Multidisciplinary project

Final report

Web of Water

www.asp-poli.it

POLITECNICO DI MILANO
Piazza Leonardo da Vinci, 32 - 20133 Milano
info-mi@asp-poli.it

POLITECNICO DI TORINO
Corso Duca degli Abruzzi, 24 - 10129 Torino
asp@polito.it

MULTIDISCIPLINARY PROJECT FINAL REPORT - WEB OF WATER

Pietro Segala, Electronics Engineering, Politecnico di Milano

Signature________________________________

Martina Francella , Communication Design, Politecnico di Milano

Signature________________________________

Karolina Pieniazek, Architecture and Urban Design, Politecnico di Milano

Signature________________________________

Giulia Mescolini, Mathematical Engineering, Polytechnic of Milan

Signature________________________________

Marco Scarzello, Cinema and Media Engineering, Politecnico di Torino

Signature________________________________

Akanksha Gupta, Design and Engineering, Politecnico di Milano

Signature________________________________

Syed Arsalan Aijaz Bukhari, Computer Engineering, Politecnico di Torino

Signature________________________________

Gianluca Acutis, Industrial Production Engineering, Politecnico di Torino

Signature________________________________

Principal Academic Tutor

Claudio Dell'Era, School of Management, Politecnico di Milano

External Tutors

Fabrizio Tessicini, Fluid-o-Tech

Diego Andreis, Fluid-o-Tech

Greta Barni, Fluid-o-Tech

Fabio Nappo, Fluid-o-Tech

Francesco Butera, Dolphin Fluidics

Index

1. Executive Summary

Web of Water (WoW) is an innovation project supported by Fluid-o-Tech, an international leader in the design and manufacture of pumps, valves, sensors and fluid management systems. The project focuses on **water quality** and on the value that can be extracted from **sharing water data**. As absurd as it may seem, this primary good's quality is often unknown. In the world, for 3 billion people, the quality of the water they have access to is unknown due to the lack of monitoring. It is one of the reasons why number 6 of the Sustainable Development Goals concerns *clean water and sanitation*.

The key point is digitizing water. Web of Water aims to create an interconnected network of nodes that share information on the quality of the water. The goal of the team was to realize this vision by investigating the possible fields of application of WoW through accurate benchmarking and developing a prototype solution in a specific one. **Three outputs** were produced at the end: the **physical prototype**, the **digital platform** and, no less important, the **business model** for this Internet of Things solution to work. As an IoT project, from a technical point of view, it involves multidisciplinary skills.

The research phase involved the analysis of existing solutions in the fields of medicine, hydroponic agriculture, swimming pools, the commercial sector and private homes. Stakeholders' needs, parameters fundamental for the specific water quality required, and working business solutions were analyzed for each industry. Finally, it was decided to apply Web of Water to the commercial sector of **coffee shops**.

In the coffee market, the project has been designed for **two distinct purposes**. The first concerns the **taste of coffee** and how it can be related to water quality. In this regard, the *Special Coffee Association - Water Quality Handbook* was fundamental for the research. The second topic to be addressed is the **maintenance** of the filters of coffee machines. In this regard, research has been carried out on the various types of filters and the water parameters through which it is possible to assess their status.

Starting from the **business model**, the solution developed from these requirements is based on a series of data exchanges. The embedded system (hardware component) produced by Fluid-o-Tech, consisting of a series of water quality sensors that upload data to a platform, is sold or rented to coffee shops and integrated into the coffee machines purchased. Different actors can therefore access the platform that contains and processes data collected on the water: coffee machine producers can check the status of their pieces, maintenance companies responsible and interested in the installed filters are notified when faults are detected, and of course, the coffee shop workers can acknowledge the status of the machine and the water quality data, too.

The second side of the developed model concerns an aspect more prone to scientific research: the end customers of coffee shops are asked a questionnaire, through a mobile application which is and endpoint of the platform, concerning the quality of the coffee just drunk and the data are correlated with the water parameters detected at that moment, in an attempt to accumulate big data useful to infer empirical laws on the relationship between water quality (quantitative) and coffee quality (qualitative).

For what concerns the **physical prototype**, the system has been created using a microcontroller, the sensors and a temporary platform to visualize the data. In the laboratory, numerous tests were conducted with these sensors: ORP (oxide reduction potential), EC (conductivity), PH (measurement of H+ ion concentration) and TOC (Total Organic Carbon) were the parameters of interest. It turned out that a linear variation in the level of water filtration corresponds to a linear variation of EC and PH: these parameters were therefore taken into account for the interface of the platform that concerns the maintenance of the filters. Experiments were also conducted on an optical sensor developed by the Fluid-o-Tech innovation team, capable of detecting, in output, feedback that depends on the constitution of the coffee blend. Although the optical sensor is not able to distinguish different types of water, it can be used to compare the current trajectory from the optical sensor against the optimal trajectory of the same blend and add an extra layer of guarantee of good coffee quality.

A **prototype of the platform** was then made on Figma and includes the interfaces for machine makers, coffee shops and customers: the first allows the user to navigate, through a map, the coffee machines distributed in a geographical area and check the status of the filters and the parameters measured, as well as set alarms; the second allows coffee shops owners to monitor both the status of their machine and the progress of coffee reviews; the third is developed on mobile and allows end users to express their opinion on the drink purchased, collecting all the data.

In conclusion, a mathematical function for correlating water quality to coffee quality has been developed, but **future developments** should involve building a model that allows the prediction of coffee quality performed at a stage at which a significantly large number of customer reviews are available, following the machine learning golden rule: the larger the dataset, the better the model. An example of this can be a neural network trained to predict customer satisfaction given a set of water parameters, which can capture nonlinear and complex relations between input and output.

Stakeholders who have been analyzed for a long time during the research phase and which could be included in the Web of Water, in the end, are the municipalities and the water suppliers. The water quality measurement endpoints in coffee shops can be useful to integrate and enrich the tests these companies are required to perform. The success of this idea depends on the tests' compliance with a standard that can be legally valid and on the presence of incentives for coffee shops and coffee chains in exchange for the data provided.

2. Introduction

This first chapter gives an overview of the objectives of the projects and of the starting points that the company gave to the team.

Web of Water (WoW) is an idea of a digital platform based on advanced sensing and digital technologies to identify and monitor the quality of water and its contaminants, proposed by Fluid-o-Tech.
The idea began with the simple questions:
What is the quality of the water coming out of your tap today?
What do we actually know about the water that we and our families drink or bathe in every day?
And the truth is that today we have more information about the quality of the water in the can of soda or bottle of water than we know about the water in our homes. And that can seem odd, knowing that each person uses around 220L of water per day. If we only considered the coffee that each of us is so eager to drink every day, we would realize that only 2 per cent of it is coffee, and the rest (98 per cent) is water. It is similar to other drinks. But there could be many more examples. Let's recall for example, the medical sector. Each haemodialysis treatment requires around 120 liters of water, making it by far the highest water-consuming treatment in the healthcare system. And that water doesn't come from the tap, but what if it could?

The issues regarding misinformation about the quality of water might be solved by the digitalization of water, which uses real-time data to provide recommendations to users — actionable intelligence that can bridge the gap between our inherent need for clean water and the practical reality of working across an ever-failing national infrastructure.

At the beginning of the project, the company presented a starting point: Fluid-o-Tech, in fact, has developed a new sensing technology able to record a light response texture coming from the interaction with coherent light. The sensor can be trained to classify fluids, detecting the smallest changes in composition, contaminants, or structure. And by digitalizing the fluids, we open the possibility of training the sensor to recognize patterns and substances - saying, in short, it can read the properties of any liquid, which makes the technology useful for many fields of interest.

In this project, we are dealing with architectural innovation that consists of the components (IoT platforms, mobile applications, sensors, valves and pumps, algorithms for data analysis), which are already widespread technologies.
The project's innovation resides in putting together these pieces and finding a market sector for the application, building a blending business model.

The keypoint of the project, *digitizing water*, means sharing information on water quality that multiple actors of interest can access, maybe even in their own customized way, on a digital platform.

2.1 Specific objectives

The project's main objective is to design a platform based on IoT technology to monitor and share the quality of water and its contaminants and control it in one specific sector after evaluating the existing market solution in homes, hospitals, and commercial spaces. As an aspirational goal, the project aims to drive the necessary meaning and technological change to digitize water, finding value in sharing this data.

The project went through different chronological phases, where different objectives where the points of focus:

1. Understanding water quality concepts in different sectors, starting from three verticals suggested by the company: medical, commercial and drinking water networks (private homes).
2. Identify business models and commercial solutions that exploit an IoT paradigm for monitoring and sharing water data.
3. Select a fertile field of application where a strong interest for a solution like this exists, but there is a lack of innovative solutions or the existence of incomplete ones.
4. Elaborate an innovative business model, build and test a physical prototype and a prototype of a digital platform for sharing water data.

2.2 Potential of the project

In the beginning, the team started to approach the three different markets that the company proposed and imagined with Fluid-o-Tech how WoW could decline itself. The following points expose the potential of how WoW could behave in the starting fields of application.

A. Water quality monitoring for domestic uses

A network of sensors deployed across the country, inside existing and new buildings, will continuously measure the water net. The data flow will be the main brick for new applications ranging from better use of resources to safer consumption. Data streams can be used for self-learning algorithms to process relevant information and translate them into information that policymakers can use for water-related decisions and distribution.

B. Water quality monitoring for beverage dispensing

At the commercial level, knowing the hardness of water and chlorine content in the fluid is valuable information for predictive maintenance. In-home applications, understanding the absence of contaminants and having a certification of efficiency of filters will be an incentive to use tap water.

C. Water quality monitoring for the medical sector

> During the average week of haemodialysis, a patient can be exposed to 300-600 litres of water, providing multiple opportunities for potential patient exposure to waterborne pathogens. Adverse patient outcomes, including outbreaks associated with water exposure in dialysis settings, have resulted from patient exposure to water via a variety of pathways (including improper formulation of dialysate with water containing high levels of chemicals or biological contaminants, contamination of injectable medications with tap water, and reprocessing of dialyzers with contaminated water). For the health and safety of the patients, it is vital to ensure the water used to perform dialysis is safe and clean.

From a broad perspective, the project could increase common consciousness on the importance of water quality monitoring and on the actual quality of the water we drink and use; also, more precise and suitable regulations for the field of interest, and positive feedback from the healthcare point of view, cause a reduction of waste of water and of consumption of bottled water (less plastic)
A web system could guarantee a fast sharing of information, an integrated database, and continuous monitoring.
There might be a chance of some negative impacts, such as an asymmetric diffusion of the technology (for example due to the cost of the sensors), and an information gap between the adopters and non-adopters.

Therefore, we may observe a reduction of the costs for the adopters as the technology spreads, an increment in the adopters' competitive advantages, and the quality of the provided services.

Some factors could prevent the diffusion of the project. Asymmetric water availability makes the diffusion of the monitoring systems not a priority for some countries where water supply is unreliable. In the poorest countries, clean water is still not guaranteed to everyone, so the purchase of the sensors cannot be affordable unless they become widespread enough to be cheap. There can be cheaper analogic solutions for water monitoring. In countries where technology (hardware/software) is not pervasive, the web-based monitoring of water cannot catch on.

2.3 Position in the water value chain

In the water value chain, the project can be placed in the management area, in particular, in quality management. Fluid-o-Tech produces components for companies that distribute water or use water for their machines; developing a monitoring system would allow the company's vertical integration in the value chain. This idea aims to be horizontally integrated, developing collaborations with telecommunication industries for data acquisition, processing, and communication with cloud or database, but also with sensing technologies’ producers.

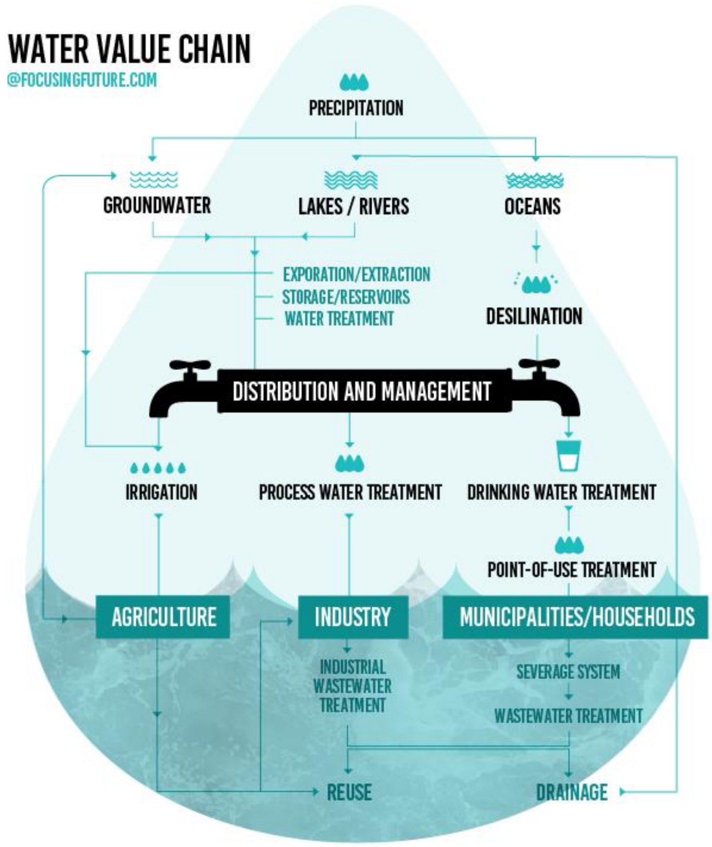


Fig.2.1 “Water value chain” Available at: https://www.focusingfuture.com/eco-city/re-creating-the-essential-the-future-of-water/

2.4 Market area selected: the challenges

After analyzing various sectors and getting to know the company's profile better, the coffee market was selected as the application area. The process leading to this choice is explained accurately in the State-of-the-art chapter and the following one.

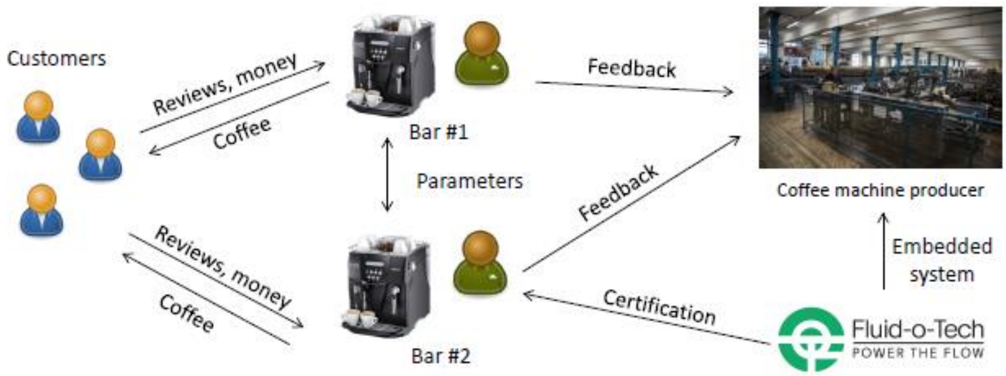


Fig.2.2. One of the first examples of data & money exchanges the team carried out in the coffee market

We know that speciality coffee depends on myriad factors that influence overall flavour. A multitude of variables, such as variety, terroir, processing method, roast degree, grind size, temperature, brew method, and extraction time, all play a part in the sensory profile of the cup. As the main constituent of brewed coffee is water, the rest being the mass of extracted soluble brewed solids, the quality of water and its ability to carry flavour potential can truly mean the difference between a ‘good’ and ‘great’ coffee. Therefore, the more we understand the chemical and mineral composition of the water that we are using, the more we are equipped to bring out the best flavour potential in our brew.

Other than being essential to all life on Earth, if there is one thing that the speciality coffee community can agree on, it is that good quality water is necessary for brewing great coffee. But how do we transform water into a high-quality input that brings out the best our coffee offers while keeping our equipment working?

In the past, water treatment has focused primarily on keeping our espresso machines and water boilers in good condition. While this aims to increase our equipment's longevity and safe operation, as well as lower maintenance costs, it can still be ineffective if the correct treatment is not employed. Even with the right treatment, many of today’s espresso machines can still break down due to scale build-up leading to blockages or in rarer cases, corrosion. Proper water treatment is, therefore a necessity for any economically viable operation.

Aside from equipment maintenance, there is also the important consideration of flavour and aroma. If the water used for extraction is unsuitable, it can mask a coffee’s full flavour potential. For example, in dilute coffee brewing preparations such as filter coffee, poor water can overpower a coffee’s acidity, leaving the brew dull and lifeless.

2.5 Measure water quality: starting points

A smaller or larger initial measurement series should be conducted depending on available data on the stability of a given water supply. For water from a single groundwater source, high stability in water composition can be expected over the short and long term. On the other hand, if multiple sources feed into the tap water network, daily and seasonal variations may occur. Therefore, an initial measurement series should be conducted to test the incoming water composition throughout the day and measure the changes from one day to the next. In addition, if the tap water source is from shallow groundwater, river or lake, it is worth looking for seasonal changes in the water composition. Analysis of water can be as simple as using a conductivity meter. However, whether or not this is sufficient depends on the type of treatment chosen and the type of potential fluctuations in tap water composition. For example, a softener will slightly increase the conductivity of the water but, in practice, is not enough to use as a reliable indicator.

Therefore, the Web of Water could speed up the processes of detecting the water of different qualities and help localize the parts of the water chain where the biggest impact on the water appears (creates pollution, changes its properties). Since it is visible that till now, trying to measure water and its management is complex, the platform collecting all the data would be essential innovation in water management. The digitalization of water might affect quicker and more efficient monitoring of its stability from the supplier to the final customer.

In essence, there are two fundamentally different approaches for characterizing a water type's composition. These are:

A. Mass Concentrations: The concentration of ions is described as mass per volume (e.g. mg/L) as this is the standard for the bottled water method. This approach is only helpful for the comparison of concentrations with stated daily intake limits of toxicological thresholds. In other words, concentrations of trace metals can occur in contaminated groundwater or old piping such as lead. Calcium, magnesium and hydrogen carbonate have different conversion factors from mass concentrations to the effective number of ions, so they can be troublesome for calculating total hardness or alkalinity.

B. Amount Concentrations: The concentration of ions, or other elementary entities such as molecules or atoms, is given in units proportional to the actual number of ions per volume. For example, this can be expressed as molar units or charge equivalent units (e.g.ppm $CaCO_3$), sometimes called American degree (°a), in which the ions enter the water by dissolution and react in an ion-exchanger or exit the water by forming scale.

After having introduced the starting concepts in this chapter, the rest of the paper is organized in the following way:

- In ***Chapter 3***, we illustrate the needs of the various stakeholders involved, not only in the selected market area, and classify the requirements.
- In ***Chapter 4***, we walk through the solutions that are already present in the market and in literature for the implementation of a smart water system. In particular, as the benchmarking done is one of the core parts of the project, we deepen into the markets of swimming pools, coffee, drinking water networks, agriculture, hydroponics.
- In ***Chapter 5***, core part of the manuscript, we present the final solution. First, we describe the decision-making process and the concept selection given the premises of the state of the art. Then, we illustrate the business model of the solution, the details of the technical system for data acquisition and processing and the specification of the platform designed.
- In ***Chapter 6***, we review the main aspects of the solution proposed by the team and propose further developments.
- In the ***Appendix***, we illustrate the team composition and division of work as well as the GANTT of the project.

3. Stakeholders: needs and requirements

3.1 Generic needs and requirements

During the benchmarking phase of the project, numerous pieces of research on the needs of stakeholders were carried out, starting from the broader problem of the digitization of water in the various sectors, ending with the analysis of the coffee shop market.

Fig.3.1. Stakeholders map

The stakeholders' map above shows, at encapsulated levels, the first possible grouping of the actors involved in an IoT solution such as that of Web of Water: in direct contact with the product, we find the manufacturers; the beneficiaries, on the other hand, extend to the managers of the companies that could encapsulate the system in their activity and the water suppliers; in the outermost crown, finally, we find those whose interests could come into contact, more or less indirectly, with Web of Water. Among the latter, we also find citizens and public institutions, such as municipalities.

The following list summarizes the generic needs and the related requirements that follow, grouping the actors involved for each need:

- Sell the system: for the system to be sold by manufacturers and embedded by buyers, the main need is compatibility with the existing structure. Compatibility can relate to transmission, material, size, or even lifespan mismatch between sensor hardware and existing machine. The choice to focus on the coffee niche also derives from the problems that would result if the path of the customer-designed product were chosen, or high R&D costs, which could only partially be solved by adopting a modular design. It is also necessary to facilitate the dismantling of the system to facilitate maintenance.
- Control on the condition of the machinery: all companies that adopt the system need, even in the absence of technical knowledge in the field of water quality, an interface that allows them to have a clear image of the state of the system. The solution concerns the design of the interface of the digital platform purely,and is explained in depth in chapter 5. As for the parameters of interest, all stakeholders are mainly interested in inorganic parameters such as temperature, hardness and concentration of calcium and magnesium; only swimming pools can need to be monitored for the presence of organic materials.
- Keep customers safe: this need becomes a particular priority in the case of hospitals. High-precision measurements, at least 40 minutes of battery backup and high process quality (ISO certified) are required.
- Knowing if water is drinkable: this need mainly concerns coffee shop owners and water providers. The parameters of interest, in this regard, are FTU/NTU, UVT, Color, TOC, DOC, Chlorine, ph, redox, temperature, and conductivity. The information shown by the system interface must be clear and user-friendly. More information about the parameters that determine the quality of coffee is explained below.
- Continuous monitoring of parameters: water providers and hospitals need high sampling frequency for constant and reliable digital data output.
- Keep customers satisfied and attract new customers: this need mainly concerns the commercial sector of coffee shops.

3.1 The coffee market

The rest of this chapter is reserved for further deepening the needs that concern the players involved in the coffee shops market, the only sector on which a business model has been developed for this project. This explanation is therefore anticipated in the current chapter, while the following one, regarding state of the art, will analyze in detail every single field of application that was taken into consideration during the benchmarking phase, among which we can find the coffee market.

Following are the schematic representations of two user personae: the owner of a bar and a company that produces professional coffee machines.

About: Owner of a bar, he buys or leases a high-quality coffee machine.	**Needs**: • Provide a high-end experience to his customers, showing the quality of a critical component of coffee: water • Attract new customers • Take care of the status of the machinery for maintenance • Control the quality of his investment in equipment • Continuous control of the output of the machine used
Frustrations: • Customers' complaints about the variable quality of their coffee • Too frequent damages to the coffee machine	**Expectations**: • Create an added value for his customers • Make people choose his shop and have a competitive advantage • Reduce the costs of maintenance • User-friendly platform to receive information • Synthetic and understandable information on the water quality

About: • Coffee machine manufacturer • Produces coffee machines, spares, and consumables for domestic and commercial use	**Needs**: • Hard water should be used for the coffee • Water should not damage the piping etc. over long term use
Frustrations: • Domestic coffee machine owners have no expertise • Bad quality of water can damage piping etc. • No mechanism to monitor the condition of piping etc. • Machines come in for repairs which could be avoided with better water quality	**Expectations**: • The water quality information is shared with user and the company • Inform user and the company about possible damage to the machine with the current water quality • Deliver information for root cause analysis for faulty machines

3.1.1 Flavour of the coffee: requirements

We know that specialty coffee depends on myriad factors that influence overall flavor. A multitude of variables such as variety, terroir, processing method, roast degree, grind size,

temperature, brew method and extraction time all play a part in the sensory profile of the cup. As the main constituent of brewed coffee is water, the rest being the mass of extracted soluble brewed solids, the quality of water and its ability to carry flavour potential can truly mean the difference between a ‘good’ and ‘great’ coffee. Therefore, the more we understand about the chemical and mineral composition of the water that we are using, the more we are equipped to bring out the best flavour potential in our brew. In the past, water treatment has focused primarily on keeping our espresso machines and water boilers in good condition. While this aims to increase the longevity and safe operation of our equipment, as well as lowering maintenance costs, it can still be ineffective if the correct treatment is not employed. Even with the right treatment, many of today’s espresso machines can still break down due to scale build-up leading to blockages or in rarer cases, corrosion. Proper water treatment is, therefore, a necessity for any economically viable operation.
Aside from equipment maintenance, there is also the important consideration of flavor and aroma. If the water used for extraction is unsuitable, it can mask a coffee’s full flavor potential. For example, in dilute coffee brewing preparations such as filter coffee, poor water can overpower a coffee’s acidity, leaving the brew dull and lifeless. Given recent advancements in coffee processing, storage, roasting, and extraction, there is now a need to work towards a common consensus on individually crafted water treatment strategies so that we can bring out the full potential of each coffee.

Some parameters are more important than others for the optimal coffee composition.
When it comes to analyzing water for espresso machines, the maximum amount of scale that can form is usually the primary consideration. Fortunately, the concepts developed regarding scale formation are also helpful when applied to coffee extraction. The water chart, therefore, focuses on two main parameters:

A) Total hardness: This is defined as the sum of calcium and magnesium in equivalent concentrations, or molar concentrations. In rare cases, other ions can contribute to total hardness, such as strontium (SMWW, 2012; DIN, 1986; ASTM, 2002; EPA, 1999).
B) Alkalinity = Acid buffer capacity: The amount of acid that has to be added to a water sample to decrease pH to 4.3. Therefore, alkalinity should be regarded as the attenuating effect of adding acid to water, also called neutralizing or buffering.

Another topic of interest regards the importance of local measurements. There are regions in the world that have significant amounts of other ions besides the ones that we have already highlighted. These ions make local water unsuitable for use in coffee extraction. A couple of examples of this are iron, which causes very noticeable flavor defects in coffee extraction, and lead, which is toxic. There are however specialized treatments to remove these components from water. Some regions also have a high content of gypsum in the bedrock, which can cause scale formation of a different kind other than the familiar build-up of calcium carbonate. Chlorine or chloramines used for disinfection also impart a strongly unpleasant flavour in the resulting brew and should be removed.

There are two main perspectives to define an optimal water composition:
a) Technical: This aims to minimize maintenance and thereby reduce repair or replacement costs, as well as downtime due to a defect or breakdown of espresso machines and/or brew boilers.

B) Sensory: This perspective aims to bring out the best flavour and aroma of a coffee by modifying the content of total hardness and alkalinity.
The most important aspects that define the optimum water composition from a technical perspective are:

- Corrosion: Caused by low levels of **alkalinity**:
  -below 40 ppm CaCO3 (also indicated by low electrical conductivity)
  - pH < 6 or pH > 8
  -and high concentrations of chlorides
  -sulphates or nitrates (i.e. more than 80% of the alkalinity in equivalent concentrations)

- Scale formation: Caused by **high levels of hardness and alkalinity** that lead to the scaling of boilers and machines, which in turn lead to:
  -Decrease in the efficiency of heat transfer,
  -Clogging of valves and jets, especially in hot water sections.

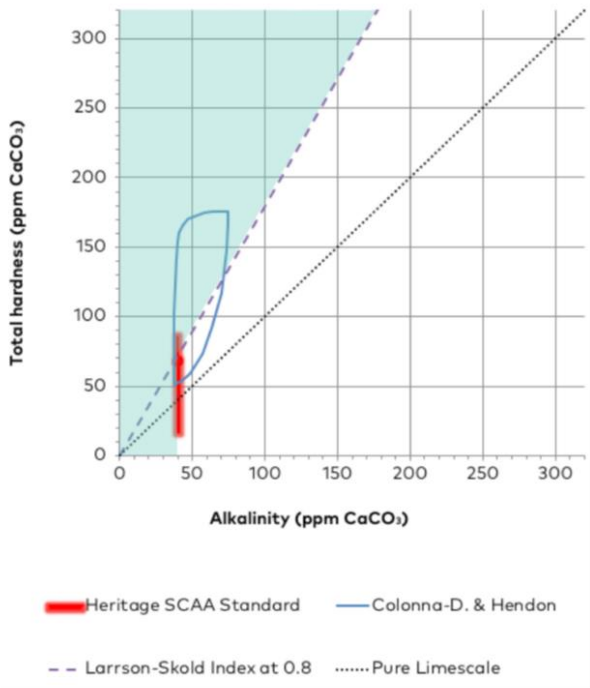


Fig. 3.2 Corrosion risk zones, source: The SCA Water Quality Handbook.

The total hardness of water can influence extraction efficiency. Higher total hardness is assumed to increase extraction efficiency (Hendon et al.,2014). In laboratory tests, this effect could not be verified by means of a coffee refractometer, although a clear impact on flavor balance and aroma was detected.

Alkalinity, furthermore, influences the perceived acidity. The higher the alkalinity, the lower the perceived acidity. Moreover, for high alkalinity (i.e. >100 ppm CaCO3), the neutralisation of acids extracted from coffee by hydrogen carbonate forms large amounts of carbon dioxide. This can **increase extraction time** and thereby **lead to over-extraction** (Gardner, 1958; Fond 1995; Navarini and Rivetti 2010).

The following are the optimal ranges of the described parameters:

a) Hardness
-Lowest suggested optimum is 51 ppm CaCO3 (2016 WorldBrewers Cup).
-Highest suggested optimum is 175 ppm CaCO3.(Colonna-Dashwood and Hendon’s Water for Coffee).

b) Alkalinity
-Lowest suggested optimum is 40 ppm CaCO3.
-The highest suggested optimum is 75 ppm CaCO3 (this applies only to total hardness values in the 150 - 175 ppm CaCO3).

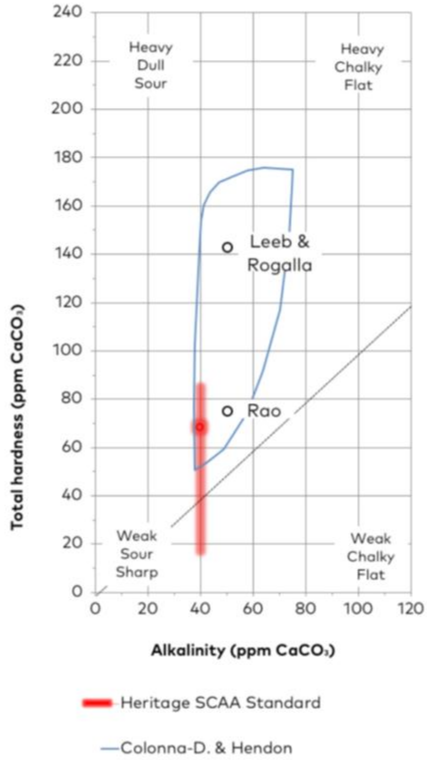


Fig.3.3 Existing recommendations of a water composition for coffee, source: The SCA Water Quality Handbook.

3.1.2 Appendix: water filters

There are two main types of filters on the coffee market: ion exchange resin filters and activated carbon filters:

- Activated carbon filters consist of an internal surface equipped with cracks capable of trapping substances such as free chlorine and other harmful substances, such as pesticides, and industrial solvents. They have no effect on heavy metals; They may be less "selective". Their duration can be estimated at one month. Their effect is to remove unwelcome odours and flavours. The cheapest ones are based on granular activated carbon

(GAC), and the more expensive ones on more effective carbon block elements.

- Ion exchange filters can work with negative, positive or mixed ions and are more selective. Their operation is based on replacing calcium and magnesium ions in hard water with sodium or hydrogen ions. They are particularly effective for applications where water needs to be kept at a high temperature. They are based on resin beads and are usually made up of units (Calcium Treatment Units) returnable to the supplier and regenerable. Hydrogen-based ionic filters are preferred as sodium increases the salinity of filtered water, legally limited to 200 mg/L.

In coffee machines, filters can be installed in two main ways:

- Inline, i.e. in the access pipes to the machine;
- In-tank, i.e. in the tank of the machine.

The effects of the filters on the measured parameters, therefore, are as follows:

- pH: it is a parameter that provides an indication of the hardness of the water. Hard water typically has a high pH, so the effect of an ionic filter is to lower the pH.
- TDS (Total Dissolved Solids): This parameter is typically reduced by filters for obvious reasons.
- Conductivity: can vary according to the ions released by the exchange filters, which can be more or less mobile. Activated carbon filters can also have an effect on conductivity, causing it to increase as ions are released from organic carbon molecules. These ions can also attract ions already present in the water by further changing the charge.

4. State of the art

4.1 Introduction

First, it is necessary to scope the sector of interest better before looking at state of the art. Web of Water would like to combine the increasing rise in performance and application of Smart, connected products, with the unsatisfied market needs of the water sector. The starting point, of course, is understanding what smart, connected products mean: the merging between physical objects and Information Technology. Smart, connected products comprises three elements: (Porter & Heppelmann, 2014): physical components, the mechanical and electrical blocks, smart components (microprocessors, sensors, software and data storage) and connectivity components (antennas, ports, and protocols). Connectivity has a dual purpose: exchange information in the operating environment and allow the existence of some product's functionalities outside of the product itself, the product cloud.

Connectivity can be classified as

- one-to-one, one product individually connects to the user or another product
- one-to-many: several products are linked to a central unit
- many-to-many: a product's family connect to other multiple products, even different from each other's

Companies willing to propose smart, connected products have to build and deliver a complete "technology stack": in the image below, we can see the different "building blocks", that should be able to receive the information flow from the external environment but manage user access and security tools:

- Product, that is the combination of product hardware and product software
- Product cloud, which comprises the product data database, the application platform and the analytics engine
- Connectivity: the protocols that allow the communication between the two building blocks

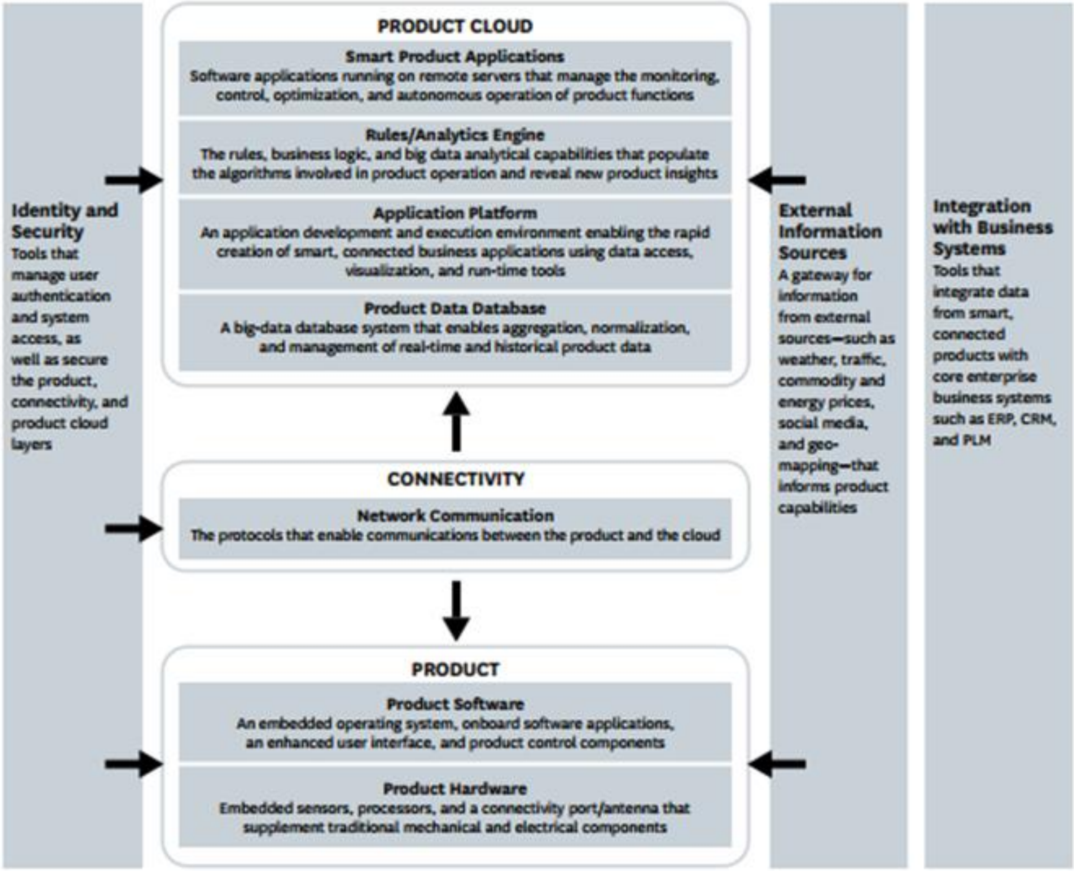


Fig.4.1 “The technology stack” (Porter & Heppelmann, 2014)

Smart, connected products present a new set of capabilities that can be classified in levels: each level is the foundation of the next (Porter & Heppelmann, 2014). The four groups are:

· Monitoring: the product’s smart components can give feedback on the product’s state and monitor the external environment

· Control: software can modify the product output in response to changing conditions. It enables the personalization of the product and its performance

· Optimization: the previous capabilities associated with optimization algorithms can enable the maximization of the product performance, following a predictive approach

· Autonomy: monitoring, control, and optimization can make the product autonomous. This capability is part of the ability to learn from the environment and autonomously adapt to user requirements.

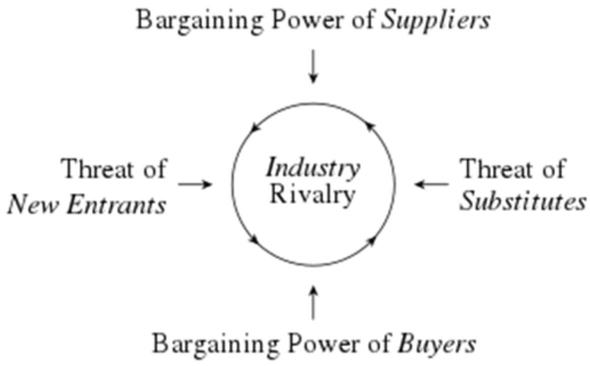


Fig. 4.2 Porter’s Five Forces Model

Industries in which the “smart, connected” paradigm is or will be adopted are changing in their structure (Porter & Heppelmann, 2014). To better classify these changes, we will use the Five Forces Diagram developed by Michael Porter. First, smart, connected products increase the ability to better understand the customer from a seller's perspective and, consequently, create closer customer relationships; however, the bargaining power of buyers can increase due to the better understanding they can have of the product's performance. Moreover, industry rivalry can shift thanks to the increasing level of personalization and customization of the product: value propositions can sometimes be tailored to the individual basis.

The” First mover” advantage can be a considerable weapon in these types of sectors, where the barriers to entry are high due to high fixed costs and complex IT infrastructures, and first movers already have customers’ and products’ data useful to improve their offer (Porter & Heppelmann, 2014). Smart, connected products, in general, do not fear the threat of product substitutes with traditional capabilities, but the wider product capabilities can result in crossing other market boundaries and being exposed to new competition forces. In general, we can state that the competition switches from the capabilities of a physical product to the performance of a wider product system or, in some cases, of a system of systems where the individual seller or supplier is only one creator of the value proposition. Specifically, competitive advantage can be pursued not only by acting, as we said before, on the product per se but on the whole value chain. Examples are the design and the after-sale services: the design of smart, connected products should combine standardization of the hardware with software personalization in order to offer updates and predictive services as after-sale services, reducing breakdowns and retaining customers. Accumulating and analyzing product data activities can be useful to close the loop: better customer tailoring means more valuable design choices and after-sale services.

Taking into account what smart, connected products are, we can now list the literature that guided the Web of Water project. At the beginning of the project, Fluid-O-Tech suggested starting from the analysis of three macro areas, in which they have scouted some potential for a Web of Water application and already have some competences and potential clients. The three sectors of interest are commercial, medical and home usage.

State of the art includes academic research in water monitoring and IoT solutions and existing commercial solutions in the market. The latter were explored through websites, whitepapers, patents and, also, interviews with specific companies operating in the sector.

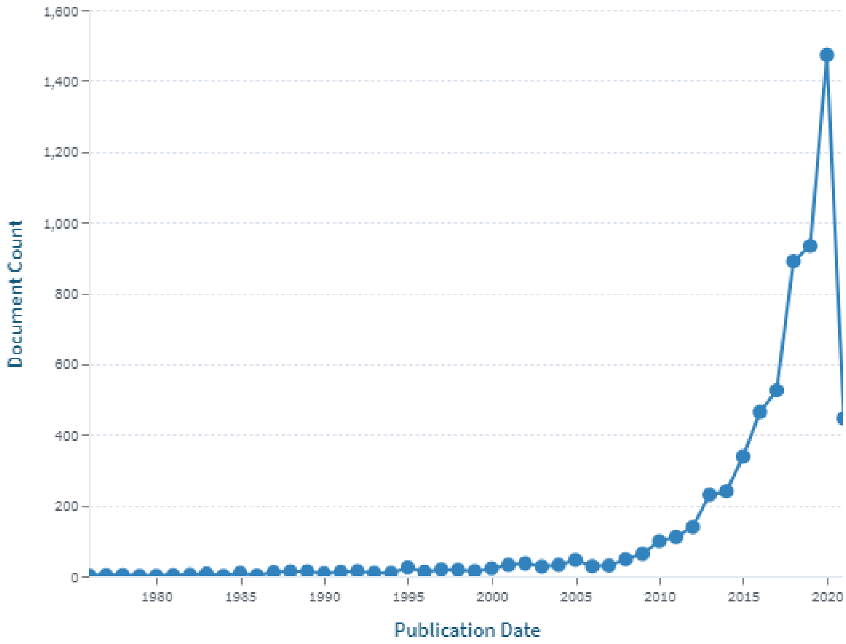


Fig 4.3. Patent statistics of the query: (Title: Water AND Title: quality) AND (Title: sensor OR (Title: measurement OR (Title: monitor OR Title: architecture)))

The market has been growing over the last ten years. The technology is becoming mature, and many industries are doing research on it, as can be seen from the increase in the overall number of patents (except 2020 due to Covid).

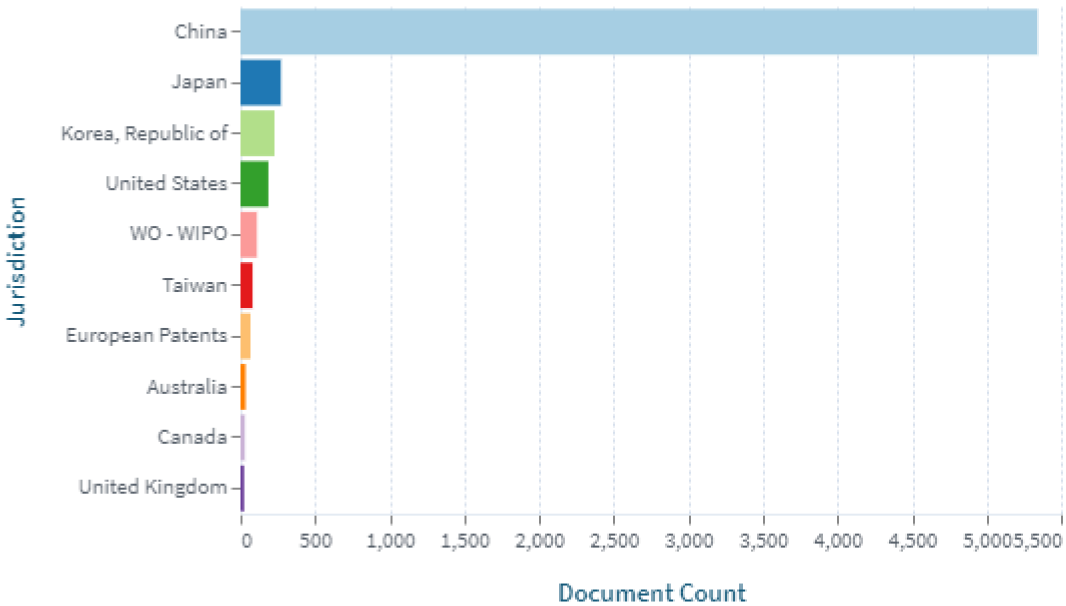


Fig. 4.4 Patents by Jurisdictions

More than 82% of approximately 6,500 patents in the domain of water quality measurement are applicable in China. This is largely due to the heavily industrialized situation in China, which holds a lot of patents in sensors, electrodes etc. This means that the market competition will be fierce there but regions like Europe, UK, Canada and Australia have very few patents. This means that there is a lot of space in these regions for registering intellectual property and marketing water quality measurement products.

This chapter will be divided in one subchapter for each sector of interest: multiple sectors of interest form a macro area suggested by Fluid-O-Tech.

For each subchapter will be present:

- concept of water quality, in terms of parameters of interest and sector's requirements
- value propositions and business models of the commercial solutions in the market
- dominant architecture, if there is any, present in the sector for IoT systems related to water quality

4.2 Swimming pools

Swimming pools are surely an example of a sector where water quality is fundamental. In the Swimming Pool category, we include both the ones for private and the ones for public use. However, the markets are different, and the regulations applied to differ. In Italy, the regulations exist only for public or private swimming pools intended for public use and are collected in the text UNI 10637:2016. The norm establishes that the overall water quality is the result of the alimentation water quality, the filtration system's efficacy and the management of the water cycle (UNI Ente Italiano di Normazione, 2016).

In general, the activities necessary to maintain the constant water quality in a swimming pool are:

- the continuous recycling of the water
- the filtration activity through membranes
- the disinfection with specific classes of chemicals
- the reintegration in the water circle of water coming from the external water network

The UNI 10637:2016 establishes both the frequency of sampling and the range of several parameters of the water immitted in the swimming: temperature, pH, turbidity in SiO2, suspended solids and free chlorine. Further details are in the image below.

Requisiti fisici e chimico-fisici	
Parametro	Acqua di immissione
Temperatura: - vasche coperte in genere - vasche coperte per bambini - vasche scoperte	 Da 24 a 38 °C Da 26 a 38 °C Da 18 a 38 °C
pH (per disinfezione a base di cloro)	Da 4,5 a 8,5
Torbidità in SiO_2	≤2 mg/l SiO_2 (o unità equivalenti di formazina)
Solidi grossolani	Assenti
Solidi sospesi	≤2 mg/l (filtrazione su membrana da 0,45 µm)
Colore	≤5 mg/l Pt/Co Oltre a quello dell'acqua di approvvigionamento
Requisiti chimici	
Cloro attivo libero	Da 0,6 mg/l a 5 mg/l Cl_2
Cloro attivo combinato	≤0,6 mg/l Cl_2
Impiego combinato ozono-cloro: - cloro attivo libero - cloro attivo combinato - ozono	 Da 0,4 mg/l a 5 mg/l Cl_2 ≤0,05 mg/l Cl_2 ≤0,01 mg/l O_3
Acido isocianurico	Valore uguale a quello previsto per l'acqua della vasca
Sostanze organiche (analisi al permanganato)	≤2 mg/l di O_2 [1)] Oltre il valore misurato su un campione dell'acqua di approvvigionamento
Nitrati [2)]	≤20 mg/l di NO_3 Oltre l'acqua di approvvigionamento
Flocculanti	≤0,2 mg/l in Al o Fe (a seconda del flocculante utilizzato)

Fig. 4.5 “Ammitted parameters range in Swimming Pools” (UNI Ente Italiano di Normazione, 2016)

Regarding the water analysis in the swimming pool, we can distinguish between three different types of contaminants: physical, chemical and biological. While the first can be removed by mechanical systems, the second and the third are usually countered by chlorine, the most essential chemical additive used to sanitize the pools. Chlorine reacts, creating chloramine or combined chlorine; however, only free chlorine is an effective sanitiser: often, a useful indicator of free chlorine is the ORP, the Oxidation Reduction Potential, a common parameter measured in every type of water. Another fundamental parameter is pH, which should be between 7.2 and 7.8: as we will see in the following chapters, pH has the potential to increase the rate of corrosion of the mechanical components, and it is necessary to keep it under control for product maintenance. Moreover, out-of-range pH and high levels of chlorine can cause health issues to swimming pool users. The hardness of the water, even if the water is not for drinking purposes, should be kept under control, as well as the temperature.

The swimming pool market presents different commercial solutions for IoT systems, able to monitor and control the quality of both the input water and the water present in the swimming pool.

In general, the suppliers of swimming pools are starting to offer to a niche segment smart pool systems that are already embedded, able to monitor the water quality and the temperature. An example is Smart Pool System Artemis by Piscine Castiglione, one of Italy's main swimming pool makers and sellers. Artemis' main feature is the control box, connectable to the swimming pool accessories, for the remote control with mobile app. Apart from monitoring the water quality, the control system enables regulations of temperature and lights.

Of course, on the market, there are solutions more focused only on the monitoring of the main parameters of the water that aim to target a wider customer segment. Examples are the companies Disrupt X, Aqua IoT and Pro Automation. The value proposition presented by those companies is similar: an IoT system composed of a floating device, a cloud platform, and a mobile/web application. The floating device embeds sensors for the four key parameters: temperature, pH, ORP and TDS. The monitoring activity is constant, and the notification about changes in water quality is automatic on the platform; the platform also communicates how much of which chemicals are needed to restore the standard. Thanks to the data present in the cloud, it is possible to create a customizable report about the history of water quality. The revenue structure of the companies differs: while some of them require a monthly fee for the services offered, others offer a one-time purchase of the floating devices and minimal after-sale services. (AquaIoT, s.d.)

Fig. 4.6 AquaEgg by AquaIoT

The offer of commercial solutions does not end here. The market was always populated by players offering water-treatment applications, but only in the years did the IoT paradigm become present. SEKO, an Italian company founded 50 years ago, is the perfect example. The company has always offered dosing systems for indoor, outdoor, public and private infrastructures, but only in the last years the offer consisted of dosing systems able to correct the fundamental parameters adding chlorine and water chemicals automatically. The automation is granted by a multi-parameter controller that turns on a solenoid -driven pump and proportional dose the water with a new water flow and several chemicals. The WI-Fi hubs integrated into the dosing system enable communication to the user of the conditions and of the water quality history over time. SEKO dosing systems also target niches of the swimming pool market, such as spas and saunas, where essences can be dosed appropriately for therapeutic applications.

In summary, the swimming pool sector already presents several solutions focused on the concept of water quality, but the smart, connected paradigm is not fully explored. The dominant architecture comprises monitoring and, in some cases, control capabilities; however, optimization and autonomy capabilities are still lacking in all the market's offerings (Smart Water Magazine, 2021).

4.3 Coffee market

Coffee is one of the most interesting water quality monitoring and control markets. First, we can assess that the coffee market is in expansion and, just in Italy, is expected to grow annually by 6.07% (CAGR 2022-2025), with 70% of spending and 28% in volume consumption, in 2023 will be imputable to bars, restaurants and all the consumption out-of-home (Statista, 2022). The market can be divided into two main areas: home consumption, based on retail sales of coffee and equipment for brewing, and out-of-home consumption, based on the presence of several intermediates and, in most cases, on the easing of the equipment to a single commercial activity. In this chapter, we will mainly focus on the IoT proposition for the out-of-home market: this is mainly because the technological development for this area is greater, and some IoT solutions are already present.

The development over time of the global coffee market can be explained in five waves, starting from the 1960s (CBI Ministery of Foreign Affairs, 2021). The first refers to traditional coffee culture, the second refers to the introduction of branded chains, like Costa Coffee and Starbucks, and the third refers to the development of independent artisan cafés and roasteries. The most recent two are more actual: the fourth wave, called the science of coffee, focuses on the application of scientific methods and principles to coffee extraction, while the fifth on investments in technology and obsession with excellence both of the product and the purchasing and consumption experience itself. In this context, understanding the bean's properties and, most of all, the water quality are the two critical values in the coffee taste. The science of coffee, even if it is mostly focused on the high-end segment of the market, is the consequence of more demanding customers and contributed to the rise of the speciality coffee segment. Speciality coffee refers to high-quality coffee in which the story of the blend, the brewing process and the environmental impact is highlighted: speciality coffees are scored according to these parameters, and one of the most famous protocols followed comes from the SCA, the Speciality Coffee Association.

In this context, several value propositions for IoT systems started to emerge. One of the most important initiatives of the last few years was the partnership between Microsoft and Starbucks, which teamed up to create what we can call a "Web of Coffee". The project is still in the initial phase, but the idea is clear: using the Azure cloud to connect the equipment of its 30,000 stores around the globe in order to gather information about the type of beans used, the water quality in input and the temperature in output. The data gathering would be useful to collect customer preferences, but also to understand the influences of different water quality to the outside of the coffee itself. Moreover, these types of data can be useful for predictive maintenance of the machines themselves: we will see it in detail further in the chapter. The project is a perfect example of the smart, connected product paradigm (Levy, 2019).

Innovations in water quality monitoring are also present in solutions from Italian companies that have manufactured coffee machines for decades and are still market leaders for professional machines for commercial activities. The first company under analysis was Nuova Simonelli: other than exploring their commercial offer and patents portfolio, the Web of Water team had the opportunity to meet with them. Nuova Simonelli patented an innovative solution of coffee machines with sensors (Foglia, 2020).The coffee machines present two sensors, one placed in the water tank and one disposed after the filter, able to measure the hardness of the water. First, the unfiltered water arrives in the tank and, when required, is pumped downstream, arriving at the filter itself. The problem emerges when the filtration activity is no longer valid, due to the degradation of the filter: the central box connected to the sensors compares the incoming hardness levels and alerts the user if the parameters are out of a threshold range. Nuova Simonelli is still testing the solution and does not have a commercial offer ready for the market.

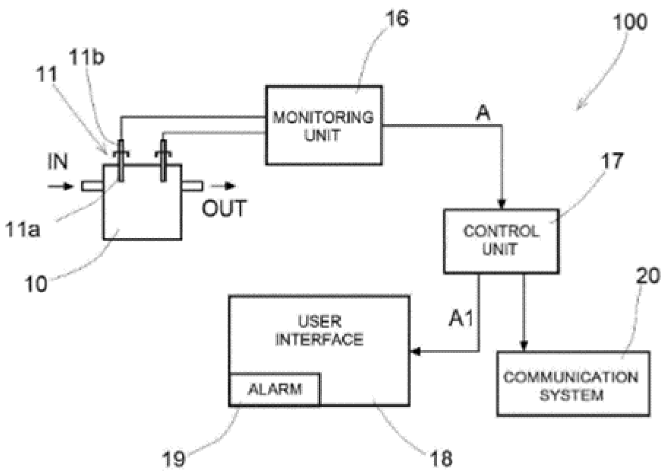


Fig 4.7 System Architecture from Nuova Simonelli patented solution

La Marzocco is another Italian brand, specialized in coffee machines for commercial activities. La Marzocco, always in 2020, patented a system for monitoring and filtering the water for the coffee machine; however, in this case, the system presents the active control and correction of the parameters of the water in the coffee machine (Bianchi, et al., 2020). The system comprises a water supply, a boiler, a pump, a dispensing group and a water monitoring system for at least one parameter of interest, usually conductivity. The water incoming in the coffee puck, where the brewing happens, is a mix between filtered and unfiltered water. The measurement of the water quality takes place after the filter and is processed by the processing unit that is connected to the throttling device. The throttling device, if the parameter or the set of parameters are out of the standard, automatically modify the flow of filtered water in the mix of water in output: for example, if the concentration of the minerals of unfiltered water is too high, the system will increase the amount of flow passing through the filter. Moreover, when the parameters reach another threshold level, the coffee machine starts to present alarms to the barista.

La Marzocco already launched in the market a solution with some of these components, the Gb5 X, the first coffee machine able to measure the conductivity as direct measure and, through a model, as an indirect measure, the hardness of the water. Moreover, the machine is compatible with the Pro-App, a mobile application that would allow the barista to have direct control of the functionalities of the machines (dosage programming, water tank's temperature…) and of the usage statistics (number of cups brewed…).

Fig. 4.8 La Marzocco Gb5 X

The concept of water quality for the coffee sector was largely discussed and analyzed in the last years. The fundamental parameters are:

· Total dissolved solids (TDS), usually obtained as an indirect measure from the conductivity of the water

· Hardness, another name for specific dissolved solids, mainly composed of calcium and magnesium. It is possible to distinguish between temporary and permanent hardness: the former is carried off with the steam, while the latter is not. It is possible to measure hardness as an indirect measure of total dissolved solids, but with a range of error

· pH, the potential of hydrogen: keeping a pH around 7 reduce the reacting potential of water because the solution is neutral

· Alkalinity, the measurement of bicarbonate concentration, is considered the capacity to neutralize an acid. The right alkalinity of the water, between 40 and 70 parts per million, avoids any change to the pH.

In a nutshell, we can say that the final goal is dual: have a tasty coffee and keep the coffee machine healthy (Nuova Simonelli, 2014). Coffee is a solution in which the solvent, the water, reacts with the solute, the coffee powder. The solvent should not react with anything before being in contact with the solute: for this reason, we should have a solvent lacking impurity. We will analyse this topic in a dedicated section, but we can start by saying that for a “tasty” coffee, we need an optimized speed of extraction: the organic acids in the coffee powder have to come to the solution's surface as fast as possible. The extraction rate is correlated with the alkalinity of the water: it is slowed down if the alkalinity is too high and it speeds it up with low levels of alkalinity, because it is impossible to hydrolyse the organic acids of the coffee.

As far as healthy machines are concerned, we have two phenomena to consider. The first is limescale, carbonate and bicarbonate crystalline formations present where there is a delta temperature, like in boiler walls and flow restrictors; the higher the level of hardness in the water, the higher the probability of the presence of limescale. Limescale can create inefficiency of heating problems and can reduce the flow in a water pipe. The second is corrosion: it is caused by high or low levels of pH and, as a consequence, a more reactive solvent. Scale is related to corrosion: the right amount of scale can prevent corrosion phenomena but, as we have seen before, can cause heating or flow issues.

4.4 Drinking water networks

According to the statistics collected in 2018 from ISTAT, Italian National Institute of Statistics, 95.8% of the Italian population has a connection with the public water supply network, using 220 litres/day per person, spending on average 14.7 euro a month for water service but with more than the 10.4% complaining about the irregular water supply. Moreover, only 72.3% of the households are satisfied with the smell, the taste and the clarity of the water coming out of the tap; one out of three families are not confident in drinking tap water and seven out of ten buy mineral waters, spending on average 12 euros a month (ISTATItalian National Institute of Statistics, 2018)

The Guidelines for drinking water quality by the World Health Organisation represent the reference text used worldwide to set standards and local regulations (World Health Organisation, 2011)

The set of parameters to monitor is broad: we will consider only the ones useful for operational monitoring. This analysis can lead to low adjustments in the drinking network to counter eventual anomalies prior to supply. We will exclude, in this way, the analysis of enteric pathogens and indicator organisms

The parameters are:

- In sources waters: turbidity, algae growth, ultraviolet absorbance, colour, conductivity and retention time

- In treatment facilities: disinfectant concentration and contact time, ultraviolet intensity, pH, light absorbency, turbidity, filtering membrane integrity and colour

- In piped distribution networks, chlorine is one of the most important parameters: low levels indicate possible microbial contamination, while high levels significantly alter the taste at the endpoint. Oxidation-reduction potential (ORP) is another indication of effective disinfection, but there is no shared threshold for all the cases, and further research still has to be done. Pressure and turbidity are other important parameters. Moreover, the presence of heterotrophic bacteria can be an indicator of increased microbial growth potential and longer stagnation times in the water networks.

In the state of the art related to drinking networks we decided to focus on just part of the drinking infrastructure, the one from the treatment facilities managed by public and private water quality providers to the water points of usage. Water providers have already implemented breakthrough technologies for water quality monitoring: on the other hand, the networks that follow treatment plants often lack capillary control and could benefit the most from implementing the "Web of Water" concept.

Water monitoring in drinking networks has transitioned over the years (Jan, et al., 2021). The first systems, still implemented in developing countries, rely on laboratory-based methods, in which samples are collected manually, and analysis is performed to detect quality and contamination. The natural follower of these methods arrived with advancements in sensing technologies, relying on portable sensors to measure the parameters. In both methods, the main problem is the inability to provide real-time feedback, creating a history of the changes as well over time. WSN-based water monitoring systems are the solution for this problem: nodes read specific water properties using sensors installed in the infrastructure and transfer the data to a server, using wireless communication such as ZigBee, LoRaWAN and Wi-Fi; The main station, that is the server, is the place where analysis are conducted.

However, in the last years, the IoT paradigm was also applied to drinking water quality. With IoT systems, it is possible to monitor from any location in real-time, thanks to the use of portable sensors, computing devices, internet protocols and internet services. Smart water quality monitoring systems are generally low cost and have low-computational cost and low energy requirements. The modules of these systems are the sensor layer module, gateway module, cloud services module and user interface module. Pipe::scan is the perfect example of this new paradigm. The company behind this commercial solution is S::can, a leader in the manufacturing of water monitoring systems. Pipe::scan is a sensor system for pipes under pressure and measures up to ten parameters: Organics (TOC, DOC), turbidity, colour, pH, ORP, conductivity, pressure, temperature and free chlorine. The system relies on a nano pump, that allows the pumping of the water from the pipes to the flow cells of the sensors and on a filter, to avoid large particles enter in the system too. The effectiveness of the system stands in the application of pipe::scan in multiple points of the water infrastructure and in the analysis: multiple nodes individually monitor, but a water map is available to the users in a platform, thanks to the data collection techniques in the cloud. Having a map and a complete history of the monitoring activities allows event detection and backtracking; on the other hand, this application do not present control and optimization capabilities. (S::can, s.d.)

WaterSense, a real-time warning system, one of the commercial solutions of ProAutomation, represents a further step in the paradigm. Even if the system relies on a small number of water parameters (pH, ORP, temperature and electrical conductivity) and it is not possible to embed directly in water infrastructure, the company developed Deep Learning algorithms to estimate a wider range of physical, chemical and biological parameters. The sensors have integrated batteries and rely on SigFox wireless communication. The Artificial Neural Network is trained with data from thousands of water quality data points. The user interface is a web application accessible from mobile devices and PCs, where it is possible to find alerts on water quality. The system does not present control capabilities, but using neural networks for parameter prediction is an example of applying the IoTs' networking abilities (ProAutomation, 2021).

4.5 Agriculture

According to the studies from the SmartAgrifood Observatory from Politecnico di Milano School of Management and the RISE Laboratory from the University of Brescia, Italy is experiencing the start of a digital revolution as far as agriculture is concerned: the number of applications of Agriculture 4.0, based on the Internet of Things paradigm applied to the cultivation and the preservation of soil, has grown by 20% in 2020, reaching a business value of 540 million euros. However, only 3-4% of the cultivated soil in Italy is already covered by smart, connected products (Bellini, 2021).

On the other hand, the effects of water quality on soil and crops have been deeply studied, finding important correlations between quality parameters and the probability of emergence of problems (R.S. Ayers & D.W. Westcot, 1985).In this section, we will briefly introduce the topic, presenting the main parameters of interest without giving details on the effects of water quality for specific crops or cultivation techniques.

The first two parameters of interest are pH and Alkalinity. As we have seen in the previous section, they are related, and the right alkalinity levels avoid any changes to the pH levels. The capacity of the crop to absorb nutrients from solutions depends on the pH levels and the activity of some preservatives and pesticides is reduced when the solution is too alkaline. Moreover, calcium and magnesium, the main components of the hardness measurement, should also be monitored because they are essential for plants' growth. Sodium and chlorine levels, instead, can be toxic and may prevent water absorption from the crops.

The water quality requirements are part of a larger bundle of requirements for the improvement of the crop's production. Precision agriculture is the field that considers these requirements: right now, value propositions are largely present in the market and have reached a common system architecture in which the IoT paradigm is present. Commercial solutions include a network of sensors that automatically collects parameters from the soil, the soil water, the immitted water and the atmosphere: there is not presence of a solution specialized exclusively on water quality. Collecting and monitoring data coming from multiple sources lead to the creation of an environmental map and can enable, through machine learning techniques applied to the datasets, the optimization of pesticides, fertilizers, and growth enablers.

Libelium, a company specialized in the design and the manufacturing of IoT systems, is an example of providers of smart, connected products for agriculture. The two typologies of projects they carried on over the years are:

- Precision agriculture and automatic irrigation in organic crops with Libelium's IoT technology
- Controlling quality of irrigation water with Libelium IoT to improve crops production

In both concepts, data are collected and stored through LoRaWAN connectivity. An example in the picture below.

4.6 Hydroponics

There is hydroponics among innovative agricultural techniques, largely developed in the last ten years. Hydroponics consists of the cultivation of crops in a nutrient solution, mainly composed of water. Hydroponic systems can be divided in two main categories: open and closed; while the first does not include the reuse of the nutrient solution once delivered to the plants, the second one does (Jensen, 1997). Compared with standard agricultural techniques using the soil as the main vector, hydroponics systems consume 97% water less, also, thanks to recirculation, they yield 100 times more than, and the use of pesticides is limited. Hydroponics systems could be the partial answer to the rising food demand and the increasing water scarcity in the next decades, providing efficient solutions to be also implemented in urban areas. The agriculture 4.0 paradigm, we have seen in the previous paragraph, is finding room to grow even through the hydroponics systems: large companies are currently using innovation in the field of indoor vertical farming infrastructures, artificial intelligence, and biology of plants. On the other hand, medium and small-scale operations in urban contexts still face difficulties leveraging these technologies' breakthroughs (Garcia-Garcia, 2022)

The fundamental element of a hydroponics system is water quality monitoring. While in traditional agriculture, soil is the vector of nutrients, in hydroponics, the water must be enriched with nutrients: nitrogen, phosphorus, potassium, calcium, sulphur, magnesium, iron, zinc, copper, molybdenum, and boron. The only air-bone nutrients are carbon, oxygen and hydrogen (Garcia-Garcia, 2022). Nutrient-enriched water presents problems in terms of growth inhibition when nutrients are too low or even toxicity when nutrients are too low.

In detail, the main parameters for water quality monitoring in hydroponics are:

· Electrical conductivity

All the nutrients are present in the solution in the form of ionic salts dissolved in water. The concentration of these salts can be measured with the electrical conductivity: higher values imply higher concentrations. However, different plants require different concentrations of specific nutrients and each nutrient influences differently on the conductivity. For this reason, it cannot be considered a complete measure.

· The pH of the solution impacts on the ability of the plants to absorb the nutrients. Acid solutions, the ones with high levels of pH, promote aluminum, manganese and hydrogen intake; extremely acid solutions, however, lead to over absorption of these nutrients and damage to the plant itself. On the other hand, of course, low levels of pH may lead to under absorption.

· Alkalinity increases the presence in the solution of molybdenum and macronutrients and decreases the presence of phosphorus, zinc and iron.

In the hydroponics market, the value propositions in IoT systems are more limited than in the other sectors we explored before: on the other hand, providers of hardware components for these systems are multiple. One leader in hardware components is Sensorex, specialising in designing and manufacturing electrochemical and optical measurement technologies, such as pH and ORP electrodes and conductivity and TDS sensors. Specifically for hydroponics, they offer both process pH sensors and modular pH sensors for inline measurements, applicable directly to pipes and tubes, other than conductivity sensors and controllers. (Sensorex, 2020)

Among the limited alternatives in the market, we decided to focus on a commercial solution in line with the purpose of our project. We had the opportunity to meet the founder of Wallfarm, the Italian-based company offering this solution, the LIA control unit. LIA is an automatic control unit composed of three modules dedicated to hydroponics:

- LIA main unit: the control unit compute the real-time analysis of two key parameters, pH and Conductivity and automatically prepare the right quantity of nutrients according to the results of the analysis

- Stream selector: the selector is composed by ten hydraulic doors, and it is possible to select the number of systems to analyse and irrigate

- Smart dispensers: patented solutions intelligently use NFC to manage and dispense quantity in different water tanks. They can embed different pumps, according to the flow required, and can be up to 12 for each LIA central unit.

LIA is a scalable automatic system adaptable to different requirements: it is possible to cultivate multiple lines of plants using just one system.

Wallfarm shifted its value proposition from sample analysis to inline analysis and automatic control. The system also includes an online database, in which the data from the dosing system are collected, and a mobile application, where the parameters are displayed, and the users can modify the formula of the chemical elements. Artificial intelligence also plays a fundamental role: thanks to the analysis of the data collected with the sensors, it is possible to provide individual suggestions to the user for the chemicals to use. Their business model is clear: sell the system and control the reselling of the nutrients. In this solution we can also find an attempt to create a network of users: they can share the results of their cultivation with other Wallfarm users.

The current sectors of interest are vertical, indoor farming and shelf, homegrown farming but the technology could also be applied to fish farming, swimming pools and wastewater. The target customers are not large industrial plants, but medium-small producers: the main competitors in the hydroponics market are Bluelab, AutoGrow and Nido Pro.

4.7 Medical sector

The medical sector presents very specific requirements in water quality monitoring, and it is surely a field where the IoT paradigm has difficulties spreading. In general, we can state that a smart quality management system should:

- Have very precise sensors, able to identify both common parameters, such as electrical conductivity and total organic carbon (TOC), and concentrations of salts (Sodium, Potassium, Calcium, Bicarbonates), amino acid, vitamins and lipids

- Provide as a precise output mixing of fluids according to the treatment of application

- Embed data collection techniques and tools for patient management systems and personalization

Dialysis treatments, for example, are one of the main applications interested in water quality monitoring and in the possible development of the IoT paradigm. The concentration of Dialysate Sodium (DNa) in dialysate fluid is controversial: usually, doctors prescribe a generic concentration for every patient. Recent studies have shown that individualized concentration might be better, but current dialysis machines cannot accurately provide this concentration by design (Davenport & Shendi, 2021). Moreover, home dialysis machines are getting popular: these require a high quality of water and using ultra-pure water bags is not feasible at home. IoT systems, able to provide real-time information about the quality of water entering the home dialysis machines, also interlocked with the alarm system to initiate safety shutdown, could be interesting solutions. This information can also be shared with the nurse/doctor and made part of the hospital's patient management system (Schoenberg, 2014)

Treatments for burn victims are another example of another application of water quality monitoring present in the literature. Burn victims need a constant and precise intake of a composition of fluids: this can be automated, and data collection about fluid intake and related patient recovery can be done. This will standardise the currently empirical practices of fluid management in burn victims (Haberal, 2010)

In the medical sector, the commercial offers are mainly focused on control and filtration rather than IoT applications or smart, connected products. Fielder is an example: the company provides solutions for pure water in endoscopy, renal dialysis, infection control, dental and sterile services. The idea is the control of water for each individual application requirements: chemical contaminant levels, bacteria and parasite control, hardness scaling pipes, waste and energy use in order to ensure patient and staff safety.

An example of application of the IoT to the medical sector is the product SiteBox by ATi, a UK based company. The system is a portable and programmable package of water quality sensors meant to replace conventional panels: live data can be generated in 20 minutes and transferred to a cloud-based platform, with water quality teams able to analyse the data in real-time, with alerts to any incidents (ATI, 2021). It has been delivered and installed in healthcare facilities in locations such as Bristol and Manchester to ensure clean, reliable and safe water during the Coronavirus pandemic. The system architecture is not specifically addressed to one specific treatment or application in the medical sector, giving in this way flexibility for the application to other markets.

In this sector, it is worth mentioning the collaboration between Jacobs, an international technical professional services firm, Cisco, a multinational company specialized in networking solutions and s::can, water monitoring systems provider already mentioned in the previous chapter. The collaboration's goal was to fight against the spread of Legionella Pneumophilia with advanced Internet of Things (IoT): sensors and wireless data capabilities are designed by Jacobs, in partnership with Cisco for wireless communication network and s::can for water quality sensors. The online systems give updates on water quality in real-time to help decrease response time and potential bacteria growth in the system. Real-time monitoring allows building managers to be proactive in managing water quality and not reactive when an incident occurs (Jacobs, 2022).

5. Solution developed

5.1 Decision making

After analyzing the state-of-the art, we identified a suitable field in which the reality of Web of Water could be set; the dishomogeneity of the stakeholders, of the needs and of the requirements among the three main sectors presented (private, commercial and medical usage) prevented us from implementing a solution that could in principle thrive in a general scenario. The selection of the commercial sector was driven by Fluid-O-Tech suggestions and by interviews with company in a similar business; for what concerns the private usage, for example, during the meeting with Thinkwater, leader company in filter business, the problem of the cost of the hardware needed was pointed out, and we concluded that, although the possibility to have high-quality data as sketched by the project would be interesting for the private user, the price of the sensors would be unfeasible and would not worth the cost. On the other hand, the medical area was excluded when brainstorming with the company as we found a high technological barrier for the entrance and more difficulties in the emergence of our paradigm. Indeed, the potential of using the full capabilities of the smart, connected product (monitoring, control, optimization, autonomy), was more limited than in other areas as in medicine the main focus is on extremely accurate measurements of numerous parameters, aimed at controlling filters or reporting faults. There was hence less room for manoeuvre, and the potential of useful tools such as an appealing platform would be reduced, as functionality would be more important than appearance and there would be no need to involve and charm the final user.

Having identified as a sector of interest the commercial macro-area, the decision-making process had to face the choice between different markets; we restricted our options to three markets: swimming pools, hydroponics and coffee-machines. Again, brainstorming with company representatives, we selected what we thought to be the most appropriate market. As pointed out before, after the discussion with Wallfarm, we decided to avoid focussing on hydroponics because on the market solutions were already present, and they suggest a focus on the internal user rather than on data sharing. Hence, there could be barriers for a paradigm that stresses on the value of exchange of information.

On the other hand, the swimming pool sector was excluded because it seemed to be a static market in which our new paradigm could find difficulties in settling down; the main focus is indeed on the appearance of the swimming pool and the common sensibility for the swimming pool water quality is still quite low: though it can have consequences on people's skin and hair health, it is not perceived as a priority and the legislation on the field is weak as it requires periodic self-controls on public swimming pools and no controls on private ones (see the Italian norm UNI 10637 of 2016), therefore it could not help in enhancing a new paradigm on monitoring.

The decision-making process therefore culminated in the selection of a field in which theWeb of Water could create immediate, tangible value: the coffee market.
Here, for example, the final user (bar customer) could directly experience the added value by means of the improvement of the taste of the coffee he/she drinks, and the intermediate actors,

such as the coffee machine manufacturer or the bar owner, could get an economic revenue or the prevention of expensive damages, as it will be explained in the following sections of the chapter.

5.1.1 Concept selection

Therefore, among all the possible declinations of the concept of “Web of Water”, we selected the water data network applied to coffee business. In that area indeed, it was possible to stress on the necessity of controlled, high-quality water both for the maintenance of coffee machines, which involves the bar owner and the machine manufacturer and for the improvement of coffee taste for the final user.
For what concerns the conception of data, we decided to use them both for visualisation and monitoring and for system improvement. On one hand indeed, we opted for data processing that could output plots easy to understand for an user that in principle is not expert in physics, as the bar owner can be, and that enabled monitoring by sending alerts to hasten interventions on faulty machines. On the other hand, we stressed on the possibility to improve the coffee quality, or to investigate its relationship with water parameters; therefore, we designed a way for a “productive” usage of data, in which data could contribute to studies within the science that is behind coffee and - as a further development, when a sufficiently big dataset is available - to the enhancement of coffee taste by the exploitation of Machine Learning techniques.

5.1.2 System specification

For what concerns the technical system on which the business model (which will be described more in detail in the following chapter) relies on, it is composed of a measurement system and a platform.

The technical apparatus is based on a raspberry and a series of sensors, measuring ORP (oxide reduction potential), EC (conductivity), pH (measurement of H+ ion concentration) and TOC (Total Organic Carbon). Other lab experiments were also conducted on an optical sensor developed by the Fluid-o-Tech innovation team, capable of detecting, in output, a feedback that depends on the constitution of the coffee blend.

The platform was prototyped on Figma and includes the interface of machine makers, that of coffee shops and that of customers: the first allows the user to navigate, through a map, the coffee machines distributed in a geographical area and check the status of the filters and the parameters measured, as well as set alarms; the second allows coffee shops owners to monitor both the status of their machine and the progress of coffee reviews; the third is developed on mobile and simply allows end users to express a judgement on the drink purchased.

5.2 Business Model of Web of Water

Having chosen the commercial sector, specifically the coffee market, as the target market for creating the Web of Water, the next step was creating an extensive business plan for Fluid-o-tech. This was done to define in detail the product, services, and values that Fluid-o-tech will create in the coffee industry through Web of Water, the organisations and businesses that will benefit, and how economic revenue can be generated through Web of Water. Moreover, creating a detailed business plan allowed the identification of the main organisations with whom Fluid-o-tech should collaborate, the main activities which need to be performed for the realisation of Web of Water, the main resources which will be required for the same, and lastly the main costs which will be associated with creating Web of Water.

The business plan for Web of Water was created using the template of a traditional business model canvas which has 9 blocks: customer segments, value propositions, channels, customer relationships, revenue streams, key resources, key activities, key partners, and cost structure. These blocks can be classified into two categories: the customer side (customer segments, value propositions, channels, customer relationships, revenue streams) and the company side (key resources, key activities, key partners, and cost structure). The activities on the customer side of the business model help in the identification of the customer, understanding their needs in depth, and clearly defining what value is provided by the business and how it will help solve the problems of the customer whereas the company side of the business model helps in the identification of the activities required from the company to realise the value offered to the customers.

5.2.1 Business Model Canva

Key Partners	Key Activities	Value Propositions	Customer Relationships	Customer Segments
. Coffee machine producers . Coffee shops . Coffee Drinkers . Municipalities	. Production of the electronic system for measurement of water quality . Creation of online platforms . Scientific analysis to understand the correlation between water quality and taste of coffee	. Providing an electronic system to be embedded in coffee machines to measure the quality of water . Creation of online platform to show the map of coffee machines and their maintenance status . Creation of online platform to show the water parameters measured at a coffee machine to produce coffee . Creation of an online platform for recording the feedback on coffee consumed . Scientific research to understand the correlation between water parameters and taste of coffee	. In-person assistance for embedded electronic measurement system . Online assistance related to the platform	. Coffee machine producers . Coffee shops/bars where coffee machines are installed
	Key Resources		**Channels**	
	. Human resources (engineers, scientists and designers) . Financial resources . Intellectual resources (related to engineering, water qulity, coffee, etc) . Physical resources (related to engieneering)		. Own channels such as company website, in-house sales, social media platforms etc.	

Cost Structure	Revenue Streams
. Main costs are associated with engineering, research and production . Other costs are related to legal, insurance, marketing, sales, logistics etc.	. Transaction based revenue through the selling of the electronic system . Subscription based through the usage of platform by coffee machine producers and coffee shops

Fig 5.1 Business model canva

The nine building blocks of the business model canvas are described in greater detail below:

1. Customer Segments

The first step in developing the business model was to identify the target population whose problems would be addressed by Web of Water. After researching different players involved in the coffee business (such as producers of coffee machines, small and large businesses selling coffee, coffee consumers etc.), it was realised that the quality of water directly affects the filters installed in the coffee machine. Moreover, research shows that the taste of coffee can be related to the quality of water. Based on these two observations, the primary customers of Fluid-o-tech for Web of Water are coffee machine producers and coffee shops where coffee machines are used.

2. Value Propositions

For the producers of coffee machines, the two main needs which are required to be addressed in terms of water quality is knowing the quality of water and knowing the status of the filters in their machines which are in operation. Knowing the quality of water helps the producers directly in the design of filters of coffee machines and the design of the coffee machine itself, at the same time, knowing the status of the filters in their lifecycle allows them to plan maintenance activities along with gathering data on how different quality of water affects filters in different ways which in turn will help with the design of filters and coffee machines themselves. The first need of the coffee machine producer is addressed by providing an electronic system which can be embedded in the coffee machines which will measure the quality of water which is being used to prepare the coffee. The second need is addressed by creation of a platform which shows a map of the coffee machines produced by the coffee machine producers which are either rented or sold to different businesses. On this map, the coffee machine producer can track the quality of water which is detected by the sensors embedded in the machine and use that to plan maintenance. The platform also allows setting of alarms when faults are detected in the machine.

For the coffee shop owners, the primary concern is serving coffee with the best taste. This need is addressed by Fluid-o-tech by carrying out scientific research on the correlation between the quality of coffee and the parameters of water. A platform is created by Fluid-o-tech for the end user who purchases and consumes the coffee where the user can leave a rating on the taste of coffee. This feedback, along with the collection of data on the water quality which was used to produce the said coffee will be gathered over time in the form of big data which will then be analysed and empirical relationships will be drawn between the coffee taste and the quality of water. Further, the coffee shop owner is provided with a platform where they can monitor the performance of their machine as well as the collection of feedback on their coffee to ensure the collection of data.

3. Channels

In order to reach the producers of coffee machines for the selling of water quality measurement system and maintenance platforms, Fluid-o-tech's own channels will be deployed such as company websites, social media sites, in-house sales teams etc. On the other hand, to reach the coffee shops, Fluid-o-tech can either reach them directly through their company's website or it can partner with the coffee machine producer whose machines are installed in the coffee shops. Lastly, the end user who consumes the coffee would be reached by partnering with the coffee shops.

4. Customer Relationships

Since the products developed by Fluid-o-tech are both physical (electronic system for the measurement of water quality) and software based (platform for coffee machine producers, coffee shops and end users), the support offered to the customers is both in-person (such as offering help and assistance related to the electronic system), as well as online (offering help and assistance related to the platform).

5. Revenue Streams

Fluid-o-tech will earn transactional-based revenue by selling of the physical measurement system which is to be embedded in the coffee machines by the coffee producers. At the same time, revenue is also generated through subscriptions in the form of subscription fee as both the coffee machine producers and the coffee shops will utilise online platforms developed by Fluid-o-tech, the former for the maintenance of the filters and the latter for the research on the enhancement of the taste of coffee. The owner of the platform, therefore the owner of the data, is the company selling this service, i.e. Fluid-o-Tech.

6. Key Activities

There are three main activities which will be undertaken by Fluid-o-tech for creating the Web of Water system – first is the production of the electronic system for measurement of water quality, second is the creation of online platforms, and the last is the carrying out of scientific research to understand the correlation between water quality and taste of coffee. Other activities which support these main three activities are designing, testing, web development, web design, user support etc.

7. Key Resources

The main resources required to perform the above-mentioned activities are as follows:

Human resources: Electronics engineers, computer engineers, mechanical engineers, chemical engineers, production engineers, mathematical engineers, data scientists, product designers, communication designers, web designers, UI/UX designers, etc.

Financial resources: To purchase and produce parts for the electronic system and to perform other developmental activities.

Intellectual resources: Related to engineering and production of electronic systems, related to coffee chemistry, related to water quality etc.

Physical resources: Mechanical and electronic resources, computer hardware and software, mechanical and electronic inventory for production, buildings and labs for design and testing, workshops and factories for manufacturing. Production and testing.

8. Key Partners

The key partners of Fluid-o-tech for the Web of Water system are the companies which produce coffee machines, small businesses such as bars, coffee shops etc. where coffee machines are installed, big coffee chains which manufacture their own coffee machines and sell coffee, and lastly, the end users who consume coffee from the coffee shops where these machines are installed.

9. Cost Structure

The main costs associated with achieving the value proposition for the customers are based on the engineering, production, and research activities. Other important costs include costs associated with legal activities, insurance, marketing, sales, logistics etc.

5.2.2 Expansion of business model

The business model described in the previous section relates to the solution developed in the project which is aimed at coffee machine producers and coffee shops; and it addresses their respective needs for the maintenance of coffee machine filters and enhancement of the taste of coffee through water. This business model can be further expanded beyond the coffee industry. Having embedded the Fluid-o-tech's electronic measuring systems in coffee machines across a city, the systems will measure the quality of water across different points in the city thereby creating a Web of Water. This data on the quality of water can be processed into useful information and can be sold, on a subscription basis, to municipalities and other public/private bodies which are responsible for the distribution of water in the city so that they can plan activities such as purification of water, maintenance of pipes, plan the maintenance or expansion of water distribution channels in the city etc.

5.3 Physical prototype

5.3.1 Objectives to be achieved

After the analysis carried out on the water market, we focused on the application of coffee, in particular the analysis of water that is used in coffee machines for both commercial and accommodation applications. From our benchmarking, this sector has proved to be the readiest to digitise water for several reasons:

- In the world of coffee, water has a decisive role since the single coffee is composed of 98% water from the municipal water system
- Thanks to market surveys carried out with many leading companies in the coffee market, we have collected positive feedback for the digitalization of water to be able to control water quality in a capillary way

The needs of the market, in the specific case of the companies that produce coffee machines, were two:

- Create a hardware and software system that would be able to analyse the water quality and subsequently the coffee quality
- Communicate the collected data to a platform that is able to display and analyse it effectively.

5.3.2 Realization

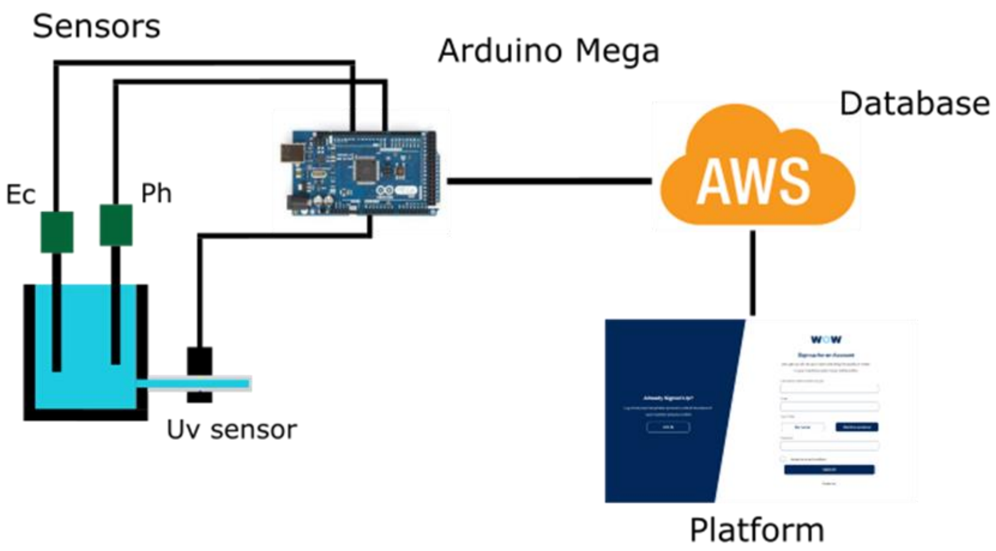


Figure 5.3.1 Scheme of the system

As a first step in the design of the system we analysed the projects in the world of research. We found in the paper *Iot Sensors Integration for Water Quality Analysis*, a system to digitise water quality. (Hermantoro, Suparman, 2021) We used this model to address the critical points and understand how to make this solution ready for the coffee market. In the second solution developed we have gone to fill the limits of this system for the demands of the market.

A key step in the design of the system was to decide which water parameters were crucial for coffee production. In order to identify the best parameters to focus on, we relied on the document "The SCA Water Quality Handbook" written by SCA which is a nonprofit association, membership-based organisation that represents thousands of coffee professionals, from producers to baristas all over the world.

This study shows that water plays a fundamental role in the extraction of coffee. The twobasic parameters are alkalinity and hardness. (see previous paragraph 3.1.1: Flavour of the coffee: requirements). Alkalinity and hardness can be evaluated indirectly thanks to conductivity and pH.

Below we will analyse each part of the system and then explain the pros and cons.

Table I
LIST OF COMPONENTS

Component	Qty	Description
Microcontroller Arduino Mega	1 unit	An integrated circuit to govern a specific operation
Carrier board e Ezo	1 unit	An integrated and analog circuit that connects the sensors with arduino
Conductivity Probe K10, Atlas	1 unit	Input sensor for EC
Orp Probe, Atlas	1 unit	Input sensor for Orp
Ph Probe, Atlas	1 unit	Input sensor for Ph
Uv sensor, Sensorex	1 unit	Input sensor for Uv
Optical coffee sensor, F-lab	1 unit	Input sensor for the quality of the coffee

Calibration of sensors and connection to Arduino

The sensors for water analysis were purchased by the market leader Atlas in America. For each sensor in our possession, we set the correct communication protocol so that it was able to communicate with the Arduino. After this we calibrated the individual sensors so that they had the most reliable measurement possible.

Automatic system to collect data from Arduino

At this point, taking advantage of the libraries developed by Atlas, we developed a program that each $T\_sampling = 10\mu s$ stores the sensor values. The program has been implemented with a polling methodology, where the value of the specific sensor is gathered at each $T\_sampling$. The pH, EC and UV sensors were connected to the microcontroller (Arduino) via an I2C bus. The Arduino sent these data packets to the computer. A python script was created which listened on the computer's communication port and wrote the incoming data packets into a CSV file.

Finally, we also connected the sensor developed by F-lab to our Arduino (reference to the patent). The developed sensor is optical, it uses two photodiodes that collect the refracted light and the one not absorbed by the flow of liquid that passes through the tube. The photodiode, depending on the light it absorbs, carries a different current. The latter through several electronic stages is transformed into an analog voltage. The analog voltage is converted inside the Arduino through an Analog-to-Digital convertor (ADC). This value is also stored inside the previously described CSV file with other parameters.

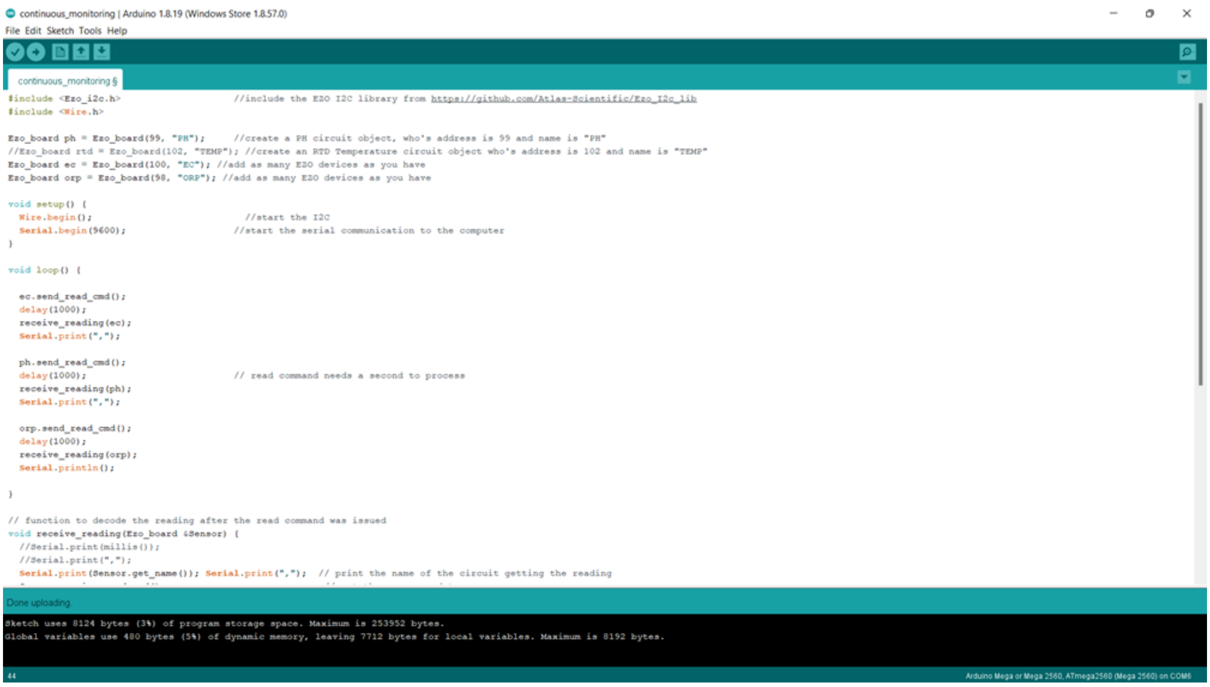


Figure 5.3.2 Script of Arduino

Arduino and AWS

In this second phase we changed the data storage mode. The goal was to send the data gathered by Arduino in real-time directly to Amazon's AWS Server. To reach the AWS Server, the computer connected to the Arduino must be connected to the Internet.

We created, first, the AWS Server and made it accessible from anywhere in the world through a username and password. Through a program developed in Python, we saved the data collected by Arduino in a MySQL database which was connected to the AWS server.

We chose to use MySQL because it ensures the ability to easily implement data management and quickly develop queries.

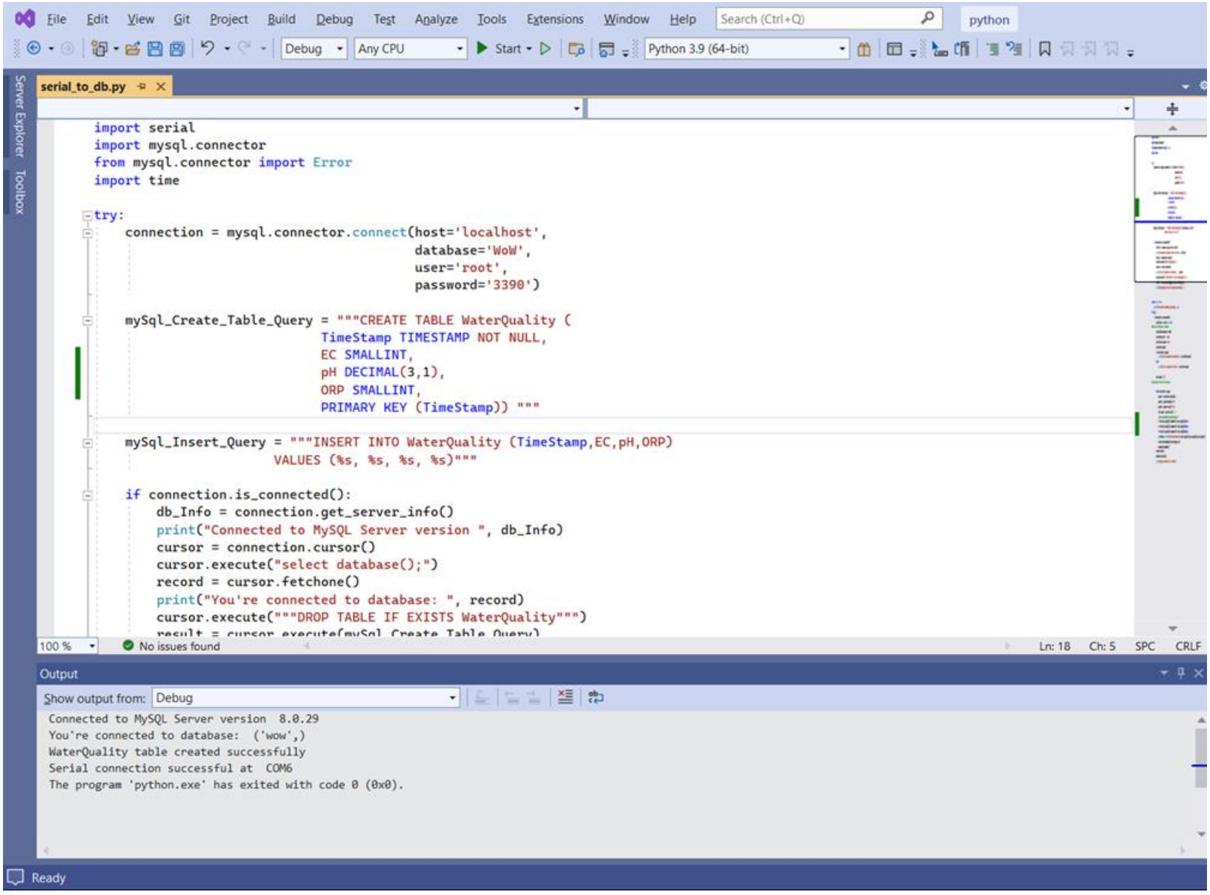


Figure 5.3.3 Script of the bridge between Arduino e Aws

AWS and Tableau

Since data collection from the sensors and data warehousing on an AWS server was complete, we needed to implement the ability to visualise the collected data. We chose the Tableau Public software for this because of ease of integration with databases, effective templates, and the free-to-use version. Users no longer need to connect to the database itself (this was also a security issue). Instead, users can connect to a webpage on the Tableau website where graphs from the collected data are displayed. They can be refreshed for real-time update, or they refresh automatically every two minutes. Access control and private hosting be implemented in deployment versions by upgrading to premium/paid versions of the software. This visualization, of course, is just for tests of the prototype. In the final vision, the platform used for this purpose would be the digital platform designed accordingly to next chapter.

Figure 5.3.4 Tableau

Second solution

By implementing the first system we realised that there was a key point to make the product ready for the market:

- In our implementation, that is using the computer as a gateway, or inserting in an Arduino an additional block to connect to the WI-FI would make it difficult to install the system inside the coffee machine. Following the path of WI-FI we would have added a degree of complexity to those who install and position coffee machines, making it difficult to create a stable and lasting connection. Likewise, there are not always WI-FI connections to connect to inside businesses or hotels.

Implementation of second solution

After a market survey we realised that a technology was needed to communicate with the server that did not need to be configured. In addition to this requirement, it was necessary for the system to be able to communicate and receive data even inside buildings.

	NB-IoT (Lte NB-IoT)	WIFI	BLUETOOTH	SIGFOX	LoRa	LTE-M/ (eMTC) (Rel 13) (Lte eMTC)	EC-GSM (Rel. 13)	ZIGBEE Pro	5G (targets)
Coverage Area	<15 km 164 dB	17-30+ (meters)	1-10+ (meters)	<12km 160 dB	<10 km 157 dB	<10 km 156 dB	<15 km 164 dB	1-100+ (meters)	**<12km 160 dB**
Spectrum Bandwidth	Licensed 7-900MHz 200 kHz shared	2.4 GHz 802.11	2.4 GHz 802.15.1	Unlicensed 900MHz 100kHz	Unlicensed 900MHz <500kHz	Licensed 700MHz-900MHz 1.4 MHz shared	Licensed 800MHz-900MHz shared	2.4G 802.15.4	Licensed 700MHz-900MHz shared
Rate	<50 kbps	150Mbps	1Mbps	<100bps	<10 kbps	<1 Mbps	10 kbps	250kbps	<1 Mbps
Terminal cost	4.00$ (2015) 2-3$ (2020)	4.00$ (2016)	4.00$ (2016)	4.00$ (2015) 2.64$ (2020)	4.00$ (2015) 2.64$ (2020)	5.00$ (2015) 3.30$ (2020)	4.5$ (2015) 2.97$ (2020)	3.00$ (2016)	<2$
Network Reforming	Small to moderate	None	None	Large	Large	Small	Moderate (LTE reuse)	None	Requires 5G NWs

Figure 5.3.5 Comparison of different technologies (Migabo, Djouani, 2020)

The best solution for our needs proved to be **Nb-IoT** for several reasons:

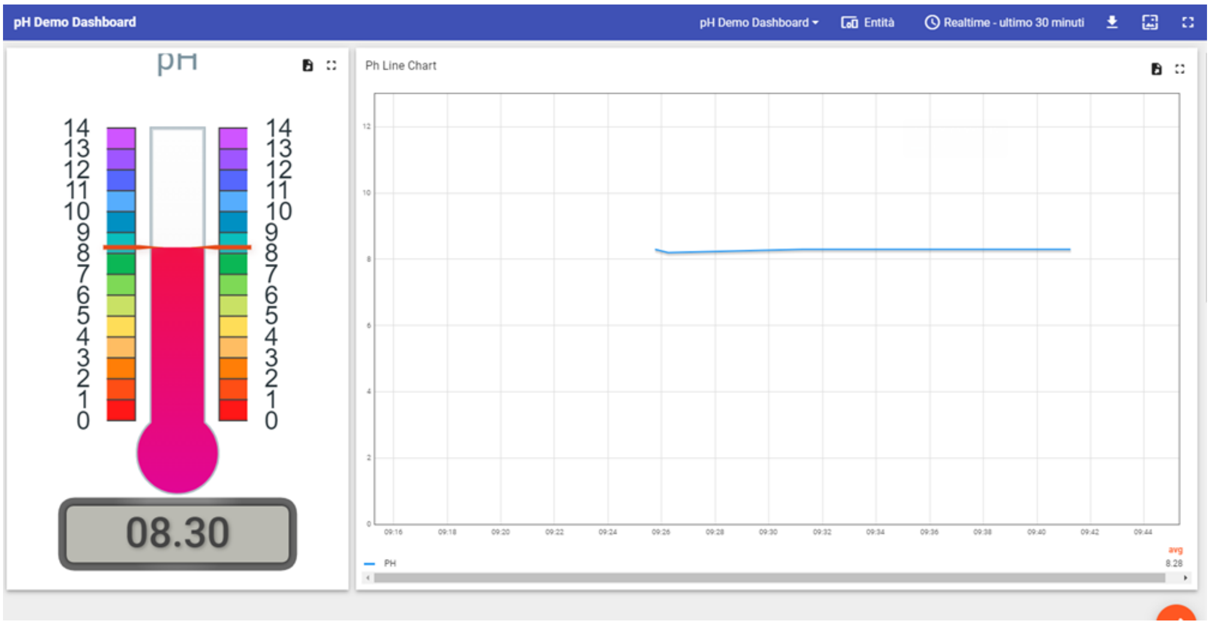
- The communication rate in our application can be quite low. The quality of the water can hardly vary even within the single day; therefore, even a data every 5/10 minutes is more than enough.
- Nb-IoT having a lower frequency than other technologies is to overcome the walls of houses, providing good coverage even in basements or places much inside a building.
- As last advantage the provider used Deutsche Telekom guarantees a coverage almost globally for a competitive price as annual fee.

We identified this as the best technology and found a company that had developed a solution in line with our needs: Logos-01. They had developed this solution and we worked with them to make their product compatible with our sensors needed to analyse water quality.

We integrated with the microcontroller present in their system the analog board to collect data from sensors and developed a platform to view the data live. The system can operate on either mains or battery power. In addition, it is easily integrated into professional coffee machines.

Figure 5.3.6 Prototype

In the figure 5.3.6, we can see the prototype built inside which is the antenna, the board with the microprocessor and the analog interfaces to connect with the sensors. The goal was to build a system that would be useful to show coffee machine manufacturers the real possibility of digitizing water data.



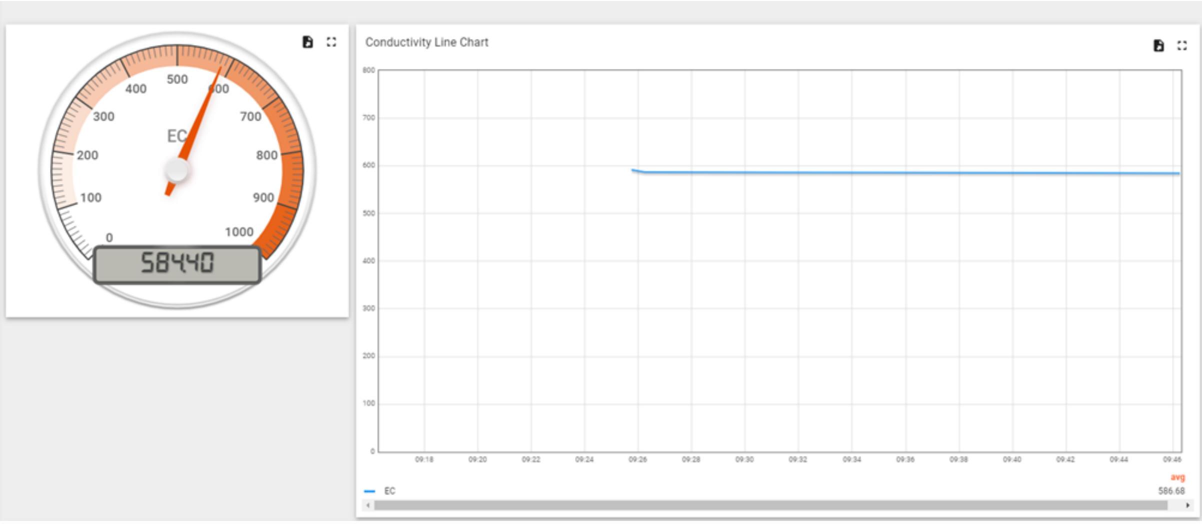


Figure 5.3.7 Data visualization

In the 5.3.7, you can see an incomplete platform, where the data is uploaded live directly from our module. In the example shown, data sampling takes place every 5 minutes, frequency already high since the water quality does not change so quickly. The diagram was built to quickly show conductivity and ph. In future this system can be integrated with possible alarms in case the water quality reaches critical values for the potability of the latter, such as shown in the platform mock-up chapter.

Possible improvements

The system is already easy to integrate into professional machines, but a specific integration will be necessary for each case. The antenna, for example, cannot be closed inside a Faraday cage, which would make communication with the cell impossible.
Finally, there would also be a work of integration with the systems already present inside the professional machines, microcontrollers that already manage and automate the operations for the extraction of coffee. This work, however, could not be done because it differs for the individual company in question.

5.3.3 Testing phase

Once the system was ready, many tests were conducted to verify the correct functioning of the sensors and to look for significant correlations between patterns.

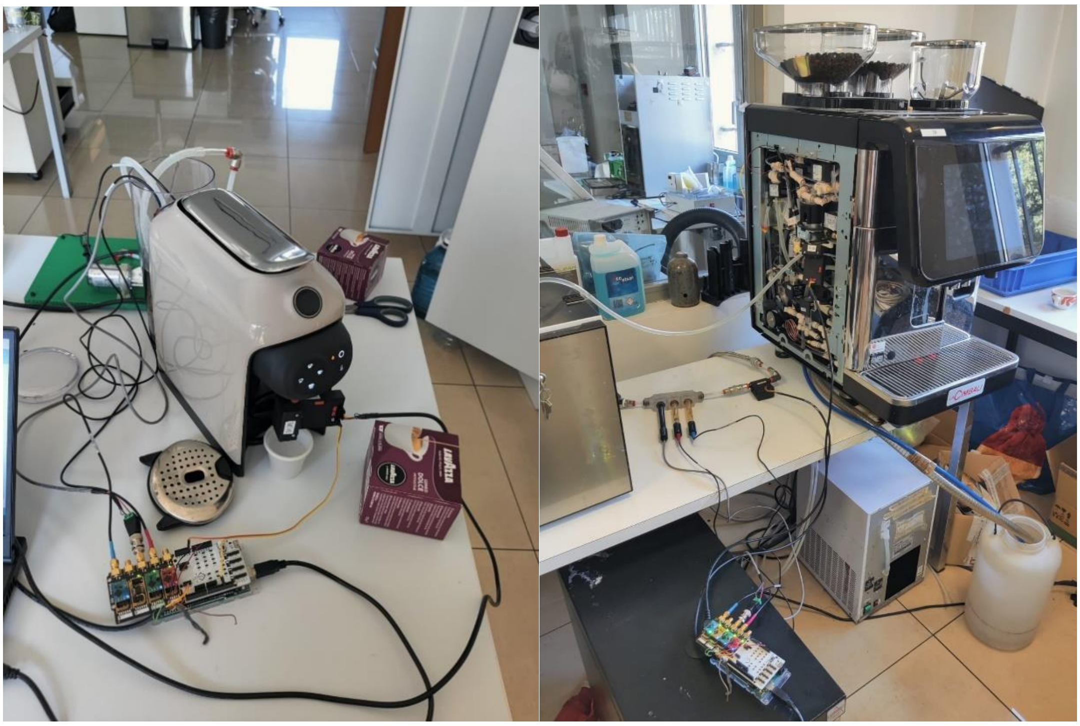
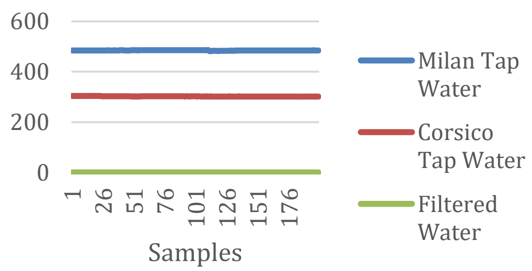
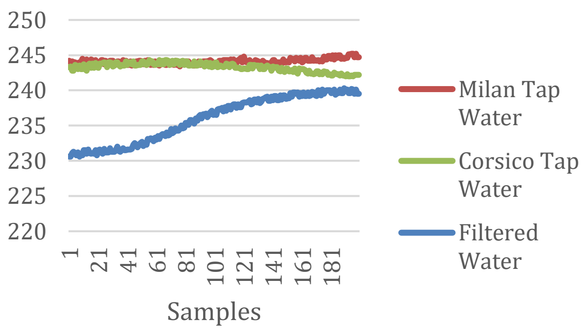


Fig 5.3.8: tests setup with Nespresso (left) and Cimbali (right) coffee machines, Fluid-o-Tech laboratory (Corsico, MI)

Test #1: water quality parameters from different sources of water.
We compared 3 different sources of water, including filtered water. We can spot a strong difference in electrical conductivity (EC) and a slight difference in pH.



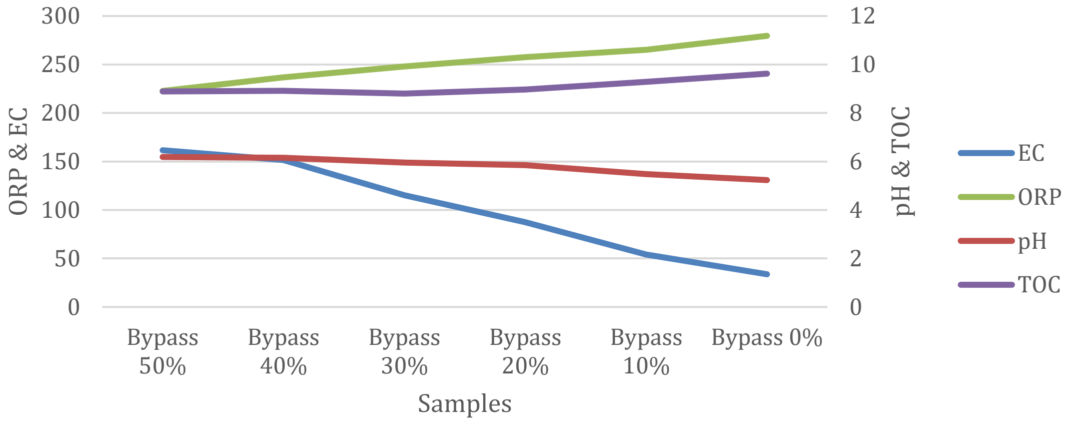


The other parameters show minute differences.

Test #2: water quality parameters in varying levels of filtration

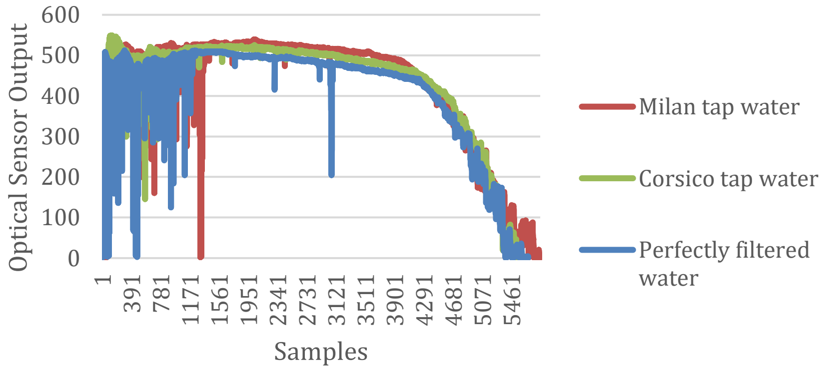
- EC strongly reflects the change in filtration levels (EC decreases with filtration)
- ORP slightly represents the change in filtration levels (ORP increases with filtration)

- pH slightly represents the change in filtration levels (water gets more acidic as filtration is increased)
- TOC displays unclassifiable behavior with varying filtration levels

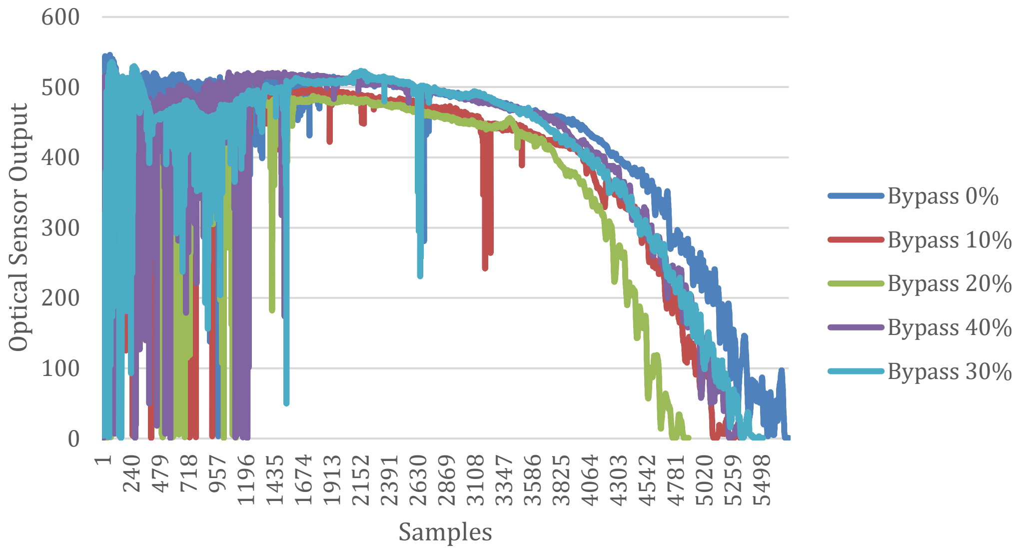


A linear variation of the level of filtering causes a linear variation of conductivity and ph. Therefore, these sensors could be useful for the detection of malfunctions or breakdowns of the filter.

Test #3: coffee quality with the same blend but different types of water
The optical sensor was used for this experiment. Its output is proportional to a voltage. Every curve decades after a certain time (samples) indicating the end of the production of the coffee.
It turned out that the sensor cannot distinguish between different types of water. The experiment was inconclusive.

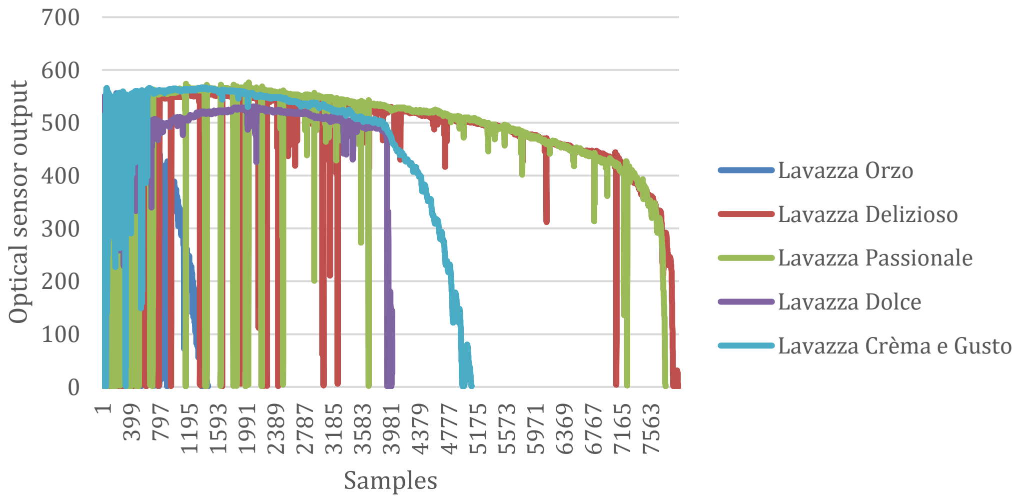


Test #4: coffee quality with the same blend but different filtration levels of water
The optical sensor cannot distinguish between same blends of coffees made from different filtration levels of water.



In the graph, bypass percentage means how much the filtration was suppressed. The bypass percentage goes down with increasing filtration level.

Test #5: coffee quality of different blends with the same type of water
In this test, different blends of the same brand, Lavazza, were used. The optical sensor can make a distinction: different blends have different curves in the graph.



Test phase conclusions

A machine learning based approach can be developed where the coffee machine is able to provide feedback about the quality of coffee made by comparing the current trajectory from the optical sensor against optimal trajectory of the same blend.
The optical sensor is currently unable to provide correlation between water quality parameters and coffee quality so different sensors or a trial-and-error approach by the coffee shop worker may be required to fix the suboptimality

A cost function which combines EC, ORP, pH and TOC can be developed to provide an indication of the filtration level of water input to the coffee machine. A feedback system (using a controller like PID and setpoint from user, manufacturer, coffee producer etc.) could control the filtration level, and resultantly water quality parameters, so the water is ideal for the coffee.

5.4 Digital Platform Prototype

In this subchapter, the information architecture and high-fidelity prototypes designed are highlighted and described following the two target users identified for the project. The use of this platform is to support the system embedded within the coffee machines. The interactive mock-ups were developed in Figma and can be navigated here.

5.4.1 Target Users

The two target users identified are **Bar Owners** and **Coffee Machine Producers**. Even though the platform is designed around the idea of simplicity and ease of use for both targets, it tries to respond to their different needs as well.

As a result of semi structured interviews with both targets, the main needs and, therefore functionalities that the system and platform should have, were identified. On one side, for Bar Owners, the main goal is to have real time feedback on their coffee and only in a second place to keep under control the usury of the filter within the machine. On the other hand, for Coffee Machine Producers the value identified within the platform mainly concerns filter usury and their constant overview throughout all the machines with the embedded system.

5.4.2 Information Architecture

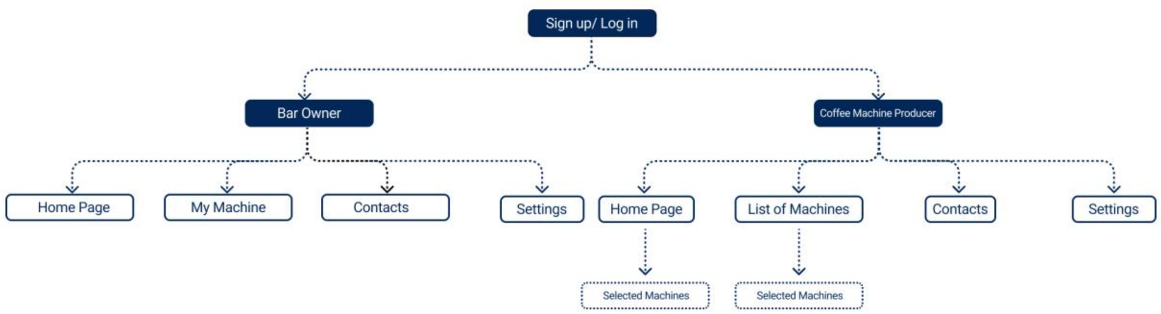


Fig. 5.4.1

As mentioned above, the platform is designed around the idea of simplicity and ease of use for both targets. As shown in Fig. 5.2 it is developed in two different branches based on which type of user is using it. Each section is composed of four sections that will be described below. In the Bar Owner section we will have a respective home page, a specific page with details about the coffee machine used in the bar, contacts and settings. In the Coffee Machine Maker section we will have a respective home page as well, a specific page with a list of all coffee machines with the system and their states, contacts and settings.

5.4.3 High Fidelity Prototypes

Before entering into the details of each section of the platform it is valuable to highlight what a UX/UI Prototype is and what are its functions. A user interface prototype is a hypothesis — a candidate design solution that you consider for a specific design problem and the most straightforward way to test this hypothesis is to watch users work with it, as stated *in UX Prototypes: Low Fidelity vs. High Fidelity* - Nielsen Norman Group, there are different types of prototypes that can change in level of fidelity, defined as the level of detail and functionality included in them. As a matter of fact, fidelity can vary in interactivity, visuals, content and commands, and other areas. High-fidelity prototypes, as in this project, are functional and interactive and they are close to the final product, with most of the necessary design assets and components developed and integrated.

- Sign up

The Sign-up process is identical for both Bar Owner and Coffee Machine Producer. At the top of the Page there is a section that provides key elements to give context to whomever is looking at the interface. Right below, there are various input sections where the user will have to specify User Name or Client Number, his/her email and specify what type of user he/she is.

On the left side of the page, highlighted by the bold difference of color and contextual text, there is the possibility for the user to switch to a login page in case he/she had already registered before.

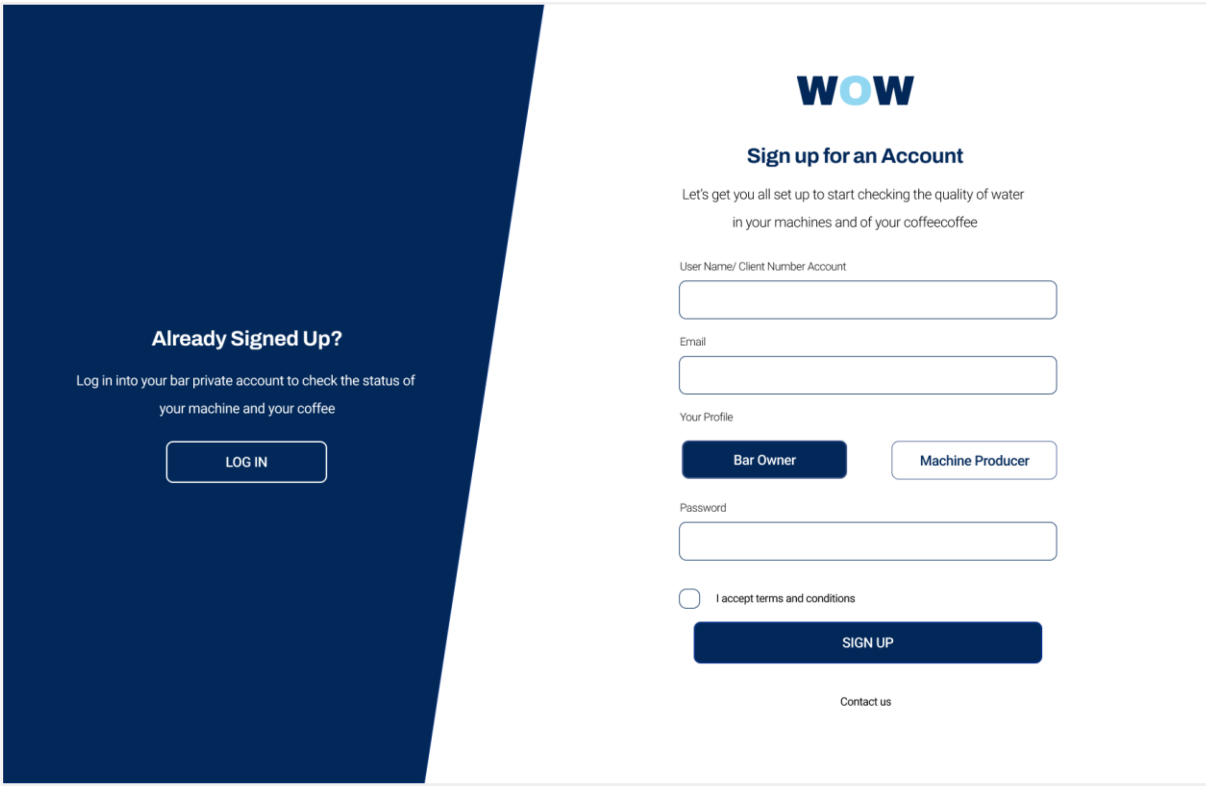


Fig. 5.4.2

- Log in

A login is a process most users will do several times a day. Whether for your personal email account or for your favourite online store, everyone knows how it works. It is a straightforward and well-known user flow among the UX community. The user enters the email or user name/ client number, then the password, and, if correct, he/she can access the service desired, in this case the digital platform.

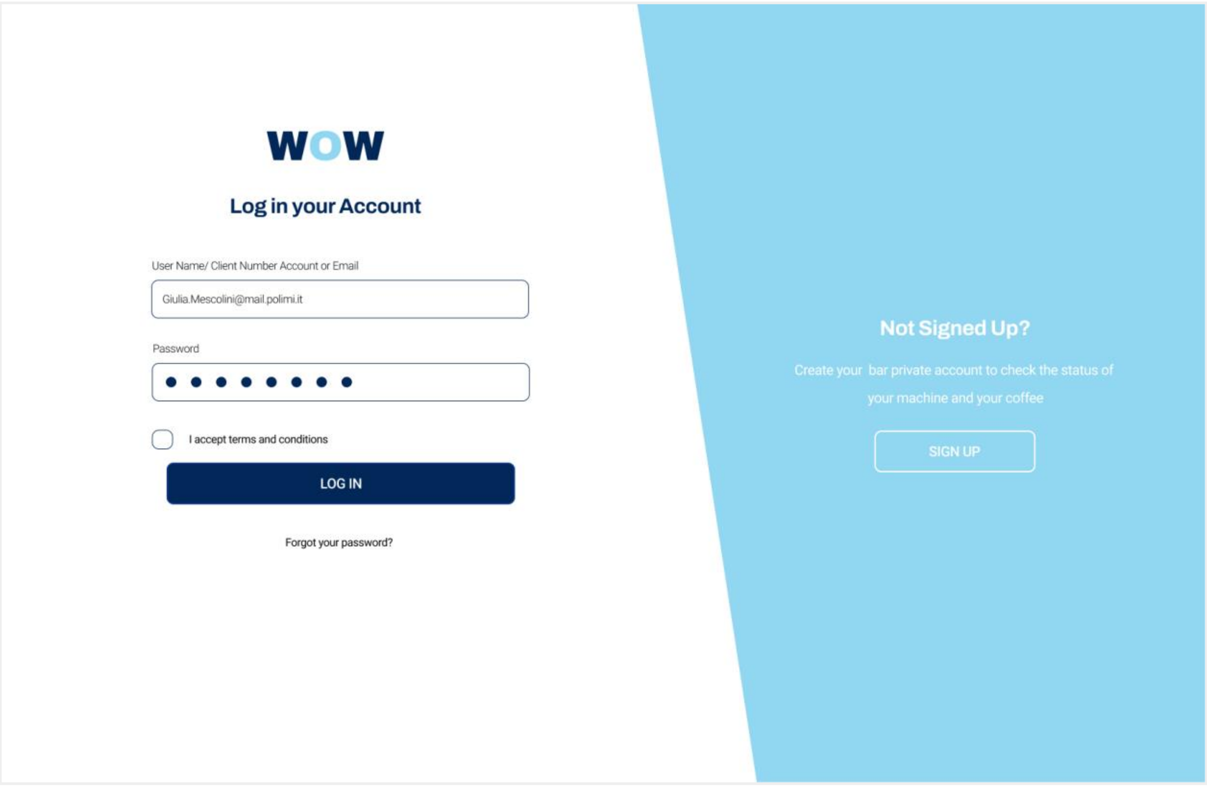


Fig. 5.4.3

- Navigation

Once logged in both user flows, a menu with the structure of a side fixed navigation bar will help explore the platform and its functionalities. Each page name is coupled with an icon that will provide a visual clue to the user on where to click and if there are any notifications.

The choice of a side fixed navigation bar as a menu was taken for a few different reasons. First, being this the first prototype designed for this solution to be tested, with this type of menus it is easier from both a design and development perspective to add menu items later on in the future development of the platform and overall project. This happens because they are extremely easy to change and scale.

Secondly, vertical menus make all the elements extremely visible, fostering immediate and simple navigation, and can adjust to all screen sizes which is preferable given the variety of screens on which this platform could be.

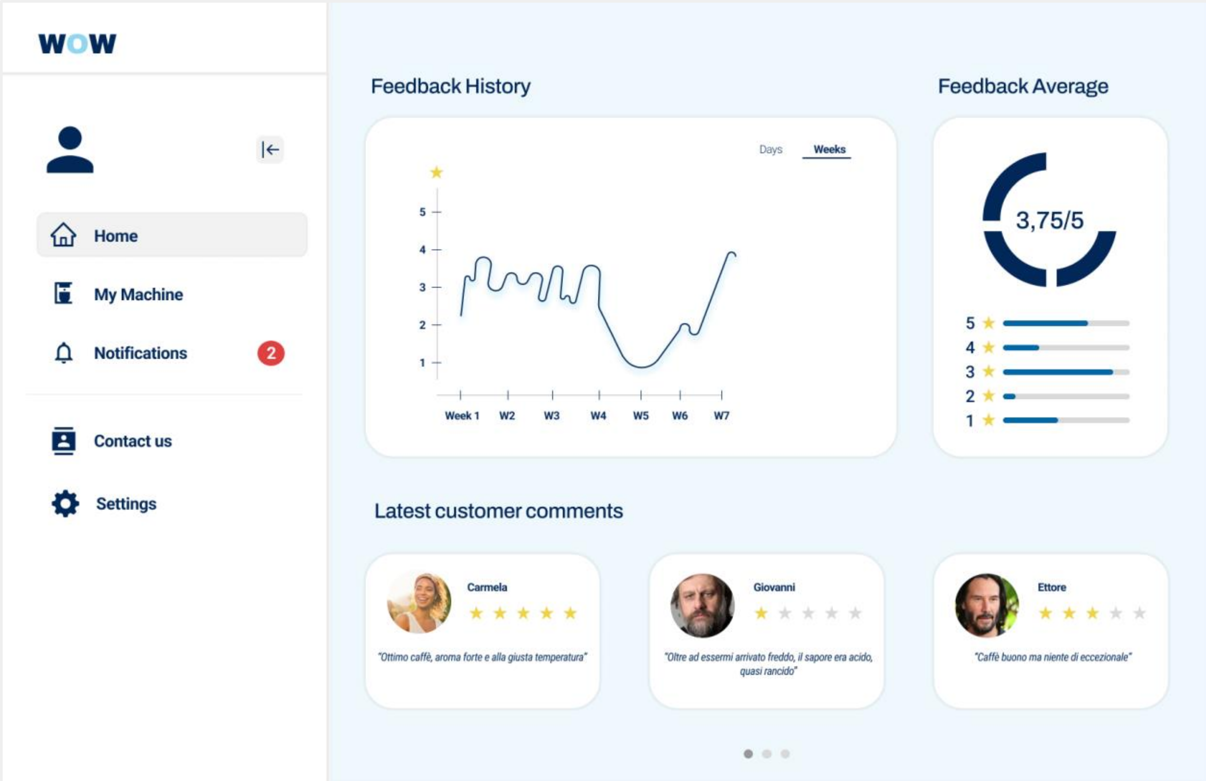


Fig. 5.4.4

- Bar Owner, Home Page

The page presents to the user an overview of all the historic information collected real time through the system.

On the left, as shown in Fig. 5.4.4, the viewer can find the feedback history provided by the customers about the coffee consumed in the specific bar/ coffee shop. This is shown both in days and weeks with the only interactive element of the page which is located at the top right section of the graph.

On the right side, the current average rating and the frequency of each evaluation can be found. At the bottom the latest customer comments are highlighted.

In this page but also throughout the platform, information is organised visually through boxes to ease the scanning of the page.

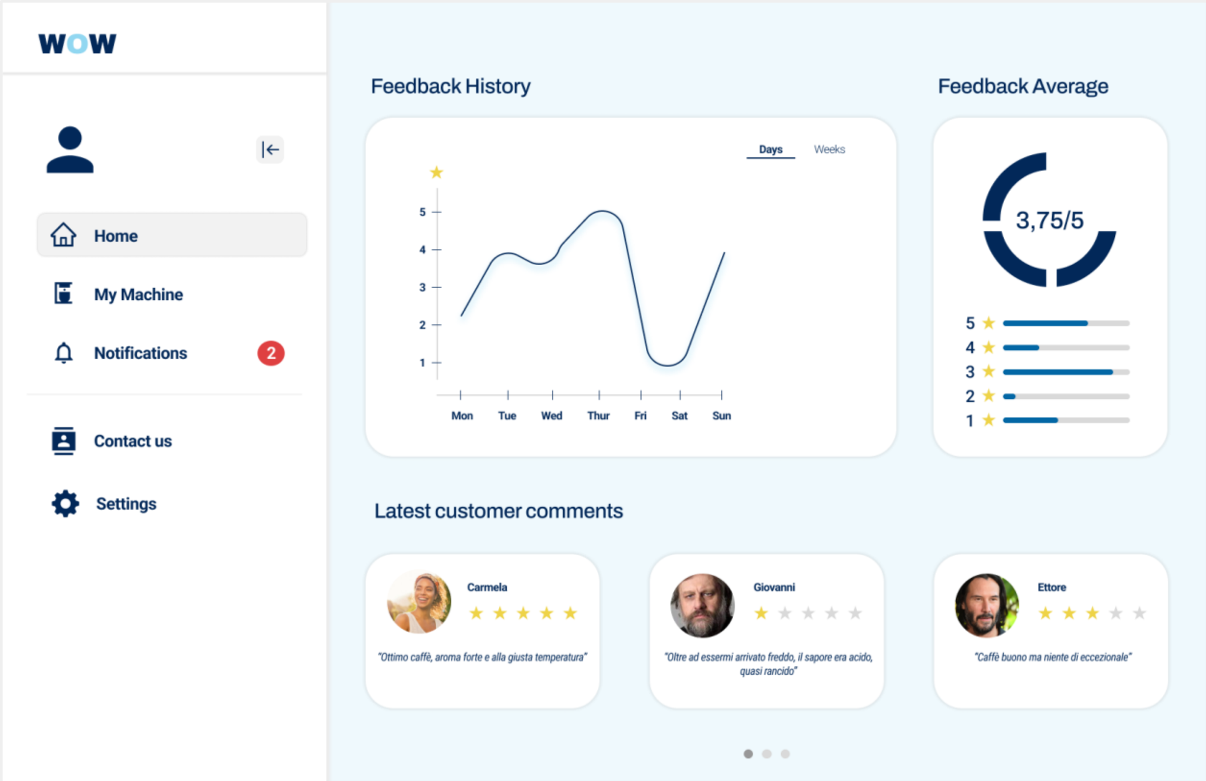


Fig. 5.4.5

- Bar Owner, My Machine

"My machine" section reports specific information about the coffee machine such as the year in which the product was installed and the current status of the filter.

The graphs at the bottom right of the page shows the trend of the pH and conductivity measured real time: these are the parameters through which it is possible to read the status of the filter. It is possible to notify the machine producer in case the read status is negative.

Again, the only interactive element of the page which is located at the top right section of the graph of the Filter Status is the one to show the different parameters, pH and conductivity. The filter status can be Optimal, underlined by the green colour, Medium, by the orange, or Inadequate, featured by the red.

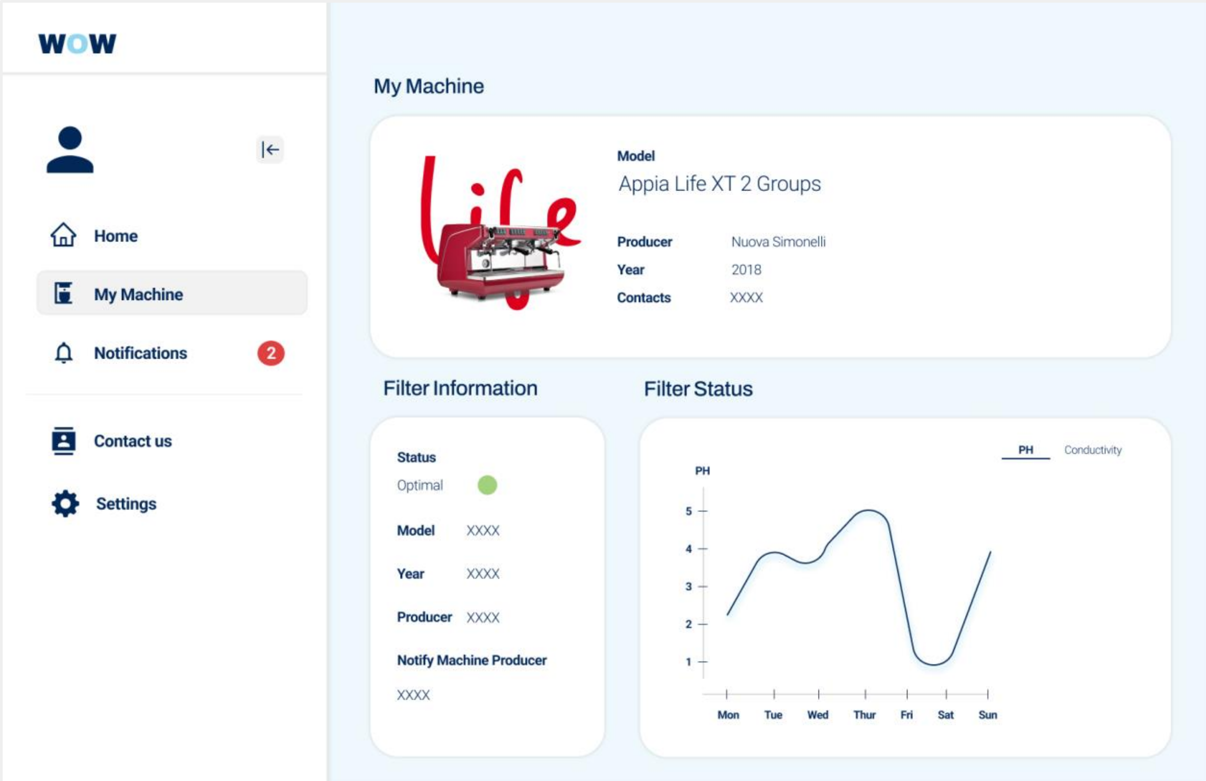


Fig. 5.4.6

- Coffee Machine Producer, Home Page

The home page main function is a locator, an interactive map that shows the endpoints where the coffee machine with embedded systems are installed. This is considered the most intuitive and simple way to navigate items through their location. Such a map can be easily integrated into a web application even using open resources such as Open Street Map, without the need to rely on Google.

By clicking on the map marker it is possible to see the details of a specific coffee machine used by a bar owner or coffee shop. In Fact, the user will be redirected to a specific page with the same characteristics of the Bar Owner - My Machine one, see Fig. 5.4.6.

The screen in Fig. 5.4.7 also features a diagram on the top right that summarises the status of the filters grouping them by geographical area. This can be particularly useful to then see if the filter status is influenced by a specific situation given by the water in a specific area of the city.

Finally an overview of the latest updates on the filters status within different machines is provided to keep the user always informed about the main changes.

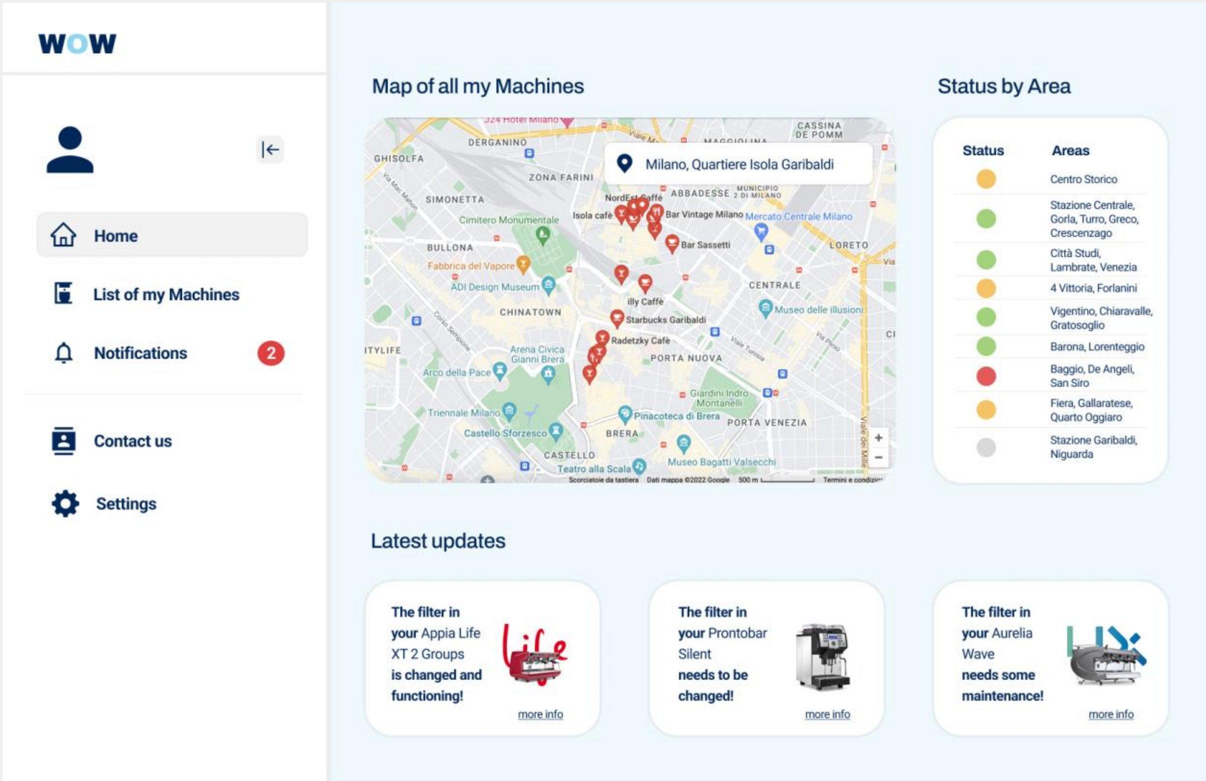


Fig. 5.4.7

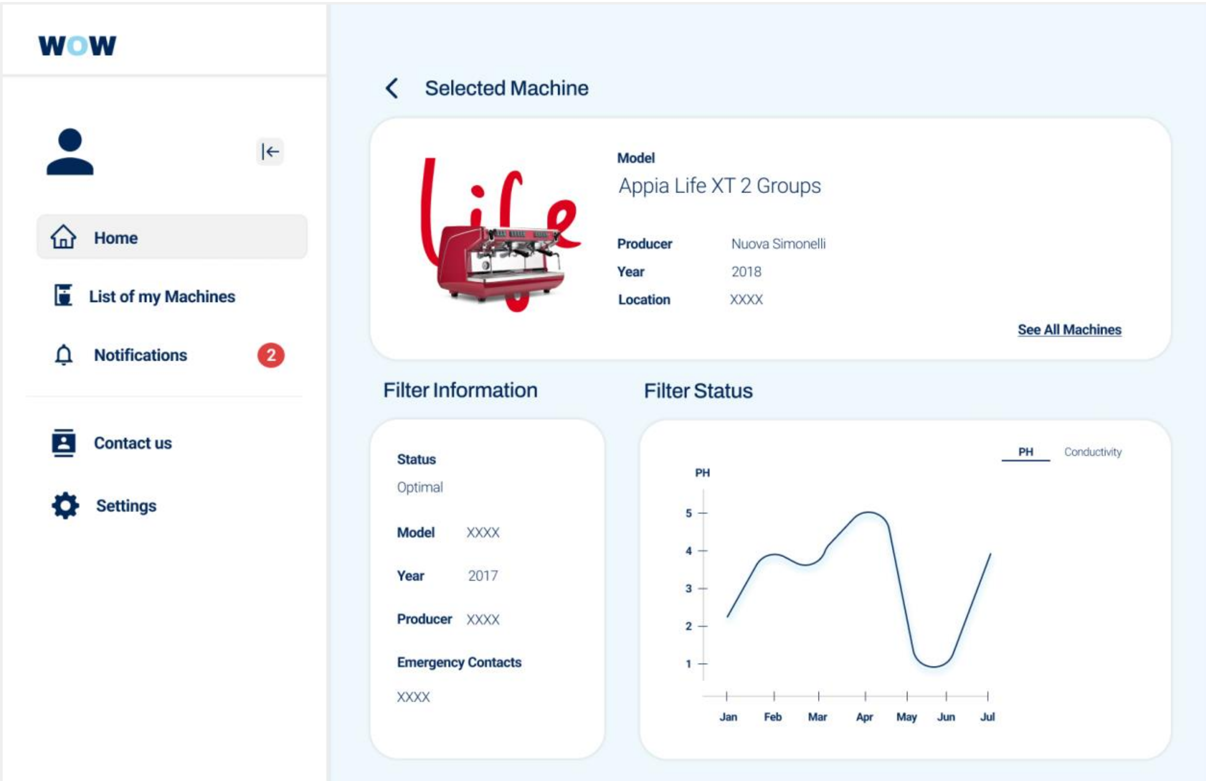


Fig. 5.4.8

- Coffee Machine Producer, List of My Machines

The list of machines is presented as in Fig. 5.9, gives an overview of all the machines that have the system embedded, which model they are, what characteristics they have and their filter status.

Assuming a high number of machines within this list, a filtering function has been embedded to facilitate navigation. As the user selects the filter through which wants to organise the items, the result should update immediately.

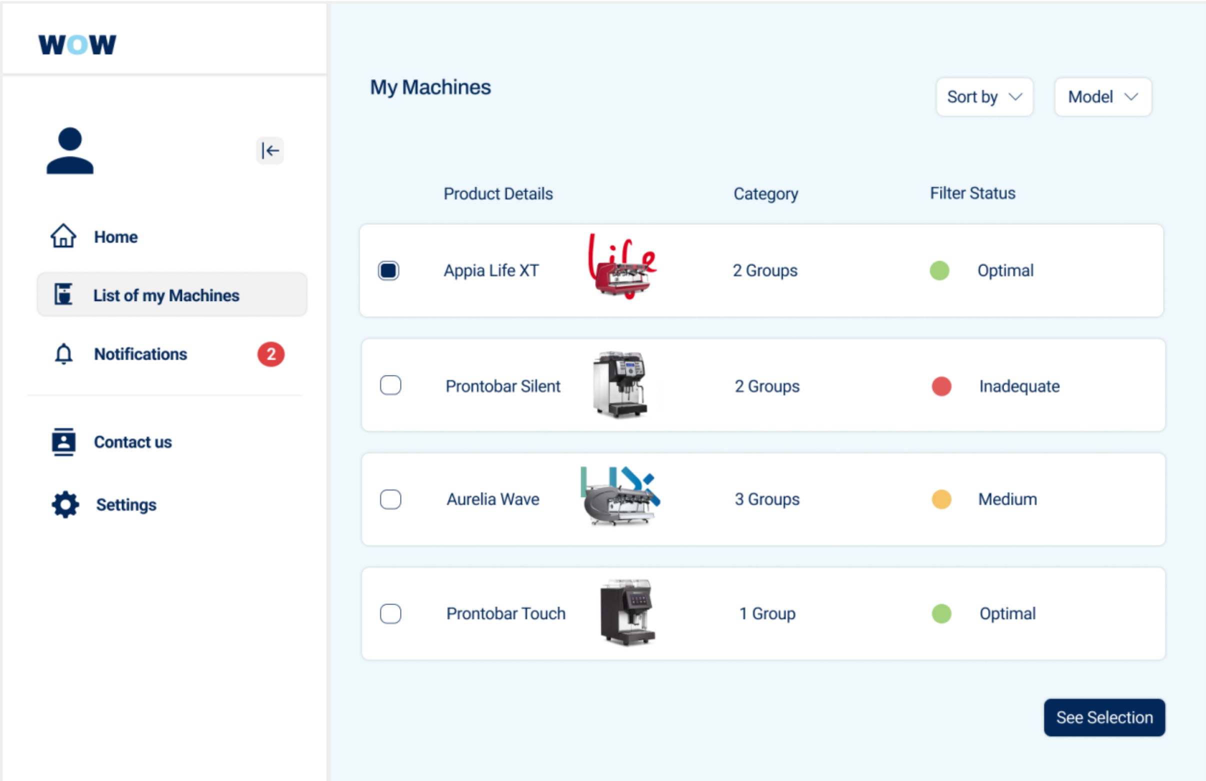


Fig. 5.4.9

An important functionality is the selection of the machine. This will permit the user, once pressed the button "See Selection" to see the details of each Machine selected and their filter status details as in Fig. 5.4.8. Here in case of emergency the contacts of the company that provided the filter are highlighted.

- Contacts

Using the contact us section it is possible to access a helpdesk that shows the FAQ regarding the problems that the user may find or the way in which to use certain functions. Moreover, the contacts of the company in charge of the platform, in this particular case Fluid-o-Tech or one of its divisions, are provided on the right side of the page.

For the Bar Owners there will be additional indications for contacting the Coffee Machine Producer as in fig. 5.4.10 while for the latter there will be information regarding the Filter providers as in Fig. 5.4.11

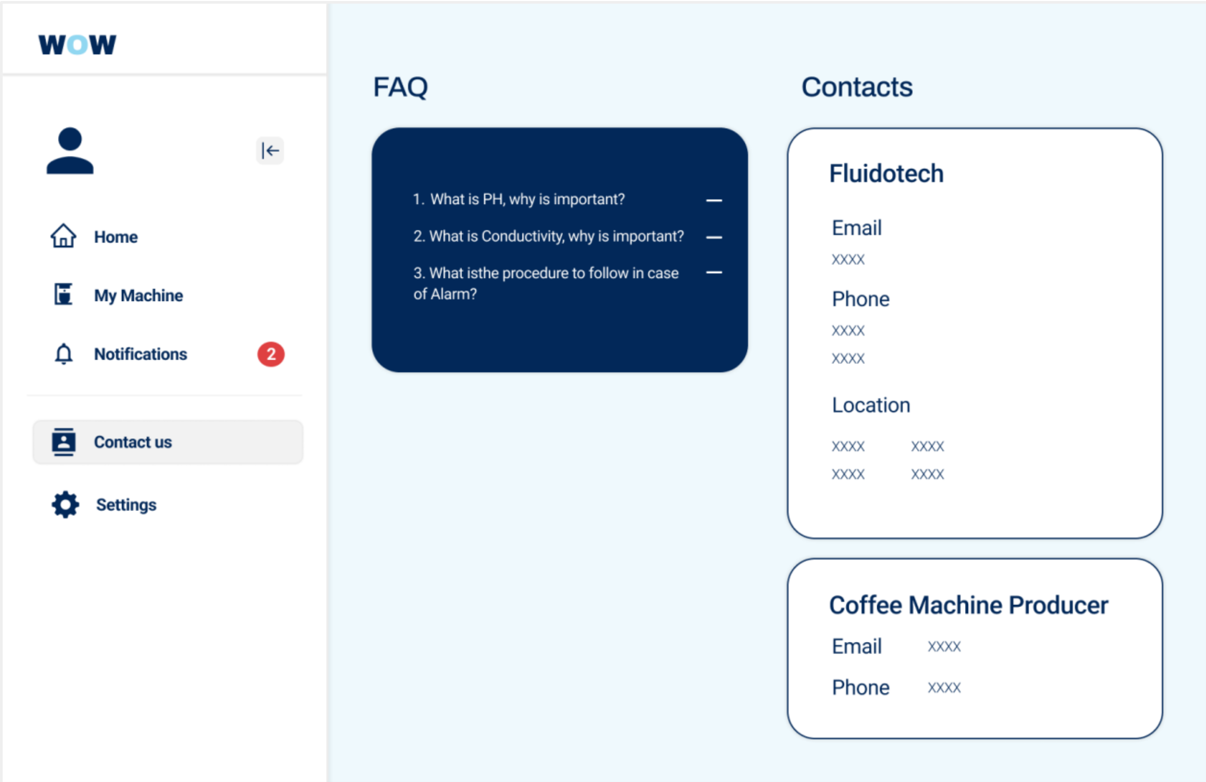


Fig. 5.4.10

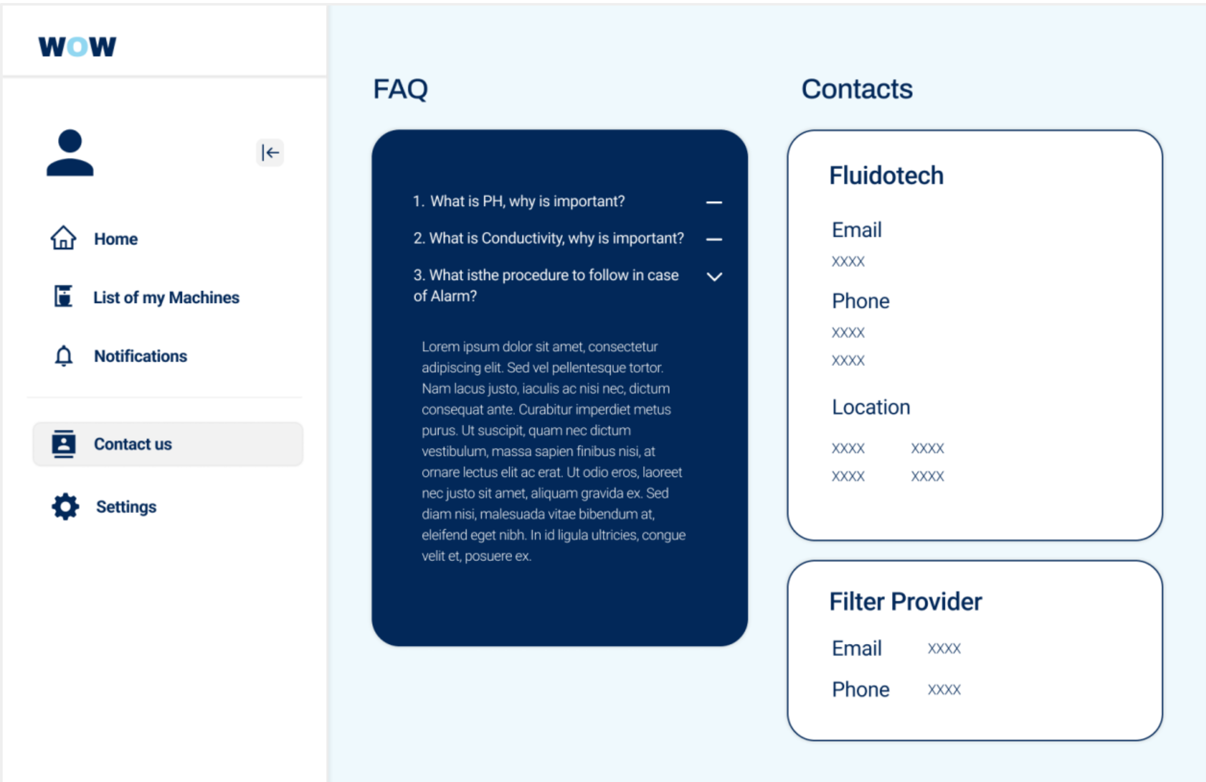


Fig. 5.4.11

- Settings

Finally, in the settings the interactive switcher permits to activate or deactivate both notifications, data privacy and Alarm notifications with a simple tap in both the Bar Owner and Coffee Machine Producer platforms. In addition to this at the bottom of the page some useful tips can be found in case of Alarm regarding the Filter Status. Nevertheless, there are some slight differences among the settings for the two different targets. Coffee Machine producers have, in fact, the possibility to also define the ranges of the pH and conductivity values outside of which the system will send alarm notifications. See Fig. 5.4.13

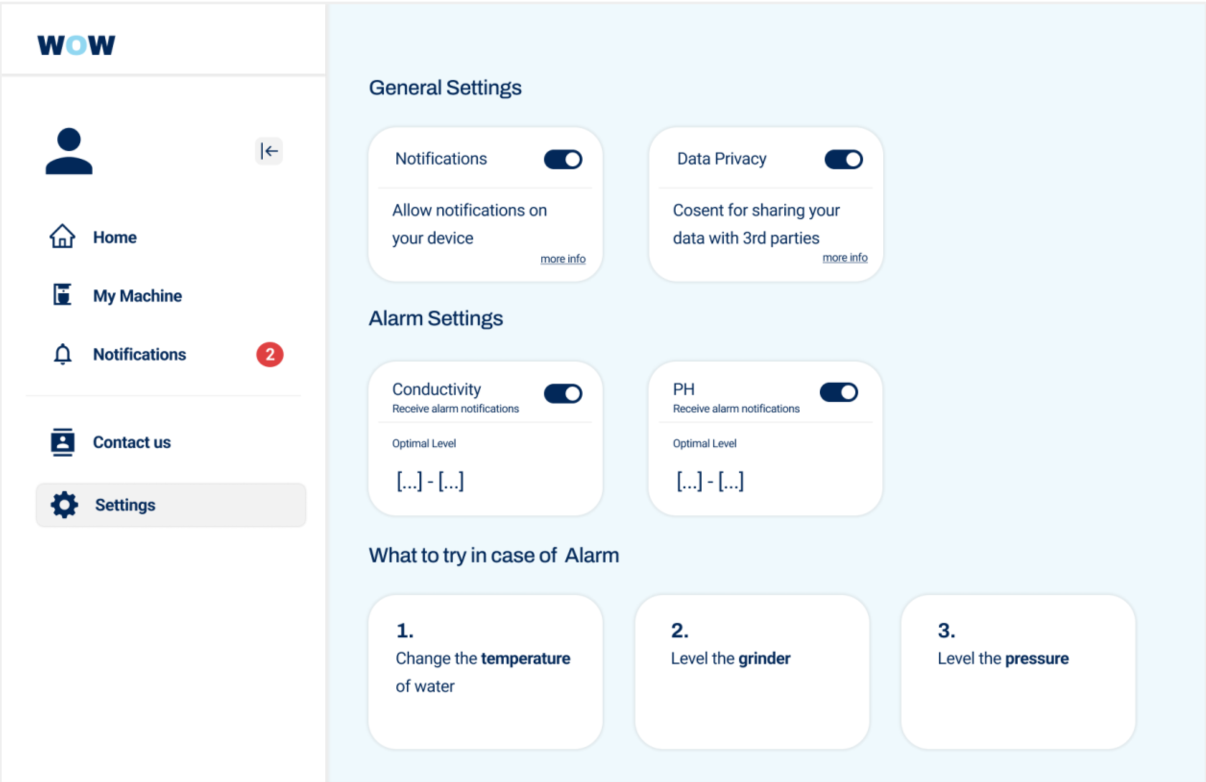


Fig. 5.4.12

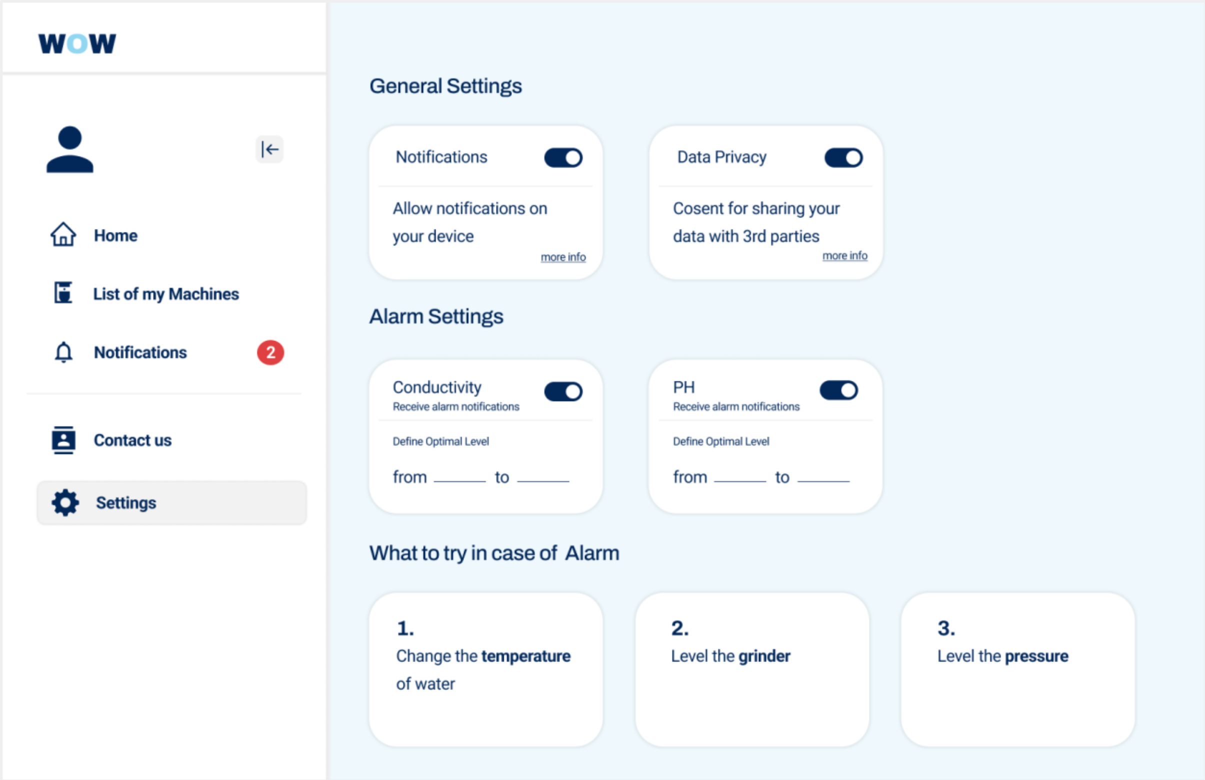


Fig. 5.4.13

5.4.4 Bar/Coffee Shop's Customers Survey

The interface has been designed to be a website optimised for smartphones, to which the customer can be directed by framing a QR code inside the coffee shop. The page simply asks the user to enter a review ranging from 0 to 5 stars, and an optional comment that can be skipped. This evaluation will be uploaded to the databases to which the bar owner can have access through his interface of the digital platform.

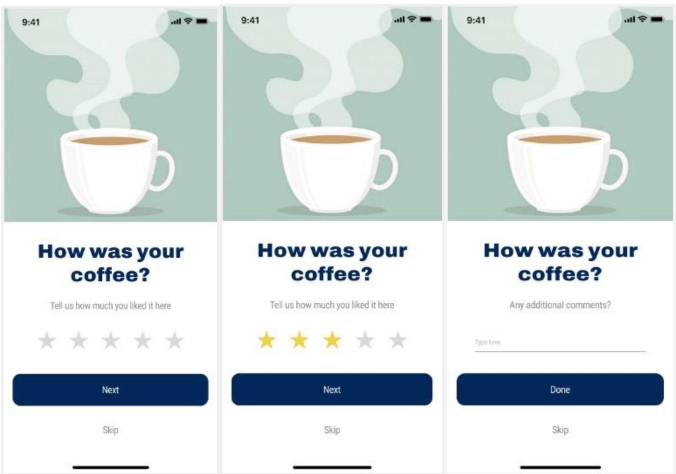


Fig. 5.4.14

6. Conclusions

In this project, we have proposed a new paradigm for water quality monitoring, applied specifically to the commercial area of coffee. With respect to solutions already present in the market, the prototype built by our team gives more value to data sharing, because it exploits the platform for a scope going beyond the mere visualisation of parameters' plots and the sending of alerts; although the above features are present in the solution proposed, the most innovative aspect is the possibility to generate value from customers' coffee review. In this sense, we managed to reach the main target of the project, that was creating value from water data, and from the mechanism of measurements and feedback further projects could extend a similar business model to other areas in which water quality plays a key role. The experimental part of the project showed the possibility to realise the physical hardware necessary for the development of the technical part: inserting a sensor inside a coffee machine and coding a system for data acquisition and visualisation. The business model proposed has been built with the support of the company, and the path that led to its creation involved external actors such as leading companies in the sectors of water and water for commercial usage. Finally, the platform that has been designed guarantees accessibility for non-technical users as well, and enriches the user experience by showing parameters' data in the form of readable plots and insights on water itself, promoting sensibility on the topic at the same time. The prototype built could be the starting point for the technical implementation of algorithms which enable to study correlations between water parameters and taste: after the collection of a sufficient number of customer reviews with the corresponding water parameters measurements, data analysis techniques can join the game, and play a fundamental role in ensuring the possibility to create value for all the stakeholders involved and give relevance to data sharing, that is one of the pillars of the project and stresses on the "web" part and on the communication between the actors.

For the usage of the review data, two main options are available: on one hand, traditional statistical tools could be exploited (possibly for an initial trial), on the other hand, in a big data regime, proceeding with machine learning would be more suitable. Concerning the first option, a possibility is indeed the set-up of a regression model, highlighting the correlation between satisfaction and parameters; here, as the name suggests, taste would be modelled as a linear combination of parameters:

$$y = a*parameter\_1 + b*parameter\_2 + \ldots$$

It could be a valid starting point and the task could be performed with classical statistical software such as R, avoiding advanced programming with neural network libraries for this first stage. In the regression scenario, the effect of the parameters could be deduced by the coefficients multiplying them in the linear relation with the taste, and in principle one could think that if they are positive, they increase customer satisfaction, whereas if they are negative they can be detrimental. But this reasoning can be tricky; the relation between parameters and taste is likely to be much more complex than linear (for example, an excess of a parameter in both directions is probably bad for taste, while the optimal value could be intermediate), and this would lead to the exploitation of the most recent and powerful discoveries; for example, a machine learning model could be set up, with the aim of the identification of an empirical law relating the taste of coffee and the physical parameters of water.

This task should be performed at a stage in which a significantly large number of customer reviews are available, following the machine learning golden rule according to which the larger the dataset, the better the model. An example of this can be a neural network trained to predict the customer satisfaction given a set of water parameters, which can capture nonlinear and complex relations between input and output.

Another aspect that can be improved is the involvement of the municipalities and of the water providers as actors in the web of water. As stated in [1], in Italy the most common system of water furniture relies upon multi-utilities companies that are public or majority public, which involves more than 95% of the supply system. These companies already own and share with citizens (through their websites) detailed water quality data, measured in several points of the urban network, ranging from the aqueducts to water collection points that are spread throughout the major italian cities (such as the “Case dell’acqua” in Turin or Milan). However, the water providers are missing what happens to water quality in private buildings’ pipelines, because they are out of their area of competence, so at the end they do not have measurements of the water received by users inside a given building (that can be either a shop or a house).

They could be involved in the water quality data market to gain a more capillary monitoring system, which can be useful in the areas which lack of “Case dell’ Acqua”, and even more in smaller urban areas where an alike system of measurement stations is not available and data are for example measured only at the source of the aqueduct. The idea that can be developed is that, given the public ownership of these societies, an exchange of data between commercial users (such as bar owners) and municipalities could be established: with the aim of protecting people’s health and wellness, municipalities are interested in the quality of the water that the final customer uses, and data at the aqueduct/measurement station may not be enough. For this reason, they can enhance data sharing by proposing reductions on the water bill to the private citizens who agree to share data, or bonuses for the maintenance or replacement of pipelines which turn out to be damaged by comparing data at the measurement station and data of the water which comes out of the tap. This economic incentive would be the value added for the private user, in exchange for the data sharing.

The effort, so, should be concentrated around providing incentives for the purchase of monitoring systems, in exchange for the data collected, for example providing tax incentives to private companies that supply quality water.

Public entities might be interested in the creation of a platform able to collect and analyse from private databases, compatible with the communication protocol of the devices on the market. The public provider itself should adopt the technology, for example, on core diffusion arteries of water.

Current actions:

- Incentives for water quality filtering (not monitoring), which helps the sensibilization on the topic. Examples: “Bonus acqua potabile” (Italy), National Water Quality Initiative (for agriculture, USA)
- Water Framework Directive (EU): European reference text for the regulation of the broad topic of water management + Full Recovery Cost for the recovery of the cost sustained.

- Italy: transparency in the information of the water quality, but communication is not efficient, and monitoring is not continuous.
- No-profit organisations in the medical area (for example AASHTO, OCHA, UNICEF).

To conclude, the model proposed could be inserted into the broader framework of number 6 of the Sustainable Development Goals: "*clean water and sanitation"*. Indeed, it spreads sensibility on water quality and highlights the possibility to generate concrete value from its monitoring, because in the designed scenario all users would have a return from water data, ranging from an economic benefit to an improved taste of coffee. After the challenging - but indeed necessary - benchmarking phase, our team managed to draw a starting point for the implementation of a smart water system which is in this project addressed to a specific market and could be therefore a first scenario to play out in the "Web of Water" and to perceive water quality monitoring in a broader concept in which data and feedback play a key role and are used to improve features, not only to detect faults.
Clearly, since nothing similar had already been done, it would be first necessary to put in place this wide concept in a tiny sector (as coffee markets can be, with respect to all water private and public usage) to establish the paradigm and this is exactly the work that the team carried out.
Therefore, the Web of Water applied to coffee could be the starting point for further developments involving different areas and possibly help for the ultimate target of a world with digital and interconnected water data.

7. Bibliography

AquaIoT, n.d. *Smart Water Monitor: Aqua-eegg saves your routine manual work on pool water checking.* [Online]
Available at: https://www.aquaiot.tech/

ATI, 2021. *Playing a key role in delivering safe, clean water to Nightingale hospitals with SiteBox,* s.l.: s.n.
Bellini, M., 2021. *L'Agricoltura 4.0 cresce del 20% a 540 mln€ e conferma un grande potenziale di sviluppo.* [Online]
Available at: https://www.agrifood.tech/convegni-e-workshop/lagricoltura-4-0-cresce-del-20-a-540-mlne-e-conferma-un-grande-potenziale-di-sviluppo/

Bianchi, R. et al., 2020. Italy, Patent No. PCT/EP2019/079672.

CBI Ministery of Foreign Affairs, 2021. *Which trends offer opportunities or risks in the European coffee market?.* [Online]
Available at: https://www.cbi.eu/market-information/coffee/trends

Davenport, A. & Shendi, A. M., 2021. The difference between delivered and prescribed dialysate sodium in haemodialysis machines. *Clinical Kidney Journal,* p. 863–868.

Foglia, S., 2020. United States, Patent No. US2020178725A1.

Garcia-Garcia, A. L., 2022. A Review on Hydroponics and the Technologies Associated for Medium- and Small-Scale Operations. *Agriculture 12(5):646.*

Haberal, M., 2010. Fluid management in major burn injuries. *Indian J Plast Surg..*

ISTATItalian National Institute of Statistics, 2018. *Urban Water Census,* Rome: Istat.
Jacobs, 2022. *How Online Water Quality Monitoring Provides Better Detection and Protection.* [Online]
Available at: https://www.jacobs.com/newsroom/news/how-online-water-quality-monitoring-provides-better-detection-and-protection

Jan, F., Min-Allah, N. & Dü¸stegör, D., 2021. IoT Based Smart Water Quality Monitoring: Recent Techniques,. *MDPI.*

Jensen, M. H., 1997. Hydroponics. *HortScience, Vol.32,* pp. 1018-1021.

Levy, N., 2019. *Microsoft teams up with Starbucks on predictive drive-thru ordering and bean-to-cup blockchain.* [Online]
Available at: https://www.geekwire.com/2019/microsoft-teams-starbucks-predictive-drive-thru-ordering-bean-cup-blockchain/
Nuova Simonelli, 2014. *Water, the main ingredient in coffee,* s.l.: s.n.

Porter, M. E. & Heppelmann, J. E., 2014. How Smart, Connected Products Are Transforming Competition. *Harvard Business Review,* Issue 92, pp. 64-88.

ProAutomation, 2021. *WaterSense: Real-time, multi-parameter water quality measurement device- enhanced by AI.* [Online]
Available at: https://www.proautomation.co/watersense/

R.S. Ayers & D.W. Westcot, 1985. *Water quality for agriculture.* Rome: s.n.

S::can, n.d. *The pipe::scan.* [Online]
Available at: https://www.s-can.at/en/the-pipescan/

Schoenberg, R., 2014. *Fluid handling in medical device design.* [Online]
Available at: https://www.todaysmedicaldevelopments.com/article/tmd0814-fluidics-design-trends/

Sensorex, 2020. *Agriculture & Hydroponics.* [Online]
Available at: https://sensorex.com/agriculture-hydroponics/

Smart Water Magazine, 2021. *SEKO revolutionizes swimming pool water quality monitoring.* [Online]
Available at: https://smartwatermagazine.com/news/seko/seko-revolutionizes-swimming-pool-water-quality-monitoring

Statista, 2022. *Coffee - Italy.* [Online]
Available at: https://www.statista.com/outlook/cmo/hot-drinks/coffee/italy

UNI Ente Italiano di Normazione, 2016. *UNI 10637:2016: Piscine - Requisiti degli impianti di circolazione, filtrazione, disinfezione e trattamento chimico dell'acqua di piscina,* s.l.: s.n.
World Health Organisation, 2011. *Guidelines for Drinking-water Quality,* s.l.: World Health Organisation.

Source for percentage of public water providers in Italy: https://www.agi.it/fact-checking/acqua_gestione_pubblica_privata-5025926/news/2019-02-20/

Nielsen Norman Group , UX Prototypes: Low Fidelity vs. High Fidelity - https://www.nngroup.com/articles/ux-prototype-hi-lo-fidelity/

The Specialty Coffee Association (SCA), The SCA Water Quality Handbook. Part One: A systematic Guide to Water Fundamentals, 2019

The Specialty Coffee Association (SCA), Towards a Definition of Specialty Coffee: Building an Understanding Based on Attributes, 2021

The Specialty Coffee Association (SCA), SCA Standard 310-2021. Home Coffee Brewers: Specifications and Test Methods, SCA Coffee Equipment Series, 2021

Hermantoro, Suparman, Dominikus S., R. Rahutomo, T. Suparyanto, B. Pardamean : IoT Sensors Integration for Water Quality Analysis, in ICCSAI 2021: 1st International Conference on Computer Science and Artificial Intelligence, 361-364, 2021

8. Appendix

The Web of Water team consists of one industrial engineering student, an architecture student, two design students, an electronic engineering student, a computer engineering student, a mathematical engineering student and a cinema and media engineering student. Given the wide variety of skills and study backgrounds of the members, the project was carried out with a unique overall vision, and through many different points of view. Two resources in particular were used in the experimental work in the laboratory for the tests with the sensors and the realization of the prototype, directly at the physical headquarters of Fluid-o-Tech in Corsico (MI), with the precious collaboration and supervision of Fabrizio Tessicini and the engineers of the innovation team. Two other resources were used for the most high-level study of the system, from the point of view of user experience, as well as for the realization of the prototype of the platform and other multimedia content useful during the project timeline. The other components were engaged in the design of the business model in all its aspects and in all its phases.

At every stage of the project, however, the attention of all members was perpetually directed. Communication was guaranteed by online meetings organized weekly and by monthly or bimonthly meetings organized with the tutors of the polytechnic and the collaborators of Fluid-o-Tech, getting more frequent and intense from the period of the ASP winter school 2021 (July 2021).

The first phase of work focused a lot on benchmarking, which taken the team busy for the first months, through the analysis of various market solutions and various fields of interest, and the realization of numerous business models canvas, that summarized the solutions encountered. This research work took shape thanks to the use of online collaborative tools such as Mirò and Milanote, and was gradually guided by tutors through periodic meetings and deadlines. In the section dedicated to the state of the art of this report, only a partial trace of this work has been reported, as many were the ways analyzed and then abandoned partially or fully, such as the idea of applying the Web of Water on reverse osmosis filtration systems, or that of creating a digital "certification" that would guarantee the quality of the water.

As this research progressed, the team stored technical information relating, for example, to the physical and chemical parameters of interest to water quality, which then proved useful in the realization of the system. Progressively, the coffee market has increasingly attracted the attention of the team and Fluid-o-Tech, also thanks to some interviews organized with producers like Nuova Simonelli. Numerous interviews have also been organized with other companies in other sectors, still related to water quality, such as Wallmart, Acqua System Italia, Cimbali, and other experts in the sector, put in contact with the team also thanks to the intercession of the company. The choice of the coffee sector came with the total understanding between the team, the company and the tutors, as it was considered an interesting field of application. Starting from 2022, therefore, the business model has been defined more clearly, tests have begun with the purchased hardware and the first wireframes of the platform have been realized.

As for the expenses made, most of the budget was first used for the purchase of the instrumentation (sensors, programmable microcontrollers and other hardware pieces). After the occurrence of some problems in the shipment from the United States, the seller gave the team back the money spent and was taken the decision, with the academic and the external tutors, to build the prototype with the hardware provided by Fluid-O-Tech. Part of the budget was then allocated for travel expenses, especially for those who went to the site or to events of interest to the project. Also valuable was the purchase of the SCA Water Quality Handbook, published by the Coffee Excellence Center at Zurich University of Applied Sciences, which focused precisely on the quality of coffee. The book has been carefully read and analysed by the team, on the advice of Fluid-o-Tech, to stay updated on the state of the art.

The following GANTT chart summarizes the macro-phases of the project.