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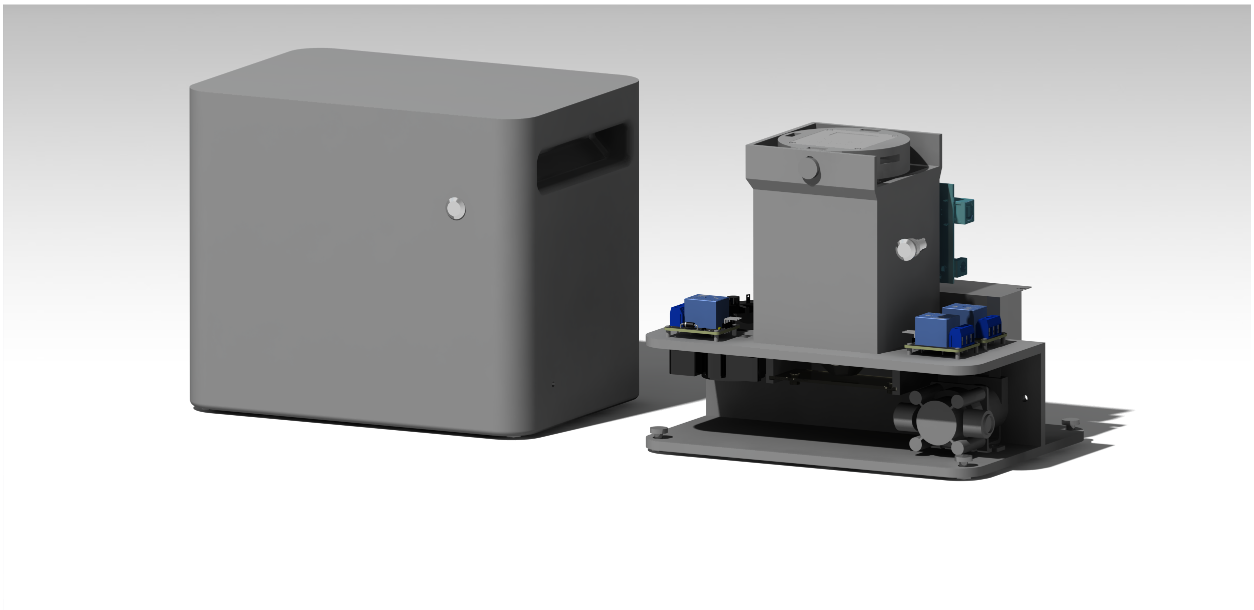

Detection system for bacteria in drinking water

Development of support systems for real-time bacteria analysis

Master's thesis in Product Development

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Department of Industrial and Materials Science
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2023
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Master's Thesis 2023
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Cover: Rendering of the concept generated though out the development process described in the report

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Abstract

This project covers a product development process for the support systems of a water analysis method for drinking water which can be used to automize the monitoring process of bacteria or to manually test the water and get faster results than current methods.

The project includes several stages: Research, concept generation, Concept selection, concept development, concept verification, and recommendations. The research stage includes all the information gathering including patent analysis, competitor analysis, interviews, and a law analysis. The concept generation stage includes a brainstorming session and a morphological matrix. The concept selection stage includes an elimination matrix, pugh-matrixes, and a focus group in order to select the final concept. Concept development stage consists of a CAD model creation and a 3D-printed model. A concept verification stage consisting of tests in order to verify the level of readiness according to the requirement specifications. And the final part of the report is a presentation of the information collected during the project and some recommendations for further work on the project.

The project was executed at a start-up company called Nocoli and the aim of the project is to support Nocoli in the development of a new era for water analysis systems. The project goal was to create a supporting system for a new technology created by a scientist at Halmstad University, the technology for water analysis worked in a lab environment and needed a product development process in order to test the functionality outside of the lab and to show potential customers and investors. The plan for the supporting systems was to move water through the model in a controlled manner through a microchannel. The project ends with a prototype that visualizes the supporting systems and shows proof of concept in transporting water through the product for the analysis to work with the help of both pumps and valves.

Keywords: Product, Product development, Bacteria, Water analysis, CAD, 3D Print

Acknowledgements

With a big project like this thesis a lot of people are involved in order to make this possible, we are very thankful for the people that made this project possible. We would like to start by thanking the people at Nocoli and especially Jacob Cahn & Jacob Nissén for providing us with this opportunity and for all the help along the way. We would also like to thank all the people at Yuncture for providing a workspace and valuable lessons in business development. We would also like to thank our supervisor in school Adam Mallalieu for providing us with all the right tools and a helping hand when needed. And thanks to Lars Almefelt our examiner for evaluating our thesis.

Nils Carlind & Oscar Pettersson, Gothenburg, 2023 June

List of Acronyms

Below is the list of acronyms that have been used throughout this thesis listed in alphabetical order:

BMS	Battery Management System
CAD	Computer Aided Design
PLA	Polylactide
TRL	Technology readiness level
IP	Ingress protection

Contents

1
Introduction

This chapter describes the information needed in order to successfully create a supporting system for Nocoli, in this report referred to as The Company. The introduction covers the information required regarding bacteria in drinking water, the background to the thesis, the thought application areas, where the technology is today, what the thesis answers, and who is involved in the project.

1.1 Background

The Company´s subsystem using a microscope to analyze the water trapped in a camber gives the waterworks the results instantly, the samples will be continuously checked against a database with all references from previously studied bacteria. The technique can be implemented as a first warning system that combined with the standardized lab technique can be very effective in finding bacteria and performing further tests on the stopped water using the old and trusted lab technique. After The Company´s method has been used long enough to be validated and accepted as a standardized method for gathering data can it replace the current analysis method of growing and counting bacteria populations.

The Company has developed an analysis system made to analyze drinking water, to find small amounts of bacteria. These tests are done using the needed hardware and manually checking every bacteria viewable on the screen. The sub-function model has been used to prove the concept in a controlled environment and to show proof of concept to potential customers. The need for a complete solution to show proof of concept when implementing it into a complete concept for handling intake sample preparation is what this master thesis will touch upon.

The samples will be continuously checked against a database with all references from previously studied bacteria. The point of the thesis is to develop the sampling hardware to work together with the analysis components by taking in a water sample, preparing it, and then ejecting it to represent a functional prototype to show potential customers and investors. Shown in Figure 1.1 is a picture of the first prototype provided by The Company. The supporting systems referred to as the sub-system or provided by The Company will be used as a black box in this project to avoid interacting with patent applications.

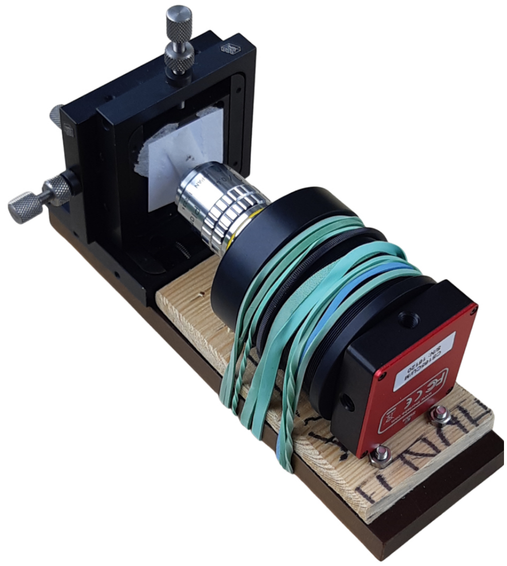

Figure 1.1: First prototype testing the technique

1.1.1 Bacteria in water

In Sweden, clean tap water is readily available in both industries and households. The quality of the water is monitored at the waterworks and with testing units both portable at the customers/consumers and mounted in the water network. The waterworks source water from local sources for example lakes, waterways, groundwater, and surface water. all of these sources can contain bacteria, bacteria from those sources can spread and contaminate the drinking water in the water distribution networks, making consumers sick. There is also a risk of contaminants spreading due to leaks when moving water through the water network to households and industries[1].

Common symptoms that people in Sweden experience related to the spread of bacteria in drinking water are gastrointestinal inflammations, which can make you feel very ill and get diarrhea. When a patient comes into the hospital with stomach aches and diarrhea, it is difficult to connect the symptoms to bacteria in the drinking water. Tracing those symptoms back to the drinking water requires the labs connected to the waterworks to get their tests back which can take several days depending on their lab. But even then, it can be difficult to trace it back to water contaminations because the bacteria that usually spread in the water are also found in other places[1]. Waterworks collects samples and tests the contaminants in a lab environment using a plate count method, this method is time consuming and requires manual loading of samples.

Although we have high-quality tap water here in Sweden, outbreaks still occur, every year around 1 000 people on average get affected by the contaminants in the drinking water. If an outbreak occurs, the bacteria cause hospital visits and the bacteria sanitizing techniques in water are costly. The cities can save money by implementing an instant testing method knowing instantly when the water is harmful to humans and knowing when the water is drinkable again. A case in Östersund, Sweden was in 2010, when 27 000 people drank water contaminated with a parasite. The city recommended boiling the drinking water for 3 months after the outbreak[1].

1.1.2 Purification process

At most waterworks today in Sweden the purification process is similar. To better get an understanding of the project and where the future product can be implemented a description of a normal purification process at a water work is provided.

Water gets taken from a water source near the water work, and the water then gets run through a sedimentation process where bigger particles in the water sink to the bottom and can be filtered out. Then the water gets run through a finer filter to remove some of the turbidity and particles in the water, with the use of UV-light bacteria that still contaminates the water get killed and before the water gets sent out in the water network a chemical can be added to ensure that all bacteria and living organisms are dead[2].

1.1.3 Application areas

The intended product can be applicable in many different places in the water's way from source to the customer/consumer. The final product can be used at the waterworks in the purification process to test for bacteria in-between all the purification steps, and at the end before it gets sent out to the user. The testing unit can be implemented in the water network at control spots to ensure the water quality doesn't get affected by leaks, and out at the customer/consumer to ensure quality hasn't changed. The full system can be seen in figure1.2.

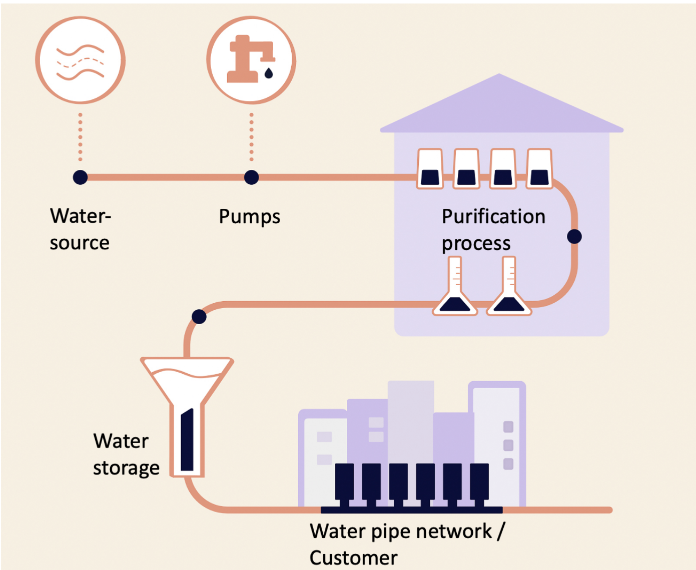

Figure 1.2: Application Areas

The first possible spot to test the water contents for bacteria is at the inlet for source water shown in the graphics in figure1.3. There are biological advantages to knowing which bacteria are found in for example lakes and streams, by constantly monitoring the water, changes can be detected early. This can be seen as an early warning system but does not need to stop the water process if detected here.

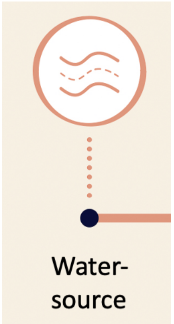

Figure 1.3: Water source application area

The second stage is to be able to follow the contents in the water throughout the different purification steps at the waterworks shown in the graphics in figure1.4 . Detecting bacteria at the treatment plant makes it possible to stop the bacteria from going on to the pipes and thus creating a spread that must later be cleaned up. This means that the treatment plants receive a direct notification when bacteria are present in the pipe and can thus stop the water flow before it is carried on creating more problems down the road in the water network systems.

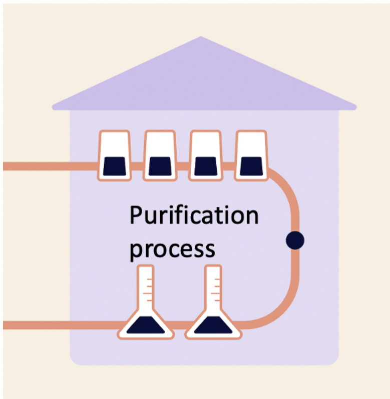

Figure 1.4: Purification site application area

The next possible implementation place is in the water network system in the cities shown in the graphics in figure1.5. By constantly monitoring bacteria in the pipeline network, you can see if there are any changes from the previous stations or if, for example, there has been a leak in the pipe after the waterworks. Small leaks or bigger damages to the water network can occur if there is work going on with the pipes or if a pipe has been damaged in another way. If there is a leak in the system and dangerous types of bacteria enter the system a warning to the customers can be sent out and a boiling recommendation can be in place before the customer gets affected.

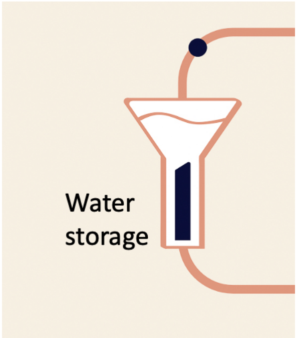

Figure 1.5: Water storage application area

The last testing spot in the potential testing sites is at the customer shown in the graphics in figure1.6. To be able to secure that the water pipe network in the city doesn't have any leaks or contamination leading to the bacteria ending up at the customer can work as a late warning system, this step is to stop the water from getting used in industries or in the households when bacteria is detected.

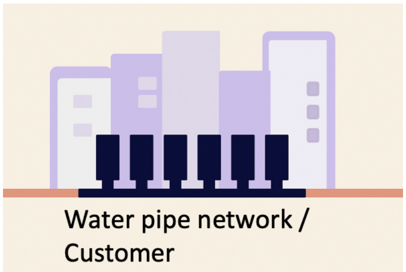

Figure 1.6: Pipe network / Customer application area

1.1.4 Opportunity identification

The measurement technology was developed by a researcher at Halmstad University and that technology was then connected to students who studied for their master's degree at Chalmers. Their master thesis was to create a business plan for the product and show potential customers that the product exists and how it could be implemented in their business.

From the interviews performed by The Company presented in the TPD study[3], the market has a great demand for better technology in water quality monitoring. but the way to carry out these checks is something the market has not pushed for. This can mean that the project can be seen as a pushing project as the market has not demanded this particular product that has been produced.

But on the other hand, it can also be seen as a pulling project as the market constantly wants the newest technology and wants the controls to be carried out as quickly as possible to ensure the quality of the goods they produce. This causes the market mindset to pull out all kinds of technology. Through The Company's meetings and pitches to the potential stakeholders, it has been received with great interest, the interested companies have tried to sign purchase agreements. This indicates a high demand for the product and a growing interest in its development.

1.1.5 Technology readiness level

The Company today has a prototype that under lab conditions provides answers to the tests that are carried out to ensure that the invention has a function. The plan for the invention is to use AI to identify different bacteria types and the learning input data and the full software is to be developed by The Company later on. The function model prototype needs to be fed with new water manually and after each test reloaded and flushed to provide a new testing sample.

The current stage of the model can be seen as operating in controlled environments, which gives The Company a good basis for seeking investors and working on acquiring future potential customers who want the future product. As the technology works in a controlled environment it has a certain validity which for many investors is a step that must be present in order to gain the confidence needed for investment. The technology is still in its early stages but is on its way to commercialization.

During the autumn, The Company has invested time in looking for Bachelor's and Master's degree students to help The Company create a product that can then be developed into a market-adapted ready-to-sell product.

The development idea within The Company this spring is that two thesis projects are working on further developing this product in order to reach higher up the ladder within the Technology readiness level or TRL for short in the near future. Our project will cover the product development of connecting the subsystem to develop a semi-functional demo product and the other thesis will cover the bio/algorithms for analyzing the output data.

TRL is a measure to evaluate where in the development stages a product or service is. The product has currently reached a stage that is associated with TRL 3. At this stage, you must be able to show "proof of concept" and as previously described, the product must be tested in a lab environment or in a controlled environment and demonstrate that it is ready for the steps towards commercialization the full ladder with classifications can be seen in figure1.7 [4].

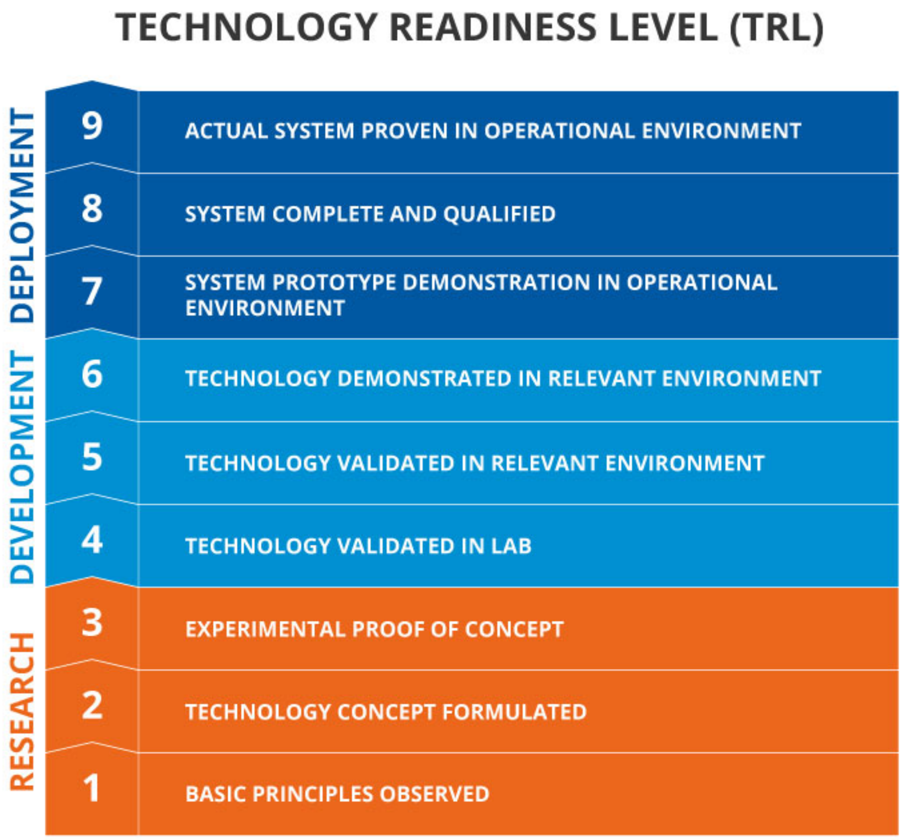

Figure 1.7: TRL chart [4]

1.2 Purpose & reserch questions

Based on the response The Company has received from potential customers and investors they need a functional example of their analysis method to get to the next stage in their technology development. The interest for The Company calls for a newly developed prototype for experimental use and visualization for a possible product with the possible operation outside of the lab environment. We will create a model to show potential customers and develop the subsystems in the model needed to show proof of concept using implementable stable techniques for real world tests. The project aims to create material for The Company to present the basic documentation planning for Productionsänglarna, a manufacturing service for start-ups. The prototype can also be used for securing additional funding for The Company during exhibitions and investor meetings.

Produktionsänglarna evaluates start-up projects in order to see where they can help the most. In order to have a good chance of being picked a good visual model and a model with good future plans are needed in order for them to invest in the idea. The goal is to provide The Company with useful information to help them search for

investments both through Produktionsänglarna and also through other investment companies.
Research questions:

- Can 100ml of water be transported through the model in a controlled manner in 30 minutes?
- Is it possible to build the equipment into a portable solution?
- Is it possible to make a prototype that can handle all user scenarios without adaptation/modification?

1.3 Scope & limitations

The scope of the thesis was to explore the design space for implementing the laboratory analysis equipment into a concept and developing the concept into a viable first-generation prototype/product. The project covers the supporting components in order for the analytical methods to work. This includes the water transportation through the model, the controller for the electrical system, and the case for the model.

The founding of the project led to a visual and testable prototype in a semi-functional state. The model does not use any analytical equipment or send any information to external units. Without a development partner, the project was restricted to Chalmers concept development lab Prototypsverkstaden. The product development laboratory is located on Chalmers campus with the aim to help the development of experimental ideas and products.

The allocated time for the project was equivalent to 30 hp during the spring of 2023 for two students from the product development master. The project started on the 16th of January and the project ended in June 2023.

The project only deals with the development of hardware and the implementation of existing parts, this sets limitations to not develop or evaluate the software part of the product. This means that other aspects of the prototype like machine learning and data transmissions won't be evaluated or developed in this project, the project will not include embedded software.

1.4 Objectives

The results of this project will move The Company's hardware technology further toward fulfilling its goal of implementing a fast and automated method to analyze drinking water. The objectives of the project defined to further The Company's goal are:

- Develop support systems for collecting and preparing the sample for the analysis method
- Build a digital prototype for the supporting systems

- Build a physical prototype for the supporting systems including a placeholder for the analysis components

1.5 Key activities

To clarify what we want to achieve in each phase before declaring it complete was key activities used to define what had to be done in each phase. The purpose of the key activities was to describe what information, knowledge, or results are expected to take from each step to the next.

- Knowledge base objectives

  Look into existing patents to avoid patent infringement and to gain inspiration for the brainstorming session.

  Explore the concurrent market to gain an understanding of minimum performance as well as see opportunities in the market.

  Define the stakeholder to inquire about their customer needs

  Establish legal and regulation requirements for a final product

  Learn about The Company's existing documentation to avoid retreading already explored opportunities. As well as finding the required system input and outputs for their technologies operation.

  Define the TRL to be able to set realistic goals for the project.
- Requirement objectives

  Describe the information gained in the previous milestone in the form of functional and non-functional requirements. This is to be able to verify the findings in milestone one against The Company's product goals and business model.
- Concept objectives

  Explore the design space based on the established functional and non-functional requirements.

  Evaluate the generated concepts to determine which one/ones are the most viable concepts and take them into the next milestone.
- Development objectives

  Create detailed representations and verification models for the concepts to be tested against the established requirements to see the feasibility of the concepts in a test environment.
- Result objectives

  Compare the results in the tests to the established specifications to see how well the system fulfills the requirements.

1.6 Actors and Stakeholders

A visualization of the Actors and Stakeholders has been compiled to get an idea of the people involved in the project and how the information is forwarded in figure1.8.

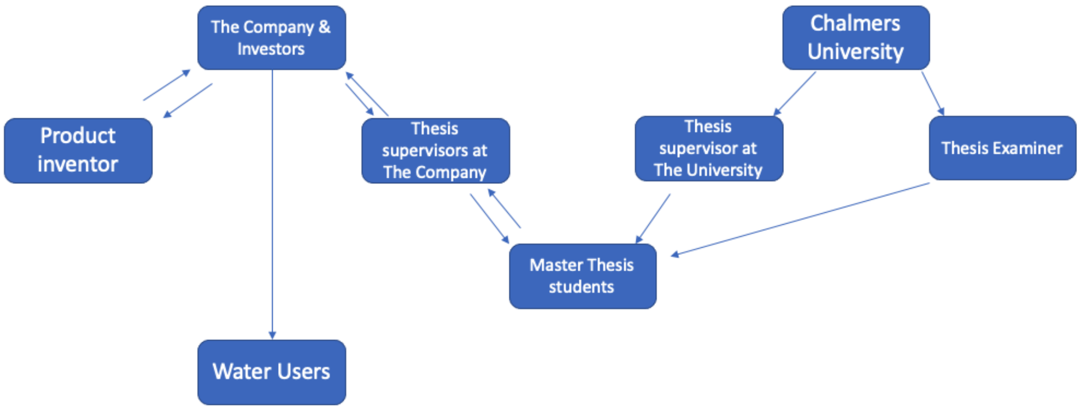

Figure 1.8: Chart of actors and stakeholders in the project

The Company provides the water user with equipment that detects bacteria in water. The Company receives and shares The Company information with the product inventor as well as with our thesis project. The thesis project gets the information via The thesis supervisors at The Company.

The thesis students get information both from the school regarding academic advice and from The Company on things like requirements and customer information. The students provide The Company with a prototype of the supporting systems for the analytical parts that The Company plans on using to detect the bacteria.
A list can also be seen below to connect the role to the name of the actor:

- Company Thesis Supervisors:
  Jacob Cahn
  Jacob Nissén
- The scientist behind the invention:
  Ying Fu, Halmstad university
- Master thesis students:
  Nils Carlund, MSc Product development
  Oscar Pettersson, MSc Product development
- Master thesis supervisor:
  Adam Mallalieu, PhD student, project supervisor
- Master thesis Examiner:
  Lars Almefelt, Senior Lecturer and Assistant Head of Department with responsibility for education at undergraduate and masters level, Examiner
- Investors
- Water treatment services
- municipalities
- Water consumers
- Beverage manufacturers
- Temporary construction sites

2
Methodology

The methodology outlines the phases of the project and the key activities performed in them to fulfill the objectives of the project. The structure of the phases is based on the theory in Ulrich and Eppinger's product development process [5].

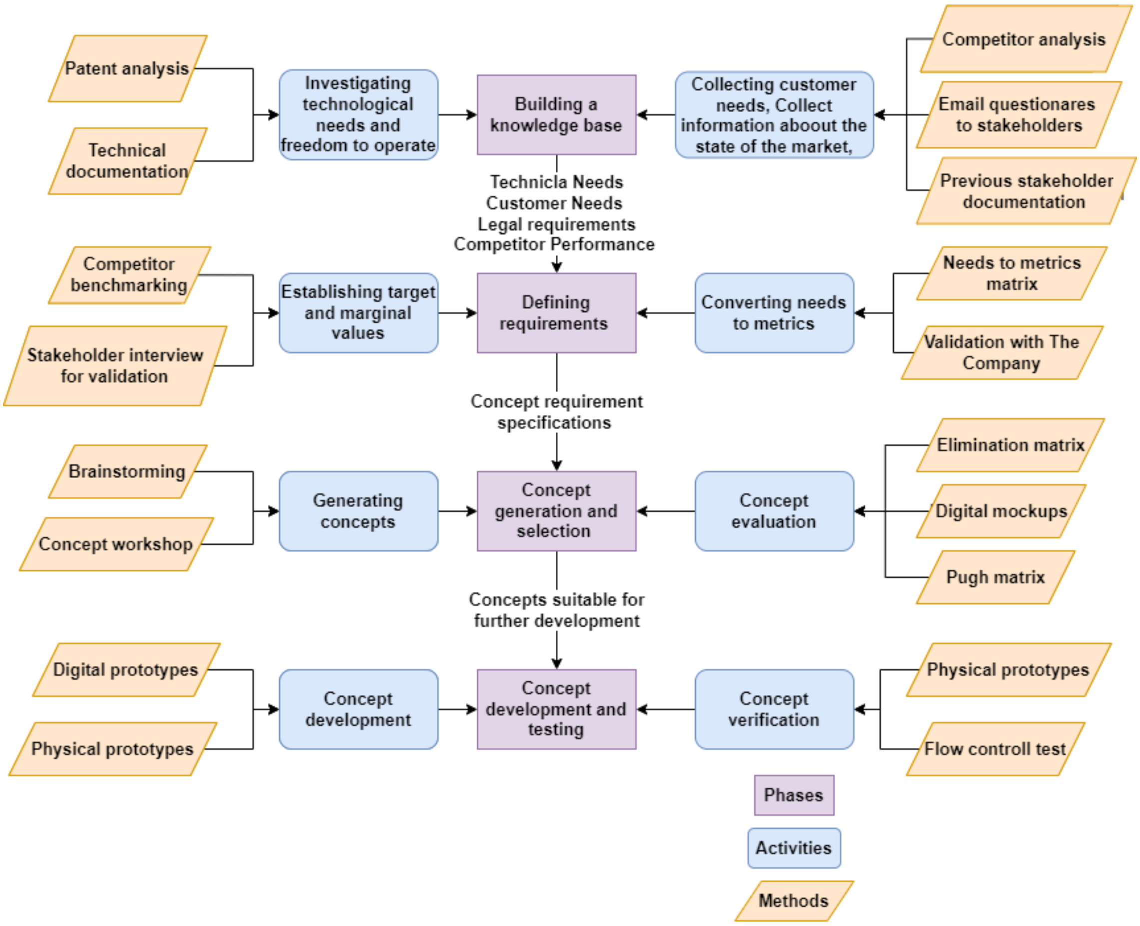

Figure 2.1: Flowchart with phases, activities, the methods used in each activity, and the results from each phase is

The project is split up into different phases due to the lack of specified deliverables to create a structure based on chronological tasks. The structure of the phases is based on the chapter structure in Ulrich and Eppinger's product development process [5]. Each phase is split up into key activities to see progress on a weekly basis to enable prioritizing activities that might have fallen behind schedule. Each phase with its key activities and the methods used in them are represented in figure 2.1.

2.1 Building a knowledge base

To gather the information required for establishing the requirements were four key activities necessary establishing the technology requirements, patent analysis, competitor analysis, and interviews with key stakeholders. Each key activity had a subset of activities to accomplish the key activities.

- Establish technology requirements
  Go through existing documentation
  Meetings with company stakeholders who developed the technology
  Function diagrams
- Patent analysis
  Going through The Company's internal documentation about their freedom to operate
  Meeting with IP exploration company
- Competitor analysis
  Explore leading market solutions for automated bacteria analysis
  Establish competitor's performance metrics based on their publicly available specifications
- Interviews with key stakeholders
  Existing stakeholder report The Company has done
  Surveys to water treatment facilities
  Exploring public data from key stakeholders

2.1.1 Establishing the technology requirements

The goal of establishing the technical requirements is defining what supporting functions need to be fulfilled and the technological needs for the analysis system to function. Due to the analysis method already being established and having a patent application. Because of this will every decision in the product development process be affected by the opportunities and limitations in the analysis components. Therefore is a complete understanding of the technology a necessity for a viable result.

The base knowledge of the technology's principles came from a video recorded during a workshop the founders of The Company had during the autumn of 2022. These videos gave an overview of how the physical and biological principles are applied for analyzing the sample and generating relevant output data. To gain a deeper insight into the analysis components was a revision of The Company's internal documents performed. The documents describing the components were a list of components[6], patent documentation[7], and a presentation of the research[8].

To validate the interpretation of the existing documentation was a function model of the analysis system and its supporting systems created[5]. The purpose of this model was to visualize the interactions between all vital components of the system.

The final step in the validation was a stakeholder interview with the researcher at The Company to make sure all the technical requirements were collected.

2.1.2 Patent analysis

To explore what previously has been done and what is to come in the field from a technological perspective was a patent analysis used. The purpose of the patent analysis is to define what has been patented and investigate potential trends in the field. This was to gain inspiration from the prior arts and establish the freedom to operate [9].

The basis for the analysis was an internal document The Company regarding their freedom to operate[10]. The patents in the document were analyzed from a support system perspective to see how other companies have implemented the systems around their analysis components. The patents that were closest to The Company on a system level were the applicants further investigated to see what they most recently had applied for to see if they are moving closer to The Company's potential product. The findings were later affirmed during a meeting with a contracted company that investigates The Company's intellectual property[11].

2.1.3 Competitor analysis

To gain an understanding of the main competitors on the market, The Company previously investigated the type of technology they used. The data collected was what type of analysis method the competitors use and The Company's perceived pros and cons for the competing analysis methods[12]. This was further investigated to collect competitive benchmarks based on the competitor's product brochures. The collected data was then compiled into a table comparing their stated performance 3.6.

To validate how The Company wanted to compete in the market was a meeting held where The Company elaborated on what areas they were aiming at being market leading. These metrics were then later used to establish target values for performance in the product specifications to set up competitive product goals3.6.

2.1.4 Interviews with key stakeholders

To get an understanding of the potential market for a finished product we gathered information from The Company's previous internal data (TPD analysis)[3] regarding key stakeholders, the analysis got complemented with an additional survey to verify that the information was up to date. The survey sent out to geographically dispersed and different sizes waterworks confirmed that The Company's internal data were up to date and the results of the survey are presented in the customer interviews section of the report. The questions can be seen in the appendix A.5 from the Thesis part of the interviews.

2.1.5 Law analysis

A law analysis was done to ensure the laws regulating drinking water analyses didn't conflict with the testing rates and testing types specified in the needs and metric table. The regulations studied are stated on Livsmedelsverkets website, the regulation LIVSFS2022:12 is according to the waterworks interviews a testing requirement that they use to regulate the internal testing program of the sites.

2.2 Defining requirements

To have practical use of the needs, wishes, and technical requirements collected in the knowledge-building phase was it necessary to convert them into measurable metrics. This was done by coupling the needs to metrics in a needs-to-metrics matrix A.4 as described in Product Design and Development[5]. The needs-to-metrics matrix was used to clearly visualize how the needs are coupled to the metrics.

With the metrics established in the needs to metrics matrix was the metrics then used in a requirement specification and formatted after exhibit 6-8 in [5]. The marginal values and target values were based on the information collected in the competitor analysis, the collected technical requirements, and the requirements and wishes of The Company and customers to establish reasonable ranges for the metrics.

To ensure the alignment of the requirement specification with The Company's plans for future products was a meeting held to discuss the results. The main objective of the meeting was to validate the findings and ensure that the marginal and target values were consistent with The Company's business plan. This meeting was also held to identify discrepancies before the concept generation stage due to the amount of influence the requirement specifications will have on the concept selection.

2.3 Concept generation

The concept generation was performed internally at The Companyy to ensure that everyone involved understood the technology and had relevant expertise within the field. To generate the base concepts was an internal open brainstorming session performed to generate sub-solutions for each function the supporting systems need to perform. The generated concepts were then categorized with classification trees. This was done to clarify what types of solutions had been generated and to manage a plethora of ideas.

Before the sub-solutions could be combined with a morphological matrix was the number of combinations reduced due to time constraints in the project. To reduce the number of potential full concepts was the least promising branches pruned based on their deemed feasibility [5]. This pruning was performed by looking into concurrent solutions for similar functions as well as the requirements established in the research phase.

When the least promising branches in the classification trees had been pruned were a morphological matrix established with the remaining sub-solutions. To create full concepts the team took turns generating concepts based on their own judgment to avoid illogical combinations of the sub-solutions.

2.4 Concept selection

Because this analysis method hasn't been implemented in a complete system before was decisions tables used for evaluating the concepts. The advantage of decision matrices is their high traceability which will make it easier to evaluate the decisions done in this project and use them as a knowledge base for further iterations.

An elimination matrix was used to evaluate the concepts generated in the morphological table to determine if the generated concepts fulfill the requirements in the project specifications. The elimination was based on characteristics in the concepts that went against the wishes or requirements previously defined in A.2.

To further evaluate the concepts was a Pugh matrix used to rank the concepts in relation to each other. This was done by taking a concept at random and using it as a baseline. This was then iterated again with one of the best-performing concepts in the first iteration as the reference. All the concepts that had placed in first or second place in the iterations were then further developed.

The concepts chosen in the Pugh matrix were further developed to specify each solution for a Kesselring matrix where the final concept was supposed to be selected. Although based on the findings were a feasibility estimation performed instead due to the new insight gained about the available components that could be acquired during the project time limitations.

After the feasibility study had been performed were a focus group held with The Company representatives to choose which concept was closest aligned with their business plan 4.5.11. The focus group resulted in a final concept that was taken into the next step of actualizing the concept into a functional prototype for the supporting system.

2.5 Concept development

All the concepts were broadly described before the elimination matrix in text, a simple CAD product architecture, and a schematic. After the Pugh matrix was the remaining concepts further detailed for more precise and verifiable concepts. The concept development was split up into two parallel tasks. One of the tasks was the development of the flow control method and the other task was the integration of the different systems into a complete concept in the form of case and user interface.

The development of the flow control system was based on an iterative exploration as seen in Figure 2.2 of the available components that were described in the concepts. The availability of components and the possibility to implement the mechanical systems were explored in each concept to further evaluate and take the availability and usability of these components into consideration.

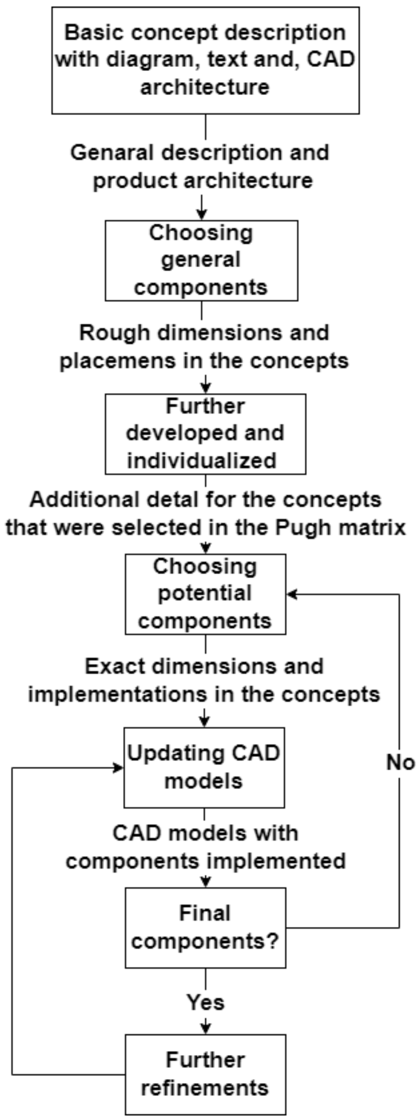

Figure 2.2: The workflow during the development of the concepts

The development of the digital prototype was done through iterative refinement where the models were updated as information about the available components came in. The basis for the digital prototype was the rough architecture. The rough product architecture was refined after the Pugh matrix where additional details were implemented in the form of estimated sizes for components and fastening methods.

The refined CAD concepts were evaluated with company stakeholders to gather their feedback and ideas for further development. Following the focus group's selection of the final concept and the identification of components for the prototype, the concept was further refined. The final design was then prepared for 3D printing, and all machine elements for fastening the components were implemented into the model.

2.6 Concept verification

The final concept proceeding the selection process gets verified through a number of tests including both virtual tests in a CAD environment and physical tests performed on the manufactured prototype.

2.6.1 CAD environment

The verifications suitable to perform in a CAD environment are theoretical measurements for ideal conditions. For this reason, was all the measurements in the verification based on the digital prototype due to errors caused by the manufacturing method. The measurements that were collected were dimensions and total weight. This was achieved using the “measure between tool” and the “measure inertia tool”. The digital model was also used to create a bill of components to verify what types of components were used in the prototype and how many of each component.

2.6.2 Functional model

The manufactured model was used in order to perform and verify the metrics regarding the final prototype. This includes IP rating testing, drop testing, transporting water, and pressure feeding testing. The destructive tests were done and a 1:1 clone was done in order to give The Company an intact model in order for them to continue testing and to show potential customers.

3
Research Results

This chapter describes the results from each activity and briefly how the results were reached. The beginning of the chapter describes the information collection method and the results and at the end of the chapter are the findings compiled into a list of specifications.

3.1 Customer Information

In this section, the place of application will be described as well as the customers for whom the product is intended to be developed for. Information is gathered through interviews and information given by The Company. The application sites are waterworks that were contacted through The Company or via direct contact.

3.1.1 Customer interviews

The Company conducted interviews with relevant stakeholders in the spring of 2022. The interviews were conducted with personnel at different waterworks and city planners. The interviews were aimed at potential customers with relevant information and feedback to The Company. The interviews are presented in an unpublished document at The Company[3] where they are mapped out and color coded to get a good visual presentation of the different results and answers from the stakeholders. Since the interviews were carried out a year ago by a person who no longer works for The Company a mail survey was conducted to find out if the information were up to date. The survey confirmed the information gathered in the interviews except for some regulation changes made by Livsmedelsverket. The questions sent out to validate the old answers can be seen in appendix A.5. An update in the regulations regarding drinking water has occurred during the past year and the new regulations called LIVSFS 2022:12 launched in December 2022 [13]. The new regulations are the new baseline for some of the waterworks instead of the precursor. So instead of using the old regulations as a benchmark the project used the new LIVSFS 2022:12 as a minimum criteria for tests done on analyzing Bacteria. A full description of relevant data to the project on the new regulation can be found in 3.1.2.2.

3.1.2 Waterworks

The waterworks that will be presented in this chapter can be divided into two groups, small waterworks & medium waterworks, and in the second group large waterworks. This division is divided because the small and medium-sized water utilities share many parts of the testing and management of the samples conducted at the facility, they also share the same ability to invest in new tech compared to the large waterworks.

3.1.2.1 Waterworks size difference

Small or medium waterworks means waterworks that produce purified water for less than 100,000 people. The waterworks that are included in this segment are often placed outside large cities or where not many people live. Small waterworks tend to test newer methods because they do not entail the same investment risk as for larger water plants due to the smaller number of tests[3].

The larger waterworks that supply drinking water to major cities have a lot of pipes to quality test continuously to ensure that there are no leaks or major problems in the pipe network. This makes them more likely to invest in technologies that continuously control the water that goes out to the customers through the water network[3].

Another difference is the testing methods used to ensure the quality of the drinking water throughout the process. All waterworks take samples between the different steps in the purification process to ensure that the previous step meets the required criteria in LIVSFS 2022:12 guidelines created by Livsmedelsverket[13]. In the smaller water treatment plants some of the tests are done in the sample taps and then tested at the facility, but some of the tests that need a laboratory are sent out to another part to get analysed[3]. These tests take up to 7 days. The large waterworks handle the analysis in-house which means they cut the transportation time down a lot[3].

3.1.2.2 Law analysis

The rules and regulations that apply to drinking water in Sweden today are described on the Swedish Food Agency's website. On the website there is information on how to test water for larger production of drinking water, but also how things like water storage or small-scale water production should be done. In Sweden, drinking water is regulated by a law called LIVSFS 2022:12, the regulation states the testing sample size and the testing rate needed for different contamination in the water.

The regulations apply to both production for household consumers and also for industries and beverage producers. All forms of produced water whose purpose is to be consumed by a person and where the water plant produces more than 10 cubic meters of drinking water per day for more than 50 people must be regulated by these provisions. If the production is lower, the water only needs to be tested for turbidity, disinfection, and pH-adjusting solutions.

In the regulations, it is specified that E.coli and coliform bacteria must be checked at the waterworks, in the water network, and at the customer. All these samples must be about the size of 100ml. The frequency of the sampling is based on how large the water production is at the facility. Where sampling frequencies can vary from once a week to continuous sampling. [13]

3.2 Performance metrics of competitors

The market analysis was done to gain insights into the current state of the market. The basis for the market analysis was a previous study The Company had done. In their study, they briefly described the technology used in each product and the pros and cons of each method in relation to their own patent-pending technology. To gain a deeper understanding of the current market these competitors further investigated to document their stated performance metrics and a brief description of each competitor's product.

The primary insights gained from the market analysis were performance ranges for the different systems 3.6, most common methods for implementing bacteria contamination warning systems, and potential product architecture for setting up supporting systems around The Company's patent.

3.2.1 Bactosense

BNovates' Bactosense utilizes flow cytometry, a technique that relies on light scattering and fluorescence emission, to monitor bacteria counts in water samples. To perform the test, a sample is first dyed with SYBR Green I and then separated into individual cells. These cells are then subjected to a laser, which induces fluorescence that is measured to determine their properties and the inputs and outputs of the process can be seen in Figure 3.1. Once the solution containing the cells is analyzed, it is stored in the same cartridge that houses the supplied chemicals. This approach enables monitoring of the total cell count (TTC), intact cell count (ICC), high nucleic acid count (HNAC), low nucleic acid count (LNAC), and high nucleic acid percentage (HNAP)[14, 15, 16, 17, 18].

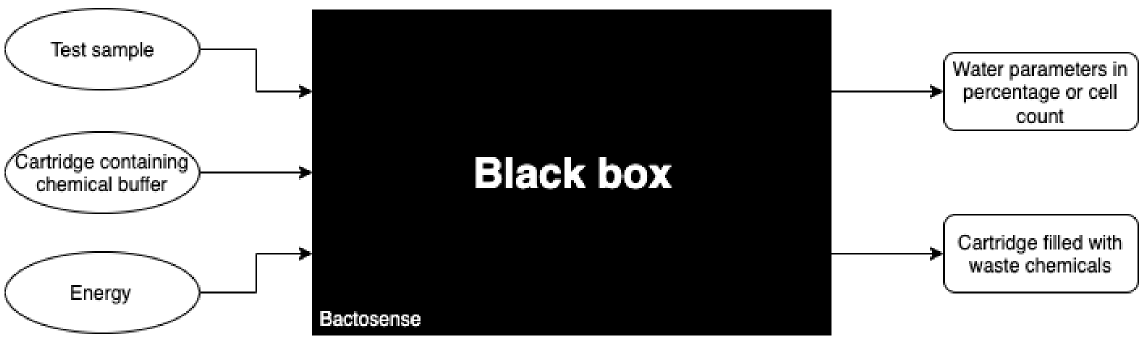

Figure 3.1: A black box diagram for defining inputs and outputs in Bactosense

3.2.2 BactoBox

Sbtinstruments BactoBox is a water testing solution that uses impedance flow cytometry as its testing method and the inputs and outputs of the process can be seen in Figure 3.2. This approach involves measuring the change in the field between two electrodes to determine the cell count in a single-cell suspension sample. By using this method is it possible to monitor the total cell count in the sample. This metric has a strong correlation with the results obtained through plate count methods. Therefore is the strength of this solution the elimination of the need for growing bacteria cultures on a plate, saving valuable time[19, 20, 21].

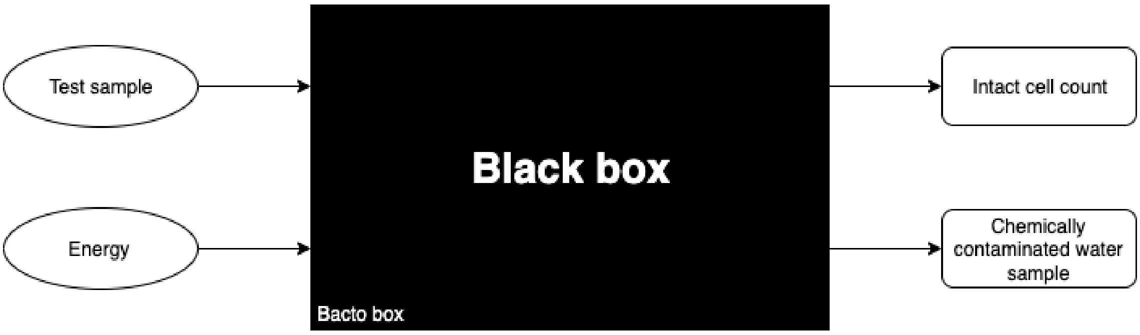

Figure 3.2: A black box diagram for defining inputs and outputs in BactoBox

3.2.3 Coliminder

The ColiMinder system works by using an optical sensor to detect changes in the metabolic activity of bacteria in water samples. When bacteria are present in the water, they consume nutrients in the sample, which causes a change in the optical properties of the water. These inputs and outputs can be seen in Figure 3.3.The ColiMinder sensor detects these changes and provides a near-real-time readout of bacterial levels in the water[18, 22, 23].

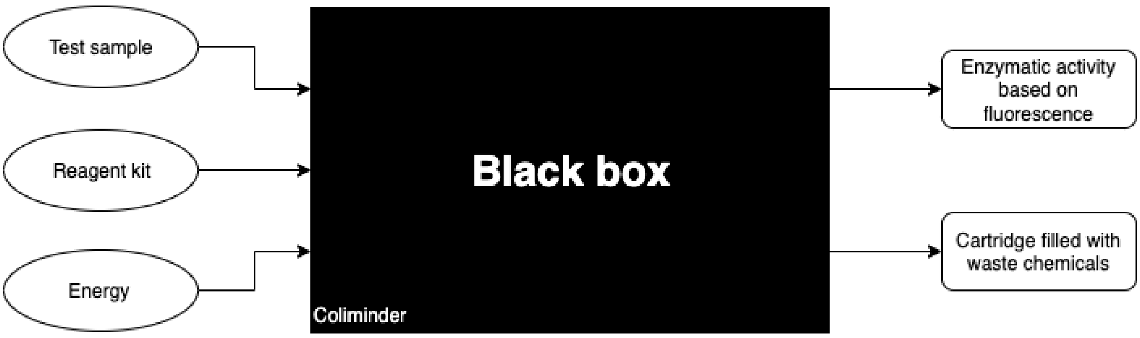

Figure 3.3: A black box diagram for defining inputs and outputs in Coliminder

3.2.4 Colifast

The Colifast Alarm is an online bacterial monitor used for continuous monitoring of water quality. It uses a bioluminescence technology to detect low levels of coliform and E. coli bacteria. The technology's inputs and outputs can be seen in Figure 3.4. The system is fully automated and stores data on a cloud-based platform. The Colifast Alarm has a low rate of false positives and negatives, making it suitable for applications related to drinking water and industrial processes[24, 25, 26].

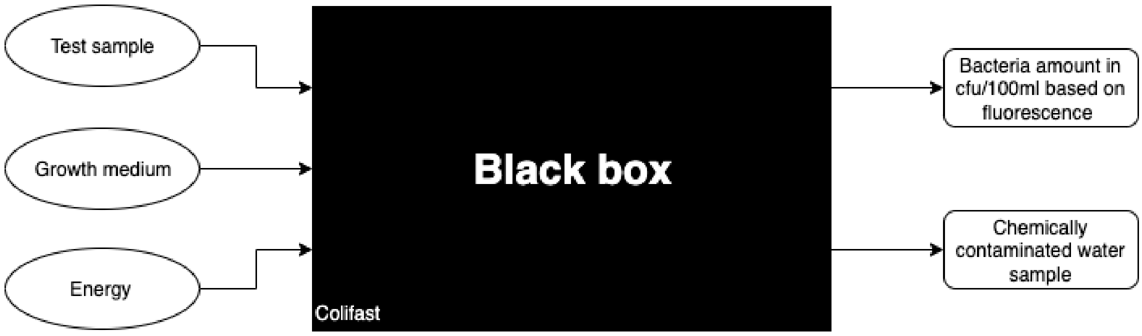

Figure 3.4: A black box diagram for defining inputs and outputs in Colifast Alarm

3.2.5 BACTcontrol

BACTcontrol is an automated water monitoring solution that automatically takes samples from a water source and performs an enzymatic analysis. The analysis measures the enzymatic activity of coliform bacteria and E.coli by measuring a fluorescent indicator as described in Figure 3.5. This allows for the detection of bacteria in a matter of hours, compared to traditional testing methods which can take days to provide results[27, 28, 18].

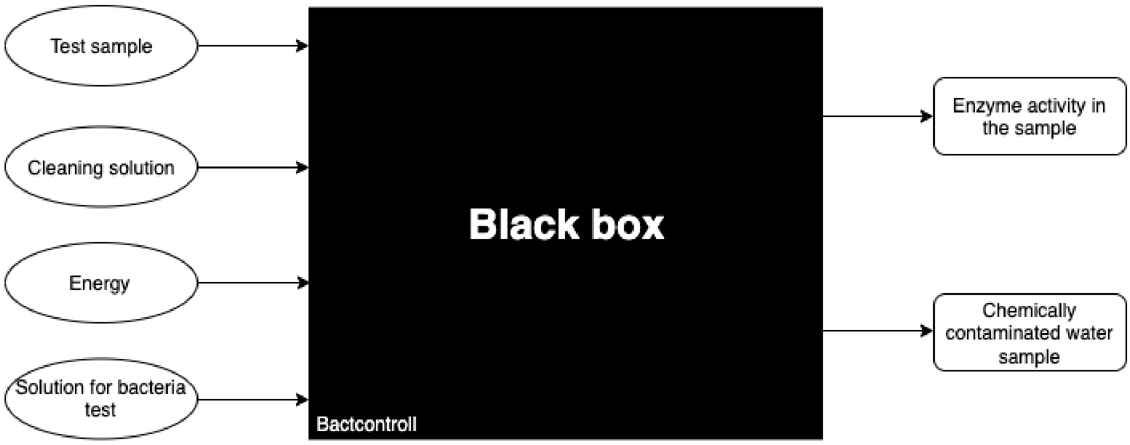

Figure 3.5: A black box diagram for defining inputs and outputs in BACTcontrol

3.2.6 Performance metrics for all competitors

To summarize the performance metrics found in this competitor study were the findings tabulated in table 3.6 with The Company's requirements and wishes. This was done to have a frame of reference for where The Company wants to take its product in relation to the competitors.

	Bactosense	Bacto box	Coliminder CMI-02	Colifast ALARM	Bactcontrol	Nocoli requirements	Nocoli wishes
Automatic	Yes	No	Yes	Yes	Yes	Yes	Yes
Response time in	20 minutes	2 minutes	15 minutes	2-15 hours	1-2 hours	60 minutes	10 minutes
Time between intervention	1000 cycles	None due to manual procedure	1000 cycles	21 days	Unknown	6 months	12 months
Waste that require special procedures	The cartridge needs to be returned when empty	None	None	None	Unknown	None	None
Used chemicals	SYBR Green 1, Propodium Iodine	Phosphate-buffered saline	Alkaline Phosphatase, Glycine buffer, NaOCl	Sodium hydroxide and other unknown chemicals	Alkaline Phosphatase	None	None
Time between measurements	30 minutes	2 minutes +time for manual preperation	24 minutes	2-15 hours + cleansing time	1-2 hours	None due to continues measurements	None due to continues measurements
Instalation options	Stationary and mobile	Mobile	Stationary and mobile	Stationary	Stationary	Stationary and mobile	Stationary and mobile
Automated alerts	Yes	No	Yes	Yes	Yes	Yes	Yes
Monitored parameters	TCC, ICC, HNAC, LNAC, HNAP	ICC	Enzymatic activity	Enzymatic activity	Enzymatic activity	E.coli bacteria count	Differntiate and classify different types of bacteria
User inpus	Manual or automatic	Manual	Manual or automatic	Automatic	Automatic	Automatic	Automatic
Measure principel	Flow cytometry	Impedance flow cytometry	Fourometric measurement	Fourometric measurement	Fourometric measurement	The companys patent pending method	The companys patent pending method
Detection range	100-5 000 000 cells/ml	10000-5 000 000 cells/ml	Not defined	1-not defined cfu/100ml	Not defined	1-100 cells/ml	1-as many as possible

Figure 3.6: Performance metrics based on information on the company's websites

As seen in table 3.6 can it be seen what sensible value ranges for the requirement specifications would be to produce a product that provides more value in some metrics. The main takeaway from the table is that there is a lack of single-cell detection methods and methods that can analyze a sample without using chemicals.

3.3 Patent analysis and freedom to operate

Based on The Company's existing documentation on their freedom to operate, it can be determined that existing patents will not affect the prototype development. The reason for this conclusion is that most of the previously relevant patents related to the product architecture are in dead patent families[10].

The project was done under the presumption that The Company's patent application would be approved. This choice was since the patent serves as the foundation for The Company's business strategy. This means if the patent would not be approved in a similar state to their application, will their business plan have to change. With this assumption would not existing patents impede the development of the product architecture if the final design does not incorporate a patented subsystem. Because the inclusion of such a subsystem would have granted the patent owner the option to prohibit the use of that particular subsystem or component.

Although patent [29] describes a similar procedure to The Company's is a method-based patent their claims are different enough from The Company's claims to avoid patent infringement. The competitor company has also started filing patents for sub-solutions. There is a possibility that they may obtain a patent in the future that could limit The Company's freedom to operate. The patent that is of most concern at the moment is a patent for a new type of microchannel that creates a specific flow profile [30].

3.4 The Company's planned user scenarios

For all scenarios are reliability and ease of use prioritized highly. Therefore is it important that the concepts can handle variability in operative conditions for the scenarios like variations in water pressure and regulations in the availability of electricity.

3.4.1 Increased efficiency for analyzing water in the field

Today are tests being done regularly in the field to ensure there hasn't been any bacteria contamination between the water treatment plant and the customer. Currently, the test is done by gathering samples which then are grown on Petri dishes for several days before an answer can be given. The new scenario would be gathering samples and testing them on-site and giving an instant response on the water quality. The site in this case would be in the pipe network or at the customer's location as seen in figure 1.2. This would increase the efficiency reviewing of the water quality and reduce the risk for the consumers.

3.4.2 Analysis during water purification

The Company's planned use scenario in water treatment plants is a situation where the quality control team will have a shorter time between measurements and results without increasing the workload for the personnel. This will be achieved by diverting a small amount of the treated water into their equipment that through its algorithm will send out an early warning based on the amount and types of bacteria it detects in the sampled water. This means the implementation is within the water treatment plant and ensures that the quality of the water is up to standard when it reaches storage before distributing it is the customers in figure 1.2.

3.4.3 Automated analysis unit in the water network

The third scenario for the analysis equipment is an installation out in the distribution network where the purpose is to detect bacteria contamination in the pipes shown in figure 1.2. In this scenario, it is important that the equipment can be installed in such a way that maintenance can be performed on the equipment if required. This scenario is similar to the scenario inside the water treatment facility but will have additional parameters to take into account like temperature differences and access points.

3.5 Establishing product metrics and specifications

For converting the information collected in the first milestone was a needs-to-metrics matrix(See appendix A.4) used. In the needs column were the found needs listed to then be coupled with relevant metrics. These coupled needs and metrics were then put into a living requirement specification for the project.

Each metric that was established in the needs-to-metrics matrix was classified into importance, measurement unit, marginal values, target values, method of validating the marginal and target values, and sources for the classifications(See appendix A.2). The classifications are based on the previously presented findings in the results chapter.

4

Concept generation and selection

This chapter will go through concept generation and the selection of a final concept to develop as a physical prototype. The chapter will start with covering the generative process of brainstorming and morphological matrix. The chapter will also cover the selection process of eliminating 30 concepts down to 1.

4.1 Classification of the generated concepts

The concept generation was split up into several activities, the first activity was generating sub-solutions for the requirements established in A.2 the support systems had to fulfill. This was done with an open brainstorming session performed internally by the development team. For each function was these solutions classified with classification trees. To reduce the number of potential full concepts was a feasibility estimation done to prune away the least plausible solutions.

4.1.1 Sub-solutions for power source

During the brainstorming session, 3 different types of solutions came up when discussing powering the system chemically, physically, and Grid/solar. These solutions were then split up into sub-solutions. The different sub-solutions represent possible ways to source power to the product. After the tree was created a discussion regarding what is possible to combine with the other trees and what will work regarding the requirements of the product. The eliminated sub-solutions are not going to be tested as a concept further on and the ones still green are going to become concepts and be developed further.

The sub-solutions eliminated in this chat were fuel cell and flywheel battery. A fuel cell is not a low maintenance solution which according to the requirements is what the project aims for, a fuel cell has a much higher power generation than the product needs which makes it over-dimensioned for the application. Flywheel battery was eliminated because of the space requirements for that type of battery, and to have that amount of momentum moving around is more likely to cause failures.

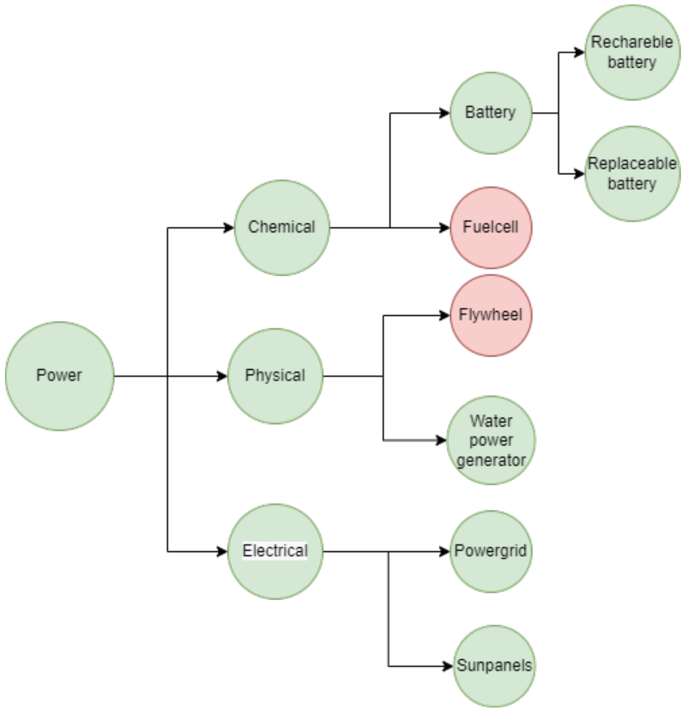

Figure 4.1: Classification tree for the energy/power solutions

4.1.2 Sub-solutions for integration of analysis system

The solutions for integration methods of the existing analysis system can be split into two different categories of permanent and semi-permanent fasteners as seen in Figure 4.2. Due to the requirements set up by The Company, the branch with permanent fasteners pruned because they want a modular product for ease of maintenance. The option of not using any fasteners was removed due to the wish for a mobile option for the product where movement without any fasteners was deemed a too high risk for incorrect measurements.

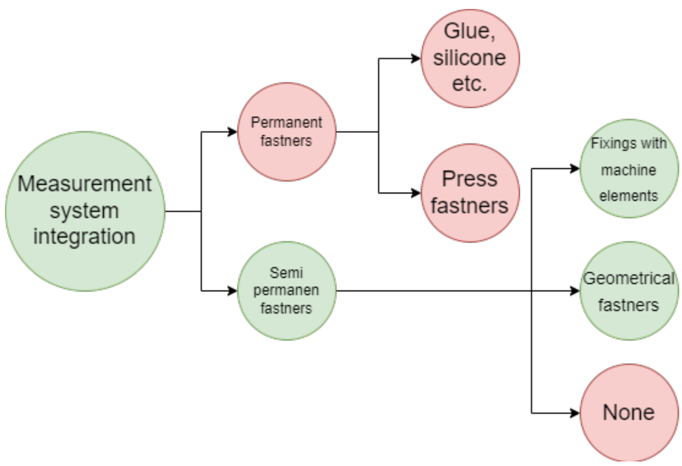

Figure 4.2: Classification tree for the integration solutions

4.1.3 Sub solutions for water control

A brainstorming session to generate a water flow control system was done in order to explore the design space of controlling the water flow in the product. Control of water flow with both overpressure and atmospheric pressure in a fluid system can be done in many different ways. The concepts generated focus on both the overpressure from the pipes but also the creation and control of pressure using pumps. Two concept ideas were canceled due to the implementation av an air compressor and a huge chamber with a floating device to shut off the water flow. Both of these could have worked although implementing a compressor and a new system is not time nor cost effective enough. The chamber technique would have taken up too much space and be unreliable and the project aim´s for a maintenance free solution.

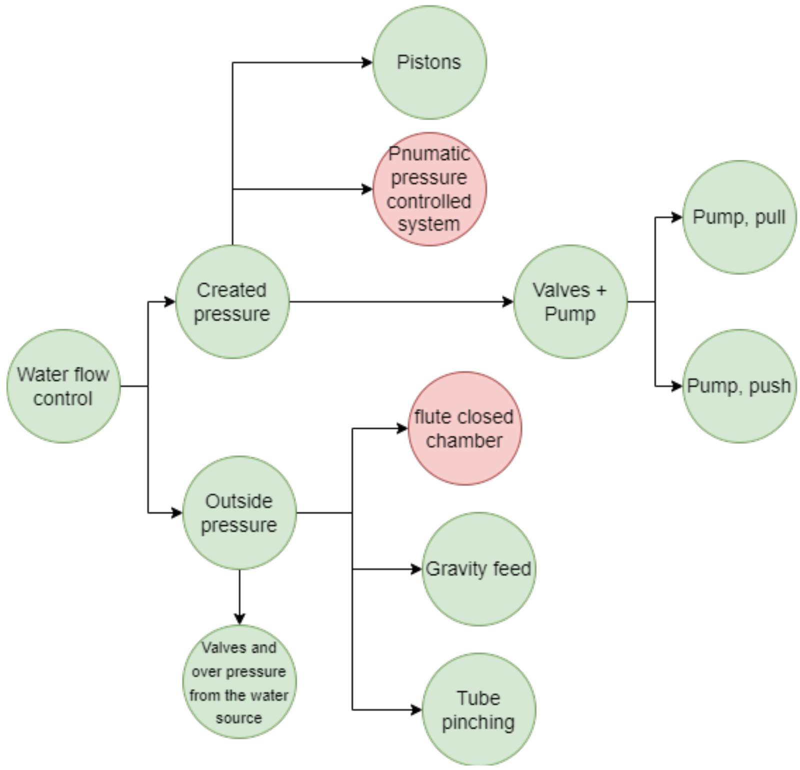

Figure 4.3: Classification tree for the flow control solutions

4.1.4 Sub-solutions for for internal flow

A brainstorming session regarding internal flow systems in the model was done, and the results were to use tubes in the model in order for the water flow to be clean and fresh. Making the channels inside the model it is hard to not make small crevices for bacteria to be trapped in, and for the model to easily have maintenance performed.

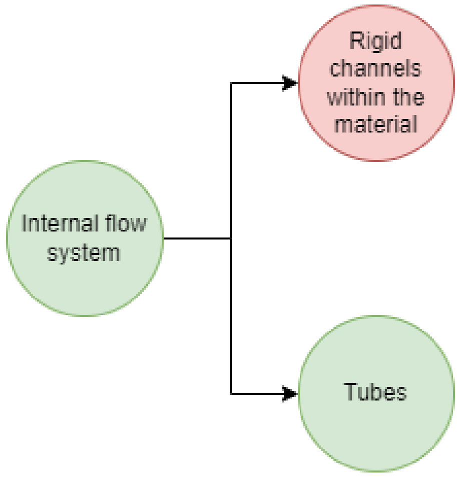

Figure 4.4: Classification tree for the internal flow solutions

4.1.5 Sub-solutions for channel connections

A brainstorming session was done in order to explore the different solutions regarding sealing methods for the water flow. The section is split up into two different categories permanent fasteners and non-permanent fasteners. The permanent ones were removed due to the model has to be able to be taken apart and easily serviced. Nito and AN-connectors were canceled because they are over-dimensioned. They are expensive and the system only needs to be able to handle 2 bars of pressure which press fittings easily do.

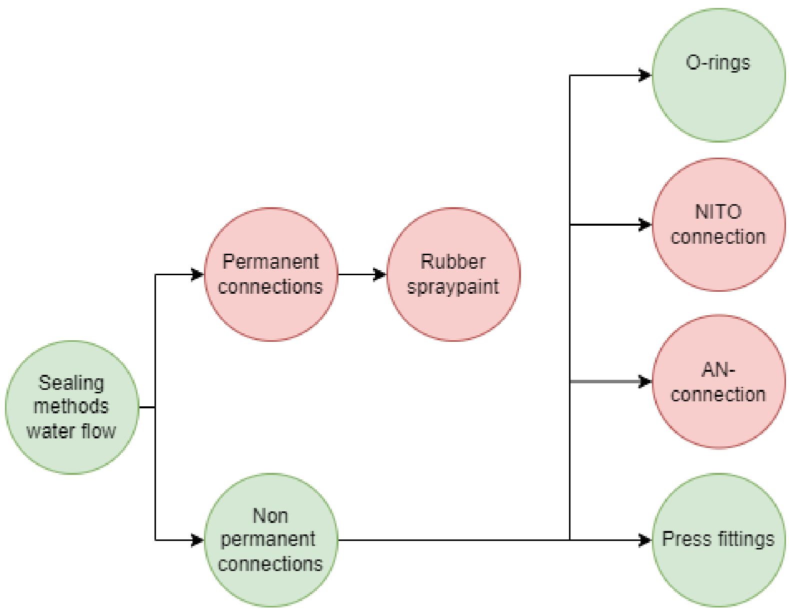

Figure 4.5: Classification tree for the channel connections solutions

4.1.6 Sub-solutions for IP rating

To ensure that the analysis isn't negatively affected by the operating environment was solutions for the IP rating generated as described in Figure 4.6. Solutions that are based on permanent seals and connections are not going to be explored due to maintenance difficulties created by permanent seals. Solutions using very tight geometrical tolerances are also avoided due to the increased cost in manufacturing due to production variance.

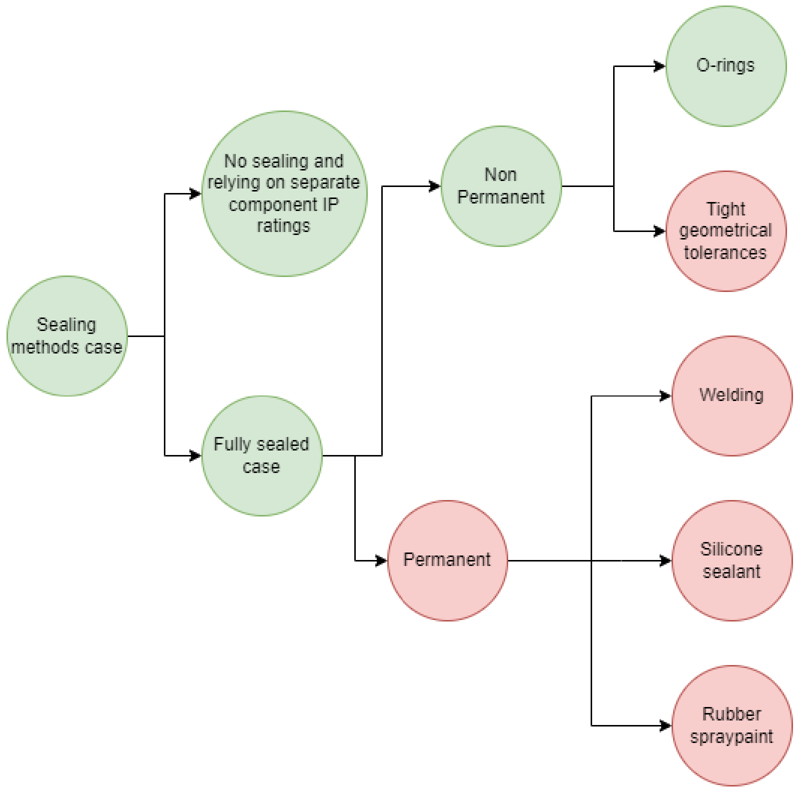

Figure 4.6: Classification tree for solving IP rating

4.1.7 Sub solutions for interface

The solutions for presenting results were split up into physical interactions with the system, digital signals, and audiovisual alerts as seen in Figure 4.7. Due to the user scenario cases, the branch with physical interactions was cut because of the low amount of interaction with the equipment. For the branch with digital signal was the app option pruned due to the preference from the water treatment plants not to include any new digital systems.

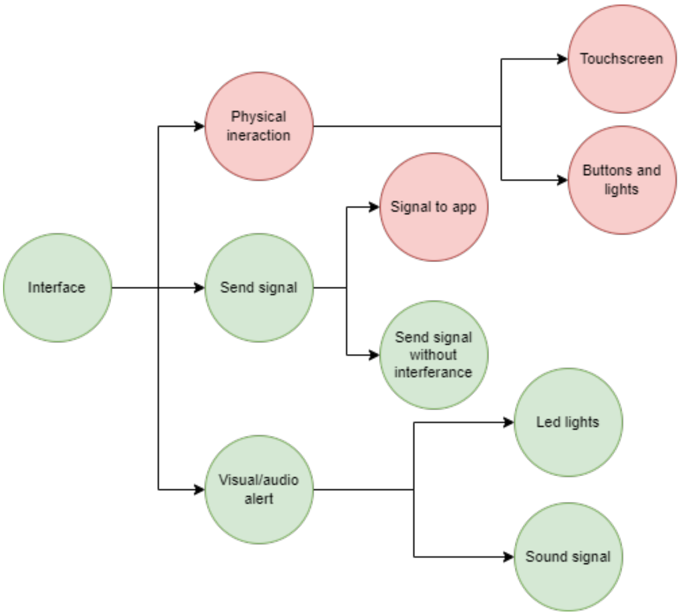

Figure 4.7: Classification tree for interface implementations

4.1.8 Sub-solutions for sample collection

A brainstorming session was done in order to explore the different possible solutions regarding sample intakes in the water analysis. In the tree below the canceled ones in red are solutions interfering with the model being applicable everywhere in the pipe network as they require a tank and not a pipe to work. The thought was to have a flute or a sink to the sample pipe and to take the sample from the bottom or the surface of the tank water. They could be replaced with a tube that also can be placed inside the pipe, therefore were these solutions canceled. The possible solutions that made it through the first step are to connect to the existing pipes or to connect to the sample hose already in the system for analysis.

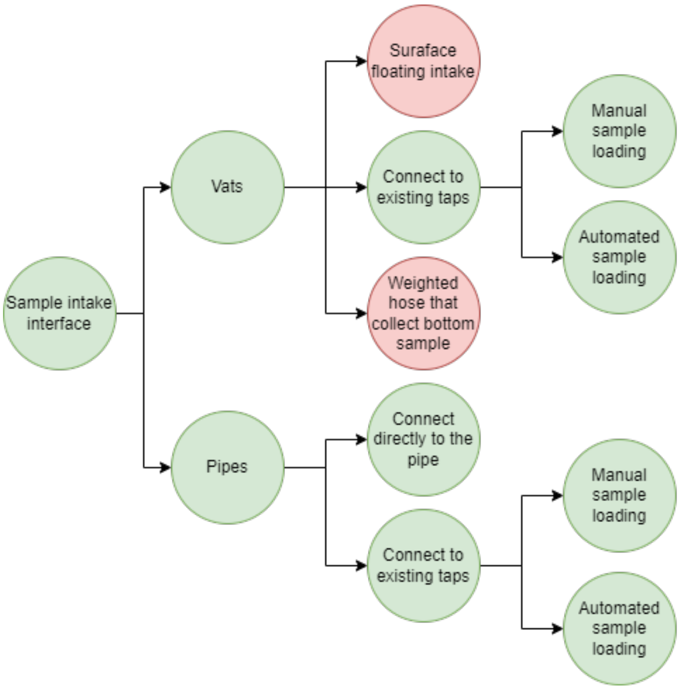

Figure 4.8: Classification tree for sample collection solutions

4.1.9 Sub-solutions for sample disposal

A brainstorming session was done in order to explore the different solutions on how to dispose of the sample after a test has been done. Three main categories were proposed: storing, reusing, and disposal of the analyzed water. Storing the water in a container and then been removed is one of the green and passed examples of a solution. The other green one is to dispose of the used water down the drain or to let it evaporate, this does not hinder the product to be fully automatic which is a good thing. the red one, reuse the water. This is a difficult one, to be able to let the water back into the main line of drinking water there are a lot of laws regarding material choices and sterile systems, which would make this project much larger. To re-circle the water into the pipe requires too much work to be able to make that happen in the timeframe of this project, therefore the best solutions for this project are marked in green.

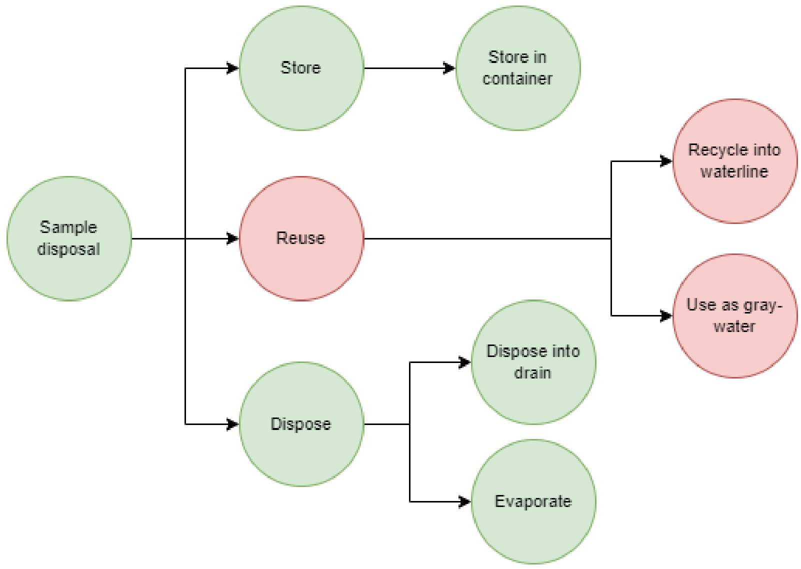

Figure 4.9: Classification tree for sample disposal solutions

4.2 Concept generation using morphological matrices

To explore the possible combinations of the generated sub-solutions were a morphological matrix used to combine solutions for complete concepts. The concepts were generated by selecting one of the solutions in each column in Figure 4.10. To ensure that the concepts had a variation were 30 iterations performed to generate 30 different concepts. Due to the nature of a morphological matrix could 4320 concepts have been generated but due to the resources in the project were only 30 concepts generated.

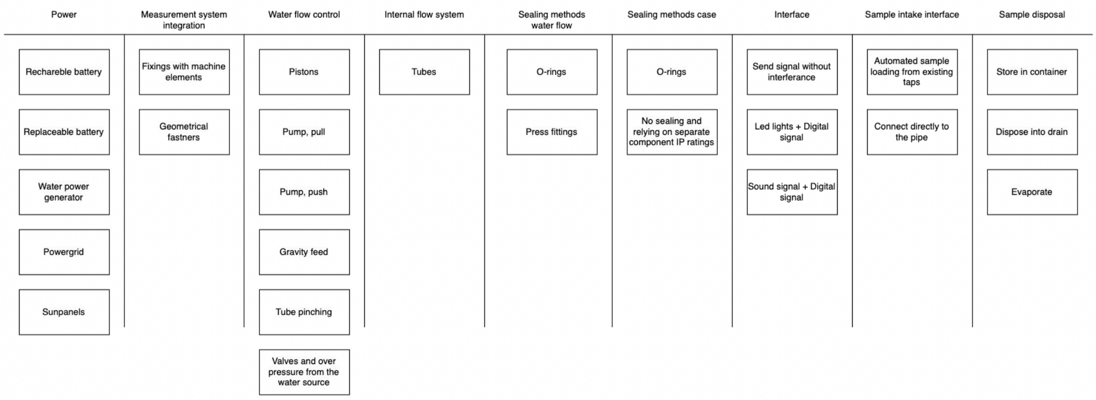

Figure 4.10: Morphological matrix used to generate complete concepts

All concepts generated were described with a diagram describing the component interactions, a general CAD model for the architecture on a flat surface, and a short descriptive text. These representations served as the basis for the concept elimination and the Pugh matrix before the winning concepts were refined in more detail.

4.2.1 CAD visualisation

Instead of representing the concepts with physical quick-and-dirty prototyping was the quick-and-dirty prototyping performed in a CAD environment. This was done by creating a library of simple models and using the tubing tool to create connections between the components and color code the tubes based on what sort of interaction was between the components. Aspects of the concepts that required high detail for a visual description were instead described in writing to spare time and were visualized in the more refined concepts in 4.5.

For the placeholder of the analysis method was a black box used based on the dimensions of the existing prototype as seen in 4.11. The connections for the analysis placeholder were the power in and signal out.

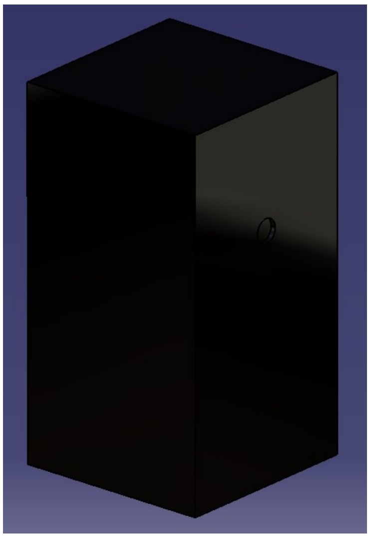

Figure 4.11: The placeholder model for the analysis unit

For the power supply were three different models used to represent how they would interact with the external environment and how they related to the system components. For representing the water-powered generator was a model placed on the pipe and power directed to the other components as seen in Figure 4.13. To represent the battery-based and power grid concepts are a simple box used to take the place of a power supply unit or battery pack as seen in Figure 4.14. The solar panel concept is represented by a rod with a solar plate and a transformer as seen in Figure 4.12.

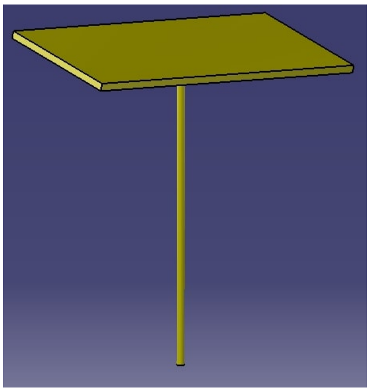

Figure 4.12: The placeholder model for the solar energy power source

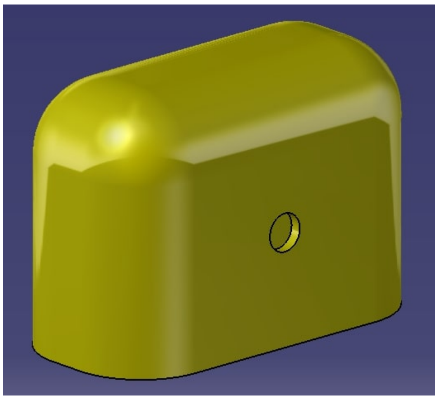

Figure 4.13: The placeholder model for the water generator power source

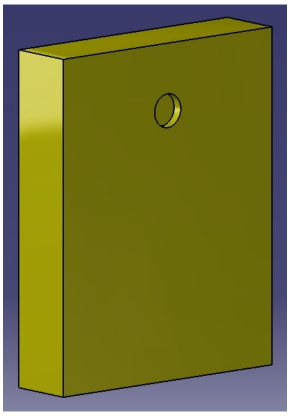

Figure 4.14: The placeholder model for the power grid and battery power sources

The pumps controlling the water flow had two different models as seen in Figure 4.15 and 4.16. To represent the smaller pump models was a cube with the pump inputs and outputs. For the larger gravity pump was a taller pillar used to represent the additional space required to function.

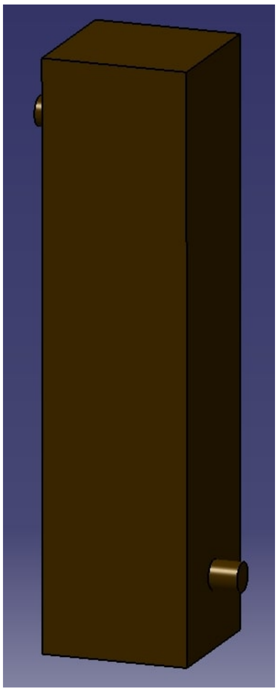

Figure 4.15: The placeholder model for the gravity based pump

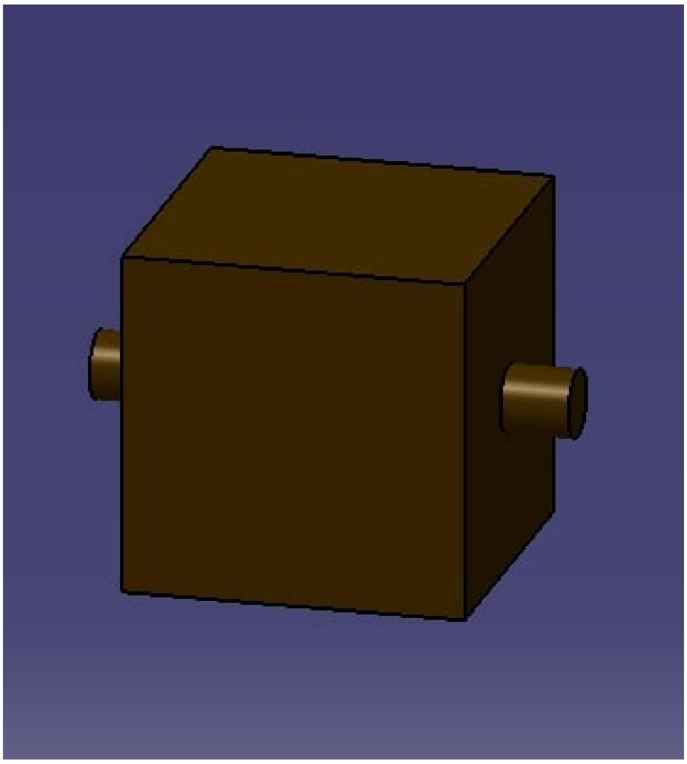

Figure 4.16: The placeholder model for the compact pumps

To represent the disposal method was a cube with water and electric input described in figure 4.17depending on if the disposal method required energy to operate.

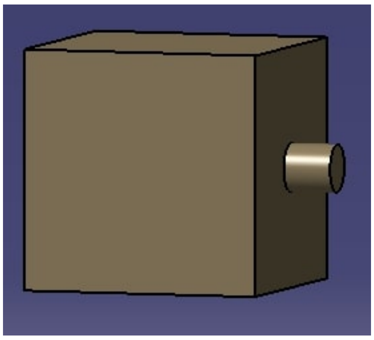

Figure 4.17: The placeholder model for the disposal method

The placeholder for the valve was a cube with a rounded top and inputs and outputs for water and electricity as shown in Figure 4.18.

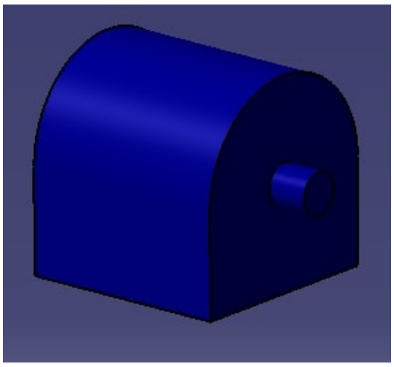

Figure 4.18: The placeholder model for the valves

The placeholders for the physical interfaces were a disk shape to represent a speaker element as seen in Figure 4.19. The concept that implements a LED has a placeholder in the shape of a basic LED as seen in Figure 4.20.

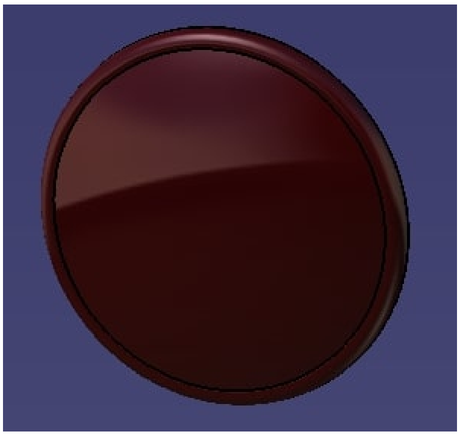

Figure 4.19: The placeholder model for the signal speaker

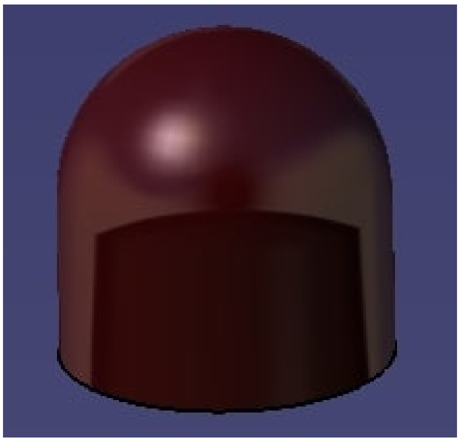

Figure 4.20: The placeholder model for the light diod

The microchannel's placeholder dimensions were estimated based on rough measurements on the supplier's web page as seen in Figure 4.21. The purpose of representing the microchannel was to give an insight into where in the process the sample would be examined.

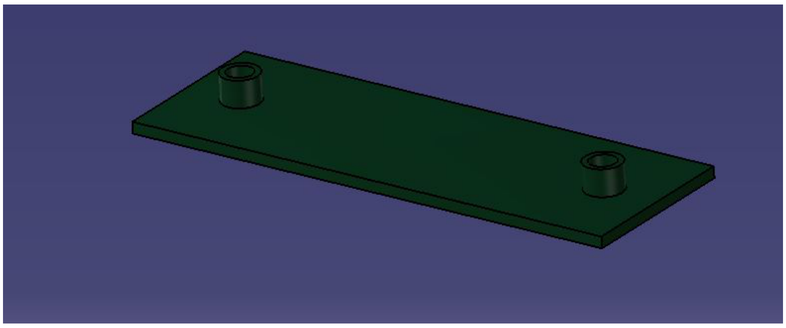

Figure 4.21: The placeholder model for the micro channel

4.2.2 Grid powered tap to pump solution (1)

Concept 1 is represented in Figure 4.22 and consists of a grid connected solution where the sensor box is connected using machine element fasteners. The water gets taken directly from existing sampling taps. The flow control in the model consists of a pump in a push configuration meaning the pump pushes the water through the system. All the water connections use o-rings to keep a seal in the water system. The cases use o-rings to keep water out of the system and to secure the IP rating of the model. The concept sends out a signal to a control unit in order to communicate the status of the water quality. After the analysis is done is the water dispensed in the drain.

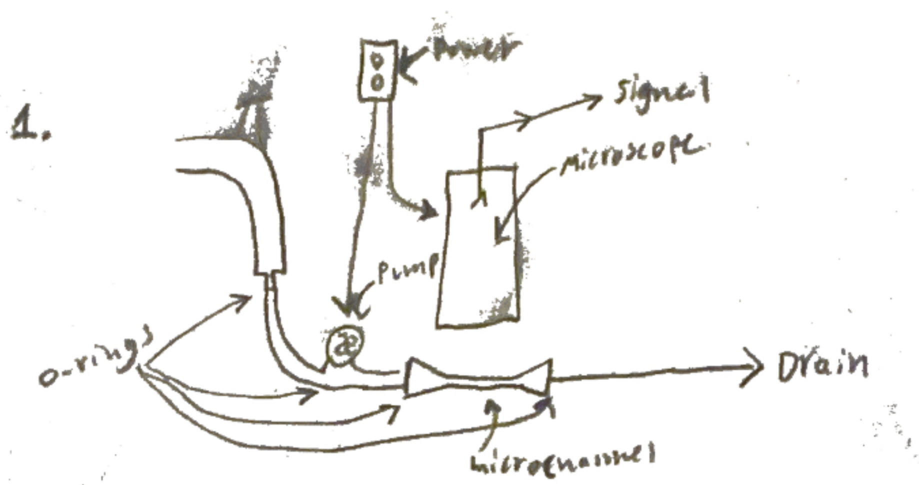

Figure 4.22: Concept drawing 1

4.2.3 Water powered control method with pinch valve technique (2)

Concept 2 is represented in Figure 4.23 and consists of a Water generator solution where the sensor box is connected using machine element fasteners. The water gets taken directly from the water pipes. The flow control in the model consists of a pinching valve technique meaning the tube gets pinched in order to control the water flow through the analysis. All the water connections use press fittings to keep a seal in the water system. The cases use o-rings to keep water out of the system and to secure the IP rating of the model. The concept sends out a signal to a control unit in order to communicate the status of the water quality. After the analysis is done is the water dispensed in the drain.

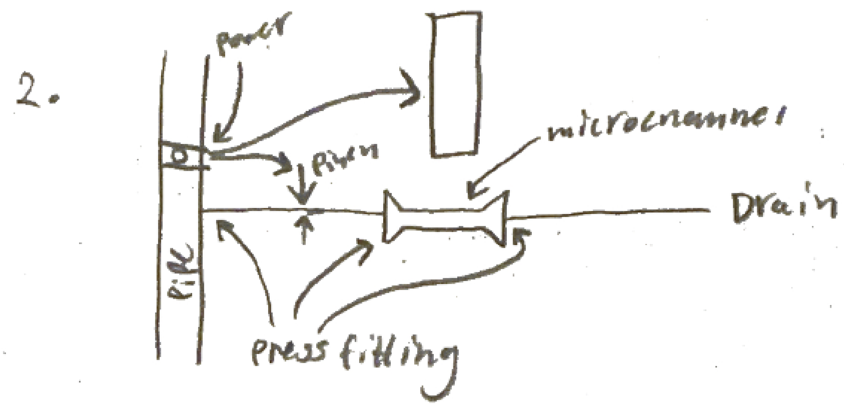

Figure 4.23: Concept drawing 2

4.2.4 Solar powered valve controlled method(3)

Concept 3 is represented in Figure 4.24 and consists of a solar powered solution where the sensor box is connected using geometrical fasteners. The water gets taken directly from existing sampling taps. The flow control in the model consists of a valve technique meaning the tube has two valves placed before and after the microchannel in order to control the water flow through the analysis. All the water connections use press fittings to keep a seal in the water system. The cases use o-rings to keep water out of the system and to secure the IP rating of the model. The concept sends out a signal to a control unit in order to communicate the status of the water quality. After the analysis is done is the water dispensed in the drain.

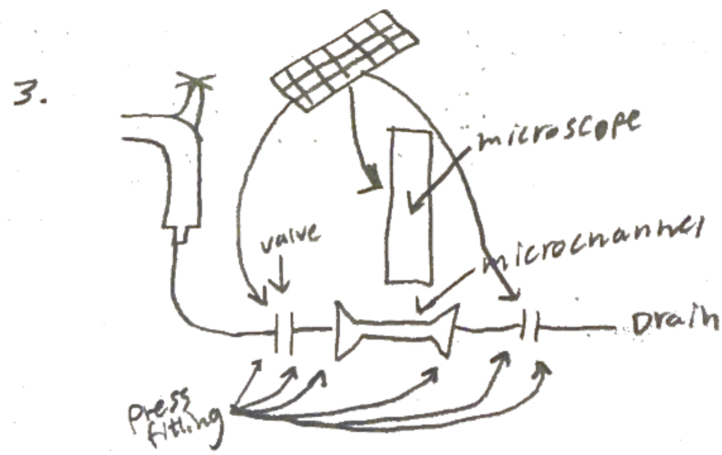

Figure 4.24: Concept drawing 3

4.2.5 Piston control system with supporting valves (4)

Concept 4 is represented in Figure 4.25 and consists of a Rechargeable battery solution where the sensor box is connected using machine element fasteners. The water gets taken directly from existing sampling taps. The flow control in the model consists of a piston technique meaning the is placed before the microchannel in order to control the water flow through the analysis. All the water connections use press fittings to keep a seal in the water system. The cases use o-rings to keep water out of the system and to secure the IP rating of the model. The concept sends out a signal to a control unit in order to communicate the status of the water quality it also uses an Led light to indicate bacteria detection. After the analysis is done is the water dispensed in an evaporation chamber.

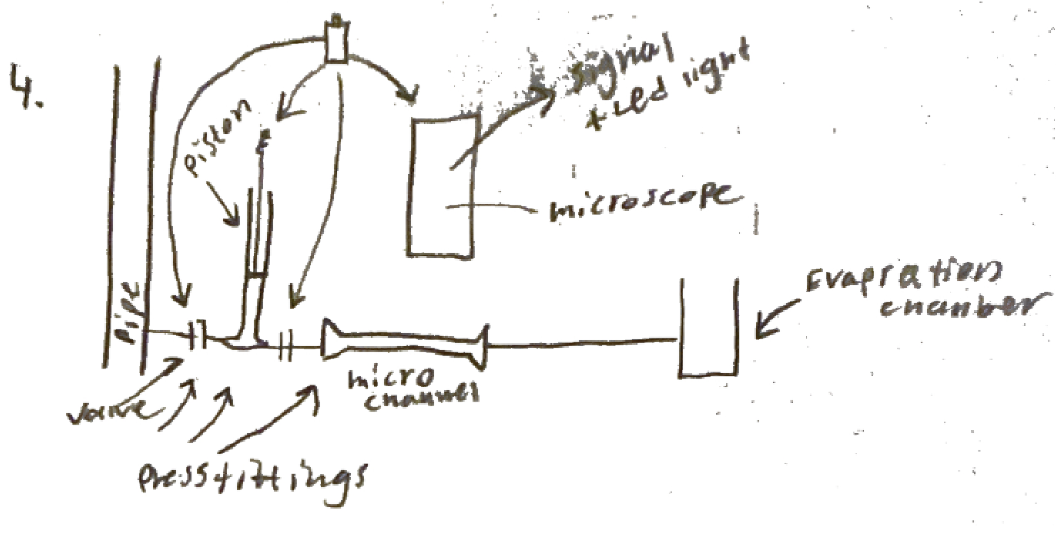

Figure 4.25: Concept drawing 4

4.2.6 Rechargeable battery powered piston system (5)

Concept 5 is represented in Figure 4.26 and consists of a Replaceable battery solution where the sensor box is connected using geometrical fasteners. The water gets taken directly from the water pipes. The flow control in the model consists of a piston technique meaning the is placed before the microchannel in order to control the water flow through the analysis. All the water connections use o-rings to keep a seal in the water system. The case uses no seal to keep water out of the system it relays on the individual IP-ratings of the components in the system. The concept sends out a signal to a control unit in order to communicate the status of the water quality it also uses an Led light to indicate bacteria detection. After the analysis is done is the water dispensed in an evaporation chamber.

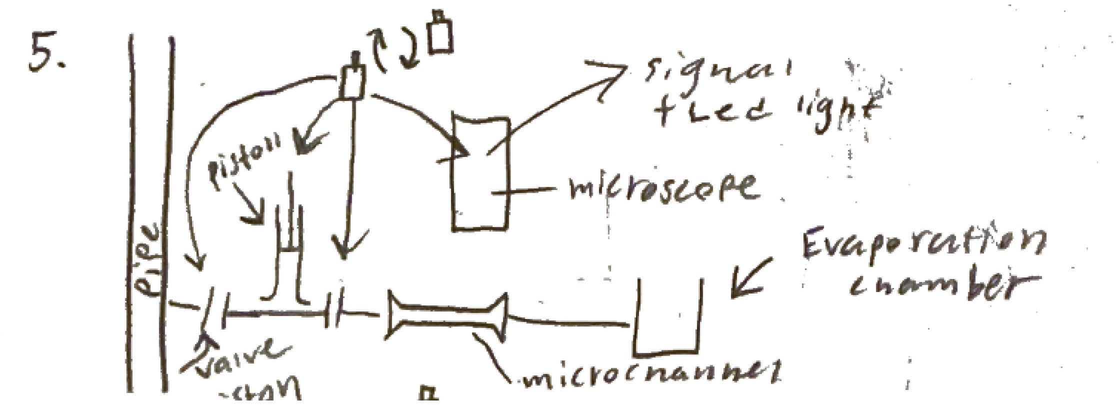

Figure 4.26: Concept drawing 5

4.2.7 Container disposed grid powered piston system (6)

Concept 6 is represented in Figure 4.27 and consists of a Rechargeable battery solution where the sensor box is connected using machine element fasteners. The water gets taken directly from existing sampling taps. The flow control in the model consists of a piston technique meaning the is placed before the microchannel in order to control the water flow through the analysis. All the water connections use o-rings to keep a seal in the water system. The cases use o-rings to keep water out of the system and to secure the IP rating of the model. The concept sends out a signal to a control unit in order to communicate the status of the water quality. After the analysis is done is the water dispensed in a container.

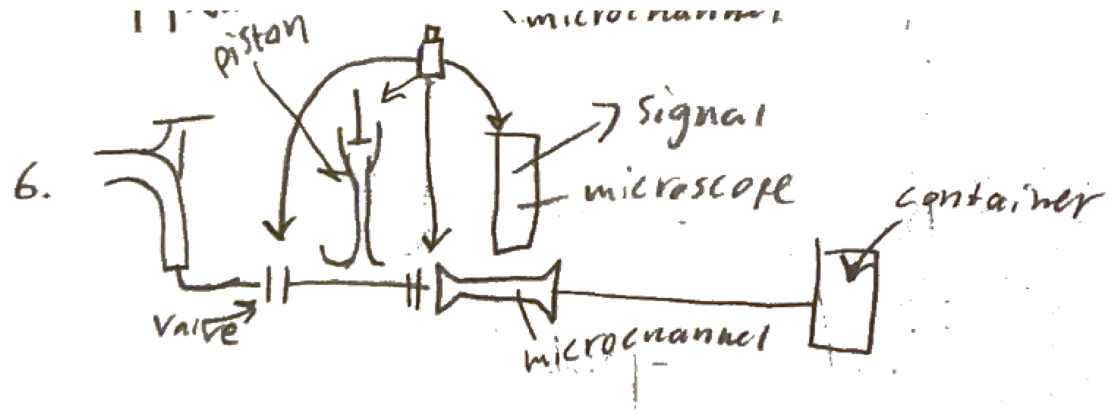

Figure 4.27: Concept drawing 6

4.2.8 Audible pinch solution with water generator (7)

Concept 7 is represented in Figure 4.28 and consists of a Water generator solution where the sensor box is connected using machine element fasteners. The water gets taken directly from existing sampling taps. The flow control in the model consists of a pinching valve technique meaning the tube gets pinched in order to control the water flow through the analysis. All the water connections use press fittings to keep a seal in the water system. The cases use o-rings to keep water out of the system and to secure the IP rating of the model. The concept sends out a signal to a control unit in order to communicate the status of the water quality it also uses a speaker to create an audible notification if bacteria is detected. After the analysis is done is the water dispensed in the drain.

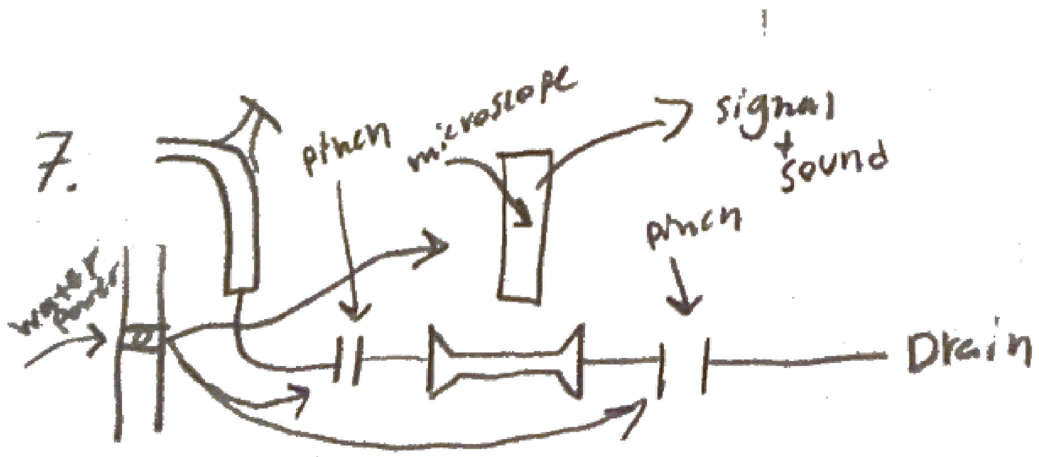

Figure 4.28: Concept drawing 7

4.2.9 Gravity feed system (8)

Concept 8 is represented in Figure 4.29 and consists of a grid connected solution where the sensor box is connected using machine element fasteners. The water gets taken directly from the water pipes. The flow control in the model consists of a gravitation technique using a chamber at a specific height to neutralize the water pressure from the pipes in order to control the water flow through the analysis. All the water connections use press fittings to keep a seal in the water system. The case uses no seal to keep water out of the system it relays on the individual IP-ratings of the components in the system. The concept sends out a signal to a control unit in order to communicate the status of the water quality. After the analysis is done is the water dispensed in a container.

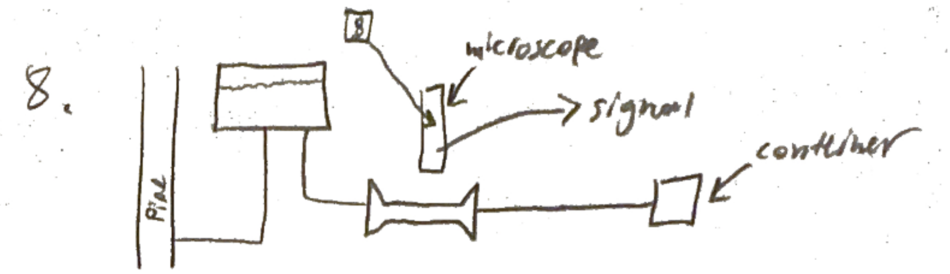

Figure 4.29: Concept drawing 8

4.2.10 Pulling pump solution with reachable batteries(9)

Concept 9 is represented in Figure 4.30 and consists of a Rechargeable battery solution where the sensor box is connected using geometrical fasteners. The water gets taken directly from the water pipes. The flow control in the model consists of a pump in a pull configuration meaning the pump pulls the water through the system. All the water connections use o-rings to keep a seal in the water system. The case uses no seal to keep water out of the system it relays on the individual IP-ratings of the components in the system. The concept sends out a signal to a control unit in order to communicate the status of the water quality it also has a speaker to give an audible signal when bacteria is detected. After the analysis is done is the water dispensed in an evaporation chamber.

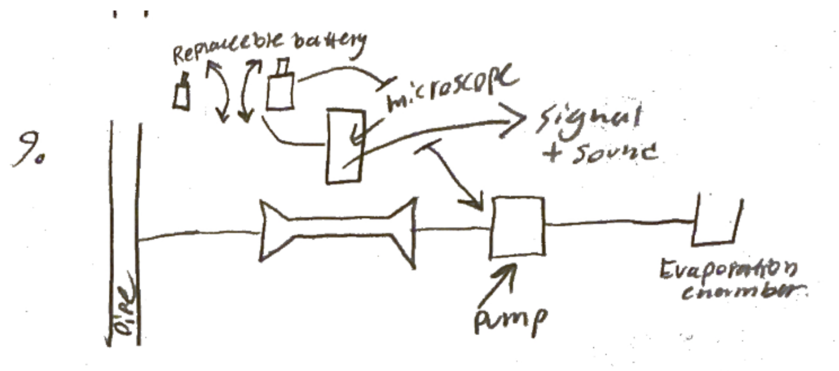

Figure 4.30: Concept drawing 9

4.2.11 Solar powered piston system (10)

Concept 10 is represented in Figure 4.31 and consists of a solar powered solution where the sensor box is connected using geometrical fasteners. The water gets taken directly from the water pipes. The flow control in the model consists of a piston technique meaning the is placed before the microchannel in order to control the water flow through the analysis. All the water connections use o-rings to keep a seal in the water system. The case uses no seal to keep water out of the system it relays on the individual IP-ratings of the components in the system. The concept sends out a signal to a control unit in order to communicate the status of the water quality. After the analysis is done is the water dispensed in to the drain.

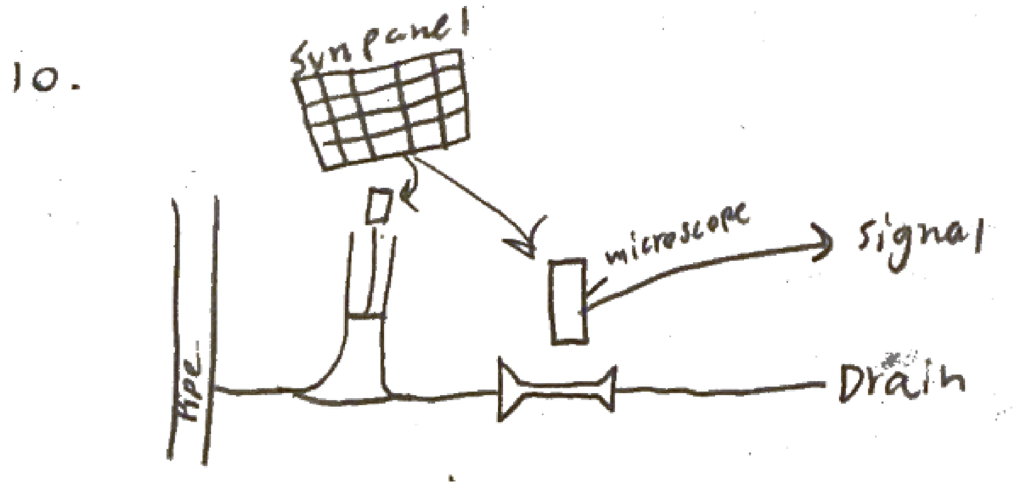

Figure 4.31: Concept drawing 10

4.2.12 Double valve technique powered by reachable batteries (11)

Concept 11 is represented in Figure 4.32 and consists of a Rechargeable battery solution where the sensor box is connected using geometrical fasteners. The water gets taken directly from existing sampling taps. The flow control in the model consists of a valve technique meaning the tube has two valves placed before and after the microchannel in order to control the water flow through the analysis. All the water connections use o-rings to keep a seal in the water system. The cases use o-rings to keep water out of the system and to secure the IP rating of the model. The concept sends out a signal to a control unit in order to communicate the status of the water quality. After the analysis is done is the water dispensed into a container.

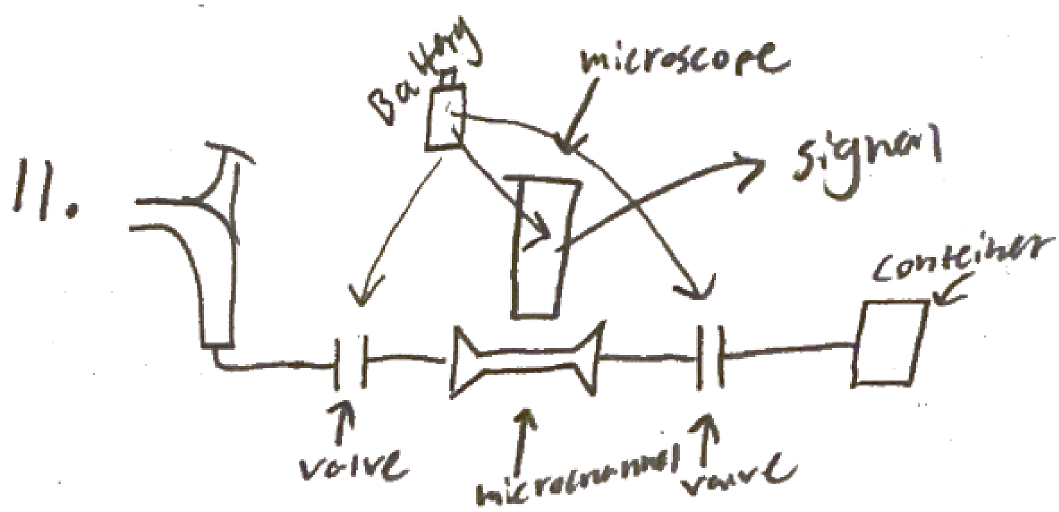

Figure 4.32: Concept drawing 11

4.2.13 Visible pipe to drain system powered by batteries(12)

Concept 12 is represented in Figure 4.33 and consists of a Rechargeable battery solution where the sensor box is connected using geometrical fasteners. The water gets taken directly from the water pipes. The flow control in the model consists of a valve technique meaning the tube has two valves placed before and after the microchannel in order to control the water flow through the analysis. All the water connections use press fittings to keep a seal in the water system. The case uses no seal to keep water out of the system it relays on the individual IP-ratings of the components in the system. The concept sends out a signal to a control unit in order to communicate the status of the water quality the model also has an LED light to indicate when bacteria is detected. After the analysis is done is the water dispensed into the drain.

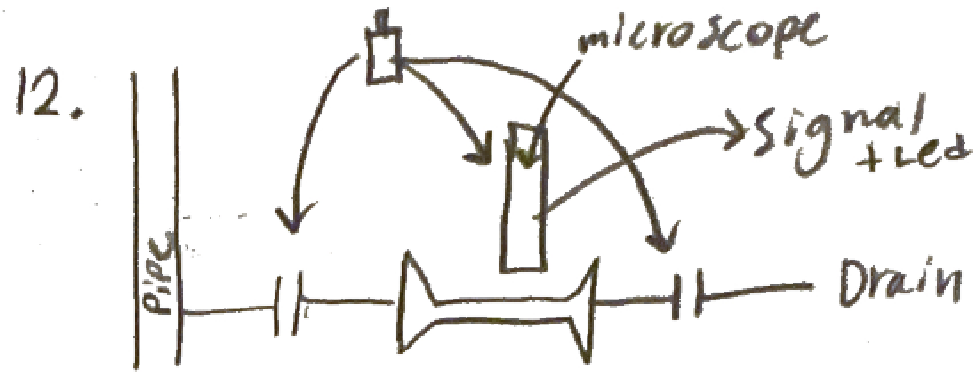

Figure 4.33: Concept drawing 12

4.2.14 Solar powered push pump system (13)

Concept 13 is represented in Figure 4.34 and consists of a solar powered solution where the sensor box is connected using geometrical fasteners. The water gets taken directly from existing sampling taps. The flow control in the model consists of a pump in a push configuration meaning the pump pushes the water through the system. All the water connections use o-rings to keep a seal in the water system. The case uses no seal to keep water out of the system it relays on the individual IP-ratings of the components in the system. The concept sends out a signal to a control unit in order to communicate the status of the water quality the model also has a speaker to send an audible signal when bacteria is detected. After the analysis is done is the water dispensed into a container.

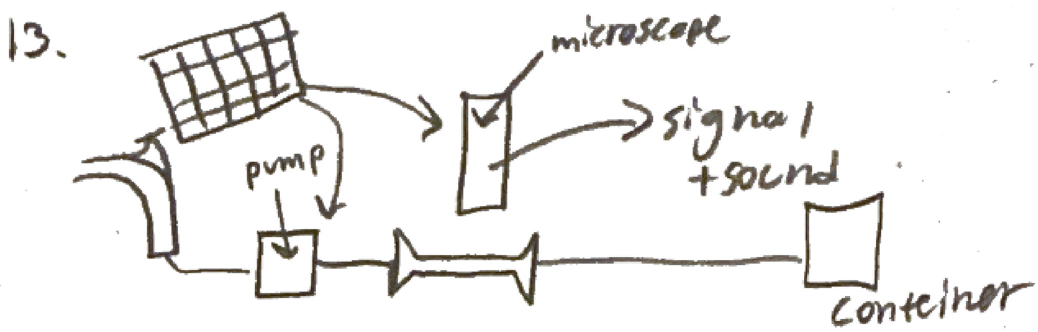

Figure 4.34: Concept drawing 13

4.2.15 Audible gravity system with grid-power (14)

Concept 14 is represented in Figure 4.35 and consists of a grid connected solution where the sensor box is connected using geometrical fasteners. The water gets taken directly from the water pipes. The flow control in the model consists of a gravitation technique using a chamber at a specific height to neutralize the water pressure from the pipes in order to control the water flow through the analysis. All the water connections use o-rings to keep a seal in the water system. The case uses no seal to keep water out of the system it relays on the individual IP-ratings of the components in the system. The concept sends out a signal to a control unit in order to communicate the status of the water quality the model also has a speaker to send an audible signal when bacteria is detected. After the analysis is done is the water dispensed into a container.

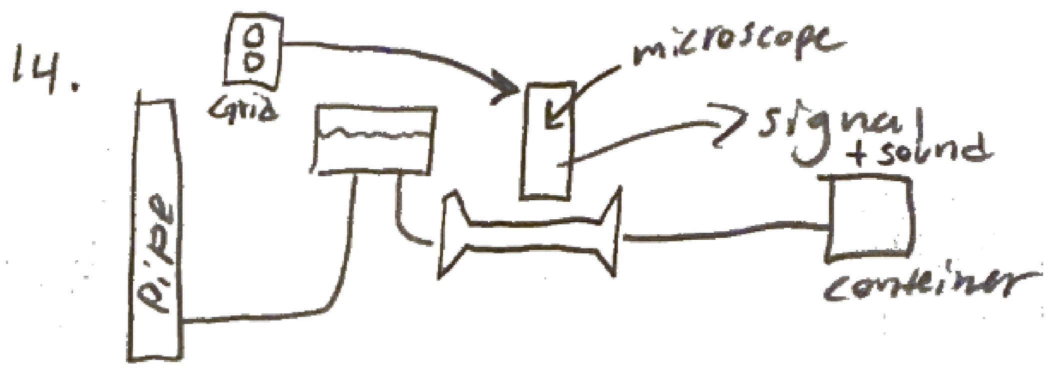

Figure 4.35: Concept drawing 14

4.2.16 Water powered push pump system (15)

Concept 15 is represented in Figure 4.36 and consists of a Water generator solution where the sensor box is connected using geometrical fasteners. The water gets taken directly from the water pipes. The flow control in the model consists of a pump in a push configuration meaning the pump pushes the water through the system. All the water connections use o-rings to keep a seal in the water system. All the water connections use press fittings to keep a seal in the water system. The case uses no seal to keep water out of the system it relays on the individual IP-ratings of the components in the system. The concept sends out a signal to a control unit in order to communicate the status of the water quality. After the analysis is done is the water dispensed into the drain.

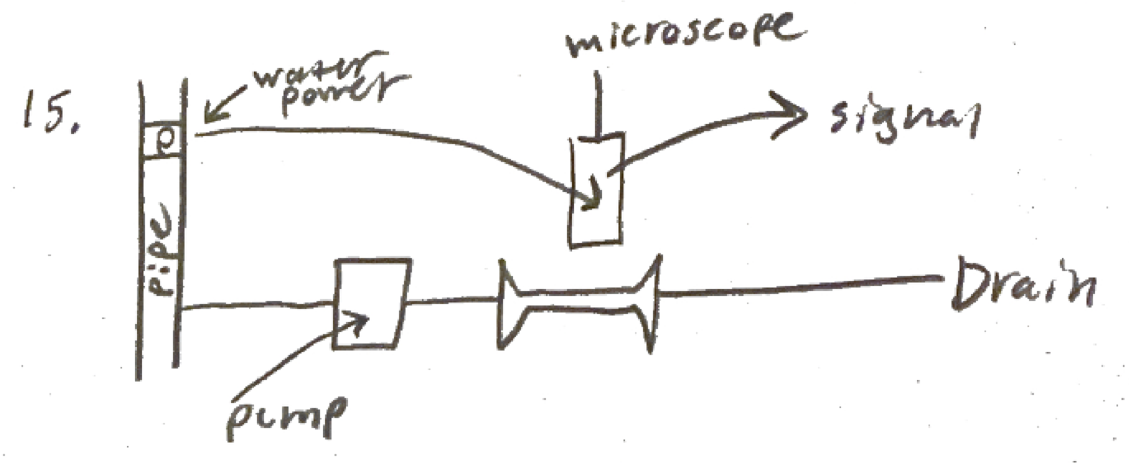

Figure 4.36: Concept drawing 15

4.2.17 Suction pump system with rechargeable battery flow system(16)

Concept 16 is represented in Figure 4.37 and consists of a Rechargeable battery solution where the sensor box is connected using machine element fasteners. The water gets taken directly from the waterpipes. The flow control in the model consists of a pulling pump meaning the is placed after the microchannel in order to control the water flow through the analysis. All the water connections use press fittings to keep a seal in the water system. The case uses o-rings to keep water out of the system and to secure the IP rating of the model. The concept sends out a signal to a control unit in order to communicate the status of the water quality. After the analysis is done is the water dispensed in the drain.

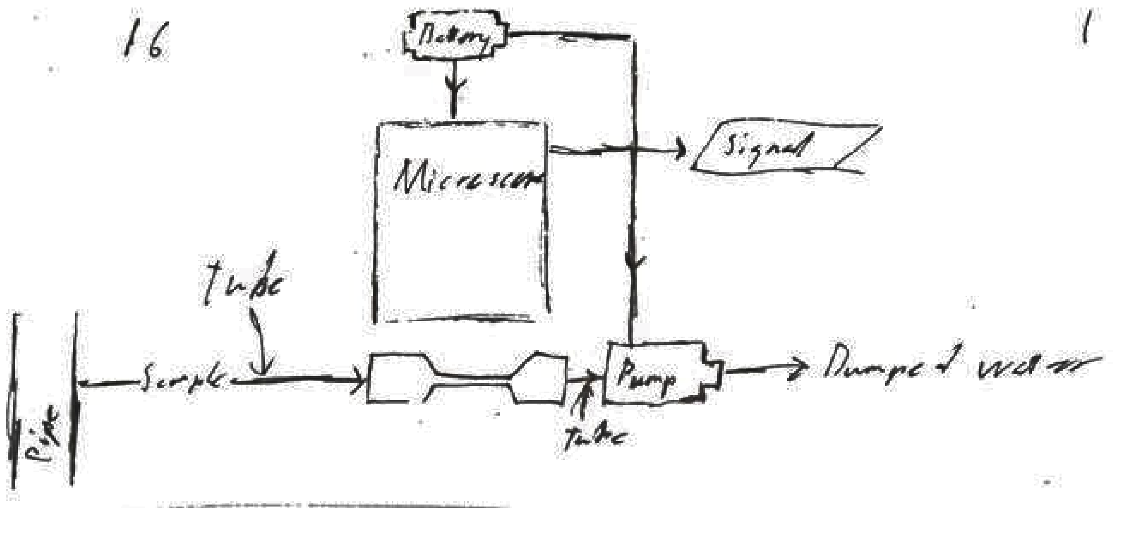

Figure 4.37: Flow chart for concept 16

4.2.18 Solar powered suction pump flow system(17)

Concept 17 is represented in Figure 4.38 and consists of a solar powered solution where the sensor box is connected using geometrical fasteners. The water gets taken directly from the water pipes. The flow control in the model consists of a pulling pump meaning the is placed after the microchannel in order to control the water flow through the analysis. All the water connections use o-rings to keep a seal in the water system. The case uses o-rings to keep water out of the system and to secure the IP rating of the model. The concept sends out a signal to a control unit in order to communicate the status of the water quality it also uses an Led light to indicate bacteria detection. After the analysis is done is the water dispensed in a container.

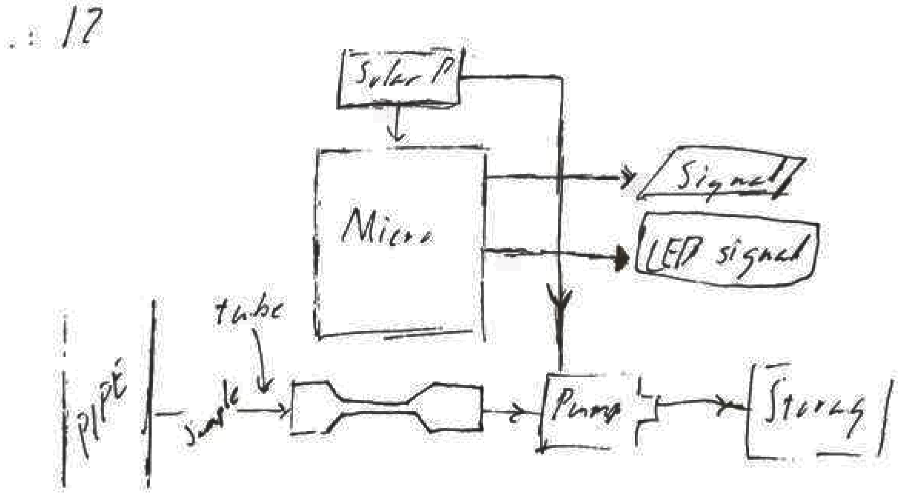

Figure 4.38: Flow chart for concept 17

4.2.19 Valve controlled flow system based on overpressure(18)

Concept 18 is represented in Figure 4.39 and consists of a replaceable battery solution where the sensor box is connected using geometrical fasteners. The water gets taken directly from existing sampling taps. The flow control in the model consists of a valve technique meaning the tube has two valves placed before and after the microchannel in order to control the water flow through the analysis. All the water connections use press fittings to keep a seal in the water system. The case uses o-rings to keep water out of the system and secure the model's IP rating. The concept sends out a signal to a control unit in order to communicate the status of the water quality it also uses an Led light to indicate bacteria detection. After the analysis is done is the water dispensed in a container.

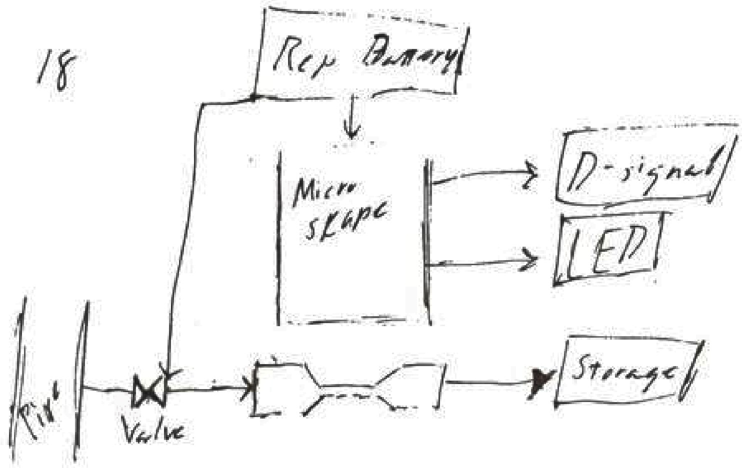

Figure 4.39: Flow chart for concept 18

4.2.20 Valve controlled flow system based on overpressure with an evaporator(19)

Concept 19 is represented in Figure 4.40 and consists of a grid connected solution where the sensor box is connected using machine element fasteners. The water gets taken directly from the water pipes. The flow control in the model consists of a pinching valve technique meaning the tube gets pinched in order to control the water flow through the analysis. All the water connections use o-rings to keep a seal in the water system. The case uses no seal to keep water out of the system it relays on the individual IP ratings of the components in the system. The concept sends out a signal to a control unit in order to communicate the status of the water quality. After the analysis is done is the water dispensed in an evaporation chamber.

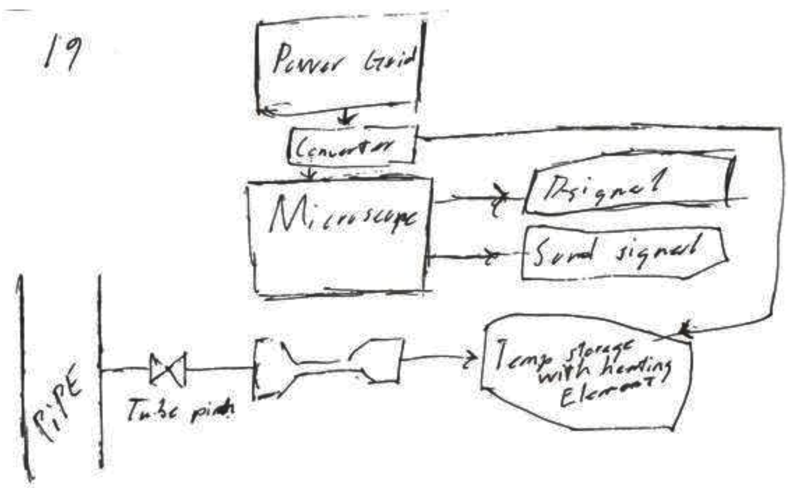

Figure 4.40: Flow chart for concept 19

4.2.21 Gravity fed flow system powered by a water turbine(20)

Concept 20 is represented in Figure 4.41 and consists of a water generator solution where the sensor box is connected using machine element fasteners. The water gets taken directly from the water pipes. The flow control in the model consists of a gravitation technique using a chamber at a specific height to neutralize the water pressure from the pipes in order to control the water flow through the analysis. All the water connections use press fittings to keep a seal in the water system. The case uses o-rings to keep water out of the system and secure the model's IP rating. The concept sends out a signal to a control unit in order to communicate the status of the water quality. After the analysis is done is the water dispensed in a container.

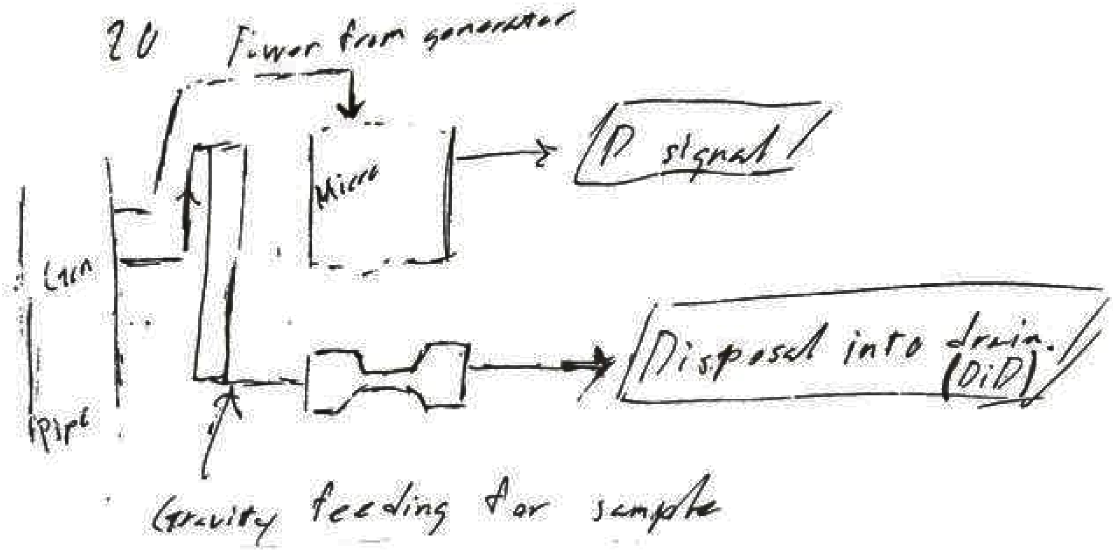

Figure 4.41: Flow chart for concept 20

4.2.22 Solar powered system with valve-controlled flow(21)

Concept 21 is represented in Figure 4.42 and consists of a solar-powered solution where the sensor box is connected using geometrical fasteners. The water gets taken directly from the water pipes. The flow control in the model consists of a pinching valve technique meaning the tube gets pinched in order to control the water flow through the analysis. All the water connections use press fittings to keep a seal in the water system. The case uses no seal to keep water out of the system it relays on the individual IP ratings of the components in the system. The concept sends out a signal to a control unit in order to communicate the status of the water quality it also uses an Led light to indicate bacteria detection. After the analysis is done is the water dispensed in the drain.

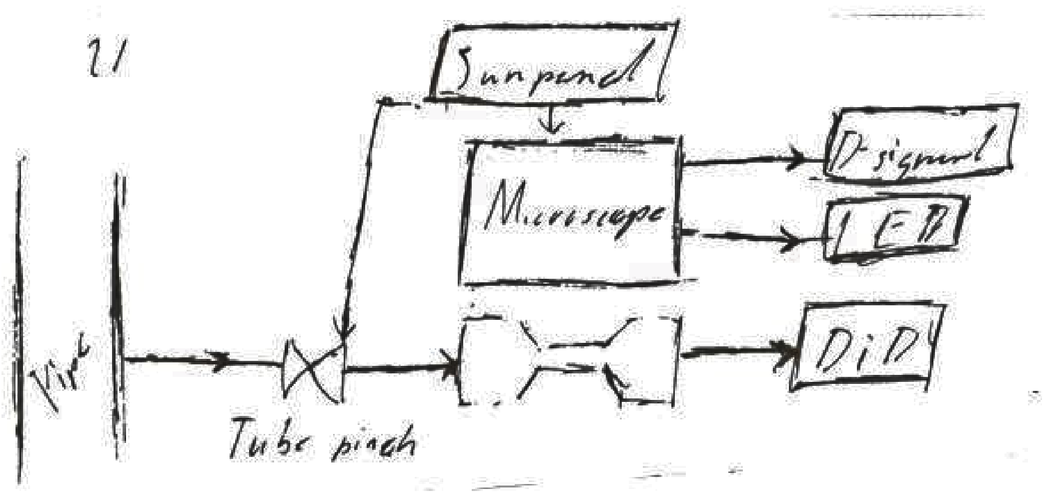

Figure 4.42: Flow chart for concept 21

4.2.23 Double valve flow control system with an evaporator(22)

Concept 22 is represented in Figure 4.43 and consists of a grid connected solution where the sensor box is connected using machine element fasteners. The water gets taken directly from the water pipes. The flow control in the model consists of a pinching valve technique meaning the tube gets pinched in order to control the water flow through the analysis. All the water connections use press fittings to keep a seal in the water system. The case uses no seal to keep water out of the system it relays on the individual IP ratings of the components in the system. The concept sends out a signal to a control unit in order to communicate the status of the water quality it also uses an Led light to indicate bacteria detection. After the analysis is done is the water dispensed in an evaporation chamber.

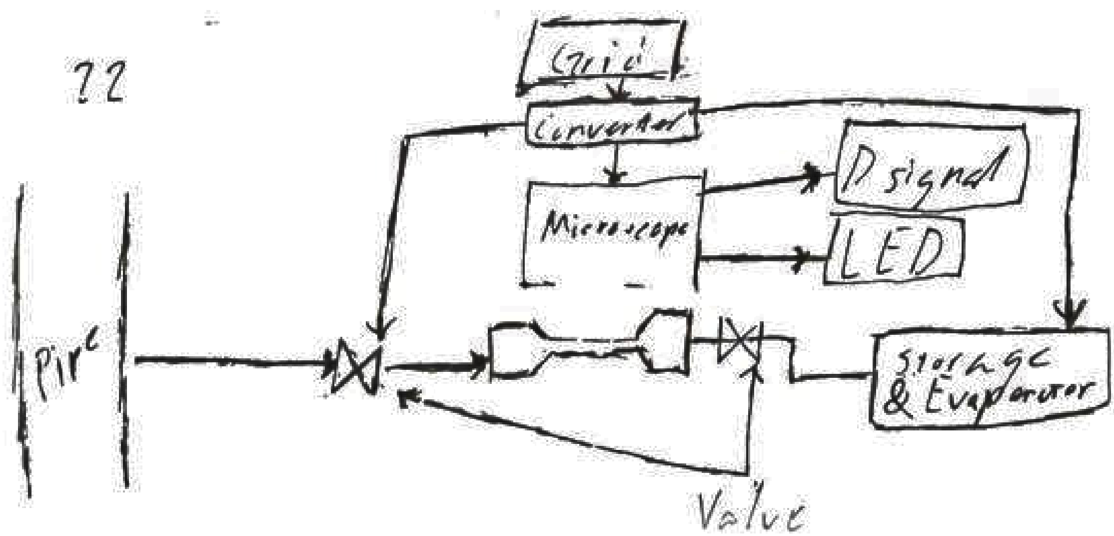

Figure 4.43: Flow chart for concept 22

4.2.24 Piston controlled flow powered by a water turbine(23)

Concept 23 is represented in Figure 4.44 and consists of a Water generator solution where the sensor box is connected using machine element fasteners. The water gets taken directly from existing sampling taps. The flow control in the model consists of a piston technique meaning the is placed before the microchannel in order to control the water flow through the analysis. All the water connections use o-rings to keep a seal in the water system. The cases use o-rings to keep water out of the system and secure the model's IP rating. The concept sends out a signal to a control unit in order to communicate the status of the water quality it also uses a speaker to create an audible notification if bacteria is detected. After the analysis is done is the water dispensed in the drain.

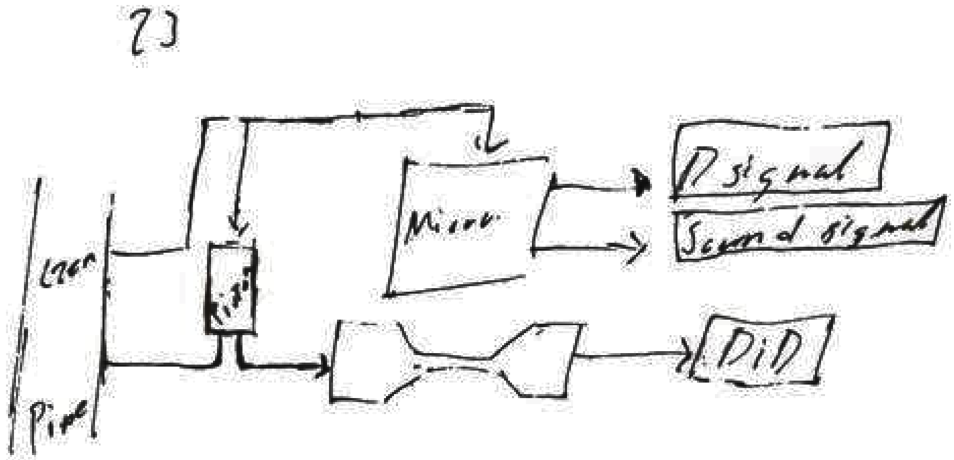

Figure 4.44: Flow chart for concept 23

4.2.25 Push configured flow system with an evaporator(24)

Concept 24 is represented in Figure 4.45 and consists of a grid connected solution where the sensor box is connected using geometrical fasteners. The water gets taken directly from existing sampling taps. The flow control in the model consists of a pump in a push configuration meaning the pump pushes the water through the system. All the water connections use press fittings to keep a seal in the water system. The case uses no seal to keep water out of the system it relays on the individual IP ratings of the components in the system. The concept sends out a signal to a control unit in order to communicate the status of the water quality. After the analysis is done is the water dispensed in an evaporation chamber.

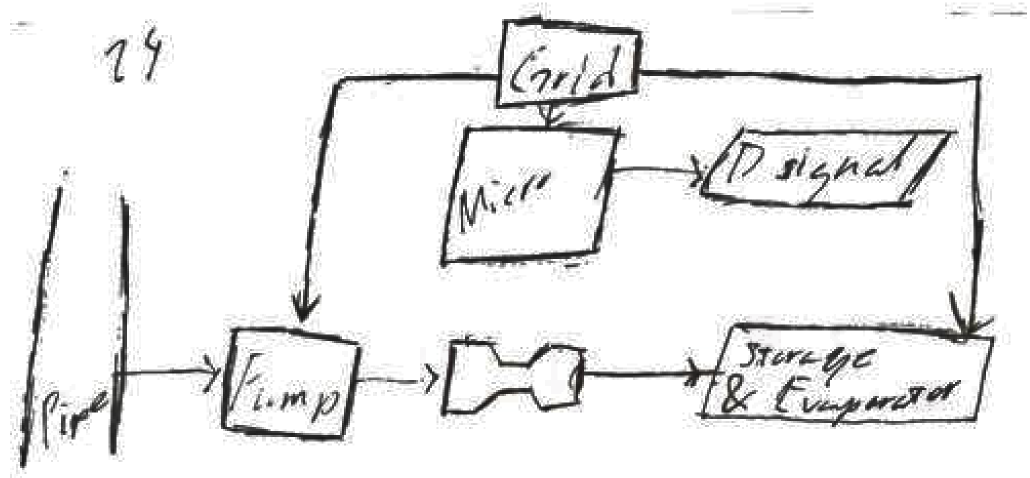

Figure 4.45: Flow chart for concept 24

4.2.26 Double valve flow control system(25)

Concept 25 is represented in Figure 4.46 and consists of a Rechargeable battery solution where the sensor box is connected using machine element fasteners. The water gets taken directly from the water pipes. The flow control in the model consists of a valve technique meaning the tube has two valves placed before and after the microchannel in order to control the water flow through the analysis. All the water connections use press fittings to keep a seal in the water system. The cases use o-rings to keep water out of the system and secure the model's IP rating. The concept sends out a signal to a control unit in order to communicate the status of the water quality it also uses an Led light to indicate bacteria detection. After the analysis is done is the water dispensed in the drain.

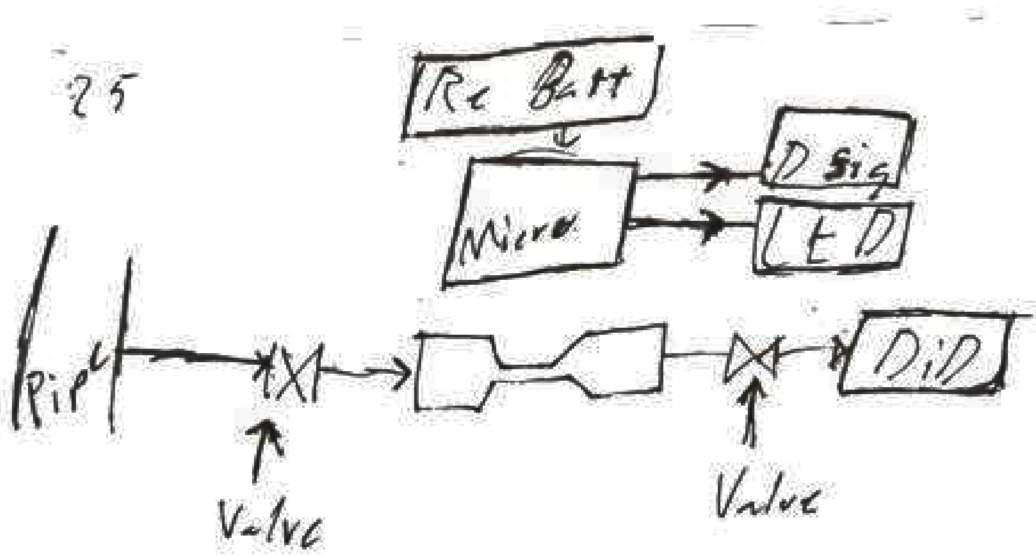

Figure 4.46: Flow chart for concept 25

4.2.27 Solar-powered double valve flow control system(26)

Concept 26 is represented in Figure 4.47 and consists of a solar-powered solution where the sensor box is connected using geometrical fasteners. The water gets taken directly from the water pipes. The flow control in the model consists of a pinching valve technique meaning the tube gets pinched in order to control the water flow through the analysis. All the water connections use o-rings to keep a seal in the water system. The cases uses o-rings to keep water out of the system and secure the model's IP rating. The concept sends out a signal to a control unit in order to communicate the status of the water quality. After the analysis is done is the water dispensed in the drain.

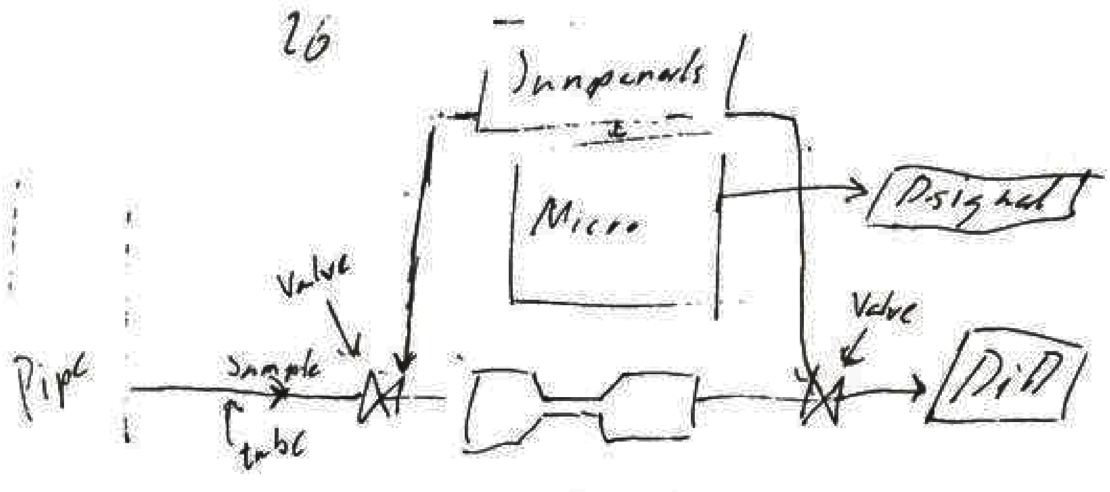

Figure 4.47: Flow chart for concept 26

4.2.28 Push configured flow system powered by a water turbine(27)

Concept 27 is represented in Figure 4.48 and consists of a Water generator solution where the sensor box is connected using machine element fasteners. The water gets taken directly from the water pipes. The flow control in the model consists of a pump in a push configuration meaning the pump pushes the water through the system. All the water connections use press fittings to keep a seal in the water system. The case uses no seal to keep water out of the system it relays on the individual IP ratings of the components in the system. The concept sends out a signal to a control unit in order to communicate the status of the water quality it also uses an Led light to indicate bacteria detection. After the analysis is done is the water dispensed in the drain.

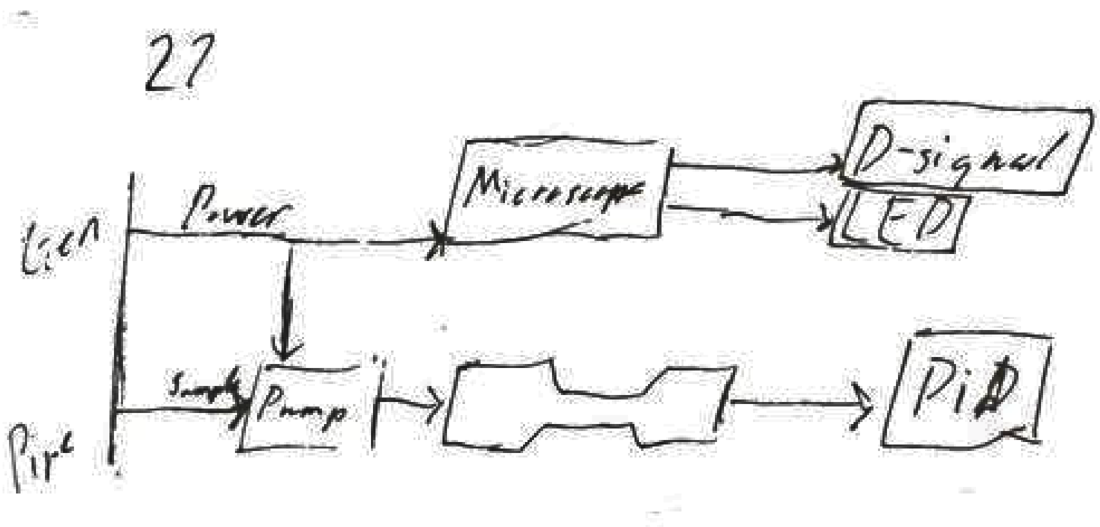

Figure 4.48: Flow chart for concept 27

4.2.29 Solar powered double valve flow control system with sample storage(28)

Concept 28 is represented in Figure 4.49 and consists of a solar-powered solution where the sensor box is connected using geometrical fasteners. The water gets taken directly from existing sampling taps. The flow control in the model consists of a valve technique meaning the tube has two valves placed before and after the microchannel in order to control the water flow through the analysis. All the water connections use press fittings to keep a seal in the water system. The case uses o-rings to keep water out of the system and secure the model's IP rating. The concept sends out a signal to a control unit in order to communicate the status of the water quality it also uses an Led light to indicate bacteria detection. After the analysis is done is the water dispensed in a container.

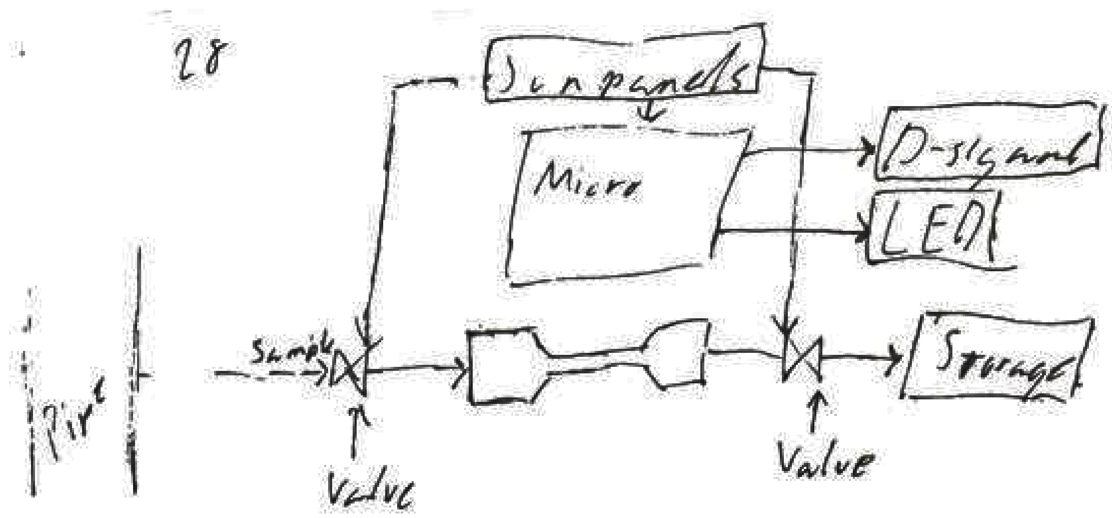

Figure 4.49: Flow chart for concept 28

4.2.30 Push configured flow system(29)

Concept 29 is represented in Figure 4.50 and consists of a Rechargeable battery solution where the sensor box is connected using geometrical fasteners. The water gets taken directly from existing sampling taps. The flow control in the model consists of a pump in a push configuration meaning the pump pushes the water through the system. All the water connections use o-rings to keep a seal in the water system. The case uses no seal to keep water out of the system it relays on the individual IP ratings of the components in the system. The concept sends out a signal to a control unit in order to communicate the status of the water quality. After the analysis is done is the water dispensed in the drain.

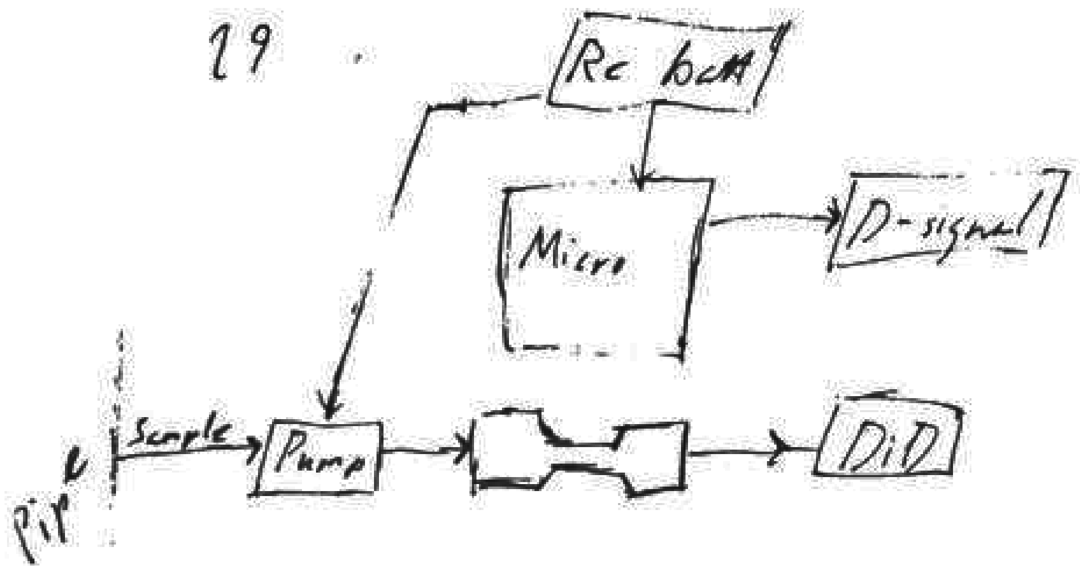

Figure 4.50: Flow chart for concept 29

4.2.31 Push configured flow system with a stopping valve(30)

Concept 30 is represented in Figure 4.51 and consists of a Rechargeable battery solution where the sensor box is connected using machine element fasteners. The water gets taken directly from existing sampling taps. The flow control in the model consists of a pump and a valve in a push configuration meaning the pump pushes the water through the system and the valve can lock. All the water connections use press fittings to keep a seal in the water system. The case uses a seal to keep water out of the system. The concept sends out a signal to a control unit in order to communicate the status of the water quality. After the analysis is done is the water dispensed in the drain.

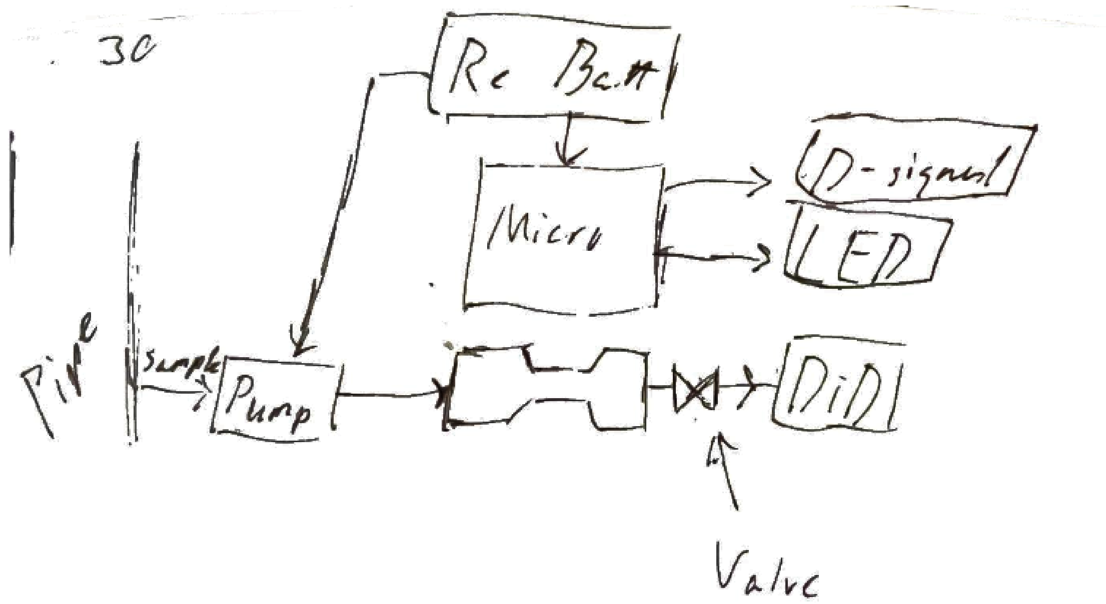

Figure 4.51: Flow chart for concept 30

4.2.32 Suitable pumps for fluid control

The options for the pumps in the concepts were limited to pumps that can fulfill criteria derived from the requirement specification. The criteria for the pumps are to be biocompatible, have a long operation time before interaction with an operator, and handle flow control in the range of µL.

The criteria for biocompatibility can be split up into two sub-criteria, choice of material in contact with the sample and geometrical characteristics for a buildup of biomass. The geometrical requirement for the pump disincentivizes pumps that use complex geometries like gears for water displacements and incentives solutions with smooth contact surfaces for the sample. The material constraints are materials that can be in contact with biomass and water without deteriorating or contaminating the sample this means that stainless steels and silicon rubbers are suitable materials for the components. This was determined with Granta Edupack using limits related to food contact, ISO 10993, sterilizable, freshwater contact, and contact with organic solvents A.3.
The requirement to have a long operation time before interaction with an operator means that the pump needs to be self-loading. Potential pumps also need to be able to operate for at least half a year without any maintenance to fulfill the requirements of The Company. Therefore will pumps that often require lubrication be avoided.

The flow control criteria are the ability to regulate the flow in the form of starting and stopping the flow, flow rate, and water pressure. The most limiting aspect of the flow rate is the precision of the flow rate due to the low requirements related to the working pressure.

Based on these criteria are peristaltic, diaphragm, and piston pumps the most suitable options for pumps. The pros of using a peristaltic pump are the low contamination risk due to the sample only interacting with the transfer tube, low maintenance due to the simplicity of the pump, and the high control of the flow rate. Although the main drawback with a peristaltic pump is that the flow rate will have a pulsating character which might be a drawback for the analysis if it is to be performed during active flow. Diaphragm pumps have the same advantage as a peristaltic pump and in addition, are they configurable to have a pulsating or stable flow with a high flow control. The drawback of diaphragm pumps is that they have a high noise level and a tendency to create vibration. Piston pumps can provide a high control for the flow rate with few moving parts, reducing the maintenance requirement. The drawback of piston pumps is that the chamber is less suitable for biomass than the other pumps and can't provide a continuous flow for larger water volumes than the chamber[31].

4.3 Elimination of the generated concepts

The concept generation resulted in 30 concepts which were too many for a detailed Pugh matrix analysis due to time limitations. To reduce the number of concepts going into the Pugh matrix was the elimination matrix in Figure 4.52used to reduce the number of concepts to a manageable number of concepts. Because the concept generation was done without taking the requirements as limitations could several concepts be eliminated based on the requirement specifications A.2.

The first elimination criterion was the possibility to reduce the water pressure before the microchannel. This elimination criterion came from requirement 16 A.2 in the specifications and eliminated all concepts that didn't control the flow between the sample source and the microchannel.

Concept	Can reduce the pressure before the micro channel	Can vary the flow rate before the micro channel	Can operate without power from the electric grid	Reduce the amount of required components
1			Fail	Fail
2				
3				
4				
5				Fail
6				Fail
7				
8		Fail	Fail	
9	Fail			Fail
10				Fail
11				Fail
12				
13				Fail
14		Fail	Fail	Fail
15				
16	Fail			
17	Fail			Fail
18				
19			Fail	Fail
20		Fail		
21				
22			Fail	
23				Fail
24			Fail	
25				
26				Fail
27				
28				
29				Fail
30				

Figure 4.52: The results of the elimination matrix where the concepts marked in red failed.

The second elimination criterion was that the concept should be able to control the flow rate through the microchannel independently from the water pressure at the sample point. This criterion eliminated concepts using a gravity pump as it can't adjust the flow rate for different water pressure levels at the sample source.

The third elimination evaluated if the concepts could fulfill requirement 21 in the requirement specifications A.2. This requirement specifies that the concept should be able to operate for at least three days without connection to the electric grid. This eliminated all concepts that couldn't generate power for themselves or can't store energy for at least 3 days worth of analysis.

The final elimination criterion was based on the wish to reduce the number of components as stated in metrics 29 and 30 A.2. For the concepts that had O-rings at the connection points, they were deemed unnecessary because of the low water pressures in the system. Therefore will all the solutions only use pressure fittings for the connection points within the system.

4.4 Pugh analysis of the generated concepts

The Pugh-matrix uses a reference concept to evaluate how well the other concepts do compared to the criteria presented in the requirement specifications. If a concept does better than the reference the concept receives a +1, if it performs equally it receives a 0 and if it performs worse it receives a -1. After the matrix, the results are combined.

In the matrix, a solution with sampling taps was considered a minus because the pipe solution was more flexible and can be mounted in places outside of the testing zone. An example of this is underground in the pipe network in order to check for leaks in the system.

Drain and container are combined to enable temporary storage in a bottle/container that then can be used to do further tests on the water in case of a bacteria detection. The evaluation based on whether it stores water or drains is negligible as a solution can be combined without the model being negatively affected.

Concept 4 got a slightly changed copy called the 4MOD for modification. The only change made to the concept is the pump solution before the microchannel, the concept was created due to the need for a concept exploring a new possible solution with existing combinations.
In a water analysis product that takes in water and processes it to only rely on a waterproof case and not the components inside is in our matrix considered to be not as good as having IP-certified products inside with a good enough IP to survive a good water splash. The results from the first Pugh matrix can be seen in figure4.53

		Concepts												
	Criterion	2	3	4	7	12	15	18	21	25	27	28	30(Ref)	4(mod)
1	Flow control precision	-	-	+	-	-	0	-	-	-	0	-	0	+
2	Exposure of sensitive componenets	0	-	0	0	0	0	0	-	0	0	-	0	0
3	Risk of water damage	-	-	-	-	0	0	-	0	-	0	-	0	-
4	Installation time	-	-	-	-	-	-	0	-	-	-	-	0	0
5	Enviromental impact	+	+	-	+	0	+	0	+	0	+	+	0	0
6	Weight	0	0	0	0	0	0	0	0	0	0	0	0	0
7	Availablility of component options	+	+	+	+	0	0	+	0	+	0	+	0	+
8	Energy consumption full system	+	+	-	+	+	0	+	+	+	0	+	0	0
9	Volume	0	0	0	0	0	0	-	0	0	0	-	0	0
10	Ease of maintenence	0	-	-	0	0	0	0	-	0	0	-	0	0
11	Feasability	-	-	-	-	-	0	-	-	-	0	-	0	0
	Sum +	3	3	2	3	1	1	2	2	2	1	3	0	2
	Sum 0	4	2	3	4	7	9	5	4	5	9	1	11	8
	Sum -	4	6	6	4	3	1	4	5	4	1	7	0	1
	Score	-1	-3	-4	-1	-2	0	-2	-3	-2	0	-4	0	1
	Ranking	2	5	6	2	3	1	3	4	3	1	5	1	1
	Continue	Continue	Abandon	Modify	Continue	Abandon	Continue	Abandon	Abandon	Continue	Continue	Abandon	Continue	Continue

Figure 4.53: First Pugh matrix iteration

In order to validate the results another Pugh matrix was done with another reference concept in order to get a different reference for the points in order to get a more accurate result. The result can be seen in figure4.54.

	Concepts												
Criterion	2	3	4	7	12	15	18	21	25	27(ref)	28	30	4(mod)
Flow control precision	-	-	+	-	-	0	-	-	-	0	-	0	+
Exposure of sensitive componenets	0	-	0	0	0	0	0	-	0	0	-	0	0
Risk of water damage	-	-	-	-	0	0	-	0	-	0	-	0	-
Installation time	0	+	+	+	+	+	+	0	+	0	+	+	+
Enviromental impact	0	0	-	0	-	0	-	0	0	0	0	-	-
Weight	0	0	0	0	0	0	0	0	0	0	0	0	0
Availablility of component options	+	+	+	+	0	0	+	0	+	0	+	0	+
Energy consumption full system	+	+	-	+	+	0	+	+	+	0	+	0	0
Volume	0	0	0	0	0	0	-	0	0	0	-	0	0
Ease of maintenence	0	-	-	0	0	0	0	-	0	0	-	0	0
Feasability	-	-	-	-	-	0	-	-	-	0	-	0	0
Sum +	2	3	3	3	2	1	3	1	3	0	3	1	3
Sum 0	6	3	3	5	6	10	3	6	5	11	2	9	6
Sum -	3	5	5	3	3	0	5	4	3	0	6	1	2
Score	-1	-2	-2	0	-1	1	-2	-3	0	0	-3	0	1
Ranking	3	4	5	2	3	1	4	5	2	2	5	2	2
Continue	Continue	Abandon	Abandon	Continue	Abandon	Continue	Abandon	Abandon	Continue	Continue	Abandon	Continue	Continue

Figure 4.54: Second Pugh matrix iteration

Concepts marked with green and yellow with the text: Continue, under passed the matrix, and will move on to the next concept stage.

7/13 concepts passed and get to continue after the Pugh-matrix, 1 of the concepts needs some modification to continue.

The concepts which receive a continue mark at the bottom of both matrices will move on to the next phase in the selection process. The next step in the process of choosing the best concept will be to further describe and develop the concepts and then present them to The Company in a focus group.

4.5 Refinement of the remaining concepts

The concepts remaining after the Pugh matrices were 2, 12, 15, 4MOD, 25, 27, and 30. A new concept was also created at this step during a workshop with The Company's representatives. All these concepts were further developed to be evaluated on a detail level suitable for a Kesselring matrix. Instead of using a Kesselring matrix were a feasibility evaluation performed to eliminate concepts that couldn't be developed or tested within the project's time limitations.

4.5.1 Refined presentation of Concept 2

The new revision of Concept 2 includes a case and fastening points to further evaluate the concept. The idea when created was to test a stand-alone case that can be mounted both on the floor and on the wall. Every component in the case is mouthed on the side of the case using bolts and mounting holes in the components. The case can also be placed on any flat surface around the operating area. The servo and the microscope needed additional mounts to be mounted, the mounts can be seen below in the CAD model 4.55.

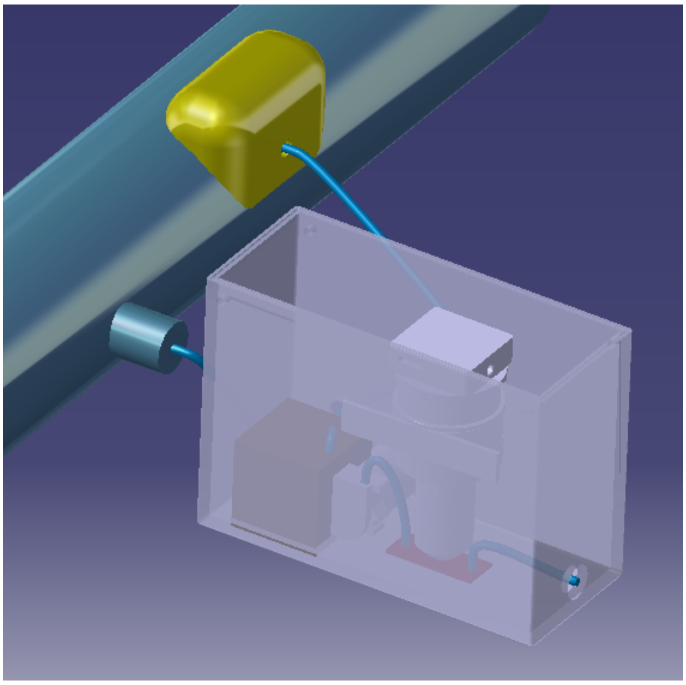

Figure 4.55: Semitransperent model of Concept 2

The concept uses a generator located in the pipe to power the controller, microscope, and valve. The generator produces 12v DC which can be directly delivered to the microscope, the controller needs a buck converter to step down the voltage from 12v to 5v in order to operate. The stepped-down voltage can then be used via the controller to operate the servo used to pinch the valve. The valve in this model consists of a servo and a bracket that pinches the tube between the servo arm and the bracket wall in order to control the flow of the water inside the model represented in Figure 4.56.

The case has a lid at the top and uses bolts to secure the lid, an o-ring around the case opening seals the case from external water to enter the case. The top opening enables easy access to the model's insides and with the use of a ratchet, all components can be removed without the need of special tools.

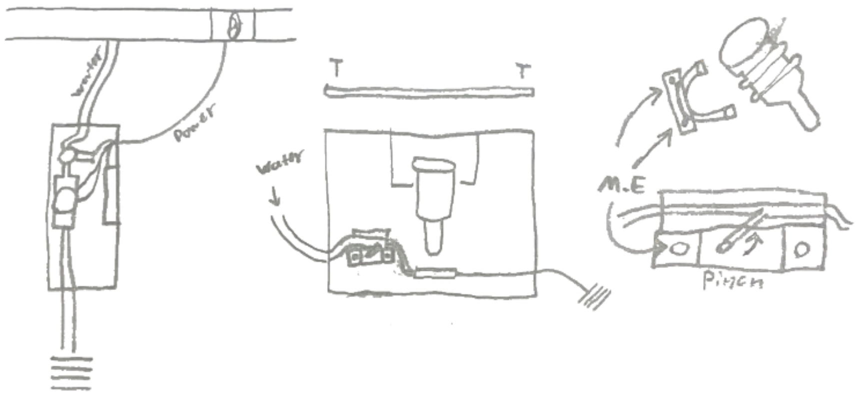

Figure 4.56: Revised version of concept 2

4.5.2 Refined presentation of Concept 12

The revised version of concept 12 consists of a round case that gets screwed onto the wall using bolts from the inside of the case, the idea is to hang the model under the pipe at the water work to minimize the need for space around the sample testing point. The case can be hung up on a wall or mounted to the side of a water pipe tunnel if needed at a testing point. The case uses geometrical fasteners for the lid to stay on and to easily be accessible from the side ones mounted to the wall. The system gets power from the grid and stores energy in batteries at the bottom of the model in case of a power outage in the grid system the detection of bacteria can still operate.

The water flow in the model is controlled by 2 valves placed at the entrance of the model and at the end before the water gets disposed of in the drain. Can be seen in Figure 4.57 and 4.58 below.

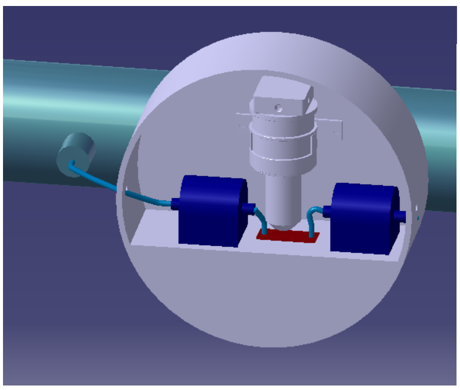

Figure 4.57: CAD-model of concept 12

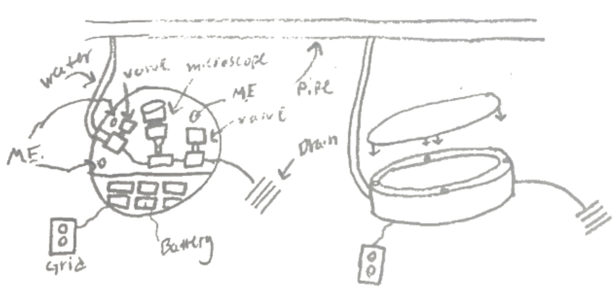

Figure 4.58: Revised version of concept 12

4.5.3 Refined presentation of Concept 15

The revised version of concept 15 uses a unique case to save storage and universality in its mounting possibilities presented in Figure 4.59. The case uses hinges in the back and a clip mount in the front to wrap around the pipe and store the analyses hardware near the application area. The case can easily be removed without special tools and can then be serviced off the pipe.

The system uses a pipe in a push configuration moving the water from the pipe into the analyses chamber at a controlled speed and force. After the analysis, the water gets disposed into the drain. The model also uses a water generator located under the case inside the pipe to save space and use less unnecessary hardware, which can be seen in Figure 4.60 below.

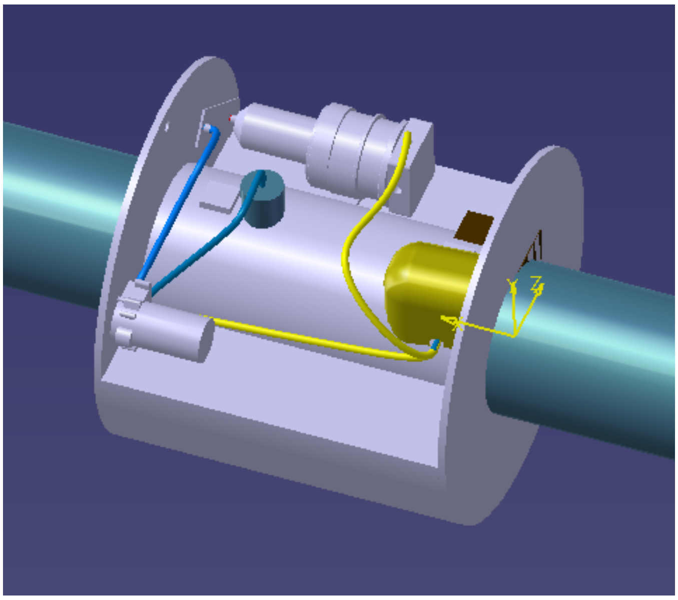

Figure 4.59: CAD-model of concept 15

The idea of the model is to make the pipes and connectors as small as possible to make a small footprint of the model.

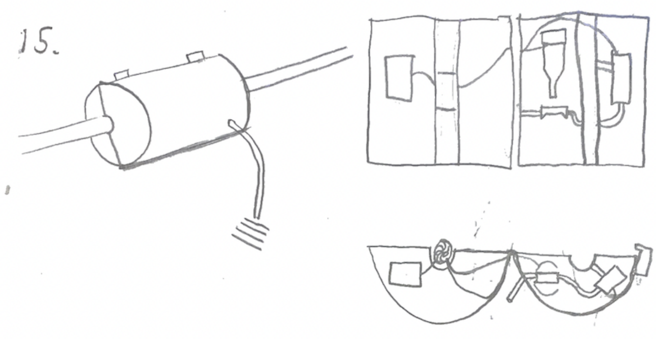

Figure 4.60: Revised version of concept 15

4.5.4 Refined presentation of Concept 4 Modification

4Mod is a concept created to test and evaluate concept 4 with another pump solution due to the minus points in the matrices because of the water control unit. The new revised model of the concept consists of the same parts except for the water pump to control the water flow. The new pump in the concept consists of a peristaltic pump, the pump pinched the line without touching the water with new hardware. In a water analysis scenario, this is a good thing to avoid water contamination.

The idea behind the concept is to be able to hang the case on the wall beside the pipe, the case itself is watertight with a removable front panel for easy access to all the parts inside for easy maintenance. The front panel is sealed using an o-ring of 1mm and the panel itself is held on by bolts from the side of the case. The unit is a stand alone unit which means it can be placed at an indeterminate distance from the pipe. The unit only needs a water supply from the pipe to operate and a hose connected to the drain connector on the case.

The microscope unit is mounted inside the case using the sliding profile technique using aluminum profiles of 10cm and a t-nut to fasten and stabilize the microscope. The profiles mount to a microscope holder which can be seen in Figure 4.61 below. The microchannel is mounted to the bottom of the case and supplied with water from the pump. The pump is mounted on the side of the case using two bolts.

The case is 200mm x 200mm x 85mm to make it mountable in many places without it being in the way. This can be seen in the CAD model shown below.

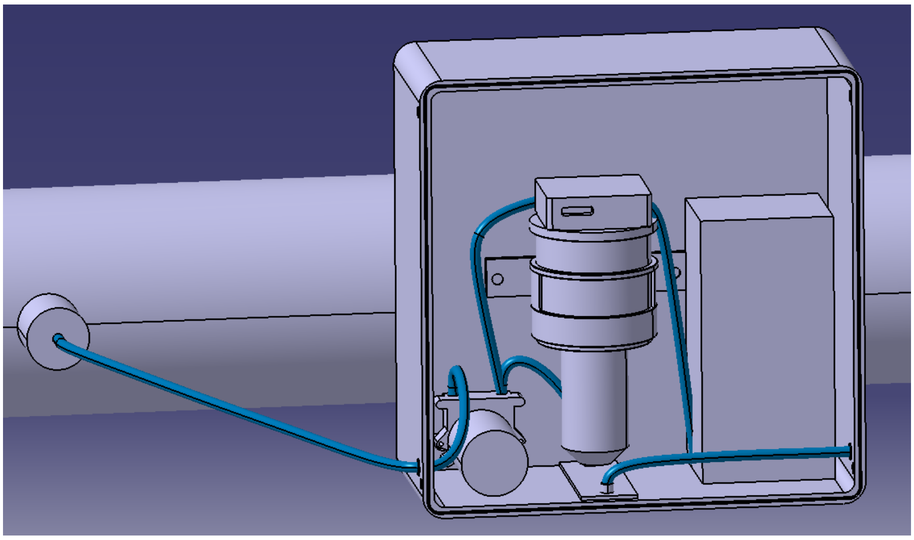

Figure 4.61: CAD-model of concept 4 (Modified)

4.5.5 Refined presentation of concept 25

Concept 25 relies on overpressure from the sample source to drive the sample through the microchannel. To control the flow and pressure over the microchannel, two valves are used. The sample flow goes from the sample source up to a valve before the microchannel, and after the microchannel is another valve before the disposal tube that leads to a gray water drain. A multicolored LED is used to provide information about the status of the equipment, and the results are transferred as a digital signal to a data analysis program. The power source is a rechargeable battery that gets its power from the electrical grid.

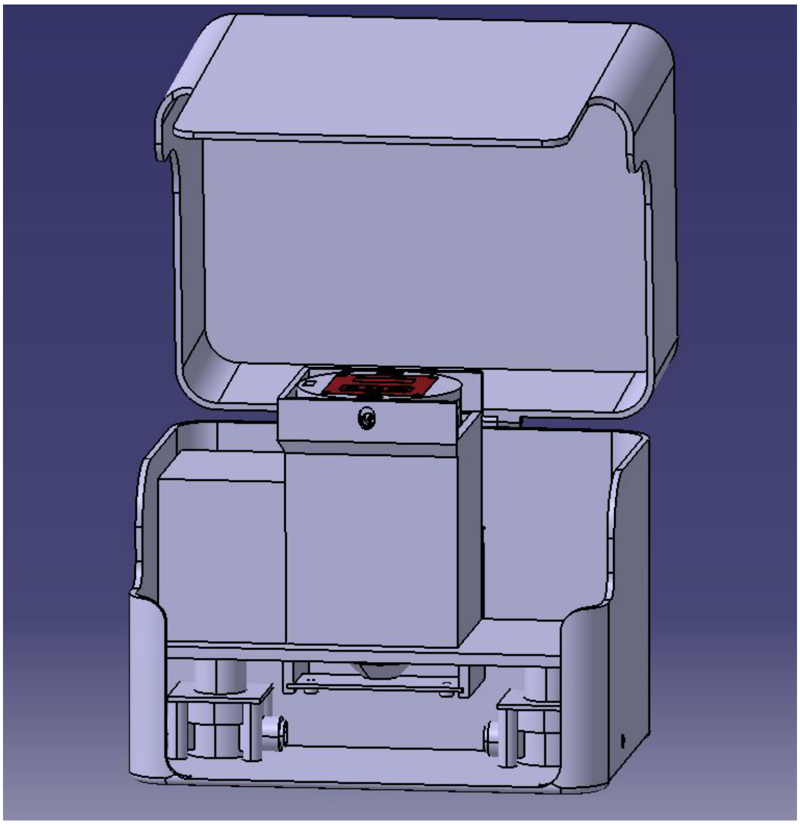

Figure 4.62: Concept 25 with the lid open

To fix the analysis components machine elements are used as seen in Figure 4.62 for adjusting the position can the components be adjusted in height and angle with the three mounting screws. The connections between the sample tubes rely on press fittings to avoid water leakage. To protect from water damage to the components are rubber seals used in the case to prevent moisture buildup which could lead to damage to the components.

4.5.6 Refined presentation of concept 27

Concept 27 controls the pressure and flow rate with a peristaltic pump placed before the microchannel. After the analysis, the sample is disposed into a gray water drain. A multicolored LED is used to provide information about the status of the equipment, and the results are transferred as a digital signal to a data analysis program. To power the equipment is a generator attached to the pipe with a water flow that generates the energy required for the analysis. To fix the analysis components machine elements are used as seen in Figure 4.63 for adjusting the position can the components be adjusted in height and angle with the three mounting screws. The connections between the sample tubes rely on press fittings to avoid water leakage. In the case of moisture buildup are all the components IP classed to handle surface moisture.

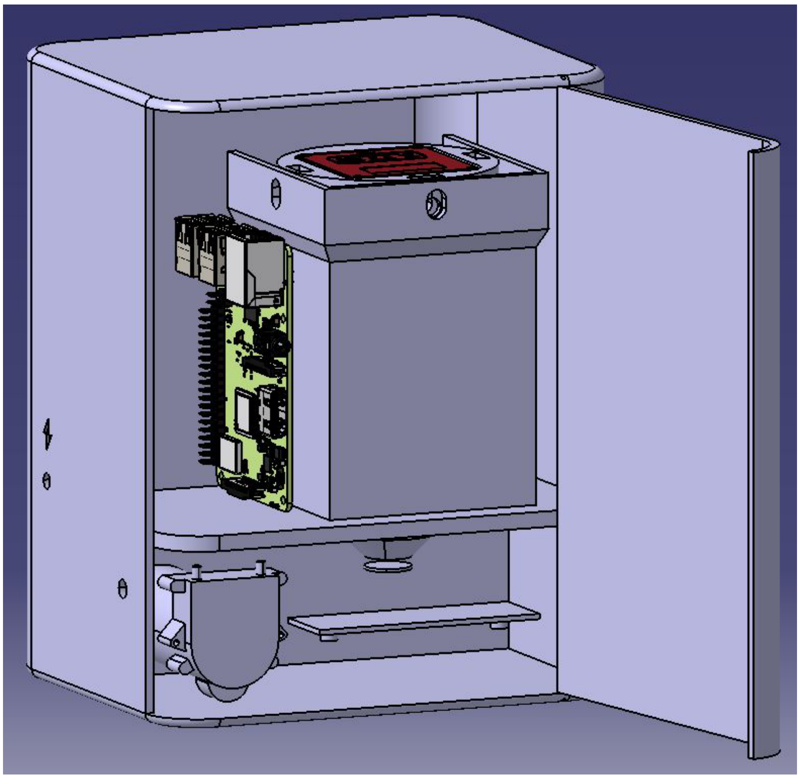

Figure 4.63: Concept 27 with the door open

4.5.7 Refined presentation of concept 30

Concept 30 is very similar to Concept 27 regarding the analysis implementation but differs in the supporting functions. For providing power to the system is a connection to the grid used in combination with a rechargeable battery for ensuring the system works without an active connection. The difference in sample collection is the sample is taken from existing taps instead of creating a new dedicated connection. Instead of IP classifications on all the components, rubber seals are used to ensure that moisture can't damage electrical components. These details can be seen in Figure 4.64 and 4.65

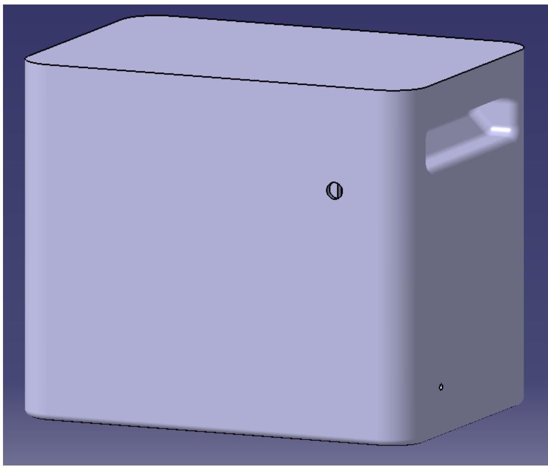

Figure 4.64: Concept 30 with the lid on

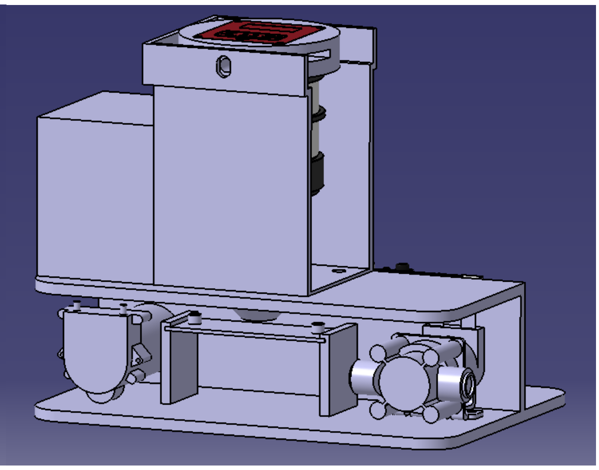

Figure 4.65: Concept 30 without the lid on

4.5.8 Company champion concept

The concept generated by The Company during the workshop used a peristaltic pump to push the sample through the microchannel. The sample should be able to be loaded directly from a sample jar or taken directly from a pipe. This means that the sample will be collected from water with pressure between atmospheric pressure up to 2 bar. After the analysis, the sample will be stored temporarily until the next test is planned. Before the next cycle will the stored sample be disposed into a wastewater drain. The power source is a grid connection and a replaceable rechargeable battery. The status and analysis results will be presented with a digital signal and a LED light. The digital representation of this concept can be seen in Figure 4.66 and4.67

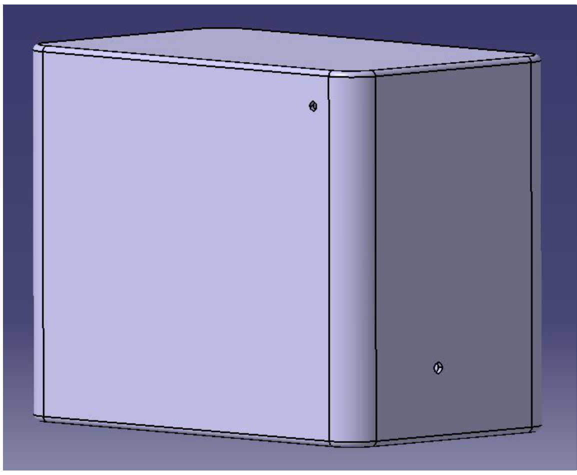

Figure 4.66: The Company's concept with the lid on

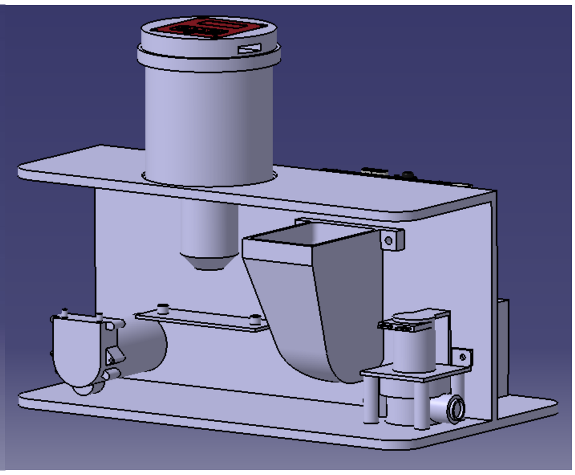

Figure 4.67: The Company's concept without the lid on

4.5.9 New component information

Since The Company is a new and small business different people within The Company have different competence. In the discussion at the beginning of the project, the business developers told us about the technology and how it works. With this description requirements list, and an operational plan was created from our side and the project began. After the Pugh-matrix during a meeting with a biotechnician, a new requirement was stated, and a new energy consumption calculation needed to be done for the innovation to work. The part was included in the description of the model from the beginning but with a significantly smaller power draw. The part is included in the Blackbox described earlier in the project.

In this discussion with 2 stakeholders in The Company and a biotechnician working with The Company the plan moving forward became to adapt to the new power consumption without redoing the elimination matrix and Pugh matrix due to the time left in the project. Moving forward a focus group with The Company and a product developer working with The Company will decide the plan moving forward with a single concept and to choose the adaptation method for the new power consumption.

4.5.10 Concept feasibility evaluation after refinement

After the Pugh matrix 8 concepts continued to the next step. Since the project timeline is a high priority a discussion with The Company led to a part feasibility analysis, to check if The Company could receive the parts before the end of the project. The Company prioritized a functional subsystem higher than using the actual parts for production in the future. The model's usage is to show proof of concept for the subsystems in order to seek more investors and show potential customers how the innovation works.

Parts eliminated due to part delivery time and availability in small batches:

- IP-certified parts
- Piston pump with the right dimensions and specifications

Due to the new component specification in the analysis model which led to a new power consumption of the analysis a water generator can no longer be used as planned. The generators can only produce 80W and are only meant for smaller receivers and signal senders. With the new power consumption of over 150W could a generator inside the waterpipe no longer provide enough power.

This narrows the concepts left down to two, concept 25, and concept 30 as seen in Figure 4.68. In order to move on from this feasibility analysis created by The Company a focus group will be used with stakeholders in order for the concept evaluation to be done and to follow The Company's product anchors and stay in line with The Company.

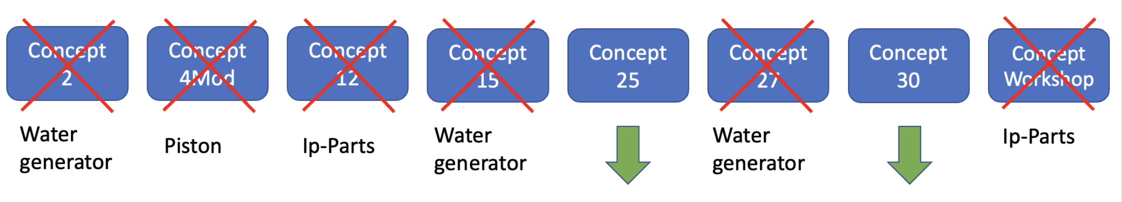

Figure 4.68: Eliminations due to feasibility constraints

4.5.11 Focus group concept validation

In order to choose between the 2 concepts left in the selection a focus group was created. The focus group included 2 stakeholders from The Company's business side and with their expertise regarding The Company's vision combined with a product developer working with The Company a good combination of competencies were gathered to make a decision moving forward eliminating 1 concept.

The agenda for the focus group was to tell all parties why they were there and give them a rundown of what was going on in order for them to get a hold of the situation. The concepts were described in detail and pictures from the CAD models were shown to visualize the different models. The big question setting the concepts apart was the technique used to control the water where one of the concepts used a pump while a valve and the other concept used two valves represented in Figure 4.69.

Figure 4.69: Concept selection final decision

To follow The Company's product anchors and stay in line with The Company. The Company chose to move on with the most flexible model which in this case was the concept with both a pump and a valve to be able to not use gravity advantage or trust the pressure from the pipe to move the water samples. The Company's decision allowed Concept 30 to continue the manufacturing of the physical prototype.

5
Final concept and prototype manufacturing

This chapter describes the final digital and physical prototype. This is presented as renditions of the components and the manufacturing of the full-scale physical prototype.

5.1 Final digital model

To evaluate the implementation of the components were a CAD model used to refine the design before the manufacturing of a physical prototype. All components except the microcontroller and the relays were created based on the physical components and recreated in Catia v5. The microcontroller and relays were downloaded from grabcad.com [32][33]. The final model consists of 42 parts and can be seen in 5.1

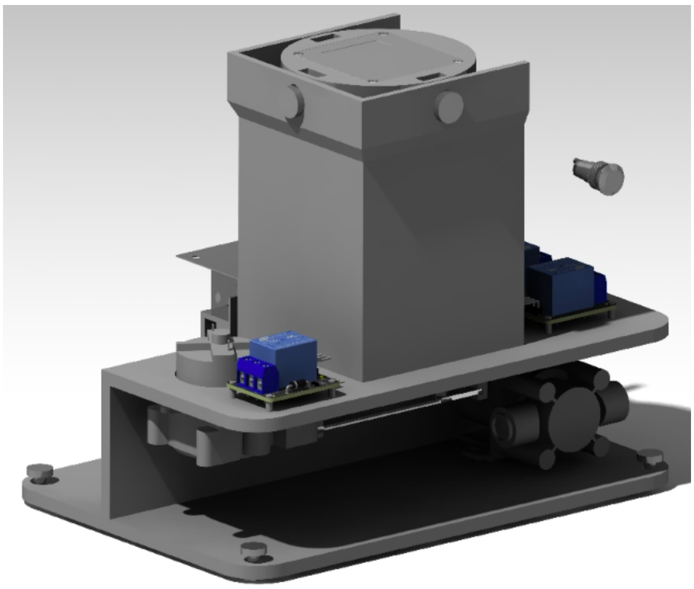

Figure 5.1: Full assembly of the digital prototype without the lid

5.1.1 Rendering of the lid

The lid seen in Figure 5.2 was designed to protect the components from water and ingress of dust as well as protect the components from knocks during operation and installation. To fasten it to the base plate were screws with o-rings used in each corner of the base plate to fasten the lid. To increase the ergonomics when moving the case does it have indentations on the side of the case to make gripping it easier.

Figure 5.2: Rendering of the lid component

5.1.2 Rendering of the base plate

The purpose of the base plate in Figure 5.3 is to serve as a fastening platform for the components and the mounting tower. The base plate has on the left side a mounting hole for the peristaltic pump which will be fastened with a silicon adhesive. For installing the microchannel is it a slot were supposed to slide in and be held in place by a mild adhesive. The tower has four screws to fasten it to the base plate and an o-ring around the microscope to protect the electronics. On the right side of the base plate is there a hole for the wires for controlling the valve and the valve itself is fastened with adhesives. To fasten the lid to the baseplate are there 4 screws to lock the lid to the base plate.

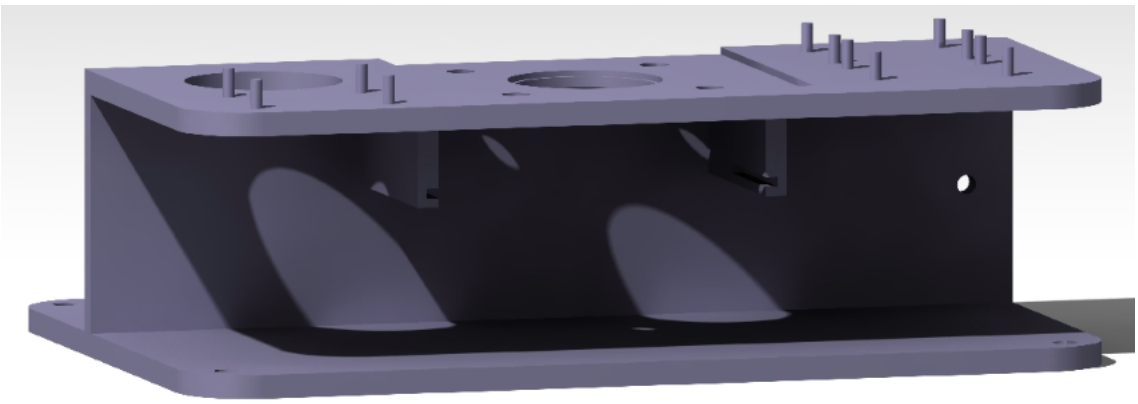

Figure 5.3: Rendering of the bottom plate component

5.1.3 Rendering of the mounting ring

The mounting seen in Figure 5.4 ring serves as an adjustable mount for the analysis components. To connect the ring to the analysis components are headless bolts used and to fasten it to the tower are 3 M6 bolts used to lock it to a certain angle and height in the groves at the top of the tower.

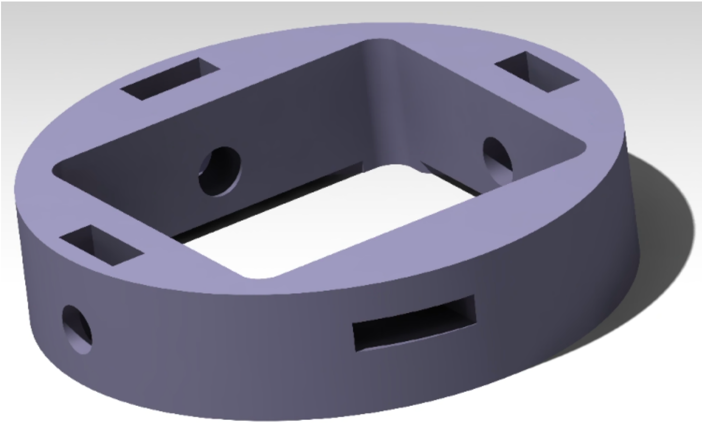

Figure 5.4: Rendering of the mounting ring component

5.1.4 Rendering of the mounting tower

The purpose of the mounting towers in Figure 5.5is to hold up the analysis equipment and allow for some adjustments of the height and angle in relation to the microchannel mounted on the baseplate. To fasten it to the base plate are 4 screws used in the bottom of the plate.

Figure 5.5: Rendering of the mounting tower component

5.2 Manufactoring process

A small testing concept manufacturing series with small changes in each batch calls for a flexible manufacturing method with a small cost per unit to allow for the model to be revised after a physical product has been produced. to make a plastic mold for the pieces would be too expensive if a change were made.

A simple and useful method that suited this project well was 3D printing using the fused filament method. A picture of the 3D-printer can be seen in figure5.6. This method uses a filament on a spool to melt the plastic in very specific places in layers in order to create the model. The method is more time consuming the plastic molding but the cost of a change or a low number of production units is beneficial. For manufacturing the prototype was E-PLA filament used in order for the model to be recyclable and easy to work with.

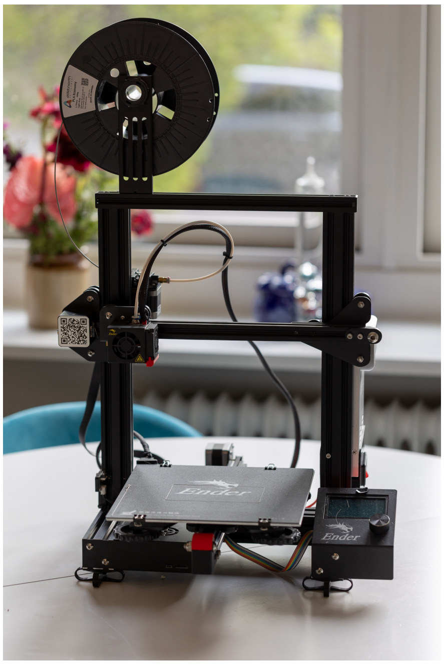

Figure 5.6: 3D-printer used to manufacture the parts

The parts were printed with support material which is a structure created with the same material as the actual parts but with a structure that is easily breakable in order to remove the supports after the print is done. A picture of the supports can be seen in figure5.7. The supports are used to help the printing layers bridge the material into the wanted place before curing, otherwise the plastic would sag down and create an unwanted geometrical form. the removal process is easy and takes a couple of minutes using pliers.

Figure 5.7: Support from 3D-printing

After the removal process of the supports, the parts needed some machining to fit perfectly and to keep a good seal to the mounting bracket.

5.3 Electronic components

The electronics of the model get controlled by a microcontroller named Arduino UNO R3 shown in figure5.8. The Arduino is controlled using a modified C++ code type called Arduino CC. The code can be seen in appendix A.6 & A.7
The microcontroller controllers the relays connected to the pump, valve, and a LED shown in figure5.9.

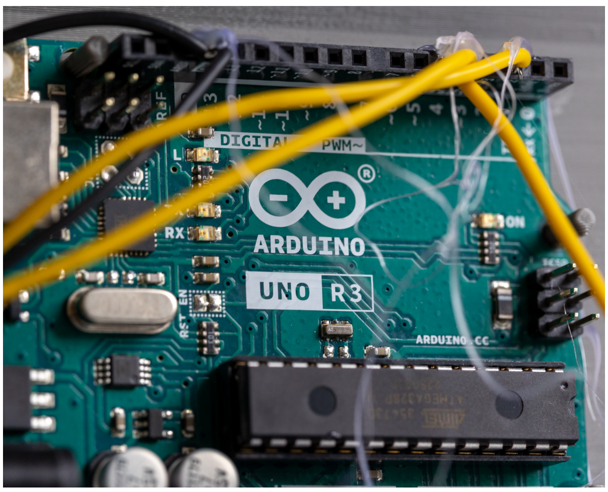

Figure 5.8: Arduino micro controller

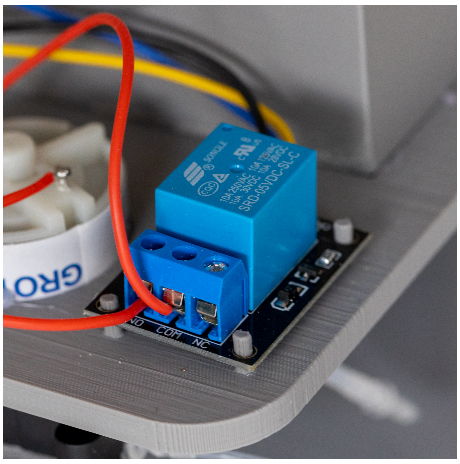

Figure 5.9: Relay controlled by micro controller

A schematic of the electronics is presented below, all cables are color coded for a better visual understanding of the model.

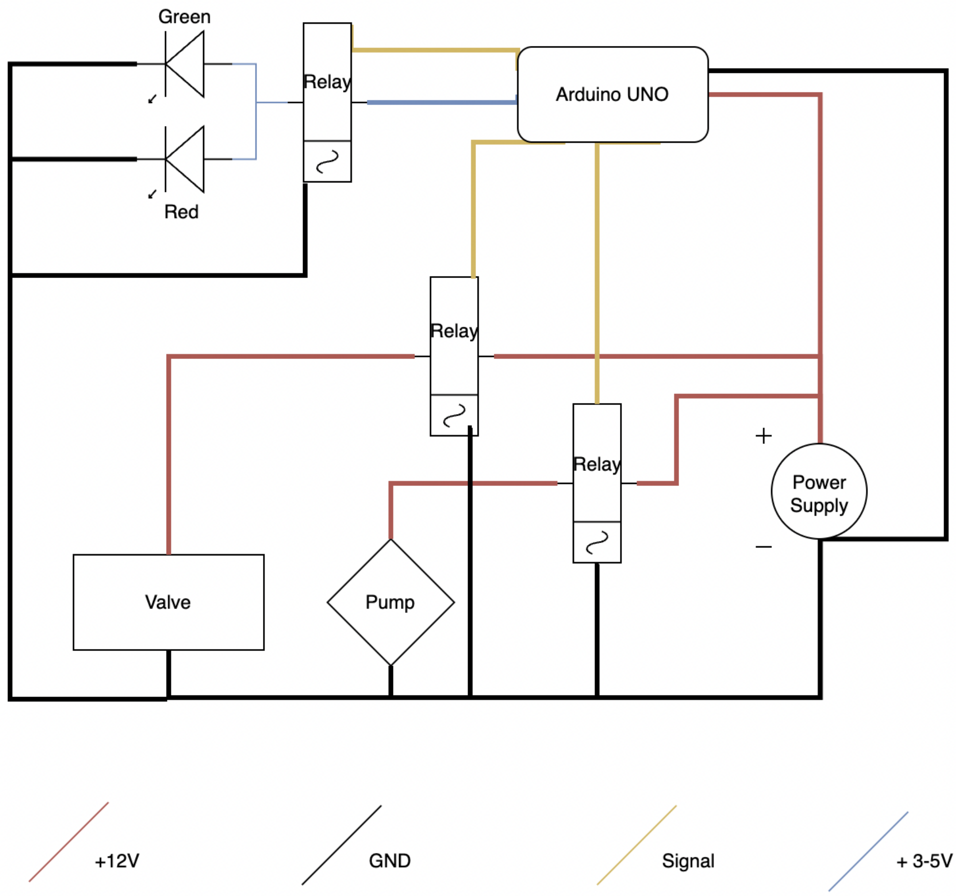

Figure 5.10: Electronic schematic

The microcontroller can be programmed and adjusted to match the analysis time of the innovation on-site in order to adapt to every scenario.

5.4 Battery implementation in the final model

Due to the increased energy consumption late into the project could the batteries only be implemented in the digital model. They were implemented into the case lid as seen in Figure 5.11and would have been fastened with an adhesive in the physical model if it had been possible to implement them during the project's time limitations.

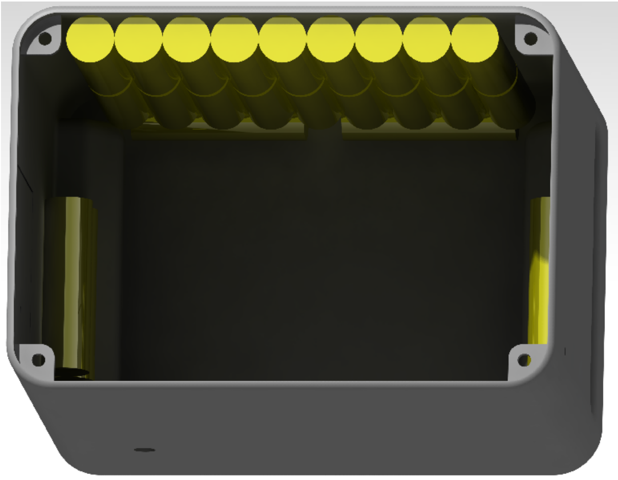

Figure 5.11: The lid with all battery cells fastened to the lid

5.5 Assembly process

The cover was printed in 40 hours and consisted of a one-piece design that covers the whole model when placed on a flat surface.

5.5.1 Cover manufacturing

The model was printed with supports in order for the channels and holes to keep their shape during the manufacturing process. A visual representation of the supports can be seen in figure5.12 & 5.13. The supports are then removed and the cover pieces. After the printing was done the LED were mounted on the side of the cover and connected to the relay for the visual signal. The part without support can be seen below.

Figure 5.12: Cover without support

Figure 5.13: Inside the cover without supports

5.5.2 Holder manufacturing

The tower holder and the analysis tool were printed using the same technique as the cover, using supports in order for the pins and holes to be the correct shape after the manufacturing process.

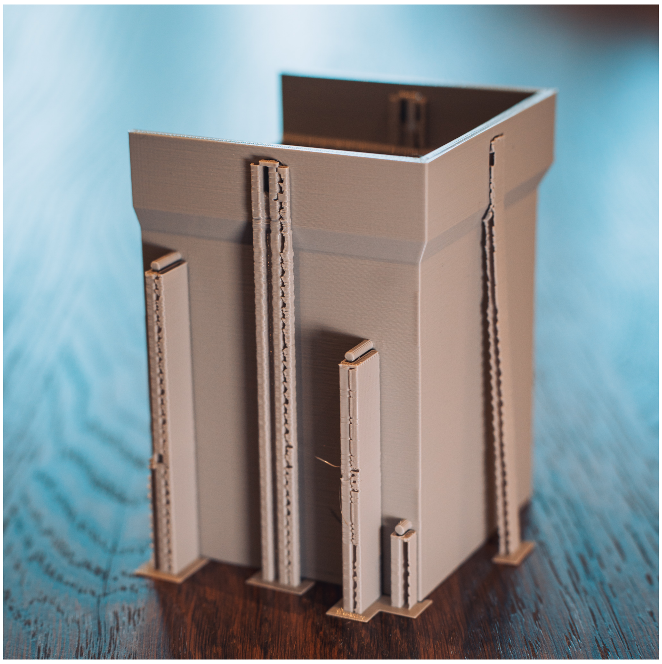

Figure 5.14: Holder with supports

5.5.3 Bottom manufacturing

The orientation of the manufacturing of the bottom part of the model is impotent, the model was printed on the side in order for the layers to better support the analysis module weight and not crack when dropped in the physical testing. the model was printed using supports that then were removed.

Figure 5.15: Bottom with supports

The tower was then assembled on the bottom part and screwed together using bolts and nuts. Shown in the picture below. The holder mounts using nuts and bolts under the holder in order for the holder to stay in place on the bottom bracket.

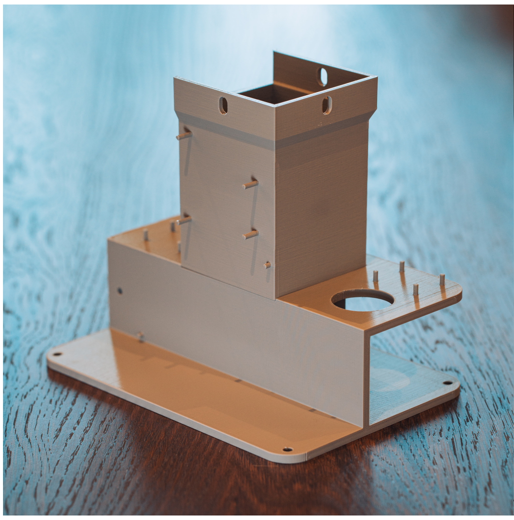

Figure 5.16: Bottom and holder without supports

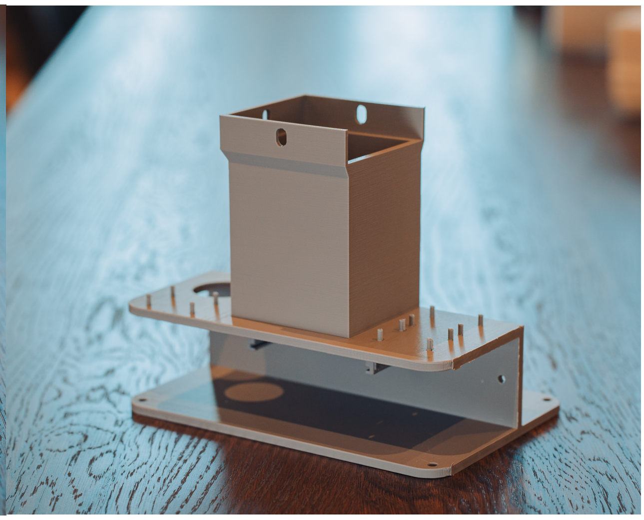

Figure 5.17: Bottom and holder without supports

5.5.4 Ring holder manufacturing

A ring was manufactured in order to hold the analysis tool in place in the tower. The model with the supports is shown below.

Figure 5.18: Ring holder after manufacturing

5.5.5 Electronics and waterlines

All the electronics were then installed according to the chart shown in figure 5.10. The water channels and lines were then put in place and the model was assembled.The final model without the cover can be seen in the picture below.

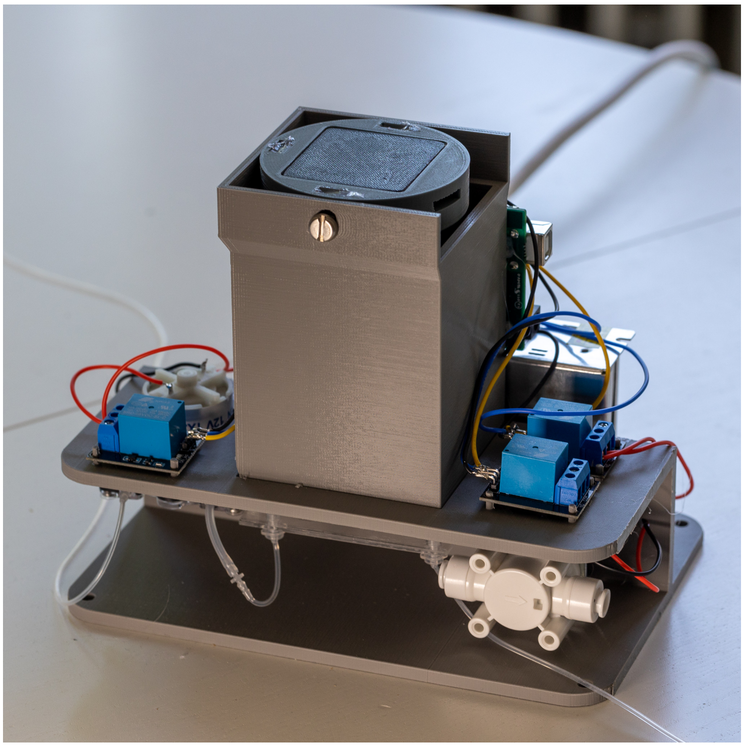

Figure 5.19: Model with electronics and water system installed

6

Verification against requirements

This chapter verifies the final concept against the list the requirements A.2. The verifications are categorized based on the method of verification which are calculations, digital measurements, material databases, and physical tests.

6.1 Metrics verified with the digital model

Several of the established requirement could be tested against the digital prototype. To avoid inaccuracies caused by the method of production were all product measurements done in Catia v5.

6.1.1 Outer dimensions of the prototype

To evaluate metric number 8 with the help of the digital prototype. The verification was performed by using the measurement tool in Catia v5 to calculate the distance between the outer surfaces of the lid and base plate to get the height, width, and depth of the prototype. The verification result was that the height was 171 mm, the width 206 mm, and a depth of 146 mm. This means that the prototype fulfills the target value with a margin of 44mm in the width measurement.

6.1.2 Total weight of the prototype

Metric number 9 was verified with the weight measurement tool in Catia. This verification was performed by assigning suitable densities to the components and then calculating the total mass of the assembly. The calculated weight excluding the cables is 3788 grams which means it is well within the margins for the target value of weighing less than 10 kg.

6.1.3 Chemical additives during the process

Metric 11 is a requirement of not introducing any chemicals into the process. As the support system only moves water from a sample source through the microchannel. Therefore aren't there any chemicals added by the support systems which means that the metric is fulfilled.

6.1.4 Compatibility with existing measurement points

Metric 14 was verified by visual estimation of the CAD model in Figure 6.2 of the tap connector and the pictures 6.1 of the tap sent by Karlshamn water treatment plan. It is deemed suitable for the connection to the tap but it will require further verification through physical testing.

Figure 6.1: The current taps at the water treatment plant

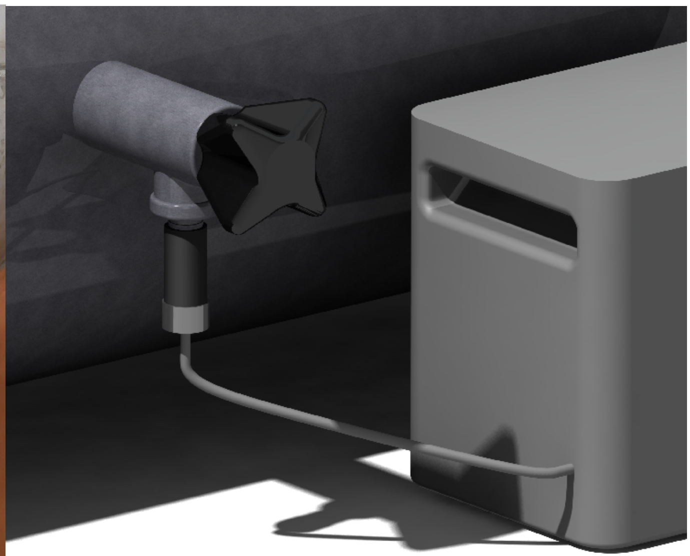

Figure 6.2: The prototype attached to the waterworks tap in a digital environment

6.1.5 Use of permanent fasteners

If metric 18 is fulfilled is a matter of definition due to some fastening of components being done with silicone to insure waterproofing. Although the rest of the fastening points are done with machine elements is this metric deemed to fall within the marginal range for the metric.

6.1.6 Grip ergonomics of the lid

Metric 20 was verified by measuring the dimensions of the handles on the digital prototype. The measurements for the indentations for gripping have the measurements 105mm in width, 20mm in height, and 25mm in depth. These measurements mean that the 95 percentile of men and women won't have any problems with fitting their hands in the indentations and that the metrics target value is fulfilled.

6.1.7 Number of components

The purpose of metric 29 is to reduce the number of fastening elements. This metric was verified with a component list derived from the digital prototype. In the list are 22 of the components fastening elements which means that the marginal target value is fulfilled. Metric 30 has the same purpose as metric 29 but takes all components of the supporting system into account. The total component count is 67 listed in Figure 6.3and falls within the marginal target value although this number doesn't take cables and tubes into account.

M5 nut	4
M5 screw	4
M6 nut	7
M6 screw	7
Analasys system	1
Analasys system fastener	1
Relays	3
Peristaltic pump	1
Valve	1
Led light	1
Base plate	1
Case lid	1
Microchannel	1
O-ring 5mm	4
O-ring 6mm	4
Batteries	24
Arduino uno	1
Fastening tower	1
Total count	67

Figure 6.3: List of components and how many there are of each type

6.2 Metrics verified with material selection

The requirement for recyclable material was only related to the case. Due to the prototyping making use of 3D printing was PLA used due to its low fume emissions during printing and its recyclability[34]. Because of this is requirement deemed to have been fulfilled for the prototype but a new material will have to be selected for full-scale production.

6.3 Metrics verified through physical tests

In this section, a description of the tests and the results against the requirements matrix done with the physical testing will be presented.

6.3.1 IP-testing

The model was exposed to a garden hose in every direction in order to test the water seal, the model stood up to the stream as expected and received a theoretical IP-class of waterproof A picture of the model sprayed with water can be seen in figure6.4. Since the model is made out of PLA the materials in the prototype can attract moisture.

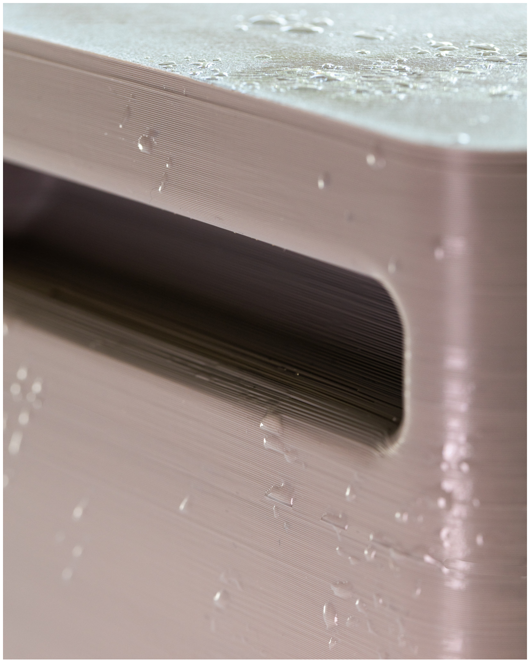

Figure 6.4: Model sprayed with hose

6.3.2 Drop test

A drop test from 50cm with the full model was conducted on asphalt. The model took the impact well, but the case around the model got a small crack as shown in figure6.5. The crack ruined the waterproofing of the case in the impact.

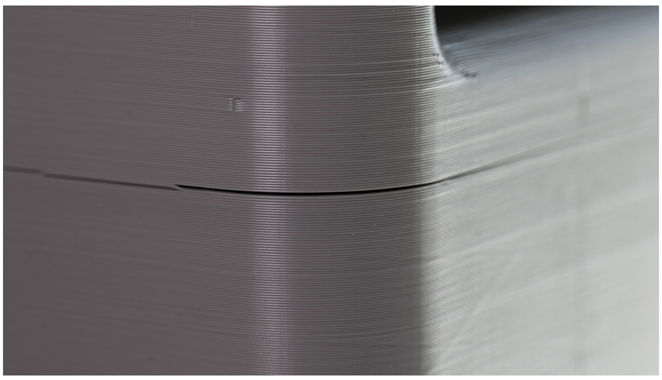

Figure 6.5: Crack in case

6.3.3 Drop test 90 degree corner

A drop test on a 90 degree corner from a 50cm drop was conducted using a box placed 45 degrees on its edge. The fasteners on the inside of the model came loose during testing. There were no visible marks neither the model nor the components inside seen in figure6.6.

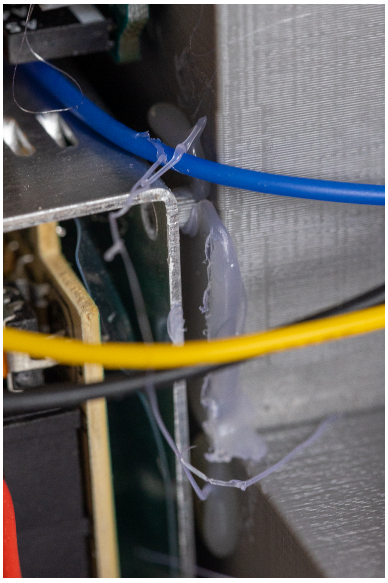

Figure 6.6: The adhesive binding broke during the test

6.3.4 Time for a 100 ml sample to flow through the supporting system

The testing done in a lab showed the result of pumping 100ml of tap water from one plastic cup to another through the model took 23 minutes and 40 seconds. Figure6.7 below shows the setup and the cups for transporting the water in a controlled manner.

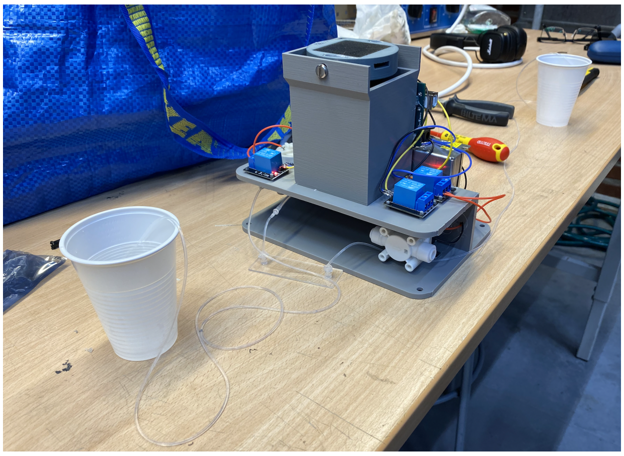

Figure 6.7: Water flow testing

6.3.5 Finish date for the prototype development

The prototype was done 5 days late according to the plan made at the beginning of the project presented in the Gant-chart. The prototype was late because of some printing issues and some latency in ordering parts. This meant that the report was in a more complete state than the plan which meant that the time spent on the project could be adjusted in order for the report to be early and the prototype to be late without the overall project being late. So overall the project kept the timeline and the results are presented in time for the end of the project.

6.3.6 Can take a sample from water with overpressure

A test was carried out in order to test the overpressure ability of the model. The prototype was fed using a syringe and the existing lines. The pump could stop the syringe pressure and the pump's ability to function as intended was not a problem. The pump used handled and stopped the overpressure from entering the microchannel. The syringe and the adapter used can be seen in figure6.8.

Figure 6.8: syringe and adapter

6.4 Metrics verified trough calculations

In this section the metrics from the needs and metrics matrix that can be tested through physical tests will be presented and the results.

6.4.1 Cost of Prototyping

The total cost for manufacturing and the parts needed in order for the prototype to exist were 2653,2Kr. The cost for manufacturing plastics was 747Kr and the rest is the components needed in the model. In figure6.9 one of the components is displayed, an Arduino UNO.

Figure 6.9: Closeup of micro controller

6.4.2 Number of days without connection to the power grid

The power draw of the model is based on short bursts of 150 watts, over the span of 3 days the power is used 3 hours in total. The sum of the power draw is equal to 450 watt hours. The battery cells used have an energy density of 18,5 watt hours. 24 cells are used in the configuration 3s8p 3 cells in series and 8 groups in parallel[35]. Since the target value in the needs and metrics matrix were 3 days the target was then achieved. The figure6.10 shows the power supply used in the prototype to supply the power when connected to the grid.

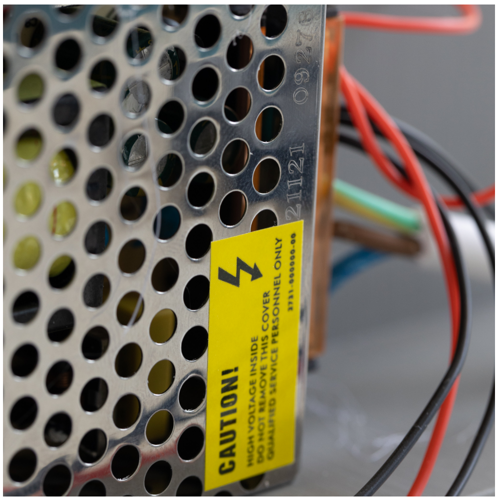

Figure 6.10: Closeup of power source

6.4.3 Rating of manual handling according to Arbetmiljöverket

With the use of Arbetsmiljöverket´s PDF Rating of manual handling, the product scored 6 in "riskpoäng" which places the product in the risk area 1. Time points resulted in a 1, the need for carrying the model more than 300m is slim to none. The load point score was also a 1 due to the low weight of the model and the work position resulted in a 4 due to the conditions when installing the product can be in inaccessible mounting positions. The working conditions reached a 1 which resulted in a calculated score of 1+4+1= 6 The target value was then reached with a lot of margin[36].

7
Discussion and Conclusion

In this chapter a discussion regarding the results created in the project is discussed, followed by a conclusion of the project and feedback to the questions stated at the beginning of the project.

7.1 Battery

In the prototype created the battery uses the cells in series and In parallel to create the battery capacity needed in order for the model prototype to operate properly without connection to the power grid. The Target value of 3 days was reached but the model can´t then recharge these battery's due to the lack of a proper Battery management system or BMS for short. The prototype can also use a proper Li-lion charger to recharge the batteries to the wanted voltage. The Li-lion cells can not be charged like a normal battery, they need to be balanced and charged equally between the series in the pack. Li-lion 18650 cell´s can be seen in Figure 7.1.

Figure 7.1: 18650 cells

A BMS can take a constant current of voltage and equally charge the cells, but they can also be expensive and take up some space in the model. Chargers on the other hand take up a lot of space and they don't provide the same security as a BMS. A BMS provides short circuit protection, overcharge protection, and low voltage protection. These things can be done using other components but overall the BMS is a good choice and for further development of the model a BMS would be relevant to look into.

7.2 Recommended adjustments for the new energy requirement

Because a new requirement was discovered late in the project estimations for the energy consumption be reevaluated. This resulted in the product architecture being less than optimal for the additional batteries required. Adjusting for the increased energy requirement should the depth of the case be increased to ease the assembly and place the extra battery cells on the back wall of the cover.

7.3 Material selection

The final prototype of this project was created using the 3D printer seen in Figure 7.2. The available materials for the prototype were E-PLA to use the machines available in the time frame of the project. PLA plastic is not meant for building structures that require a lot of strength, due to the material being brittle. The working temperature range for the plastic is up to 60 degrees Celsius and in some scenarios like being left in a car under the sun the material can begin to soften and lose its shape.

The manufacturing process used is optimized for small production runs where small things can be changed in each new print without changing the individual cost of each part. It´s optimized for prototyping but can be rather expensive and not so effective when working with larger quantities. The machines must be manually started between each part and the print time is much slower than molding for example. For the final product, molding is a good option but for making a mold The Company must test the product and the functionality and make all the changes before due to the big costs of making a new molding tool. But after the tool is made, each part costs a lot less.

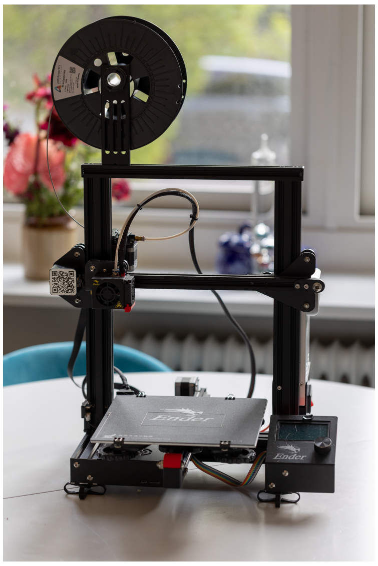

Figure 7.2: 3D-Printer

In the next development phase and for the final marketable product The Company must investigate a new material for making the product. Both the manufacturing process and the materials are optimized for a small prototype run to prove the concept outside of the laboratory as mentioned in the introduction of the report.

7.4 Microcontroller

The Arduino microcontroller seen in Figure 7.3 was used in the prototype and is well suited for prototyping with different valves and pumps driven via relays. But the microcontroller is big and costs more than a custom microcontroller for the final product. The recommendation is to use a microcontroller that is custom made to both work with the innovation for analysis and for controlling the subsystems in order to save space and cut down costs in the final product. The microcontroller used today can't read the innovation and process the data received from the microscope.

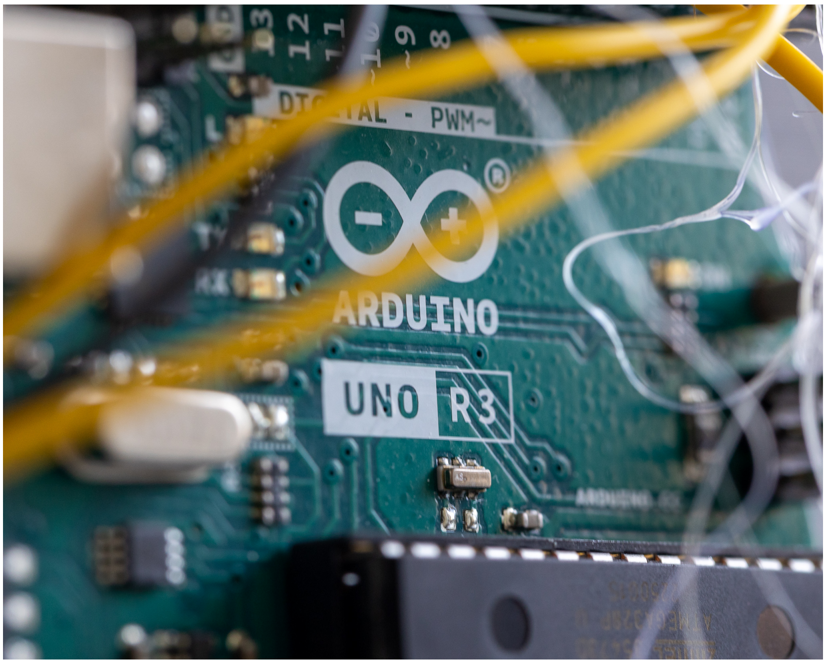

Figure 7.3: Microcontroller close-up

The innovation needs a microcomputer that can process both images and write data signals to different ports at the same time in order to operate both the valve and the pump. The data signals must then be sent to a signal sender that transmits the signal to the control person operating the analysis of the drinking water in that area. The signal transmitter is outside our scope and The Company is in charge of implementing the transmitter and a suitable controller for the system when marching the innovation with our subsystem.

7.5 Early startup environment

Due to The Company still being in its startup phase there is a flat hierarchy. This leads to easy contact with all employees at The Company although access to existing documentation has been varied as it hasn't always been clear what data exists and how it's allowed to be disclosed in the report. The uncertainty of what was possible to present without risking limitations for their patent applications led to an avoidance to discuss the analysis method in any greater detail. The lack of structured data storage led to some information being missed during the establishment of the knowledge base which caused some improper dimensions for the energy consumption.

7.6 No recirculation of analyzed water

To avoid the strict regulations for materials in contact with drinking water was a decision made to discard the sample after analysis instead of recirculating it into the water network. This meant that the materials doesn't need to conform to Swedish drinking water standards [13]. Although the materials selected were classified as food safe and biocompatible according to Granta EDUpack. This means that the water could be recirculated in theory but the equipment would need to be verified for that usage to ensure it doesn't release any harmful materials during the analysis.

7.7 TRL level

At the start of this project the TRL level for the innovation was level 3, Experimental proof of concept. This is something that has not changed, since the model cannot be tested with the analysis part we can't say that the model has reached the status "Technology validated in lab"[4]. But with some time in a laboratory and the right equipment for the full system testing the development of the supporting systems makes it possible to reach TRL 7 without much modification.

7.8 Narrow area of expertise

The project was performed by two students who have very similar academic backgrounds. Both students have a bachelor's degree in mechanical engineering and a master's in product development.

Due to the similarity of the education of the project members there is a risk that opportunities have been missed which would have been identified by a multidisciplinary team. Another drawback of the narrow area of expertise is that more advanced mechatronic systems were avoided. This means that the design space could have been investigated more thoroughly by a team with multidisciplinary instead of only a perspective of mechanical engineering and product development.

Therefore, should further developments for the supporting systems be performed by a multidisciplinary team instead of a development team with very similar academic or work experience. This could be done with the help of Produktionsänglarna as they help startup companies to scale up and go into production. This would reduce the need to employ a team but would have the drawback of not developing any in-house knowledge. One option would be to employ a small in-house team which would be supported by Produktionsänglarna to strike a balance between keeping costs low and gaining internal knowledge.

7.9 Objective fulfillment

The objectives were established at the beginning of the project with the goal of furthering The Company's technology. The result of this iteration of the design process resulted in a system that can control the sample flow through a microchannel. The developed system also implements placeholders for the analysis components. These results fulfill the first objective which was developing a sample preparation system.

The second objective was to develop a digital model of the prototype. This model also served as the basis for achieving the third objective. The purpose of the model was to create a basis for further developments in collaboration with Produktionsänglarna. The result of the digital modeling was one complete concept and 7 refined concepts. These models can serve as a basis for further developments and fulfill the second objective.

Lastly was a functional prototype developed based on the complete digital concept. The functional prototype was manufactured with the help of 3D printing and electronic components to control the microfluidic system. This prototype was then verified against the established requirements, thus fulfilling the third and final objective.

7.10 Fulfillment of research questions

The first research question was related to the speed at which 100 ml of water could be transported through the microchannel. This was verified with the test in 6.3.4 where it was shown it could be transported in 23 minutes and 40 seconds. This fell well within the range and proves it's possible to perform a complete analysis below 30 min assuming the analysis can be performed within one second for each partial sample.

The second research question was closely connected to the first objective which was to develop a microfluidic system with the caveat of incorporating it into a portable concept. The results the tests in 6.1.1, 6.1.2, and 6.4.3 show that the final concept has dimensions and weight specifications that make it reasonable to transport.

In the results in Chapter 6 where it was shown it could be connected to existing taps, be transported by hand, autoloading, analysis time, and pressure variation.

These tests verified the viability of the field scenario and the treatment plant scenario requirements. For the water network scenario is runtime without maintenance one of the most important requirements which couldn't be tested during the project. Therefore it can be concluded that two scenarios can be fulfilled and the third scenario has too much uncertainty for a definitive answer. Because of this was this research question only partially answered.

7.11 Handover to The Company

In conclusion this project contributed to The Company by the deliverables of this project in form of the digital models, a physical prototype, verification of their data, and a list of requirements. The digital models add value by serving as a basis for further development and are a great tool for visualizing or simulating this stage of the current concept maturity. The physical prototype creates a tangible representation of what direction The Company is moving towards. It also allows for some hands-on testing and can without major modifications be converted into a test rig for the analysis components. Therefore it can be used to further develop the analysis method and serve as a proof of concept for investors. With the data generated in the project have several of The Company's internal documentation been validated with new studies. The two most relevant documents for further development are the requirement specifications and the competitor benchmarking.

Overall, this project increased The Company's internal documentation and knowledge about what support functions are required and how these functions can be executed. These handovers give The Company the necessary documentation for the next iteration where the support system will interact with the analysis system to achieve the systems full function.

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A
Appendix

A.1 List of requirements

Metric Number	Needs Number	Metric	Importance	Units	Marginal Value	Target Value	Verification	Source
1	1	Drift from the true value over time	5	Standard deviations	0	0	Full system validation	Water treatment interviews
2	2	IP classification for water resistance	4	List	IP54	IP65	Physical tests	The Company(Planned user scenarios)
3	3	Testing technicians on how long it takes to learn the product	3	Minutes	180	20	Full system validation	Competitor study
4	4	Drop test from 0.5 meters hight onto asphalt with the prototype	4	Subjective	Cosmetic damage	No damage	Physical tests	Water treatment interviews
5	5	Drop test onto a wedge with 90° edge from 0.5 meters hight with the prototype	3	Subjective	Cosmetic damage	No damage	Physical tests	Water treatment interviews
6	6, 17	Time for a 100 ml sample to flow through the supporting system	1	Minutes	60	10	Running a 100ml sampele throug the system	The Company(Previous documentation)
7	7, 21	Allow for a purification process without additives to ensure that particles and bacteria are flushed through	3	kWh	Pass	Pass	Full system validation	The Company(Meeting)
8	8,9,26	Outer Dimensions x*y*z	3	Meter	<0.5*0.5*0.5	<0.25*0.25*0.25	CAD models	https://antropometri.se/calc.php, https://www.av.se/halsa-och-sakerhet/belastningsergonomi/manuell-hantering/
9	8,9	Total mass	2	kg	<15	<10	Weighing	https://www.av.se/halsa-och-sakerhet/belastningsergonomi/manuell-hantering/
10	10	Sum of the cost of buying components for the prototype	5	Sek	<70 000	<50 000	Cost calculation	The Company(Meeting)
11	11	No chemicals used in the process	5	List	Pass	Pass	Product arcitecture	The Company(Meeting)
12	12	Sending out an alert when cells/100 ml is higher than target value	3	Binary	Pass	Pass	Full system validation	The Company(Previous documentation)
13	13	Number of days between user input for standard measuring	5	Days	>6 months	>12 months	Full system validation	Competitor study
14	14	System interface points match existing standards	3	List	Pass	Pass	CAD models	Water treatment interviews
15	15	Specifications found in Swedish water regulation act LIVSFS 2022:12	5	List	Pass	Pass	Bill of materials and CAD models	LIVSFS 2022:12
16	16	Change in bar from the water system to a suitable pressure for the micro channel	5	Bar	Pass	Pass	Full system validation	The Company(Previous documentation)

Figure A.1: Requirement specifications

17	17	Maximum water speed where the equipment still can detect bacteria correctly	3	m/s	Pass	Pass	Full system validation	The Company(Previous documentation)
18	18	Subsytems doesn't use permanet fasteners	1	List	Fail	Pass	CAD models	The Company(Meeting)
19	19	Percentage of recyclable material in the shell	3	%	>50	100	Granta EDUpack	The Company(Meeting)
20	20	Grip surfaces are within dimensions for the 95th percentile	3	List	Fail	Pass	CAD models	https://antropometri.se/calc.php
21	21	Number of days without connection to the electric grid	2	Days	3	5	Calculation	The Company(Planned user scenarios)
22	22	The particle size of residual contamination must be able to pass the microchannel	3	µm	2	10	Full system validation	The Company(Previous documentation)
23	23	System for presenting the collected data	4	Binary	Pass	Pass	Full system validation	Water treatment interviews
24	24	Time untill debree in the sample affects the measurements	4	Days	>6 months	>12 months	Full system validation	Competitor study
25	25	Number oh hours to install the system	3	Hours	8	1	Full system validation	Competitor study
26	26	Rating of manual handling according to Arbetmiljöverket	4	List	2	1	Matrix analysis	https://www.av.se/globalassets/filer/publikationer/broschyrer/bedom-risker-vid-manuell-hantering-lyfta-bara-broschyr-adi627.pdf
27	27	Finish date for the prototype development	5	Date	##########	2023-05-01	Calender	Gant chart
28	28	Can take sample from water without any overpressure	5	Binary	Pass	Pass	Test run	The Company(Meeting)
29	29	Number of components required for fastening	3	list	30	10	Component list	The Company(Meeting)
30	29	Number of components for operation	3	list	80	40	Component list	The Company(Meeting)

Figure A.2: Requirement specifications

A.2 Material chart

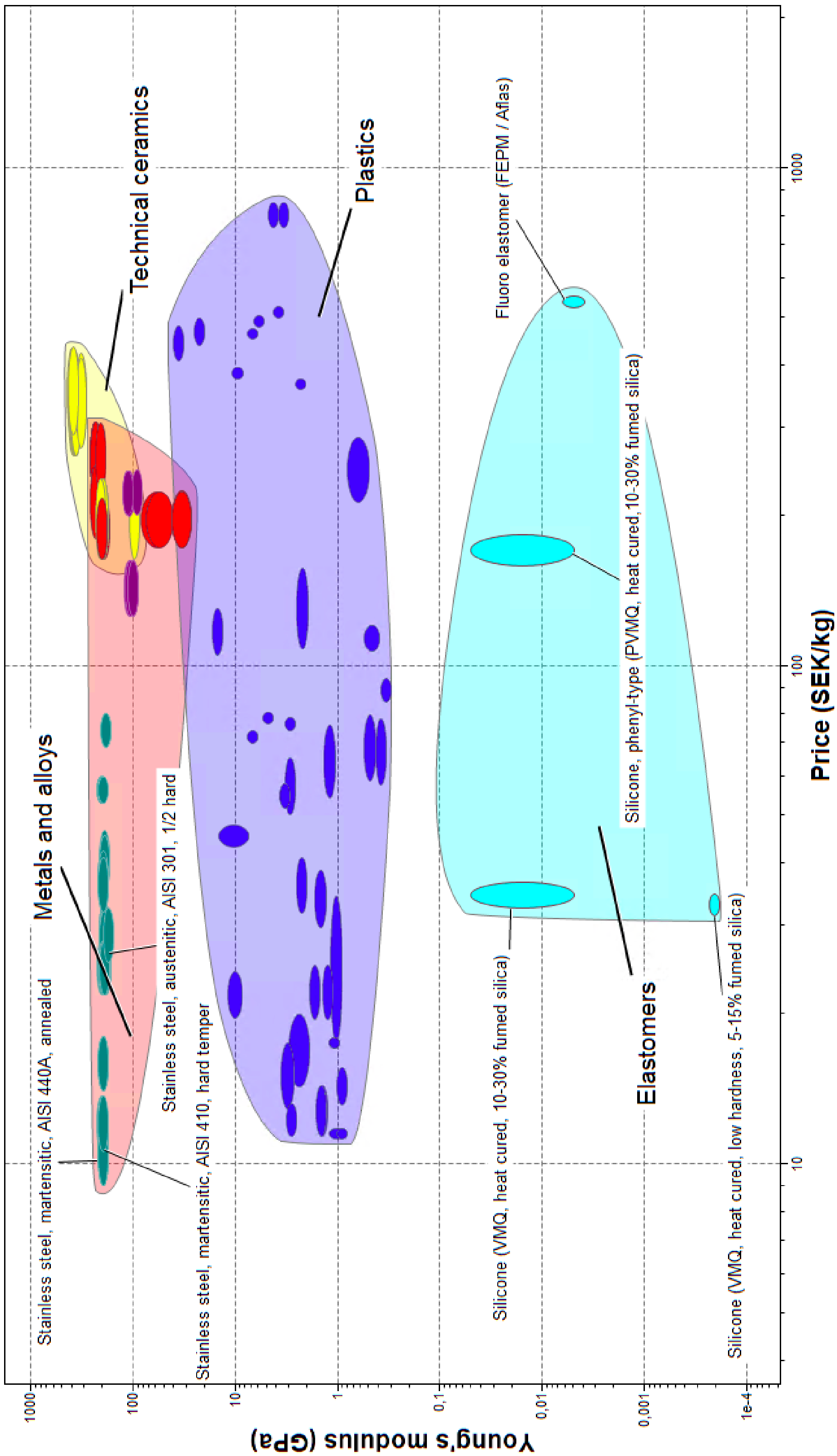

Figure A.3: Chart with suitable materials

A.3 Needs to metrics matrix

Metrics

1	Drift from the true value over time
2	IP classification for water resistance
3	Testing technicians on how long it takes to learn the product
4	Drop test from 0.5 meters hight onto asphalt with the prototype
5	Drop test onto a wedge with 90° edge from 0.5 meters hight with the prototype
6	Time for a 100 ml sample to flow through the supporting system
7	Allow for a purification process without additives to ensure that particles and
8	Outer Dimensions x*y*z
9	Total mass
10	Sum of the cost of buying components for the prototype
11	No chemicals used in the process
12	Sending out an alert when cells/100 ml is higher than target value
13	Number of days between user input for standard measuring
14	System interface points match existing standards
15	Specifications found in Swedish water regulation act LIVSFS 2022:12
16	Change in bar from the water system to a suitable pressure for the micro channel
17	Maximum water speed where the equipment still can detect bacteria correctly
18	Subsytems doesn't use permanet fasteners
19	Percentage of recyclable material in the shell
20	Grip surfaces are within dimensions for the 95th percentile
21	Number of days without connection to the electric grid
22	The particle size of residual contamination must be able to pass the microchannel
23	System for presenting the collected data
24	Time untill debree in the sample affects the measurements
25	Number oh hours to install the system
26	Rating of manual handling according to Arbetmiljöverket
27	Finish date for the prototype development
28	Can take sample from water without any
29	Number of components required for
30	Number of components for operation

Needs		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1	The result must not be affected by changed conditions such as wear or temperature changes within the operating tempertur range	•																													
2	Protected against splashing water from all angles		•																												
3	An operator should understand its interface within one hour of training			•																											
4	Handle a small drop without damaging the usability or water resistance				•																										
5	The equipment should handle minor scratches without damaging the usability or water resistance					•																									
6	Analysis time that is shorter than the slowest of their competitors						•																								
7	Automated cleaning between cycles to insure correct measurments							•																							
8	Should be able to be transported in a work truck								•	•																					
9	Should be able to be lifted and moved by a single person								•	•																					
10	Components should cost less than 70 000 Sek for the first prototype										•																				
11	Carry out a test for bacteria without using any chemical additives											•																			
12	Alerts are automatically sent out in case of detecting high concentrations of bacteria												•																		
13	Automated and doesn't require user input for regular measurements													•																	
14	Compatibility with existing measurement points														•																
15	Comply with Swedish law for handeling drinking water															•															
16	Reduce the pressure between the pipe and the micro channel																•														
17	Maximize analyzed water volume without negatively affecting the accuracy of the measurements						•											•													
18	It should be possible to repair if one component fails																		•												
19	The shell must be recyclable																			•											
20	Grip surfaces for easier lifting																				•										
21	Operational without connection to the electric grid							•														•									
22	Manage water control after segmentation of large particles																						•								
23	Simple data representation																							•							
24	Avoid clogging of the measurement system																								•						
25	Fast instalation time																									•					
26	Ergonomic installation process								•																		•				
27	Finish the protype before the end of the project																											•			
28	Can be implemented independently of pressure																												•		
29	Minimize the number of components																													•	•

Figure A.4: Needs to metrics matrix

A.4 Stakeholder interview questions

- Vad använder ni för vattenkälla?
- Vad använder ni för reningsteknik idag?
- Hur mycket dricksvatten producerar ni?
- Hur många människor producerar ni dricksvatten till?
- Hur stor vattenvolym testar ni under en dag?
- I vilket intervall gör ni testerna?
- Vilken testmetod använder ni idag?
- Hur lång tid tar den testmetoden ni använder idag?
- Hur samlar ni in vatten som används i testerna?
- Vilka bakterier och organismer testar ni vattnet för idag?
- Vart i processen testar ni för bakterier och organismer? Hur relaterar värdena med varandra om ni genomför tester på olika punkter i reningsprocessen?

Figure A.5: Questions for Thesis customer interviews

A.5 Arduino code

```
const int relay1out = 4;
const int relay2out = 5;
const int bactsignalin = 1;
const int GreenLED = 3;
const int RedLED = 2;
int x = 1;

void setup() {
  pinMode(relay1out, OUTPUT);
  pinMode(relay2out, OUTPUT);
  pinMode(bactsignalin, INPUT);
  pinMode(GreenLED, OUTPUT);
  pinMode(RedLED, OUTPUT);
}
void loop() {
  int FlowintervalWater = 1000;
  int FlowintervalAnalysis = 2000;
  int StartSequenceTimer = 10000;

  if (x == 1) {
  digitalWrite(relay1out, HIGH);
  digitalWrite(relay2out, HIGH);
  delay(StartSequenceTimer);
  digitalWrite(relay1out, LOW);
  digitalWrite(relay2out, LOW);
  x = 0;
  }


  if (digitalRead(bactsignalin) == HIGH) {
    digitalWrite(GreenLED, HIGH);
```

Figure A.6: Arduino code 1

```
if (digitalRead(bactsignalin) == HIGH) {
  digitalWrite(GreenLED, HIGH);
}
else {
  digitalWrite(RedLED, HIGH);
}

digitalWrite(relay1out, HIGH);
digitalWrite(relay2out, HIGH);
delay(FlowintervalWater);
digitalWrite(relay1out, LOW);
digitalWrite(relay2out, LOW);
delay(FlowintervalAnalysis);
}
```

Figure A.7: Arduino code 2

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