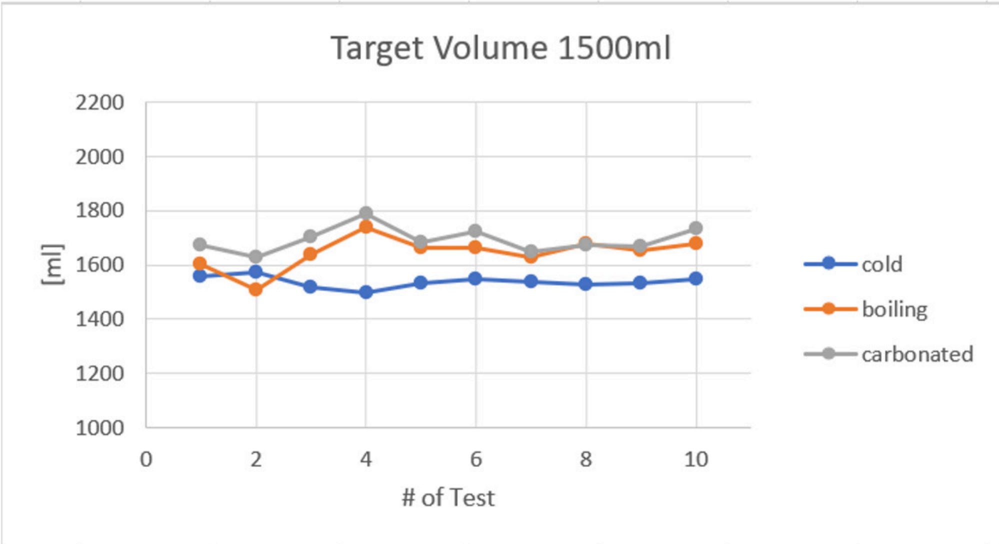
Graph 6. Volume deviation during tests for 1500ml target volume, Vortex Flow Sensor Outlet

Turbine flow sensor

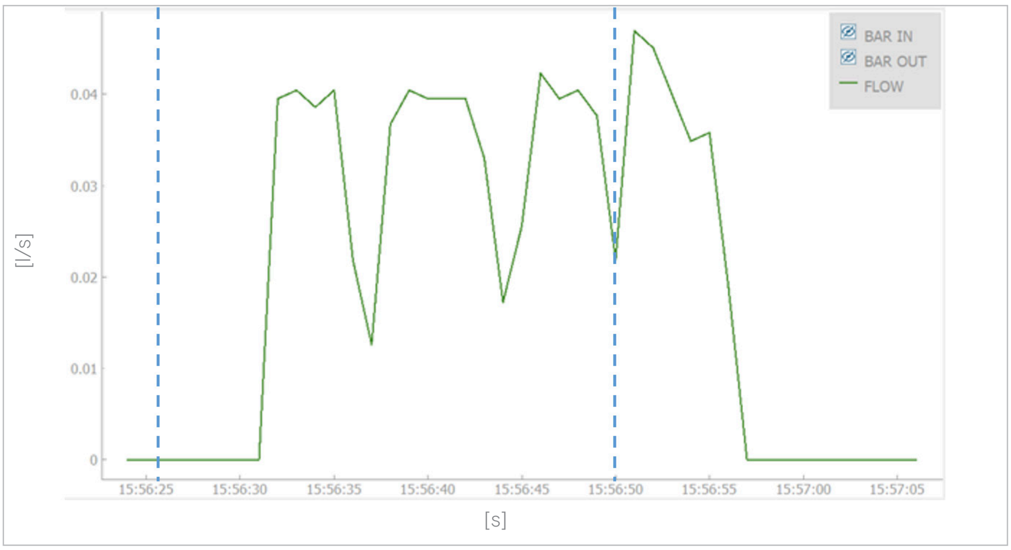
The Turbine flow sensor was tested at the inlet of the Quooker. It had to be placed before the reducing valves of both the Quooker and the CUBE in order to measure the inlet flow in both devices. As expected, the results from this flow sensor are more consistent due to the constant temperature and state of the water flow, without any steam or gas bubble buildup.

The initial results showed some overshoot in the volume dispensed by the system. For the chilled water, the overshoot ranged approximately from 27-48ml, while for the boiling water the overshoot was higher at 85-155ml. The deviation from the target volume of 1500ml is mapped in Graph 7 bellow. The more consistent curves contrary to Graph 6 already show the better performance of the Turbine flow sensor in comparison to the Vortex.

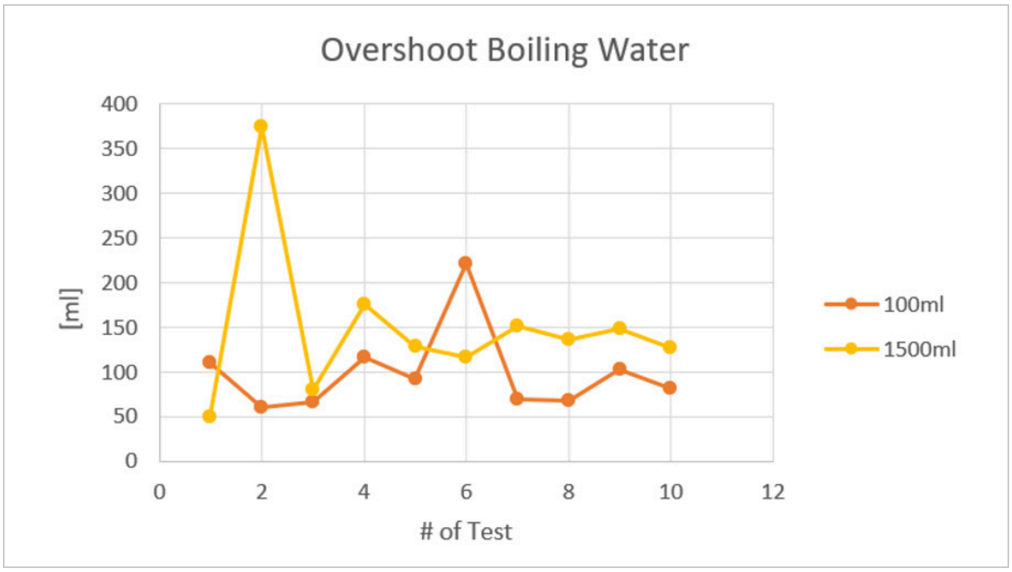
As also seen in Graph 7, there were many inconsistencies in the results of the carbonated water, connected to the core functionality of the CUBE. When the user taps carbonated water, a certain amount is first dispensed from the CUBE reservoir and after the pump starts pumping water in the system. This is also shown in Graph 8. During this time interval, there isn't any water flowing through the flow sensor, so the system thinks that the flow rate in the outlet is zero as well. The water dispensed before the pump is activated is approximately 200-300ml, a significant amount especially when smaller water volumes are targeted. The pump stops pumping water in the CUBE several seconds after the dispensing has ended, to reach the desired water level in the reservoir. Other than that, the system rinses itself with clear water to remove CO2 for a couple seconds at the end of the tapping of carbonated water.



Graph 7. Volume deviation during tests for 1500ml target volume, Turbine Flow Sensor Inlet



Graph 8. Green: Inlet Flow rate, Carbonated water, Blue: Tapping starts and stops



Graph 9. Volume deviation during tests for 1500ml target volume, Turbine Flow Sensor Inlet

	100ml	250ml	500ml	1000ml	1500ml	2000ml
	110,2	67,1	59,6	49,3	102,3	90,3
	60,6	74,9	70,3	373,9	6,9	320,8
	66,5	77,6	46,1	79,5	136,7	180,8
	115,7	129,2	147,9	175,2	240,1	91,6
	92,1	83,3	124,5	128,8	164,3	343,9
	221,13	89,2	139,7	116,9	161,5	199,1
	69,4	112,9	178,3	151,2	128,5	419,9
	67,45	126,4	119,6	135,4	179,6	154,2
	102,3	122,8	88,9	148,4	154,3	421,2
	81,8	129,6	96,7	126,4	175,7	214,9
Avg.	85,116667	101,3	107,16	123,45556	150,3625	155,15
%	0,8511667	0,4052	0,21432	0,1234556	0,1002417	0,077575

Table 11. Volume overshoot for boiling water

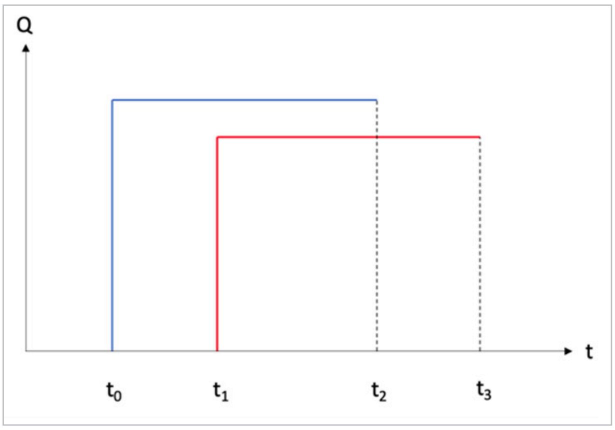


Figure 73. Illustration of the effect of the Bellow in the flow sensor measurements (approximation)

All these parameters contribute to irregular volumes of carbonated water that are hard to predict or approximate with the implementation of the flow sensor at the inlet. After consultation with Quooker engineers, the best option for this application would be to use a timer for the dispensing of carbonated water, to approximate the targeted volume.

The effect of the Bellow tank is also evident in the turbine flow sensor results. As seen in Table 11, some of the results indicate a significant increase in the overshoot. This effect stems from the expansion of the Bellow tank.

While the water in the tank is being heated up, the water volume expands. This extra volume in the expansion is first dispensed when the valve opens, before new water flows into the reservoir. Fig. 73 illustrates the effect of the Bellow. When the valve opens at time t0, the flow sensor doesn't pick up any inlet flow. Only at t1, when the Bellow has fully retracted and new water is entering the reservoir, the flow sensor starts measuring the dispensed volume and then closes the valve at time t3 (red line) even though it should have stopped tapping at t2 (blue line).

7.3 Pressure Sensor Testing

The flow rate in a pipe exhibits a proportional relationship with the pressure. An increase in pressure results in a corresponding increase in flow rate. Within any given section of a pipeline, pressure solely originates from one end, indicating a unidirectional flow. When the outlet is closed via valve closure, the fluid within the pipe remains stagnant. Upon opening the outlet, the flow rate becomes dependent on the pressure present within the pipe.

There are two mathematical equations commonly used to calculate flow rate within pipes, the Darcy-Weisbach equation and the Hazen-Williams equation. They are as follows:

- The Darcy-Weisbach equation is used to calculate the flow rate in pipes when con sidering the effect of pipe roughness.

  Q = (π/4) * D^2 * (ΔP / (f * L))^(1/2)

  where:

  Q is the flow rate (volume per unit time),
  D is the pipe diameter,
  ΔP is the pressure drop along the pipe,
  f is the Darcy friction factor, and
  L is the length of the pipe.

  The Darcy friction factor (f) depends on the Reynolds number (Re) and the pipe roughness. It can be determined using various empirical equations or obtained from Moody's diagram. [18]

- The Hazen-Williams equation is often used for estimating flow rates in pipes for water systems. It is a simplification of the Darcy-Weisbach equation. The Hazen-Williams equation is primarily used for water flow calculations in municipal water supply systems.

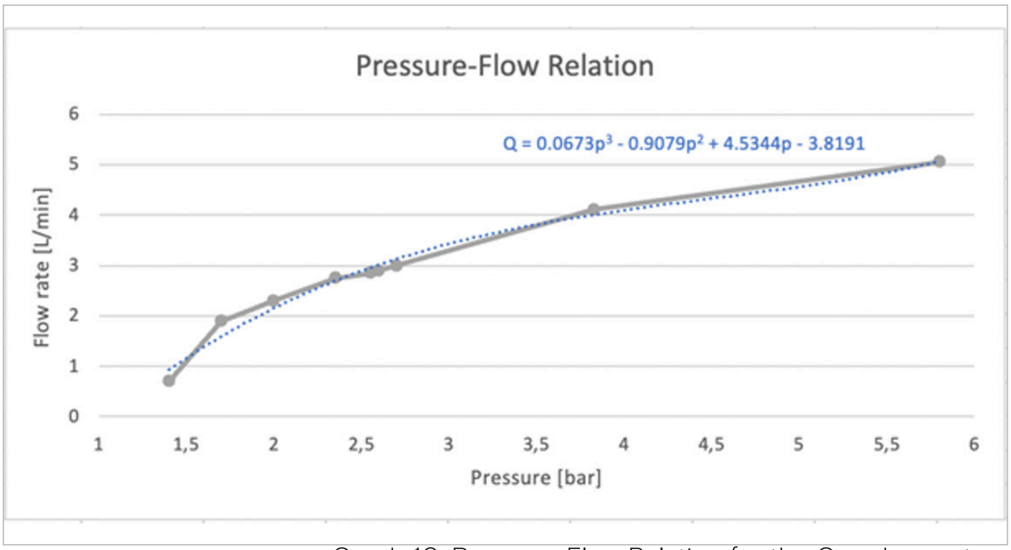
  Q = (C * D^2.63 * H^0.54) / (L^0.63)

  where:

  Q is the flow rate (volume per unit time),
  C is the Hazen-Williams coefficient (depends on the pipe material and roughness),
  D is the pipe diameter,
  H is the hydraulic gradient (difference in water surface elevation divided by the pipe length), and
  L is the length of the pipe. [19]

The parameters affecting the flow rate in the pipe include pipe properties such as diameter, length and height difference, water pressure and temperature, affecting the density and viscosity of the water. Since pipe properties and temperature are usually constant in the inlet setup of the Quooker, to simplify these formulas, a new equation was derived from experimental values obtained from tests on the Quooker (Graph 10).

This equation describes the relation between pressure and flow rate and approximates the flow rate at the inlet of the system based on



Graph 10. Pressure-Flow Relation for the Quooker system

measurements obtained by a pressure sensor. Pressure sensors are quite common and widely used in various industries and applications and pose a more inexpensive alternative to the previous methods mentioned.
The pressure measurements are to be obtained after the reducing valve at the inlet of the Quooker, since the reducing valve regulates the inlet pressure. The Quooker reservoir and the CUBE each have a separate reducing valve, meaning that the flow is split before reaching each individual reducing valve. For this reason, the flow rate-pressure measurements were only conducted on the boiling water system.

The tests showed promising results under higher pressure (7-10 bar), with a deviation of 30-40ml from the requested water volume for both small and big volumes. The overshoot was quite consistent in all range of pressures, however, in lower pressures (<=6 bar) the overshoot was too high. This can be attributed to inaccuracies in the derived formula.

In conclusion, the pressure sensor poses an interesting and inexpensive alternative to flow sensors. However, it still needs to be optimized for a wider range of pressures for measuring the volume of boiling water. For the CUBE (chilled and sparkling water), a timer could suffice for volume dispensing, calibrated accordingly for the pump in the system. Furthermore, the derived formula should be verified based on the aforementioned Darcy-Weisbach and Hazen-Williams equations, by implementing a temperature sensor and the specific pipe properties. Due to time constraints, this method wasn't explored further.

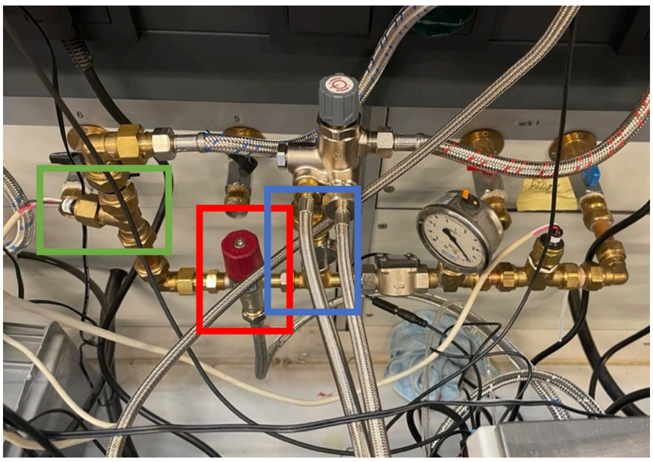
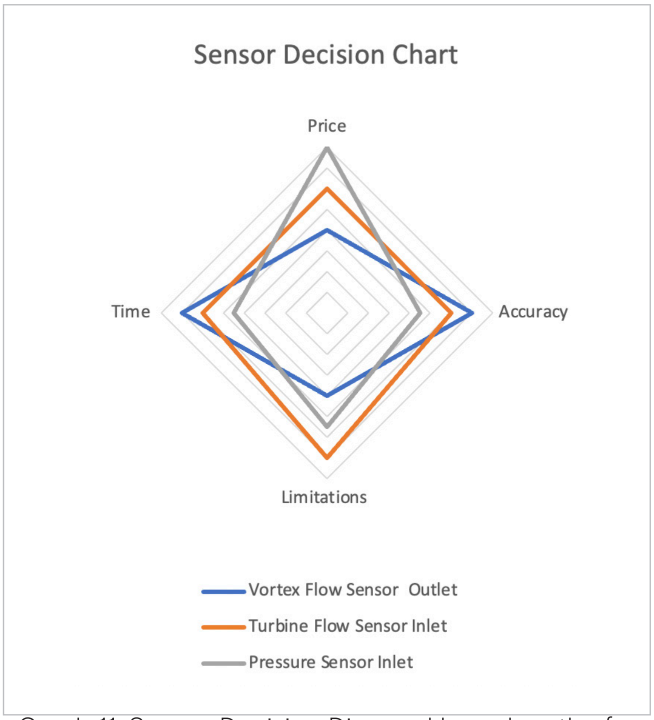


Figure 74. Pressure sensor inlet set-up with pressure sensor (green), Quooker reducing valve (red), CUBE reducing valve (blue)

7.4 Selection & Iterations



Graph 11. Sensor Decision Diamond based on the four parameters; Price, Accuracy, Time, Limitations

Out of the three flow tests, the Turbine flow sensor was deemed as the best candidate due its performance in terms of deviation consistency, price and adaptability/ placement in the system. Graph 9 illustrates the performance of each sensor based on the four parameters:

- Price: The cost price of the sensor plays an important role, as it is meant for a consumer product.

- Accuracy: The Vortex Flow Sensor showed the best initial accuracy when measuring water volume (excluding carbonated water, see Section 7.2). The accuracy for the other candidates can be improved by proper calibration.

- Time: This parameter refers to the time needed for further testing, optimization and calibration of the sensor to implement in the system, in order to achieve the desired accuracy of 4-9% as presented in the list of requirements (Section 6.5).

- Limitations: external variables that might affect the performance of the flow sensor include; limescale buildup, temperature variations and gas particles. This parameter shows how susceptible the sensor is to limitations.

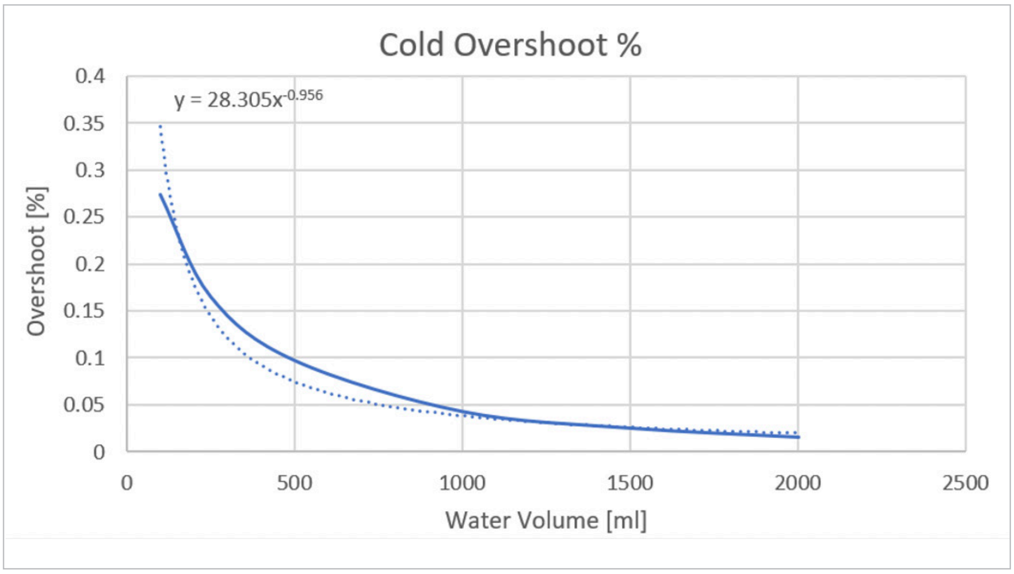
The Turbine Flow sensor offers the best trade-off for this applications and it has been chosen for implementation in this project.
In order to improve the performance of the flow sensor, several steps are decided upon for calibration.

Cold and Boiling Water Overshoot

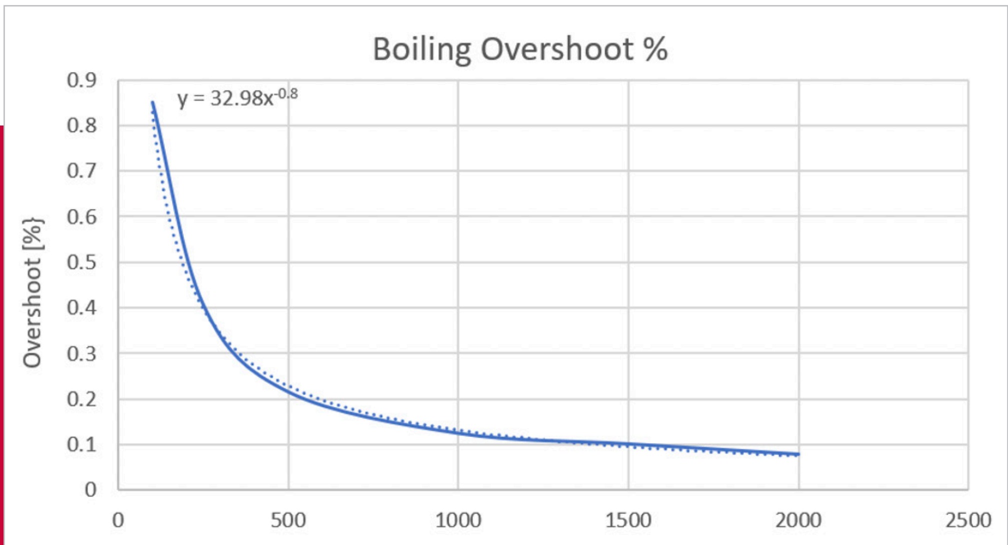
The percentage of the overshoot per volume of water is mapped in Graph 12 for cold water and Graph 10 for boiling water.
3
The trend lines in both graphs provide a mathematical approximation of the overshoot percentage, meant to calibrated the tapped volume of water in order to approach the target volume as much as possible.

In this formula, y is the overshoot percentage, a known parameter from previous tests, and x is the unknown tapped volume. The goal is to retrieve y. In order to calculate x, the Newton-Raphson method is applied in form of an algorithm.

T = x * (1 + y) , T: target volume
y = T/x - 1
y = 32.98 * x^(-0.8) , for the case of boiling water
T/x - 1 = 32.98 * x^(-0.8)
T = 32.98 * x^(0.2) + x , substitution u = x^(0.2)
T = 32.98u + u^5
f(x) = 32.98u + u^5 – T, with T const. target volume selected by the user



Graph 12. Exponential relation of overshoot for Cold Water



Graph 11. Exponential Relation of Overshoot for Boiling wate3

The Newton-Raphson method is an iterative numerical method used to find the roots of a differentiable function, by producing successively approximations to the roots [21].

This algorithm has been applied to the system and shows very promising results, with an improved accuracy of around 98%.

The Bellow effect

The Bellow effect increases the overshoot as explained in section 6.4. This effect was discussed with engineers within the R&D specializing in the production of the Bellow. Upon recommendation, in order to eliminate this effect, the system should recognize when the valve is open, while no water is flowing through the flow sensor. In this case, the flow rate in the interval t1 - t0 (Figure 73) will be approximated to 3L/min, the average flow rate of the Quooker system.

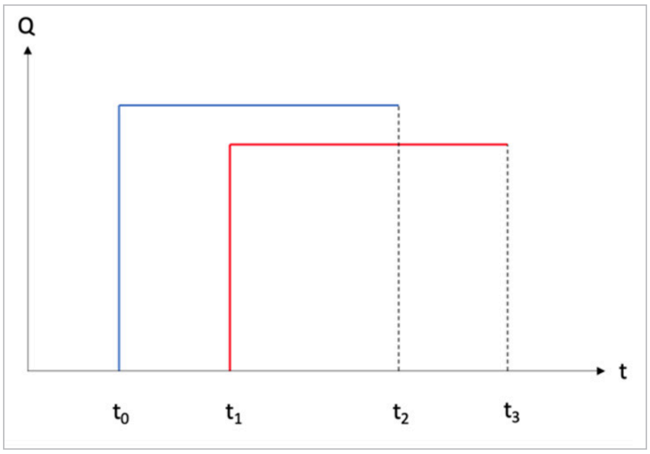
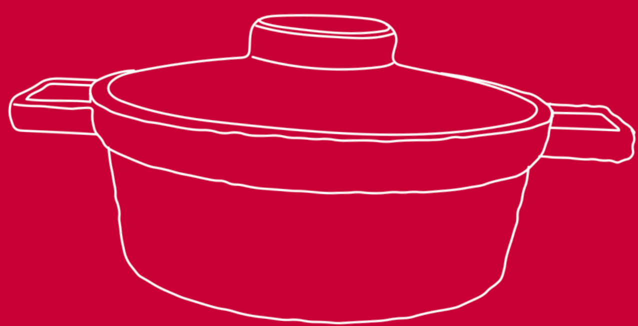


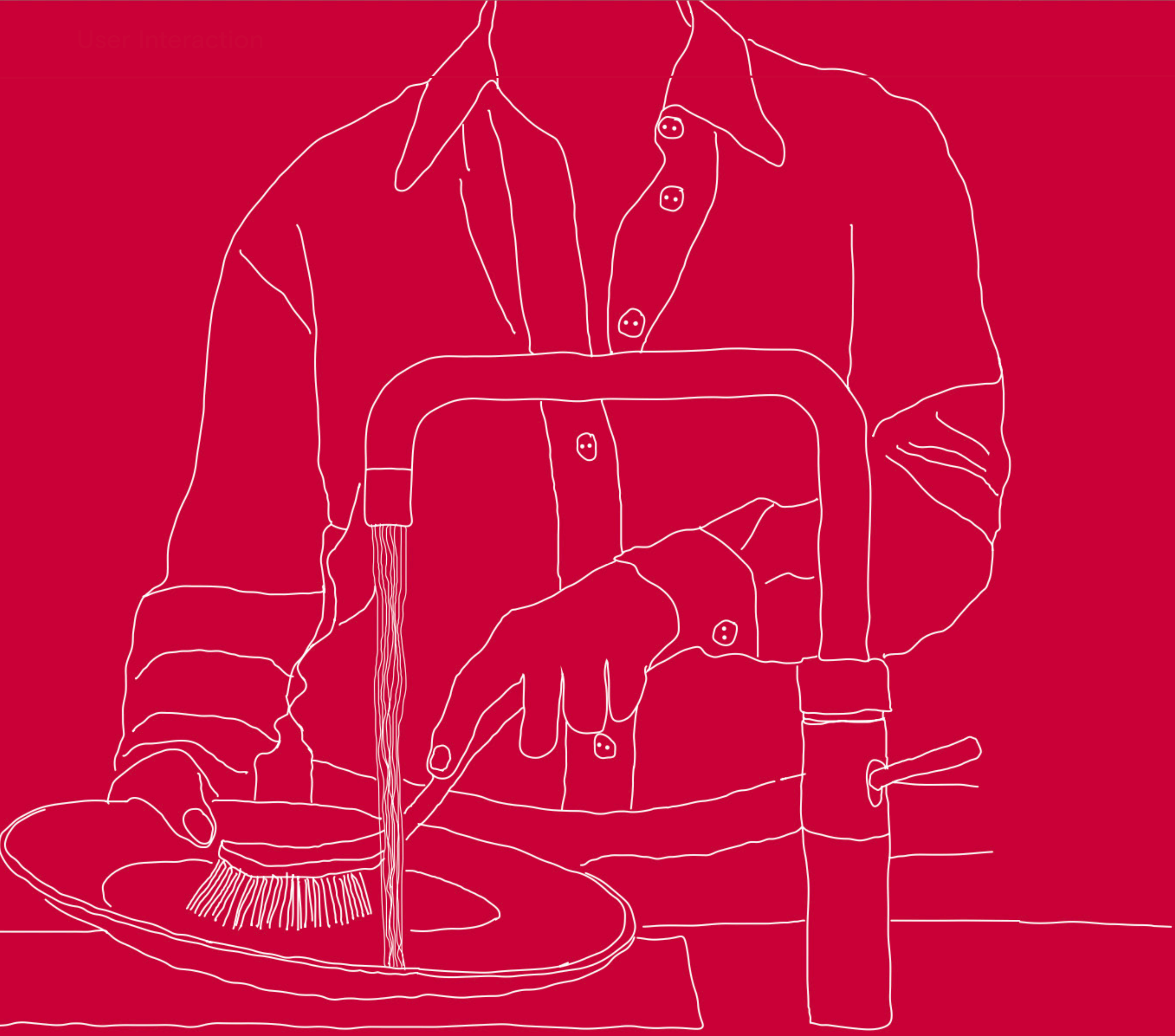
Figure 73. Illustration of the effect of the Bellow in the flow sensor measurements (approximation)

Carbonated water with timer

As mentioned above, a timer for the dispensing of carbonated water will be implemented to approximate the target volume. A rule of thumb is that the CUBE pump dispenses water at a rate of 2L/min based on the pumps rpm. This depends on the pump's efficiency, so it would be advised to calibrate the system upon installation.

Figure 75. Bellow reservoir within Quooker, expands when water is heated up and retracts upon valve opening





FLOW MEASURE- MENT

8

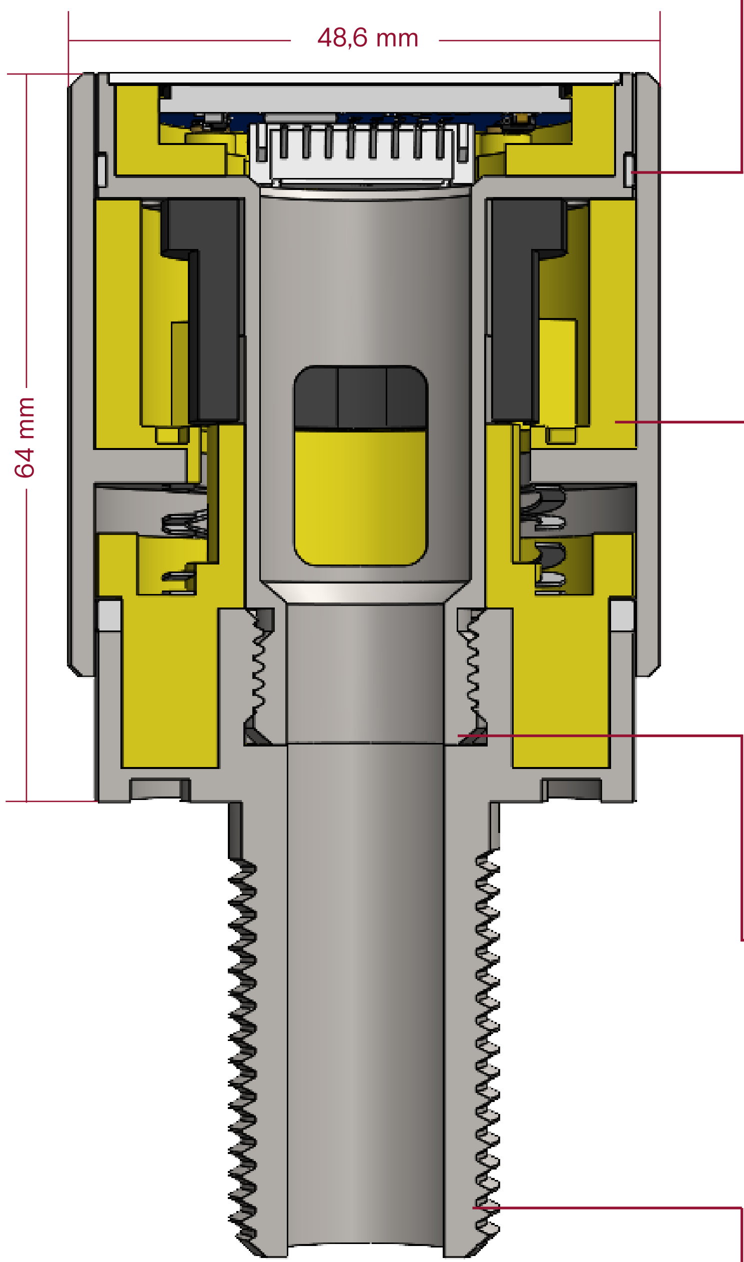
Deliver
embodiment

This section will present the final design choices for both the user interaction module and the flow sensor unit, as well as how they are connected and function as one (embodiment).

A preliminary Cost Analysis will be included to provide a guideline for Quooker for further development and production, as well as changes to the initial design to ensure manufacturability.

Lastly, recommendations will be provided for the implementation of the product and next steps in the design process.

8.1 Design decisions



POM sliding rings

POM stands for Polyoxymethylene, a highly crystalline and durable material with excellent mechanical properties. The sliding rings are placed between the outer ring and bottom/middle components to establish better friction between the parts and reduce noise. POM has a low coefficient of friction, which means it has excellent sliding properties.

Plastic Inserts

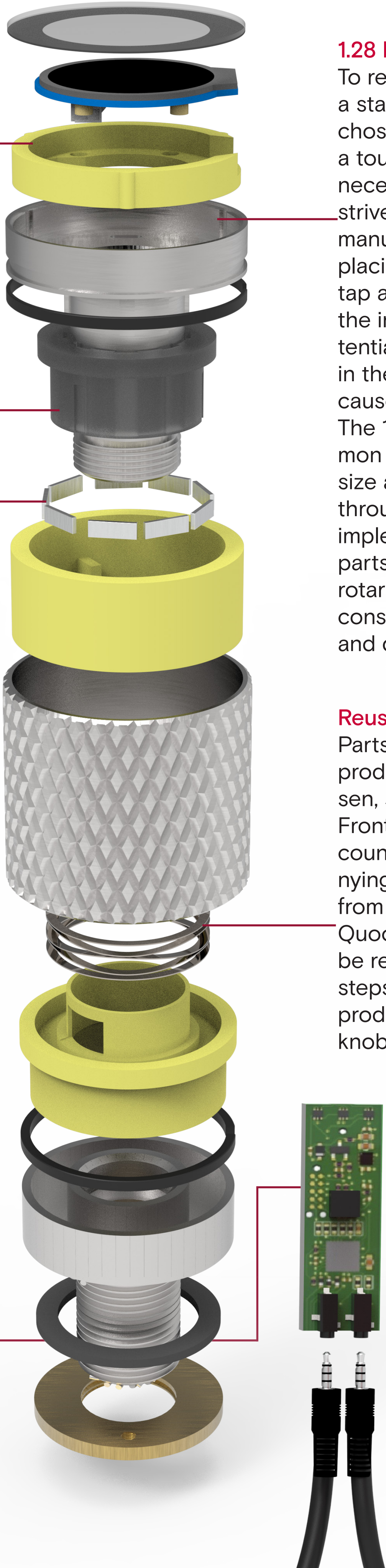
Plastic inserts are placed within the outer shell to hold the inner components in place. These inserts are designed to be injection moulded in China, similarly to other Quooker components within the tap and reservoirs. This reduces manufacturing costs and increases design flexibility within the outer shell. These plastic inserts will be out of Nylon 12, a polyamide which exhibits low friction, good chemical resistance, for instance against kitchen detergents, and low water absorption, maintaining its mechanical properties in humid environments.

Assembly

Assembly has been taken into account during the design of the knob. The middle and bottom component are connected through a thread, the plastic inserts have push-fit connections to the outer shell and the electronics are push fitted, in the case of the rotary encoder, as well as mount by screws (screen on plastic insert). This way, assembly is facilitated when manufacturing the knob, as well as disassembling it for repair.

Counter Mount

The bottom component of the knob is inspired by the counter connection of Quooker's soap dispenser. The electronics' cables run through the hole in the middle and the outer part is identical to the soap dispenser mount, made to be fed through a 25mm hole and fastened with a ring on the bottom side of the counter.



Tempered Glass
The LCD screen is protected with a tempered glass on top against water, dirt and scratches. This glass panel is silk printed with a black rim to cover the edges of the display and offer a more aesthetic and professional look. The glass is connected to the inner casing with glue strips, thus providing a watertight seal.

Rotary Encoder Hollow Shaft
This component is another off-the-shelf part alongside the LCD screen. The hollow shaft feature was chosen as an iteration from the previous encoder to enable placement around the central axis of the knob and provide space for the electronics' cables to run through. The encoder is chosen to be placed on top, upside down, to allow vertical movement of the outer knob and provide more space for the components below.

Magnets
Magnets are placed in the plastic inserts that rotates the encoder and slides up and down with the outer knob. These magnets replace the pushbutton used in previous prototypes and operate alongside a hall sensor that senses the change in the magnetic field. This is easy to implement, since Quooker already has experience with magnets and hall sensors in taps.

PCB
Both units are operated by a single PCB. The PCB is placed within the UI Unit, since it contains most electronics; display, encoder and hall sensor. The PCB connects with an AUX cable to the Quooker reservoir for power and to control the tapping. The second AUX cable is connected to the flow sensor.

1.28 Inch Round Display
To reduce manufacturing costs, a standard size LCD display was chosen. The implementation of a touch screen wasn't deemed necessary, since the design strives to stick to Quooker's manual interaction. Furthermore, placing a touch screen near the tap appears impractical due to the involvement of water, potentially leading to obstructions in the screen's functionality caused by wet or dirty fingers. The 1.28 inch is the most common size in the market, and its size and visibility was confirmed through user evaluation. The implementation of off-the-shelf parts such as this one and the rotary encoder dictates design constraints in terms of shape and dimensions.

Reuse Quooker parts
Parts from Quooker's current production line have been chosen, such as the spring from the Front tap, the soap dispenser's counter mount with accompanying ring, as well as the O-ring from the Fusion tap. This way, Quooker's current parts can be reused, thus decreasing the steps needed to establish a new production line for the volume knob.

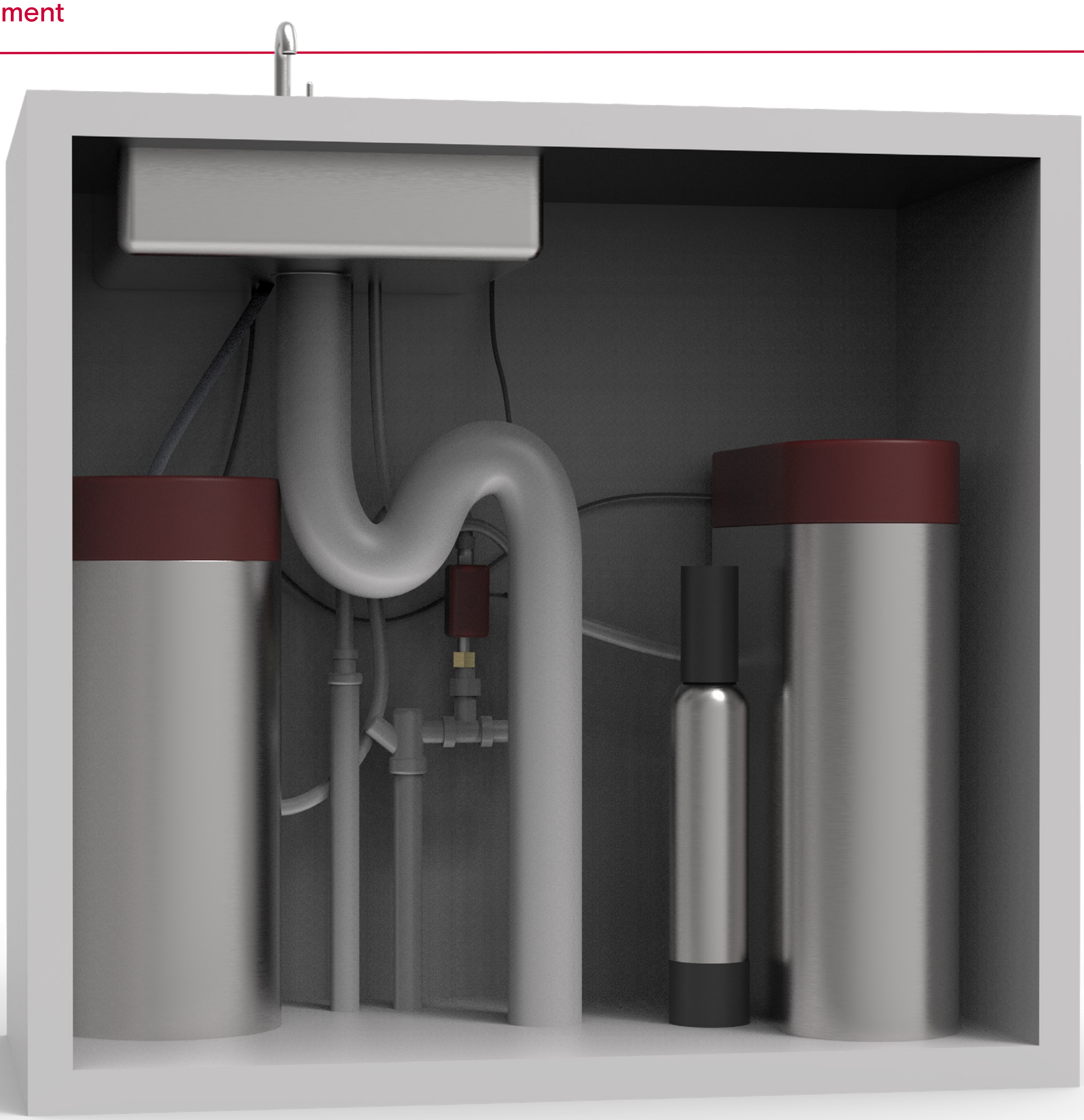
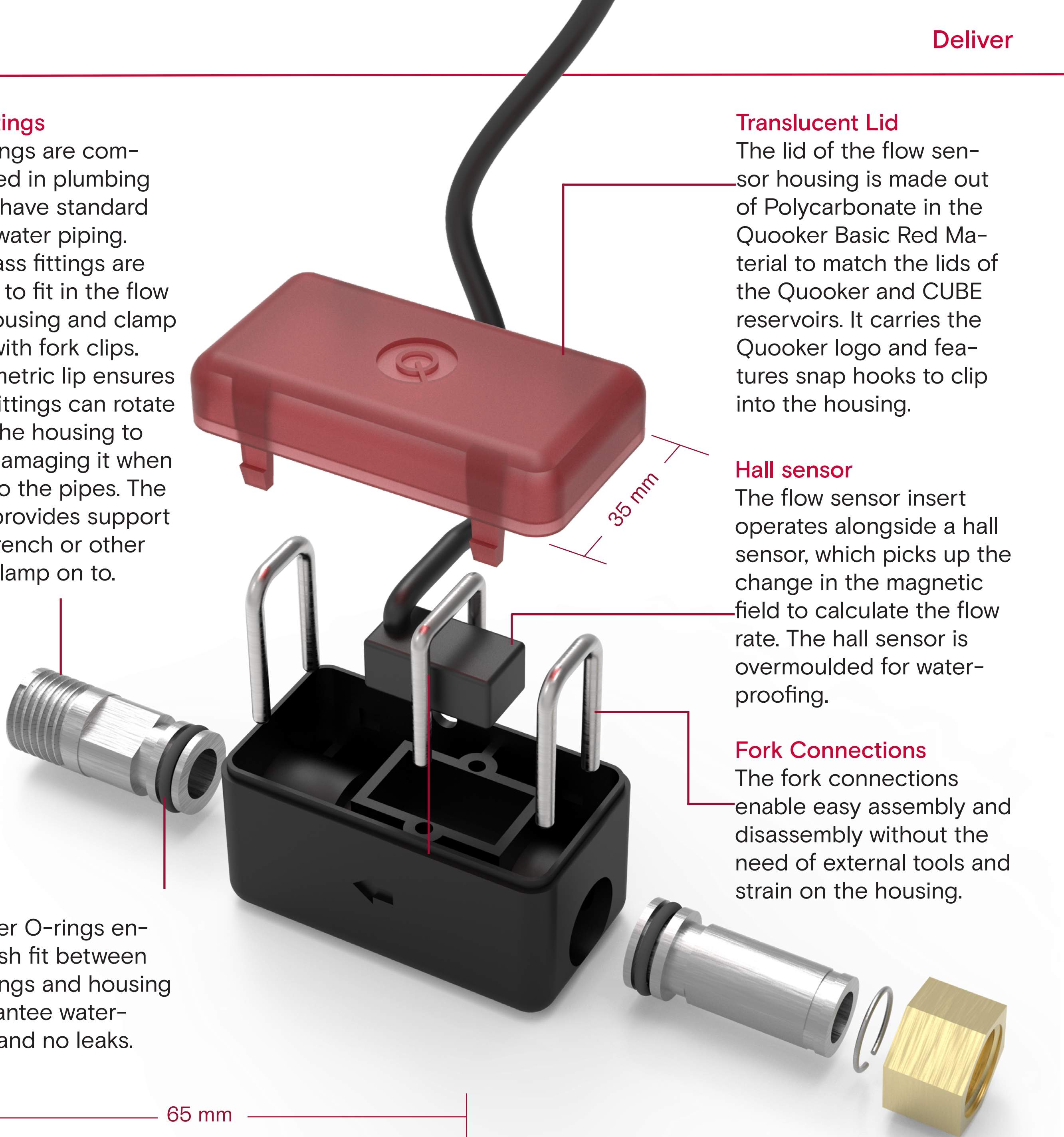


Figure XX. Illustration of pipings and system connections below the counter

The Flow Measuring Unit below the counter is placed at the inlet of the water supply. After careful consideration and discussion with Quooker engineers, it was decided that the optimal placement would be after the Quooker's reducing valve. This way, the flow sensor monitors the flow rate of the water entering the Quooker reservoir and is protected against pressure oscillations and high pressures, since these are controlled by the reducing valve. For the CUBE, the Flow Measuring Unit is calibrated accordingly with the pump in the reservoir (800 rpm for sparkling, 900 rpm for chilled water) controlling the chilled and carbonated water.

The Unit is rigidly connected on the reducing valve via brass fittings and swivel nut, eliminating the need for additional connections to the kitchen cabinet and extra piping. The current tubes of the Quooker inlet can be used, since the connections and distance from the reducing valve don't change. The AUX cable that connects to the UI Unit is the same as the ones used to connect the Quooker to the tap and Quooker to CUBE.

Due to the small size of the housing designed around the turbine insert and hall sensor, the available space below the counter does not pose a problem, making the unit versatile and adaptable to all cabinets housing a Quooker system.



Brass Fittings

Brass fittings are commonly used in plumbing and they have standard sizes for water piping. These brass fittings are designed to fit in the flow sensor housing and clamp in place with fork clips. The symmetric lip ensures that the fittings can rotate freely in the housing to prevent damaging it when fitted onto the pipes. The flat side provides support for the wrench or other tools to clamp on to.

Translucent Lid

The lid of the flow sensor housing is made out of Polycarbonate in the Quooker Basic Red Material to match the lids of the Quooker and CUBE reservoirs. It carries the Quooker logo and features snap hooks to clip into the housing.

Hall sensor

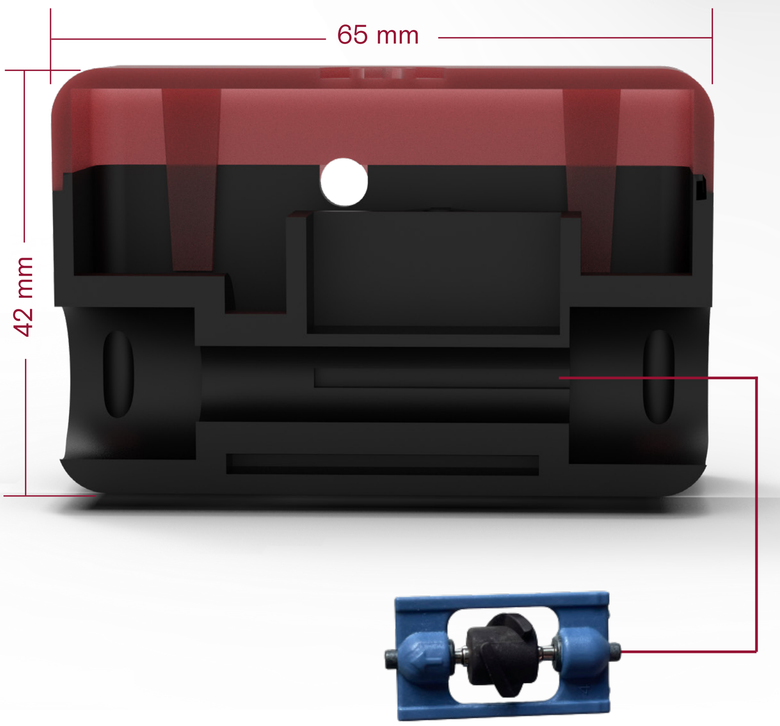
The flow sensor insert operates alongside a hall sensor, which picks up the change in the magnetic field to calculate the flow rate. The hall sensor is overmoulded for waterproofing.

Fork Connections

The fork connections enable easy assembly and disassembly without the need of external tools and strain on the housing.

O-Rings

The rubber O-rings ensure a flush fit between brass fittings and housing and guarantee waterproofing and no leaks.



Housing

The flow sensor housing is made out of PPSU, a high temperature thermoplastic offering high temperature and chemical resistance and long service line. PPSU is WRAS approved [23] and can be easily molded into complex shapes using injection moulding. The design is optimized for injection moulding by taking into account constant wall thickness (3mm for water tube and 2mm for structural function) and shape properties. The embossed arrow on the side indicates the correct orientation flowing the flow direction. For the flow sensor, a GEMS turbine insert is implemented, which is already widely used in the food and beverage industry [24]. By using an insert, the housing can be custom designed and manufactured by Quooker, making it compatible to the current system and optimizing production.

8.2 Features

Pattern

During user interviews the participants emphasized that they associate water volumes with a certain level reached in their containers. To recreate this mental interrelation, the volumes are represented in an incremental pie chart. This leads the user to creating mental connections between the pie segments and the water level in the pots. As the users go through this learning curve, similarly to using a Quooker tap, the pie-water level correlations will become ingrained in their cognitive faculties.
In general, images can be processed more quickly and effortlessly compared to numbers, as they can convey information in a visual and intuitive manner. Our brains are highly skilled at processing visual information and recognizing patterns, which can make images easier to understand and remember. [15]
Numbers, on the other hand, typically require more cognitive effort to process. Numerical information often needs to be decoded, interpreted, and manipulated mentally. [16]

Tolerances

For the design of both the User interaction and Flow Measurement Unit, tolerances were taken into account for fitting the separate parts together. The following tolerance classes were used:

- **Machining (Milling and Turning)**
  ISO 2768: This standard provides general tolerances for linear and angular dimensions without individual tolerance indications. It is commonly used for medium to large-scale production with moderate precision requirements.

- **Injection Moulding**
  ISO 20457: This standard specifies the tolerances for plastic injection molding and is commonly used for ensuring consistency and quality in the production of plastic parts.

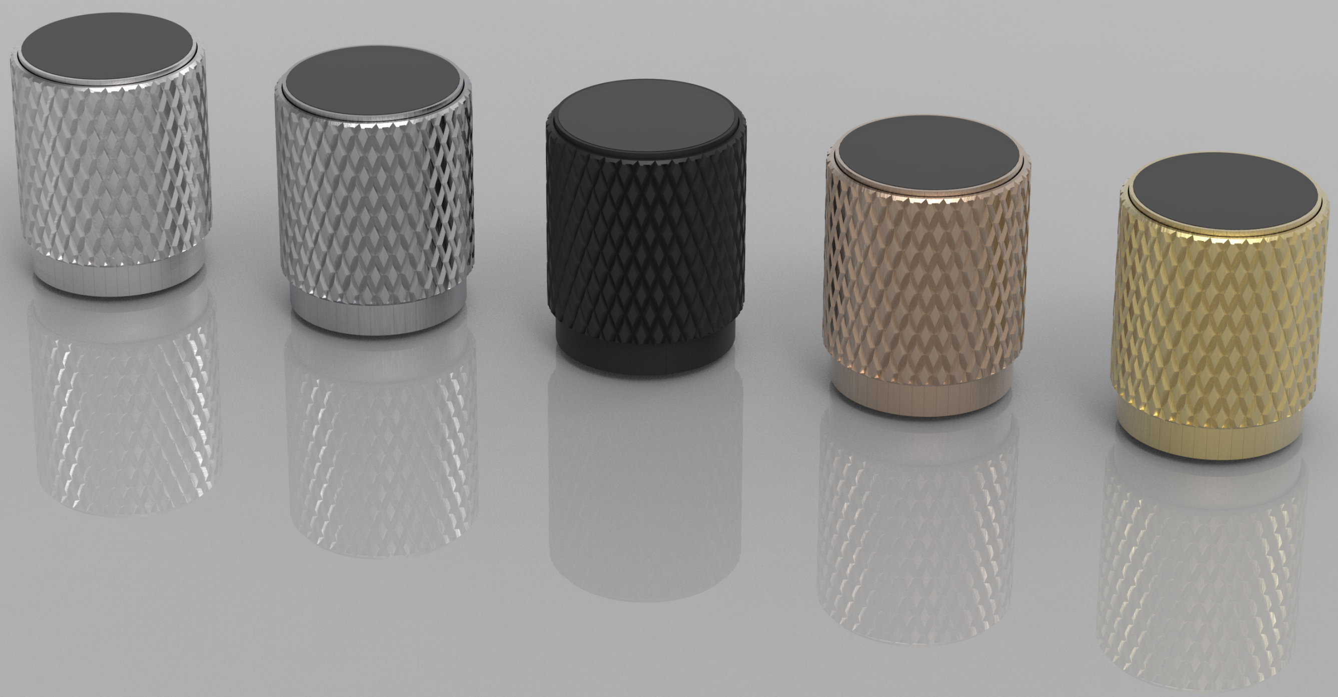
Figure 76. a) Rotating to set volume b) Pushing for preset c) Push and wait to switch modes

Visual Communication

The pie chart was implemented in the final design. Similar to the initial prototype when the outer knob is twisted counter- or clockwise, the pie chart decreases and increases respectively (Figure 76a). When the knob is pushed down, presets can be chosen.

Push once is preset one and push twice is preset two (Figure 76b). More presets can be provided if requested by the user, however, sequential pushing can turn out to be awkward and uncomfortable. This is the reason why two presets are the standard, one for small and one for bigger quantities set by the user.

When the knob is long pressed, the display switches to the number mode to display the exact volumes for the cases when the user needs exact amounts of water (Figure 76c). This feature eliminates the user of other measuring devices.



Similarly to the soap dispenser, the user interaction unit will be provided in all five of Quooker's finishes to match all taps; stainless steel, chrome, black, patinated messing and gold.

The outer knob features the characteristic knurl to visually connect to the tap and invite the user for interaction.

The cost estimation presented in the next section takes into account the RVS knob finish, since this is the most commonly used in taps and soap dispensers.

8.3 Cost Estimation & Manufacturing

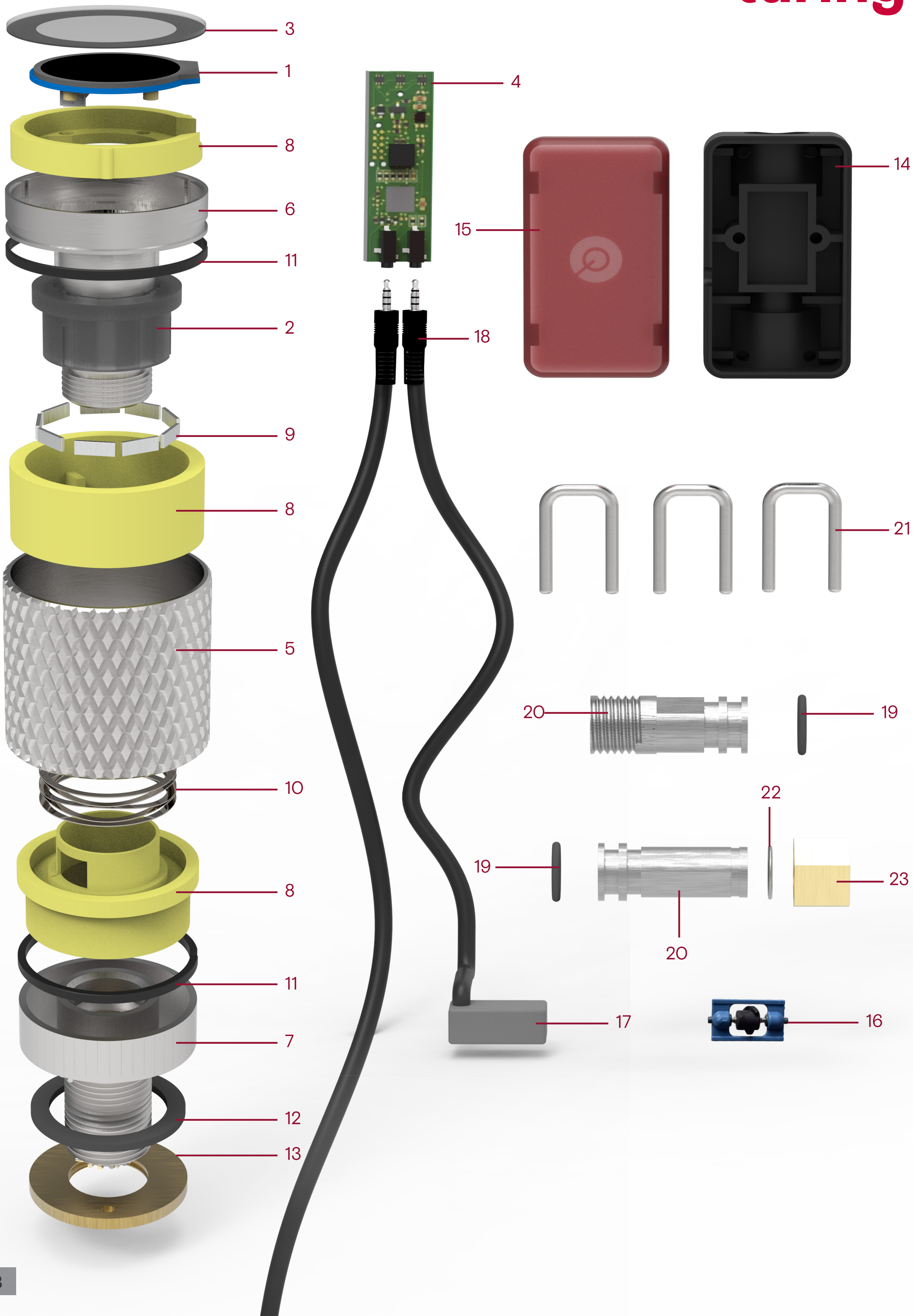


Table XX. Bill of Materials, Cost Estimation and Materials Used

	Part #	Component	Units	Unit Cost [%]	Cost [%]	Material	Manufacturing
User Interaction Unit	1	1.28 LCD Display	1	2,5	2,5	-	Standard Part
	2	Rotary Encoder Hollow Shaft	1	2	2	-	Standard Part
	3	Tempered Glass 46mm	1	0,4	0,4	Mineral Glass Watch Crystals	Standard part
	4	PCB	1	5,6	5,6	Epoxy infused fiberglass	PCB Manufacturing
	5	Outer ring knurled	1	8,9	8,9	RVS 304 / 316	Turning
	6	Middle Part	1	2,5	2,5	RVS 304 / 316	Turning / Milling
	7	Bottom Part	1	3,3	3,3	RVS 304 / 316	Turning / Milling
	8	Plastic Part Inserts	3	0,2	0,6	PA12	Injection Moulding
	9	Magnet	9	0,1	0,7	Ferrite	Standard Part
	10	Wave Spring	1	1,4	1,4	Spring Steel	Cold Coiling
	11	Sliding ring	2	0,1	0,1	POM	Injection Moulding
	12	O-RIng Counter	1	0,01	0,01	SBR	Extrusion
Flow Measurement Unit	13	Fastening RIng	1	0,3	0,3	Brass	Turning / Milling
	14	FS Housing	1	1,3	1,3	PPSU	Injection Moulding
	15	Translucent Lid	1	1	1	PC COM	Injection Moulding
	16	Turbine Insert	1	2,5	2,5	-	Standard part
	17	Hall sensor	1	0,2	0,2	-	Standrad part
	18	AUX cable	2	0,4	0,8	-	Standard part
	19	O-Ring	2	0,01	0,01	EPDM shore A 70	Extrusion
	20	Brass Fitting	2	1,5	3	Brass	Extrusion
	21	Fork Clip	3	0,04	0,11	Brass	Rolling / Stamping
	22	Clip	1	0,04	0,04	Brass	Rolling
	23	Swivel Nut	1	0,3	0.3	Brass, Nickel coated	Turning Milling
Subtotal				**37,2**			
Assembly Costs				**62,8**		Confed (external)	
Total				**100**			

The System Design was analyzed alongside Quooker engineers and the Cost Analysis and Manufacturing Methods of all different parts were discussed.

For the cost estimation, current Quooker parts were used as reference to approximate the manufacturing costs of the volume control design. The costs are presented in percentages with respect to the total cost, since the actual prices cannot be disclosed. Following the total costs, the consumer price is calculated, which falls within the indicated margin from the list of requirements.

The company CONFED is chosen for the assembly of the units, an external partner of Quooker's, tasked to assemble Quooker's accessories such as the soap dispenser, so that the Quooker production line focuses on the reservoirs. Quooker B.V. doesn't consider tooling costs (e.g. Moulds for injection moulding) in the cost estimation, since these are considered investment costs.

Table XX shows an overview of the Bill of Materials for both units.

8.4 Conclusion

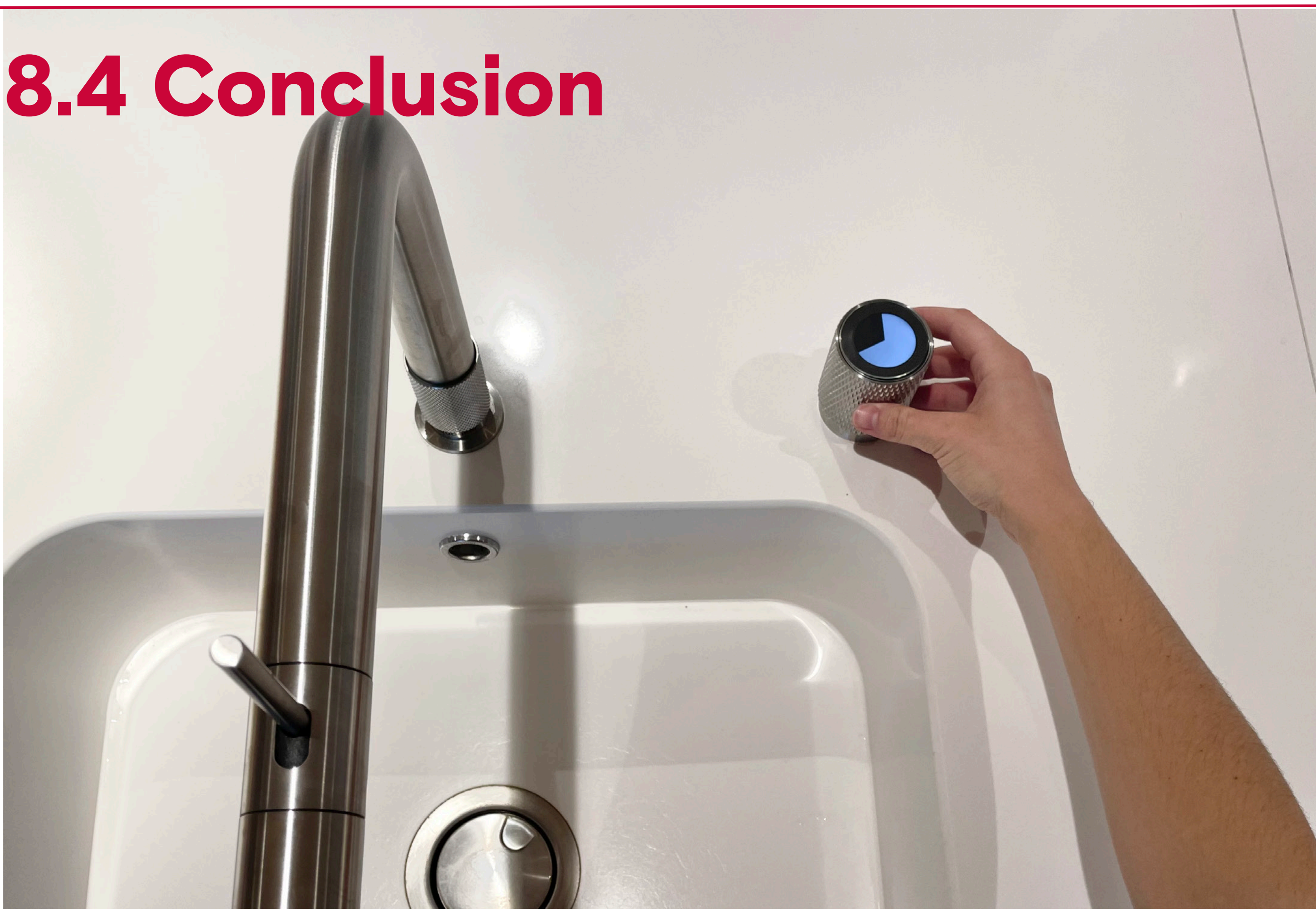


Figure 77. Pictures of prototype alongside the Front tap, Quooker showroom Ridderkerk

As presented in the introduction of this report, the goal of this project was as follows:

"Design a volume unit as an addition to the current product system, which will allow the user to control boiling, chilled and carbonated water volumes."

This assignment was initiated with research, both internal and external, to identify user needs and wishes, habits, as well as Quooker characteristics, system limitations and available technology to tackle this problem. After generating a list of requirements, ideation took place, consisting of exploration of different ideas through sketching, brainstorming and testing. The final concepts were evaluated by users and R&D engineers and a conclusion was drawn in the form of a final concept; an external knob for volume selection and a turbine flow sensor for flow measurement. These units were then developed and tested separately as proof of concept, and iterated to improve performance and system compatibility. The final design, cost analysis and preliminary manufacturing plan are presented in sections 8.1-8.3.

The business case for this assignment was set at the beginning of the project by Quooker B.V. It was researched and developed to provide a fitting solution for volume control, both in terms of the user and functionality by addressing the three main drivers of performance, ease of use and compatibility. The unique selling point of this design is that it provides a new accessory alongside the tap and an opportunity for previous Quooker customers to return to Quooker for a new purchase in the form of an upgrade for their system. This design and prototype allows Quooker to make the next step in the development process to validate the business case of a volume control system separate from the Quooker tap. The resolution of the project doesn't allow for conclusive decisions at the moment, therefore recommendations for design, manufacturing and testing are presented in this section, as well as questions that need to be addressed, to assist Quooker B.V. with the further development of a volume control system.

Evaluation based on requirements
Revisiting the list of requirements, the final design can be evaluated based on the criteria set in the Define sections. All categories were considered during the design development and the final design fulfills all set requirements. This section proposes further testing and iterations to improve even more, both in terms of this criteria, as well as manufacturing and assembly.

Usability
• Relieve the user from **mindful volume measurement** (e.g. measuring cups, “eye-balling”, weighing scale etc.)
• Be **intuitive** to use and require minimal explanation to users, no more complex interaction than current Quooker products.

Performance
• Work for all three types of SFW; boiling, chilled/filtered and sparkling.
- Operating Temperature: 4-107°C
- Pressure: 1-5 bar
- Flow rate: 0.7-5 L/min

• Dispense a predetermined amount of water with accuracy:
- 4-6% for small quantities (200-500ml)
- 6-9% for bigger quantities (1.5-5L)

Compatibility
• Be backwards compatible - compatible with previous Quooker system components from 2017 onwards.

Standards, Rules and regulations
• Be watertight (hidden and insulated electronics)
- Outside IP21, inside to outside double working pressure (max. 10 bar)
- Made of water-safe materials
- WRAS approved and 4Metals

Aesthetics
• Fit the Quooker house style.

Size
• Fit easily:
- Below the counter (ca. 200 x 270 x 250mm (BxDxH))
- Next to the tap on the countertop (ca. Ø35-60mm, H80mm)

Cost Price
• 200-300 € (consumer price)

Design for Manufacturing

DfM has been taken into account in the current design to provide a baseline for Quooker B.V. to continue with. To improve part manufacturability and reduce costs, the separate parts need to be revisited. For instance, in the volume selection knob, three parts are designed for machining; the outer ring, middle and bottom components. These three parts are chosen to be machined for higher quality, since these are visible to the user. Parts of these components are hidden in the inner side of the assembly. Therefore, these components, especially the middle one, can be split up for manufacturing. The non-visible parts to the user can be made out of a different material and production process, e.g. injection moulding. This would reduce production time, part complexity and manufacturing costs.

To include the different knob finishes in the production line, a coating process could be implemented to retain the same manufacturing process for each knob and avoid additional costs for expensive materials such as gold. This, however, needs to be optimized to offer quality results.

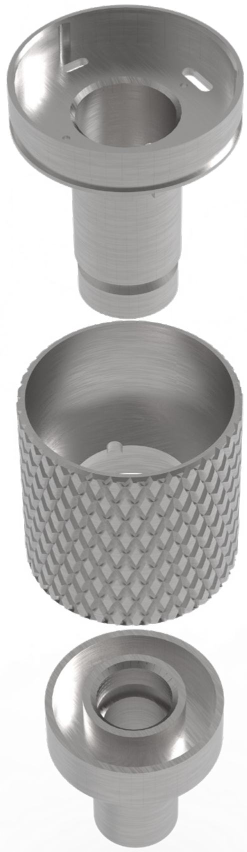


Figure 78. Middle Part, Outer Ring, Bottom Part

Testing Plan

Further testing needs to be performed to validate the design and business case of the volume control system. This testing should include user, performance and endurance trials.

- **Quantitative Testing**
  Quantitative testing can be conducted on both the user interaction, as well as the flow measuring unit. For the user interaction unit, extensive testing can provide quantitative insights into tap usage and user behavior when measuring water volumes to optimize the interface and functionality design. Regarding the flow measurement unit, longer tests with the turbine flow sensor need to be executed to optimize volume dispensing and identify edge cases that need to be taken into account. Testing can be also done with a proper prototype of the current design to validate the design decisions and make iterations.

- **Qualitative Testing**
  Qualitative testing in terms of Quooker's mission can provide valuable feedback when it comes to users. The volume control system should be tested for an extended period of time to evaluate if this system evokes positive feelings and plays a significant part in assisting and improving users' everyday life. Test panels, as well as real users should be recruited for this type of testing. Qualitative testing can also provide insights regarding the consumer price and if users are willing to pay it for this unit.

Design for Assembly

Assembly has been taken into account as well, especially throughout the prototyping process. Assembly instructions can be found in Appendix III. The assembly process of the UI knob still requires optimization, which could be feasible through the changes proposed in "Design for Manufacturing".

Design Changes

Based on the use cases and user feedback, users appreciate the ease that the volume control unit offers in the kitchen. The list of use cases the volume control system could assist would increase if mixing water (non special feature water) could be handled by the volume control unit as well. Such use cases include; watering plants, making special types of tea, baby formula, cleaning, filling up pet water bowls etc. The functionality and flow sensor placement need to be adapted to accommodate such a change.

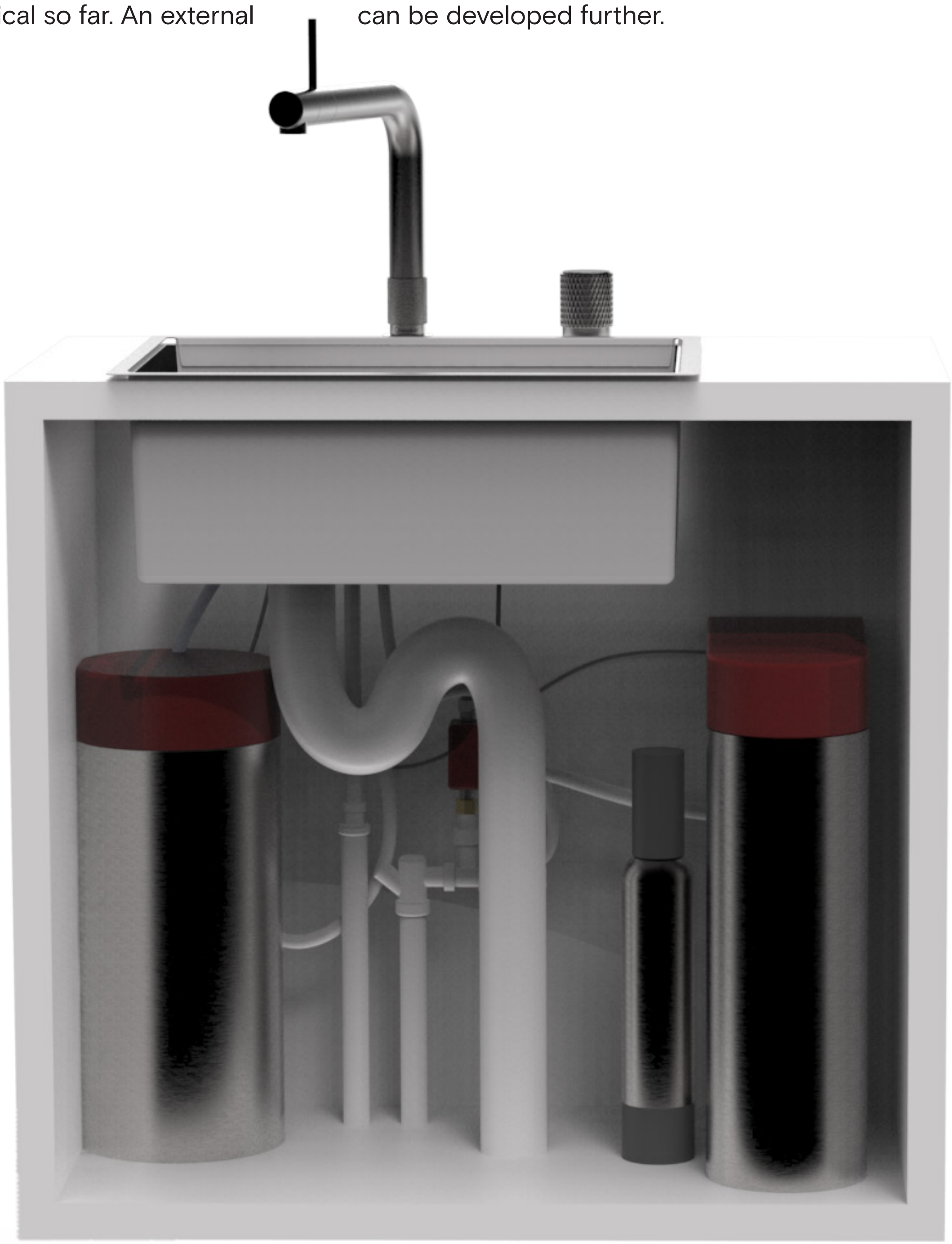
Other than including the volume control unit as an external feature, the direction of implementing it in the tap should be critically reviewed. By incorporating the volume control within the tap, user interaction could be simplified, as well as the technology below the counter. A flow sensor can be placed within the reservoir for better control and performance. Quooker B.V. is already headed in this direction with new product designs, and this project could provide valuable input to take along the process, thus confirming the project's desirability aspect in terms of Quooker as the main stakeholder.

Future Opportunities

The design of an external knob, featuring a display, opens up new doors and opportunities for Quooker B.V. The user interaction and use cues have been mostly mechanical so far. An external knob as a new interaction point for the user can offer more control over several aspects other than volume control, such as temperature settings, water dispensing patterns or IOT connections to lead Quooker B.V. into a new direction.

Other than new features, the volume control unit can serve as a maintenance alert. For instance, in case the unit picks up on gradual reduction in flow rate, it can inform the user and Quooker's service technicians that it is time for maintenance due to limescale. Rapid changes in flow rate and specific patterns can also indicate errors in the system such as leaking, or insulation breaks.

Overall, there are several interesting directions and opportunities provided by this design that can be developed further.



Reflection

As I come to the conclusion of my graduation project at Quooker, I find myself reflecting on the ambitions statement I made at the beginning of this journey. My goal was to combine the disciplines of Industrial Design and Mechanical Engineering to create functional products with a purpose, and I can proudly say that this project has been a significant step towards achieving that aspiration.

Throughout my time at Quooker, I have had the invaluable opportunity to work within a real-life project. As I delved into the world of taps and water systems, I was able to revisit familiar concepts from my Mechanical Engineering Bachelors, such as fluid-dynamics, pumps, and valves. However, this time, I had the chance to apply this theoretical knowledge in a practical way, fusing it with my Industrial Design expertise to develop design solutions.

The technical nature of the project, coupled with the incorporation of design elements, aligned perfectly with my interests and future career aspirations as an engineer designer. Exploring different technologies and alternatives to optimize the design solutions provided me with a deeper understanding of the balance between aesthetics, functionality, and engineering principles.

Another aspect that brought immense value to this project was the hands-on experience and exposure to new prototyping methods and tools. As someone already familiar with 3D-printing, and low-fidelity prototyping techniques, I was eager to expand my knowledge and skills. Learning from seasoned professionals in the field allowed me to refine my approach to prototyping, adding another layer of proficiency to my skill set, as well as learning about design for manufacturing and important aspects that need to be taken into account.

Furthermore, the experience of holding myself within the workplace has been instrumental in my personal development. As an international student stepping into a professional environment, I was conscious of the need to adapt to the company's culture and values while staying true to my own principles. I learned the importance of maintaining a positive attitude, being open to feedback, and continuously seeking opportunities for improvement.

Throughout the completion of my graduation project at Quooker, effective planning and project management played crucial roles in ensuring the success of the endeavor. From the outset, I recognized the importance of a well-structured plan to guide me through the various stages of the project, especially when dealing with the dual character of this project. In the process of planning and executing the project, communication with stakeholders emerged as a pivotal factor in achieving alignment and meeting expectations. Regular meetings and updates with my advisors and supervisors at Quooker allowed me to seek valuable feedback and make necessary adjustments to my work. Engaging with the stakeholders effectively fostered a collaborative environment, where ideas and insights from different perspectives were shared, enriching the overall quality of the project.

Additionally, the project exposed me to the intricacies of managing expectations and deadlines. I learned to balance my ambitious ideas with the realities of time constraints and resource availability. By being proactive in addressing potential roadblocks and challenges, I was able to mitigate risks and ensure a smooth progression of the project. This experience has shaped my ability to prioritize tasks, make well-informed decisions, and deliver results that align with stakeholders' expectations. Undoubtedly, the journey of completing my graduation project at Quooker had its fair share of ups and downs. At times, I faced technical hurdles that required creative thinking and perseverance to overcome.

In retrospect, this graduation project has been an excellent way to complete my studies and embark on my journey as a design engineer. Not only did I get to work on a project that aligned with my ambitions, but I also gained valuable work experience from a notable Dutch enterprise.

As I move forward from this project, I carry with me a sense of fulfillment and gratitude for the knowledge and experiences gained during this time. I am excited about the opportunities that lie ahead and look forward to using the valuable insights from this project to continue making a difference in the world of engineering design.

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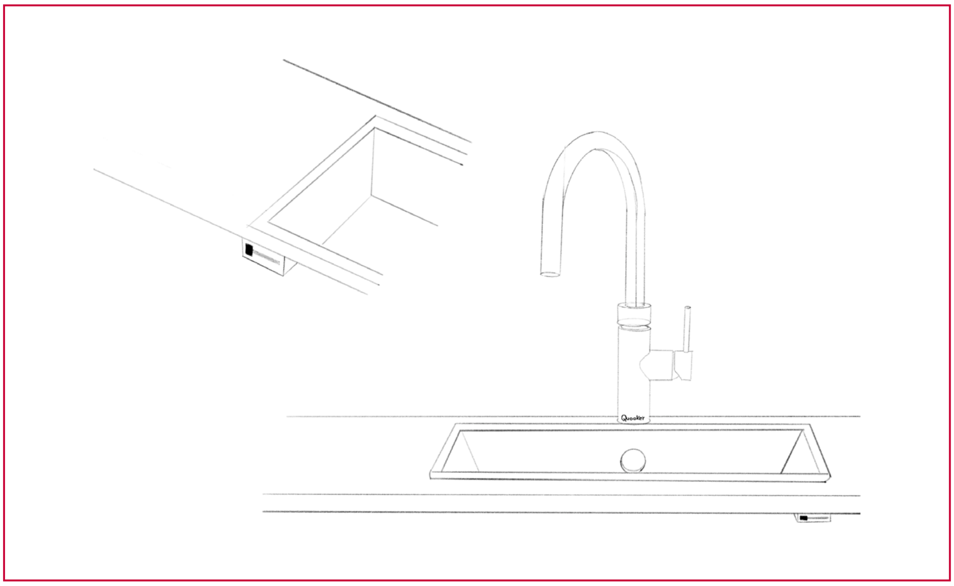
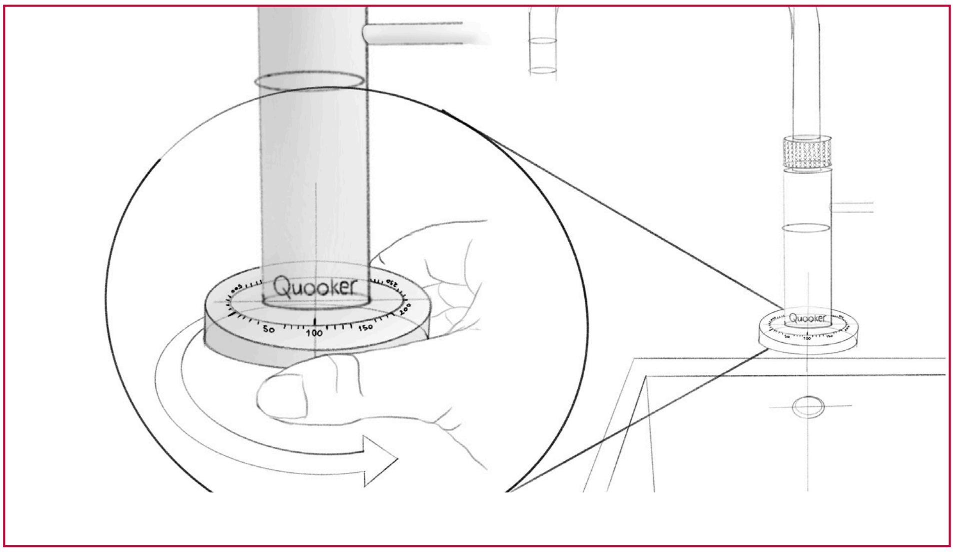
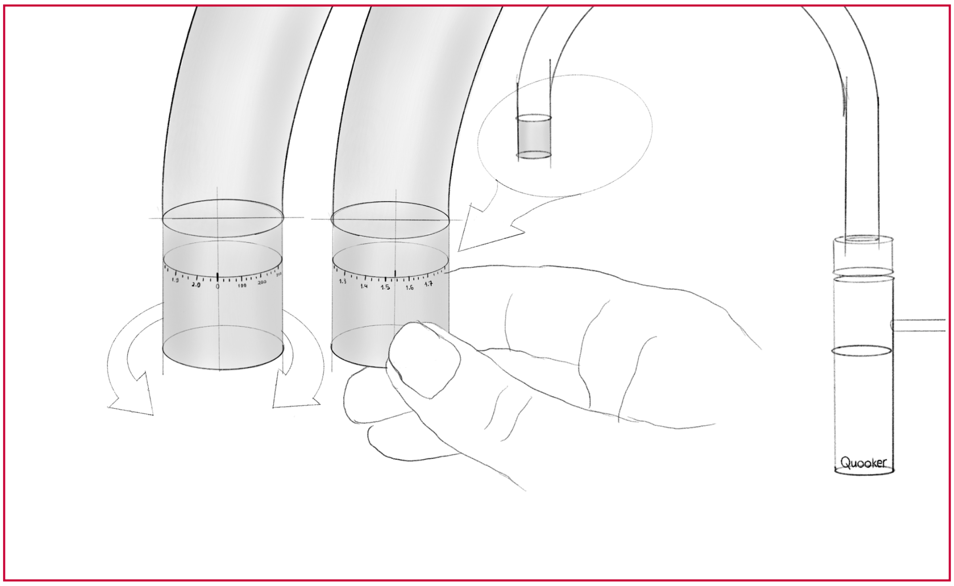
All Images of Quooker products and schematics are sourced internally from Quooker’s brandbook, website and dealer’s brochure

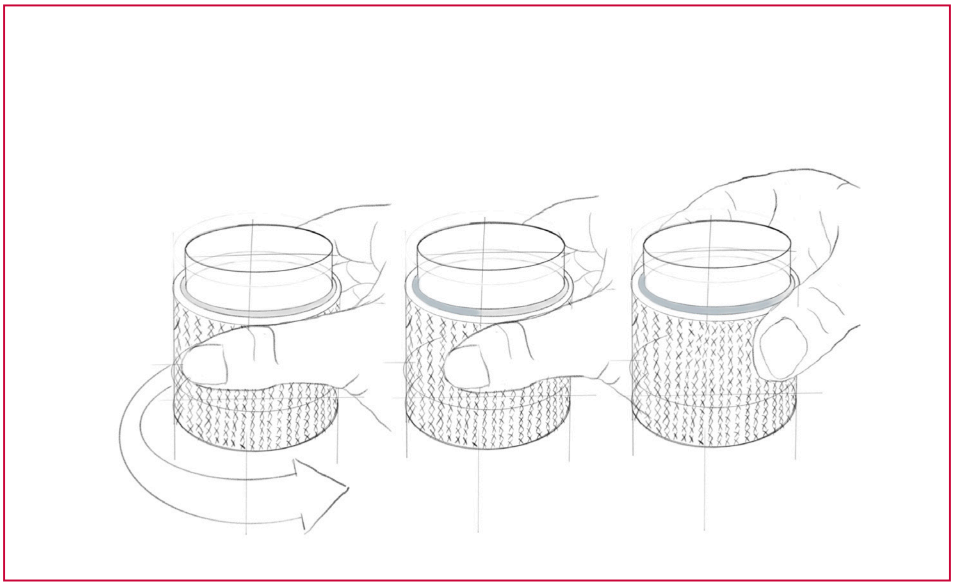
All illustrations on the title pages are sourced from Quooker’s dealer brochure

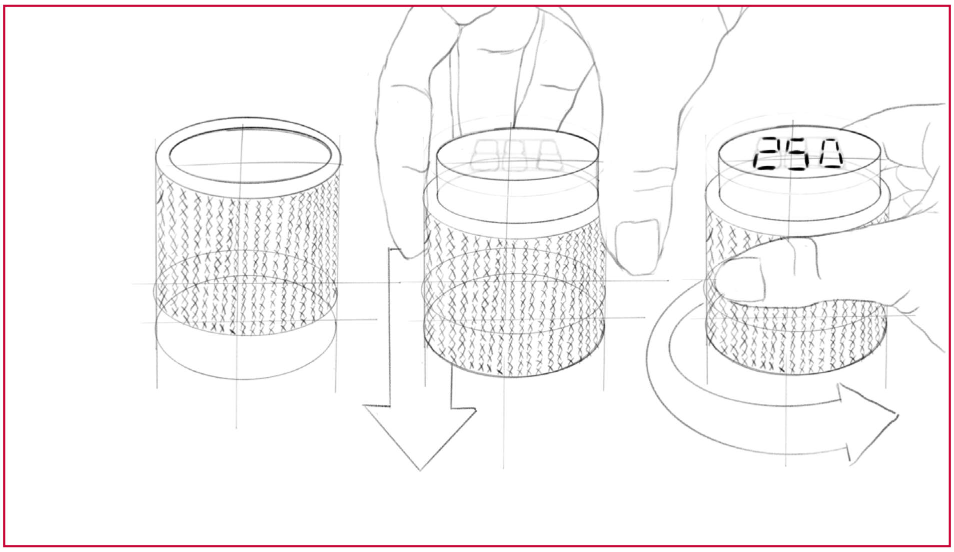
Appendix I
ideation







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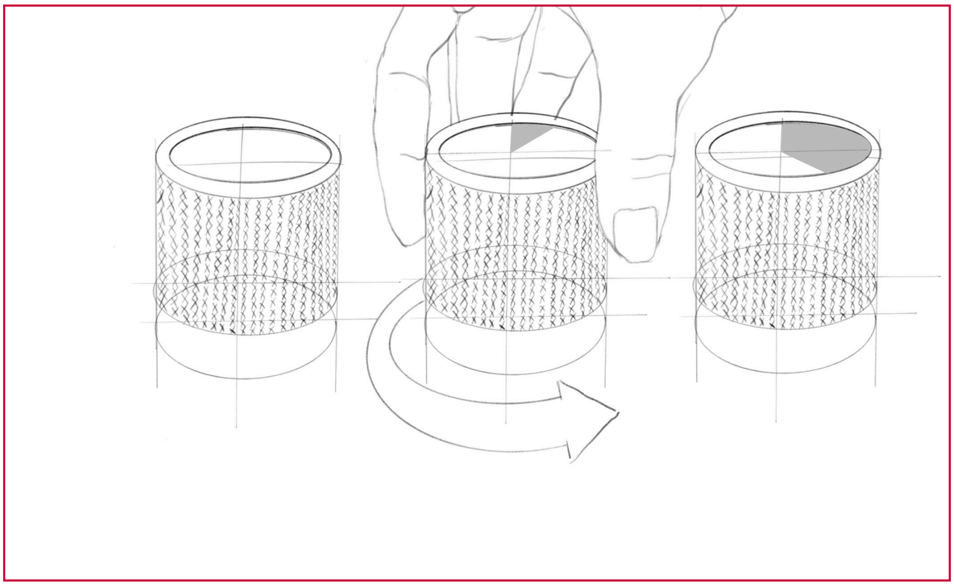
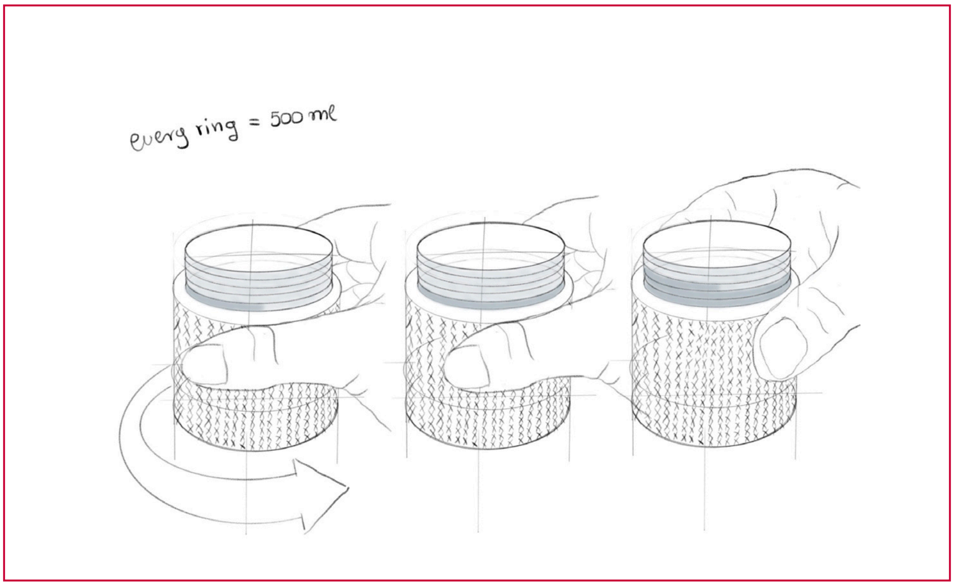
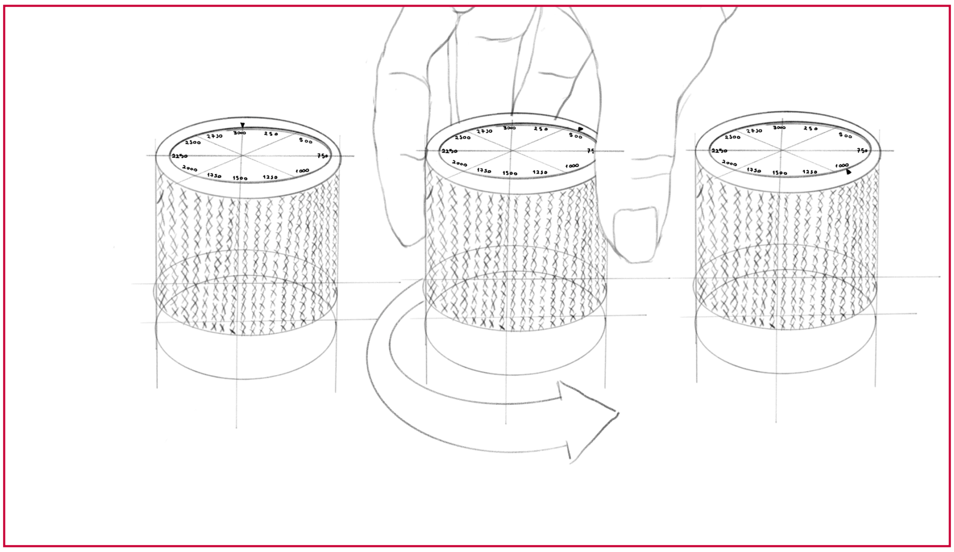
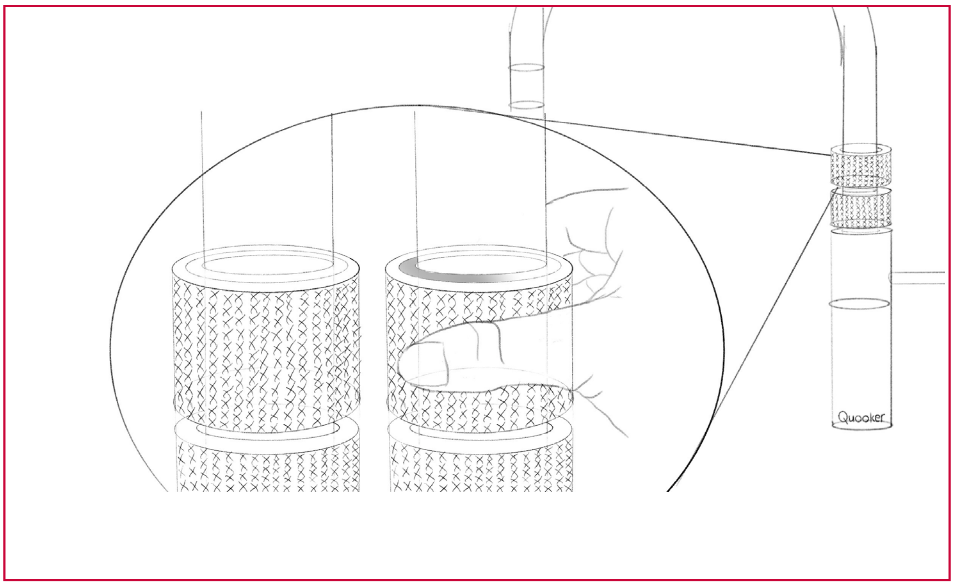



every ring = 500 ml

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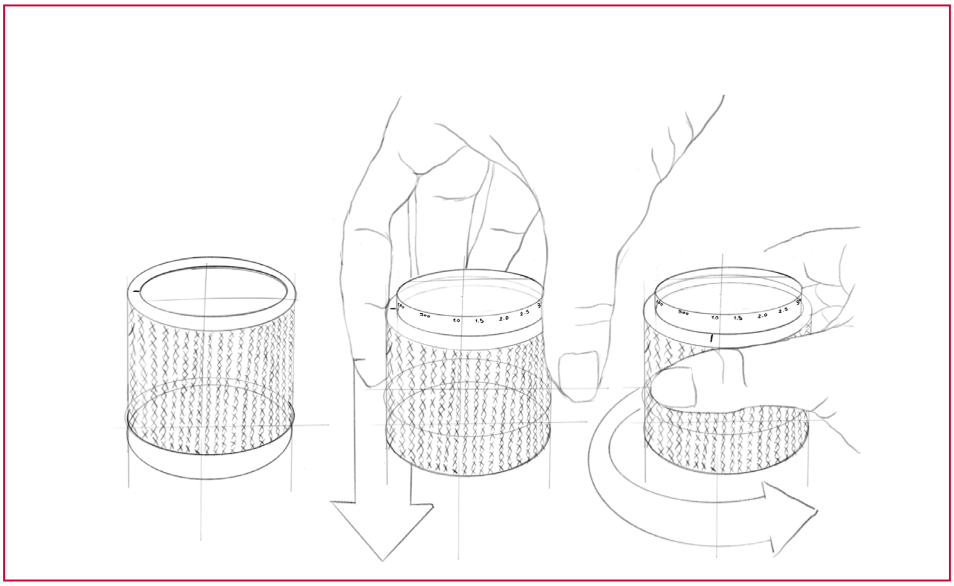

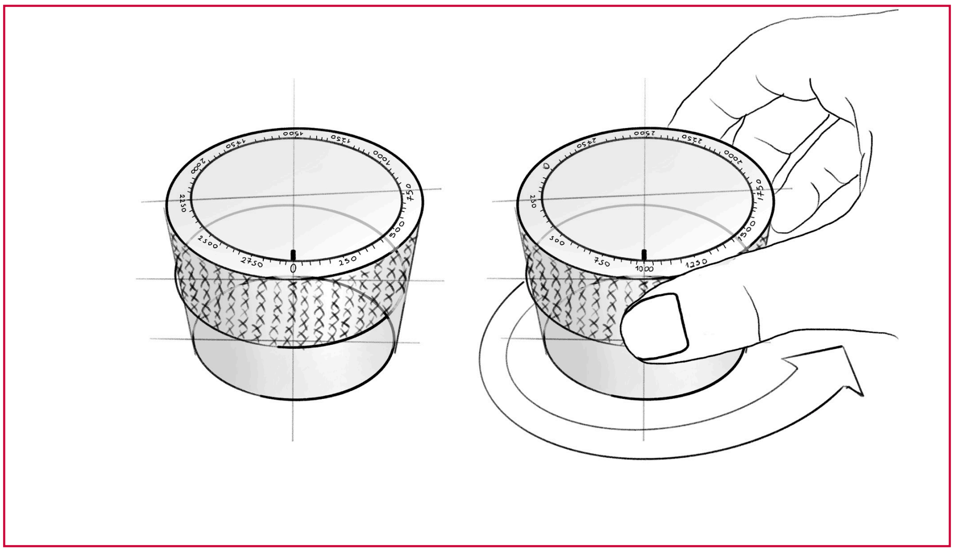

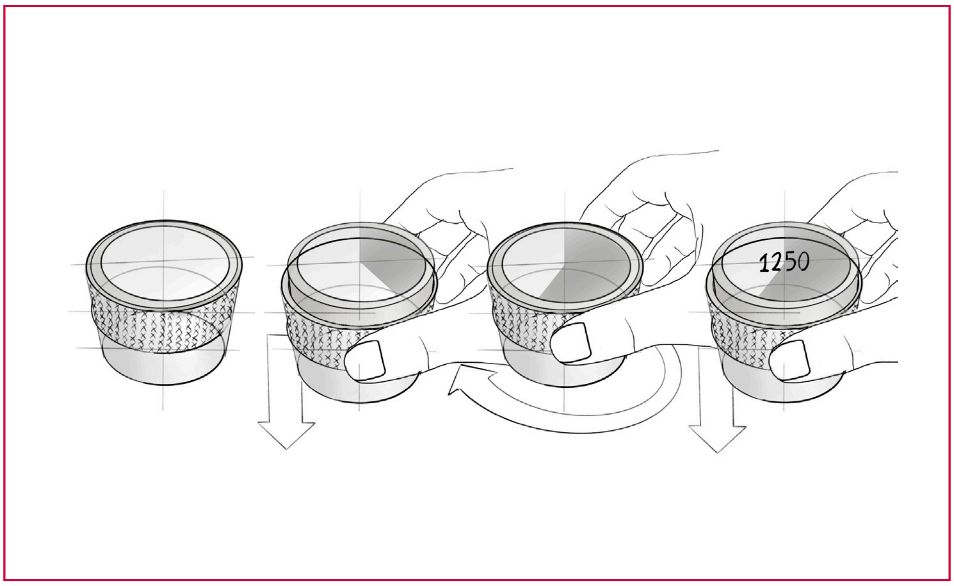
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Appendix II
testing results

Vewin Water Usage

Water use kitchen tap in liters per person per day										
	1992	1995	1998	2001	2004	2007	2010	2013	2016	2016 (correcte
Dishes	8,8	4,9	3,8	3,6	3,9	3,6	3,1	3,6	3	3,5
Food preparation	2,6	2	1,7	1,6	1,8	1,7	1,4	1	0,8	1,2
Cleaning	-	2,4	1,6	1,5	1,6	1,5	1,4	1	0,7	-
Handwash	-	1,4	1,3	1,3	1,5	1,4	1,3	0,5	0,5	-
Watering Plants	-	-	0,7	1,4	1,2	0,5	1,2	1	0,6	-
Coffee & Tea	-	1,5	1,1	1	1	1,2	1,2	0,6	0,5	0,8
Laundry	-	-	0,7	0,6	0,7	0,8	0,5	0,4	0,4	-
Drinking water	-	0,5	0,4	0,5	0,6	0,6	0,6	0,4	0,3	0,5
Other	3,3	2,9	1,8	1,8	1,5	1,1	1,4	0,8	0,8	-
	14,7	15,6	13,1	13,3	13,8	12,4	12,1	9,3	7,6	6

	Frequency of use (average per day)			Duration of use (seconds at a time)		
	210	2013	2016	2010	2013	2016
Food preparation	3,4	3,3	3,3	18,7	15,7	12,9
Cleaning	3,5	3	3	30,4	23,5	17,6
Hand washing	5,2	5,4	5,8	12	4,6	4,4
Watering plants	2,7	2,8	2,4	53,8	36,3	41,4
Coffee & Tea	4	3,9	4,1	11,1	5,6	5,2
Laundry	2,5	2,4	2,5	48,9	59,5	60,6
Drinking water	4	4,1	4,1	6,8	4,3	3,6
Other	3,5	3,3	3,1	24	15,7	16,3

User Filling Tests

	Big Pot	Medium Pot	Small Pot	Teacup
Average % 1-5	5,2253631	6,67934827	7,394041723	4,53972966
Average % 6-10	6,915549911	11,54407273	5,775406845	4,825666428
Average %	6,070456506	9,111710501	6,584724284	4,682698044
min. 1-5	3,828383649	2,703579046	4,215309388	3,374427142
min. 6-10	2,437722418	5,210048974	2,743410525	3,424803817
max. 1-5	7,018731908	9,944546847	12,24932299	6,408699445
max. 6-10	11,69100407	19,12611875	8,64532599	6,634195559
min.	2,437722418	2,703579046	2,743410525	3,374427142
max.	11,69100407	19,12611875	12,24932299	6,634195559

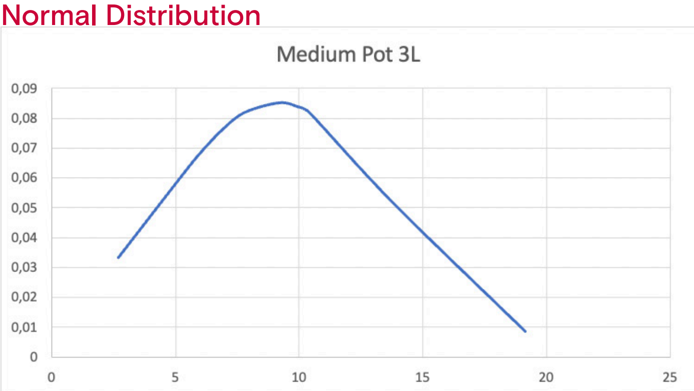
	Big Pot	Medium Pot	Small Pot	Teacup
min.	2,44	2,7	2,74	3,37
max.	11,69	19,13	12,25	6,63

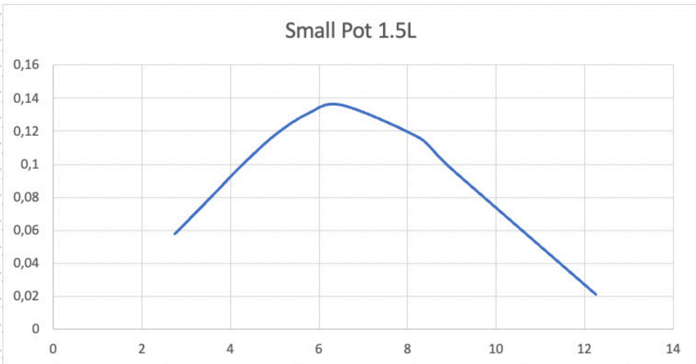
	Big Pot 5L	Medium Pot 3L	Small Pot 1.5L	Teacup 200-300 ml
V1				
	4078	2144	773	271
	4139	2077	743	303
	3594	2244	825	296
	3847	2411	797	283
	3965	2501	816	293
Average	3924,6	2275,4	790,8	289,2
Deviation	215,8988189	178,1131663	33,33466664	12,4579292
RSD %	5,501167479	7,827773854	4,215309388	4,307721024
V2				
	3583	1589	382	291
	3271	1211	326	281
	3376	1482	276	273
	3720	1521	354	254
	3888	1499	312	301
Average	3567,6	1460,4	330	280
Deviation	250,4002796	145,2301622	40,42276586	17,94435844
RSD %	7,018731908	9,944546847	12,24932299	6,408699445
V3				
	3039	1591	669	170
	2940	1756	761	155
	3145	1688	666	161
	3206	1913	646	164
	2953	1808	684	149
Average	3056,6	1751,2	685,2	159,8
Deviation	117,0183746	121,5388827	44,48258086	8,105553652
RSD %	3,828383649	6,940319933	6,491911976	5,072311422
V4				
	3230	2041	660	188
	3538	2145	656	185
	3536	2118	802	188
	3464	2028	770	183
	3544	2144	736	173
Average	3462,4	2095,2	724,8	183,4
Deviation	133,9805956	56,64538816	65,30849868	6,188699379
RSD %	3,869587443	2,703579046	9,010554454	3,374427142
V5				
	2546	996	562	190
	2357	1157	628	205
	2229	1114	602	205
	2574	1090	635	193
	2380	1031	631	202
Average	2417,2	1077,6	611,6	199
Deviation	142,831019	64,44610151	30,59901959	7,03562364
RSD %	5,908945021	5,98052167	5,003109809	3,535489266
V6				
	2778	974	437	151
	2728	837	476	142
	2311	990	424	160
	2283	932	418	149
	2400	1080	379	146
Average	2500	962,6	426,8	149,6
Deviation	235,6257626	88,5652302	34,98142364	6,730527468
RSD %	9,425030504	9,200626449	8,19620985	4,499015687

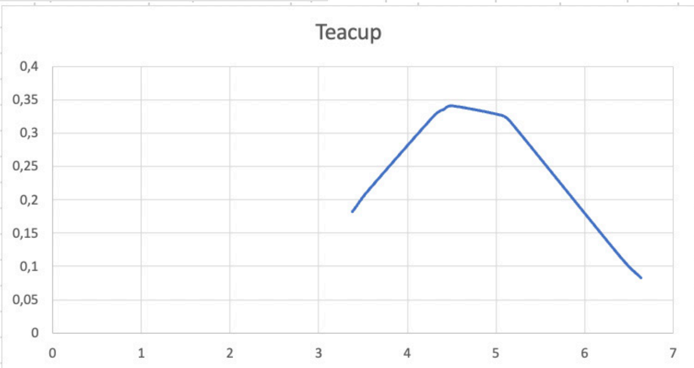
V7				
	3166	1632	710	172
	3201	1618	667	171
	3169	1702	651	167
	3038	2064	680	175
	3046	1811	701	160
Average	3124	1765,4	681,8	169
Deviation	76,15444833	183,5641577	24,15988411	5,787918451
RSD %	2,437722418	10,39787911	3,543544163	3,424803817
V8				
	1558	726	500	171
	1787	972	591	169
	2134	1070	625	184
	1790	1042	597	169
	1964	1263	544	188
Average	1846,6	1014,6	571,4	176,2
Deviation	215,8860811	194,0536008	49,39939271	9,093954036
RSD %	11,69100407	19,12611875	8,64532599	5,16115439
V9				
	3281	1993	702	170
	3223	2079	796	186
	3473	2112	741	171
	3627	2211	746	155
	3450	1933	809	165
Average	3410,8	2065,6	758,8	169,4
Deviation	161,450302	107,6187716	43,61994956	11,23832728
RSD %	4,733502461	5,210048974	5,748543696	6,634195559

V10				
	3451	1464	773	166
	3213	1898	744	159
	3534	2018	759	177
	3645	2005	736	169
	3808	2148	720	160
Average	3530,2	1906,6	746,4	166,2
Deviation	222,0668818	262,8379729	20,47681616	7,328028384
RSD %	6,290490109	13,78569039	2,743410525	4,409162686

Normal Distribution







	Offset between tapped and requested volume					
	100ml	250ml	500ml	1000ml	1500ml	2000ml
	65,8	34,74	61,6	67,3	58,3	41,83
	43,43	21,8	74,1	65,87	74,8	72,3
	5,9	54,3	17,6	39,2	18,8	27,8
	47,89	29,9	50,3	54,3	-0,55	37,8
	33,75	28,3	51,45	14,6	32,4	33,9
	-3,28	57,85	35,85	27,53	47,34	0,4
	7,95	40,9	48,1	45,15	39,2	6,2
	17,05	35,4	56,1	33,5	27,2	25,16
	30,08	72,8	61,9	33,05	32,1	9,5
	24,93	36,2	31,05	47,9	49,03	57,2
Avg.	27,35	41,219	48,805	42,84	37,862	31,209
%	0,2735	0,16488	0,09761	0,04284	0,02524	0,0156
	196,38	212,42	262,42	181,6	174,6	128,8
	201,7	225,5	227,4	187,11	130,04	104,2
	189,7	216,2	246,6	209,7	202,7	91,6
	197,5	232,3	211,1	179,8	289,4	98,6
	178,42	214,54	214,4	198,5	183,65	97,9
	186,64	352,6	225,9	212,8	221,6	71,4
	242,3	197,3	246,5	247,3	149,8	47,01
	174,7	229,3	219,1	230,9	173,7	86,9
	203,5	215,6	268,1	190,8	168,9	92,77
	191,4	225,9	338,06	238,8	232,1	79,3
Avg.	196,224	232,166	245,958	207,731	192,649	89,848
%	1,96224	0,92866	0,49192	0,20773	0,12843	0,04492
	100ml	**250ml**	**500ml**	**1000ml**	**1500ml**	**2000ml**
	110,2	67,1	59,6	49,3	102,3	90,3
	60,6	74,9	70,3	373,9	6,9	320,8
	66,5	77,6	46,1	79,5	136,7	180,8
	115,7	129,2	147,9	175,2	240,1	91,6
	92,1	83,3	124,5	128,8	164,3	343,9
	221,13	89,2	139,7	116,9	161,5	199,1
	69,4	112,9	178,3	151,2	128,5	419,9
	67,45	126,4	119,6	135,4	179,6	154,2
	102,3	122,8	88,9	148,4	154,3	421,2
	81,8	129,6	96,7	126,4	175,7	214,9
Avg.	85,1167	101,3	107,16	123,456	150,363	155,15
%	0,85117	0,4052	0,21432	0,12346	0,10024	0,07758

Turbine Flow Sensor, Inlet: Chilled, Carbonated Boiling respectively

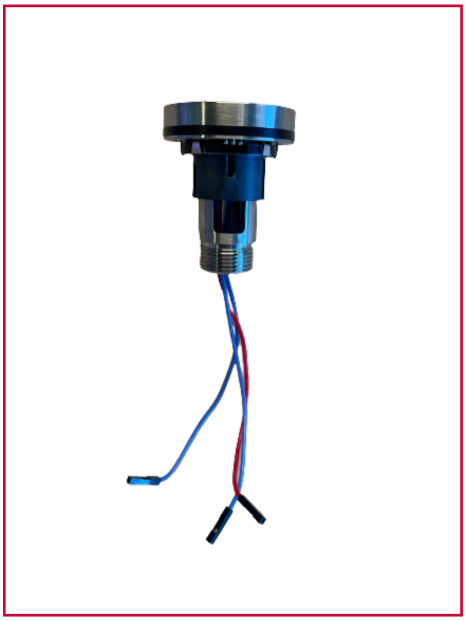
Offset between tapped and requested volume					
71	78,5	97,7	190,73	238,6	268,2
51,13	85,6	109,08	181,55	217,5	277,6
41,89	87,6	112,3	161,4	254,9	296,7
52,61	95,76	110,3	150,9	224,7	303,9
63,7	75,1	96,4	160,9	218,9	313,9
48,2	75,1	112,7	180,9	232,9	321,25
41,03	70,4	109,56	157,5	254,5	311,7
33,77	75,3	105,85	173,3	205,05	278,8
77,1	99,2	112,3	108,4	200,3	285,2
76,15	68,15	122,6	161,8	225,4	270,5
55,658	81,071	108,879	162,738	227,275	292,775
0,55658	0,324284	0,217758	0,162738	0,151517	0,146388
174,49	150,8	159,1	-163,4	-339,2	-243,4
376,87	180,22	145,01	-130,9	396,6	-128,3
93,7	11,42	244,85	618,7	137,3	205,9
89,03	18,7	-34,44	-67,4	508,7	216,8
91,6	82,05	140,5	263,15	12,16	-434,64
82,33	232,5	1,8	-59,5	-209,7	-42,4
86,9	248,5	-45,5	202,8	674,5	-21,3
83,28	328,02	97,1	28,9	163,2	370,2
65,1	26,35	547,3	39,27	180,8	86,5
191,59	264,8	-51,1	122,4	260,3	210,5
133,489	154,336	146,67	169,642	288,246	195,994
1,33489	0,617344	0,29334	0,169642	0,192164	0,097997
82,36	85,8	139,9	134,2	177,3	209,5
69,45	102,9	72,6	129,4	160,3	177,08
68,6	77,9	115,6	144,62	176,2	204,59
103,2	84,3	118,9	178,5	138,5	175,7
49,2	96,5	100,9	111,1	173,6	212,1
96,1	62,7	94,2	152,3	164,2	206,6
66,7	83,6	123,9	145,4	163,8	216,2
114,19	59,3	97,6	148,55	166,4	204,1
57,9	80,42	106,1	163,1	153,4	258,44
67,88	124,8	104,3	136,45	141,2	208,1
75,49778	85,822	107,4	146,0244	164,5125	201,4317
0,754978	0,343288	0,2148	0,146024	0,109675	0,100716

Vortex Flow Sensor, Outlet: Chilled, Carbonated Boiling respectively

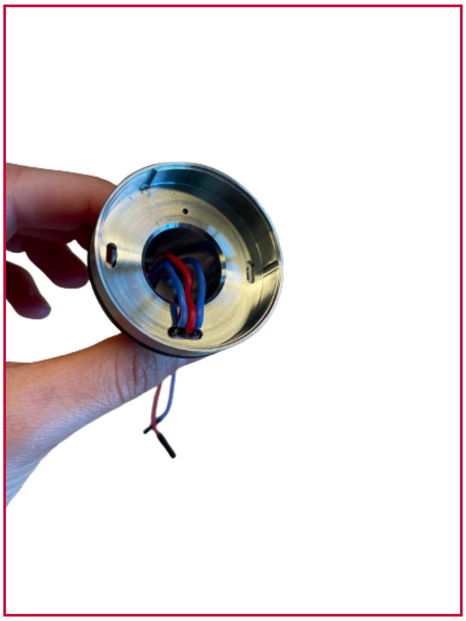
Pressure Sensor, Inlet: Offset for chilled and boiling water respectively

100ml	250ml	500ml
95,56	249,4	388,3
98,57	227,9	448,9
129,65	241,3	413,9
130,6	230,9	433,6
136,3	224,5	455,8
28,7	37,9	35,4
43,7	3,3	58,9
21,7	11,7	17,5
30,67	48,1	46,8
62,9	29,45	73,2
83,29444	130,445	237,23
0,832944	0,52178	0,47446

Appendix III
assembly

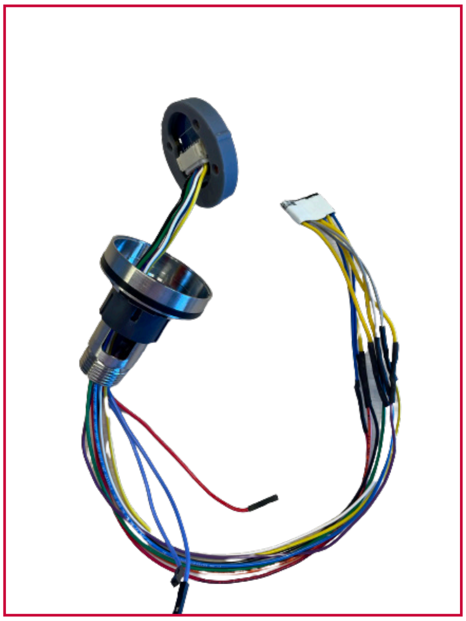


1. The encoder is slid through the middle part and the sliding ring in the groove on top.



2. The cables are fed through the slit and run through the middle part.

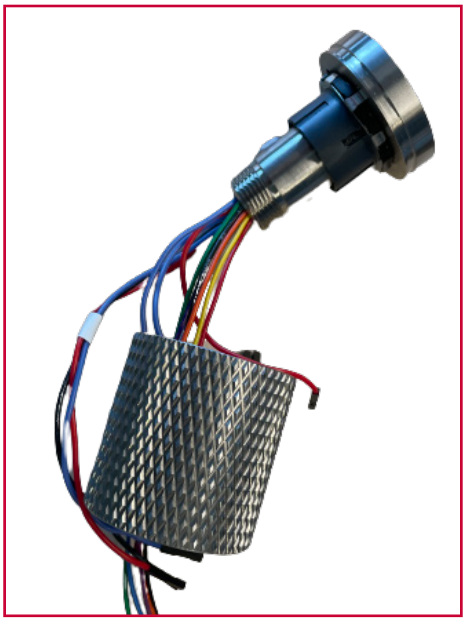
3. The screen is placed on the screen holder.



4. The screen sub-assembly is fed through the middle part and push fit in place.

5. The tempered glass in placed on top and glued with glue strips.

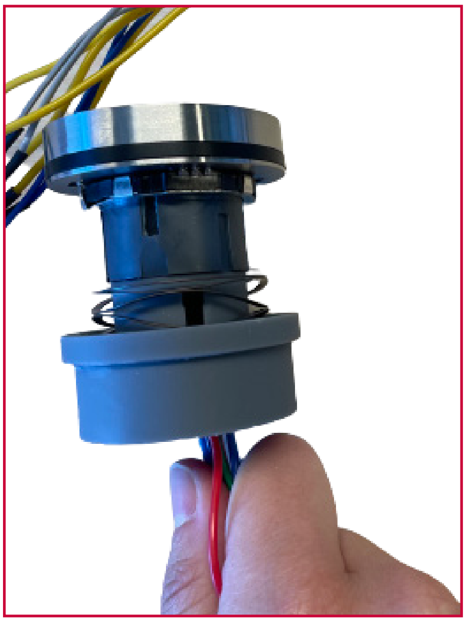
6. The magnets are placed in the plastic insert and the part is press fitted in the outer ring.



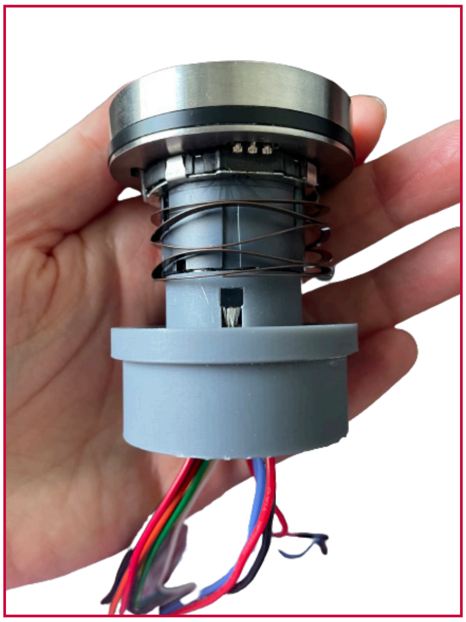
7. The middle components is fed through the outer ring.

8. The plastic insert is inserted in the bottom part, alongside the sliding ring.

9. The wave spring is placed in the groove.



10. The plastic insert is slid onto the middle part (incl outer ring, not shown in the picture)



11. The hall sensor is placed in the opening through the middle part and plastic insert. This step will be eliminated in the final product thanks to the SMD hall sensor on the PCB.

12. The cables are fed through the bottom part and all three parts are screwed together.

As mentioned in Chapter 8, the design needs to be optimized for assembly and disassembly. So far there's been improvement in that direction, but more steps need to be taken for the final product.

The FS Housing hasn't been prototyped beyond a presentation rendering as part of the development phase [25], thus no assembly instructions are provided for that. However, the assembly of the flow sensor unit is more straightforward that the one for the external knob due to the housings low complexity. The steps include:

1. Inserting the turbine insert and hall sensor
2. Inserting the O-rings, clip and swivel nut on the brass fittings and placing in the housing.
3. Securing all parts with the fork clips.
4. Placing the lid on top.