# Development of an IoT sensor for legionella prevention

**Irene Verduijn** | Master thesis report


Integrated Product Design | Delft University of Technology

# Executive summary

Legionella is a serious thread to public health. For a lot of facilities, obligated water safety plans need to be executed to minimise the chances of a legionellosis outbreak. Unfortunately, these water safety plans are not always executed properly.

With the stoppage sensor of Octo Facility Management, there is an opportunity to create a difference in public health, by making it more convenient to execute these water safety plans. Tap points within these facilities need to be weekly flushed for at least two minutes to make sure there is no stagnant water in the water pipe system. The sensor registers if a tap point is used, eliminating the tap points that already have been refreshed during the week. This method can save a lot of water, time and money, and also creates a much better overview of actual risks of legionella contamination in buildings. Subject to this graduation project was to improve the technical performance and usibility of the sensor.

The new generation sensor is improved in usability, by creating a vision for the installation process and general use of the product. Guiding the user with a step-by-step guide through the installation process, the user is able to install the sensor without the help of Octo. The sensor itself is designed in a way that it is easy to install and easy to understand by colour coded clamps.

With the use of a reference sensor the sensor output can be validated to meet the legionella prevention regulations. New use of data can also initiate the discussion in how the regulations can be interpreted differently.

***Development of an IoT sensor for legionella prevention***

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# 1. Glossary

## Abbreviations and jargon:

### IoT
Internet of Things, a network of connected products and systems that work together as a whole

### Legionella
Group of waterborne bacteria that can cause legionellosis

### Legionellosis
Generic name of all types of diseases caused by legionella bacteria

### LoR
List of Requirements

### LoRa
Long Range, a low power wide area network that is used for IoT networks

### NTC
Negative Temperature Coefficient, a temperature sensor

### PCB
Printed Circuit Board, a board that contains all kinds electronic components and code

### RIVM
Rijksinstituut voor Volksgezondheid en Milieu, the Dutch National Institute for Public Health and the Environment

### WHO
World Health Organization

### Water Safety Plan
A plan, specific for each facility, that covers the measurements to keep the water in a building safe

## What I mean with:

### Tap point
A point in the water system where water can be tapped (not necessarily a faucet)

### Flushing
When a tap has ran long enough to meet the legionella prevention regulations

### Use of a tap
When a tap is used, but not necessarily a flushing

### The sensor
The physical sensor, including the housing, PCB and NTCs.

### The product
The product in its whole, including the sensor, dashboard and mobile application

# 2. Introduction

At the time of writing this report (July 2020) the world is captivated by a worldwide virus-pandemic caused by COVID-19. Schools, gyms, swimming pools, restaurants, entertainment venues and so on have been closed for months by government decisions. People all over the world are told to stay at home as much as possible. Why this is relevant for this project? Hundreds of buildings are barely used or even empty, and Legionaries' disease-outbreaks are lurking if no action is taken.

Legionnaires' disease (Veteranenziekte) is an illness caused by Legionella, a group of water borne bacteria. It is a form of pneumonia that can be fatal, especially for elderly people and people with health issues (WHO, 2018). Until today no cure is available. This is why Legionella prevention policies are so important.

In the Netherlands, building owners are obligated to perform an active legionella prevention policy. Water taps that are not used frequently need to be flushed weekly to prevent legionella from developing in water systems. This process is sensitive to errors and takes a lot of time and water. Octo, specialised in IoT solutions for facility management, saw a business opportunity to develop a sensor that takes care of a big part of this process by eliminating tap points that already have been flushed. This so-called stoppage sensor has the potential to save these facilities a lot of water, time and money, and create a better overview of the legionella risks in general.

This project focusses on further developing the sensor of Octo and translate it to a real product that is reliable, user friendly and feasible for the scale of production.

This report covers the analysis of legionella prevention and the original stoppage sensor of Octo. In addition of that, extra research has been done to get insight in the steps that need to be made, to proof the sensor meets the legionella prevention regulations. With those insights a product proposal was created, including both the installation and use of the product and the physical sensor itself.

# 3. Assignment

The goal of this project is to (further) develop a sensor that will help prevent Legionella risks in buildings and facilities making use of IoT systems. This sensor should be easy to install, use and maintain by the customer himself. The two main themes during the process were the functionality and usability of the product.

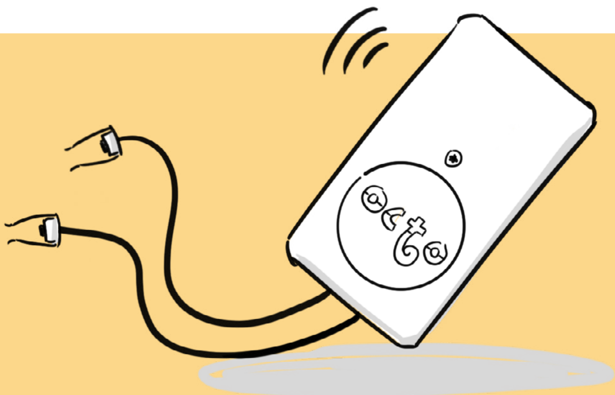
In the initial graduation proposal (Appendix A) quite a big part of the assignment was to do an impact analysis. However, during the analysis was found that there were still a lot of questions about the reliability of the sensor. The decision was made to further research the functionality and reliability of the sensor.

Since there is only a limited amount of time within this graduation project, the impact analysis was discarded from the assignment. More thorough research was done about the reliability and how to cope with regulations.

The ambition for this project was to reach the end of the embodiment stage of product development. At the end of the project, there will be a fully working prototype/demonstrator that as close to the final product as possible.

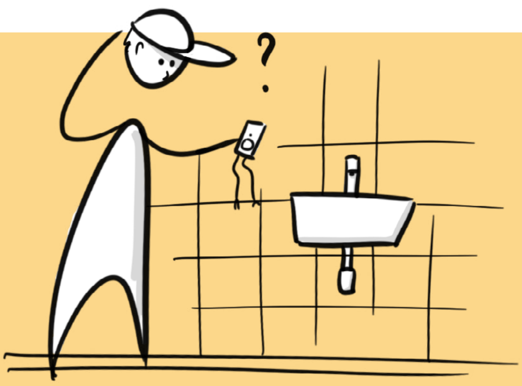
### Technical performance

*How can be ensured the legionella sensor is a reliable device that meets the legionella prevention regulations?*



### Usability

*How does the product look like when it is easy to install, use and maintain for the user and provides all data and analysis the user needs?*



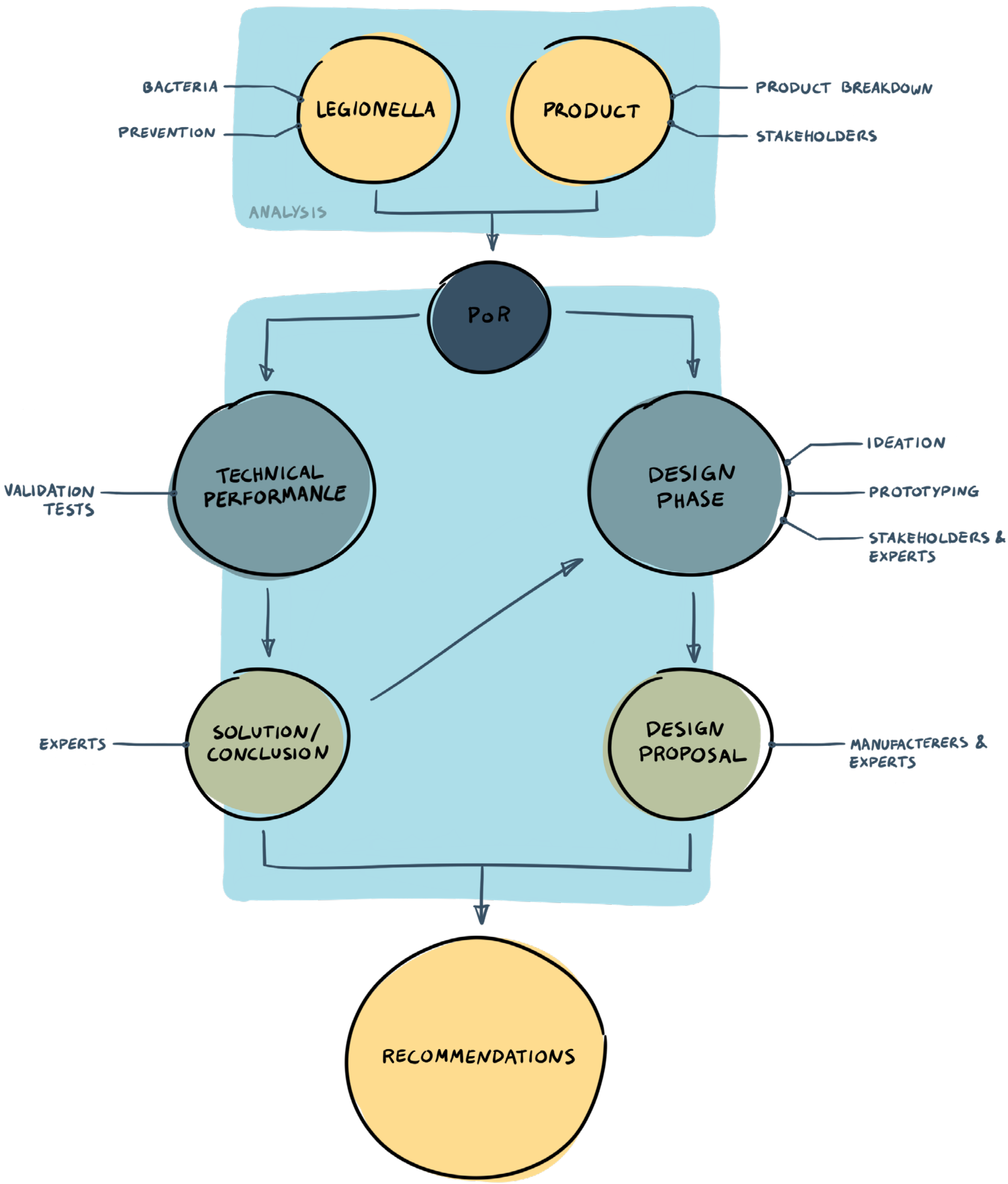
## 4. Problem definition

# 5. Method & process

The structure of this project is visualised in the image below. The project was started with an analysis, covering roughly two main subjects: legionella related and product related. The insights of the analysis where used to compile a List of Requirements. From there the project split in two parts: validating the technical performance, and redesigning the sensor and its use.

In all stages of the process experts, including stakeholders and manufacturers, where consulted to gain insights and validation.

At the end of the project recommendations were formulated to secure the future succes of the product.



# Analysis

The first part of the analysis is focussed on gaining insight in the subject of legionella. What is legionella, why is legionella prevention needed and how is it done? Next to that, a thorough analysis was done about the stoppage sensor of Octo and opportunities for improvement.

# 6. An introduction to Legionella

The stoppage sensor that is the subject of this project is meant to support the prevention of legionella outbreaks. In this analysis, a brief introduction to legionella and Legionellosis is given to get an understanding in the relevance of legionella prevention.

Legionella is a group of bacteria that can cause serious illnesses in humans. These illnesses are grouped under the name Legionellosis. The species that is most known to cause Legionellosis and is present in natural sources of water and soil. The quantities of these bacteria are mostly harmless, but can grow if circumstances are beneficial for the bacteria. With large quantities of Legionella bacteria people can get infected by it.

## Risks in artificial water systems

Within artificial water systems bacteria (including legionella) can grow and spread quite well within protozoa (single-celled eukaryotes) and biofilms. Biofilm consists out of slime that sticks to the surface of a water pipe, and forms an ecosystem with micro-organisms that are naturally present in water. Biofilm emerges when the water is stagnant. (WHO, 2018)

The optimal temperatures for growth and survival of legionella bacteria are between 20°C and 50°C. Below and above these temperatures the bacteria are dormant. Above temperatures of 60°C the bacteria die. (WHO, 2018; RIVM, 2019)

## Legionellosis

Infection of legionella happens by inhaling contaminated (vaporised) water or soil. Most people will not get sick after being infected by Legionella. Risk groups are elderly people, people who smoke, people with health problems and people with a reduced resistance. (WHO, 2018; RIVM 2019)

There are roughly two forms of legionellosis: Legionnaires' disease and Pontiac fever. Legionnaires' disease is a serious form of pneumonia (lung infection) and can be fatal for the risk groups. Pontiac fever is an influenza-like illness and considered to be not fatal. (WHO, 2007)

Many patients that survived the Legionnaires' disease suffer from long-term health issues and chronic fatigue (van Loenhout, 2014).

According to the RIVM (2019), there are annually 300 to 400 cases of pneumonia caused by Legionella in The Netherlands. These actual numbers are most likely higher, since not all cases are reported or are hard to properly investigate. These numbers are increasing and even doubled in the past years, but it is hard to say if this is caused by an increasing number of infections or a better registration of the infections (RIVM, 2019).

## Conclusion

Legionella can cause serious illnesses for which some no cure exists yet. With the increasing amounts of cases it can be said that this subject becomes even more relevant over time.

This is why prevention of legionella growth is important. Therefore, the chances of biofilm emerging need to be eliminated. In the next chapter is discussed how this needs to be done.

Additional information can be found in Appendix B.

# 7. Legionella prevention

Since the Legionella bacteria are present in natural sources of water it is hard to entirely eliminate it from the water in the mains water network. This is why Legionella prevention is crucial.

## Legionella risks in water systems

Stagnant water with the right temperatures create optimal circumstances for bacteria to grow and for biofilm to arise.

The biggest risks in artificial water systems are listed below. These situations must be prevented as much as possible.

- Stagnant water.
- Water temperatures between 20°C and 50°C.
- Dead ends of the pipe system. Within these dead ends the water is mostly stagnant. Therefore creating a big enough flow to prevent biofilm from arising is nearly impossible.
- Warm and cold water pipes too close to each other. This can warm up the cold water pipe or even cool down the warm water pipe to reach a temperature between 20°C and 50°C.

## Dutch legislation

After the outbreak in 1999, the Dutch government introduced a legionella prevention policy for all public facilities (RIVD, 2019). Over time this policy changed due to more research in risk factors. Nowadays the regulations only apply to certain facilities. These facilities are places where people with a weaker health stay or where vaporisation of water is likely to happen, like hospitals, elderly homes, swimming pools and cooling towers. For these facilities it is by law obligated to practise an active Legionella prevention policy.

These so called priority facilities have to meet the following measures in according to prevent a legionellosis outbreak (Drinkwaterwet, 2009; ILF, 2012).

- A risk analysis has to be done by a certified company
- Having a water safety plan (beheersplan)
- Keeping up a logbook of temperature and flushing rounds
- The water needs to be checked for Legionella at least twice a year
- If the colony-forming units per litre (CFU/L)

- exceeds 100, actions need to be taken to reduce the CFU
- If the CFU/L exceeds 1000 this should be reported to the inspection of the government and the users of the water

Non-priority facilities that provide drinking water are obligated to make sure the water in their system is safe. This is called the “zorgplicht” (duty of care) (Drinkwaterwet, 2009). They will not get inspected, but still need to make sure no legionella outbreak occurs.

This means that, apart from the priority facilities, a lot more facilities execute legionella prevention measures.

## Legionella prevention in practice

There are several legionella prevention methods, these are discussed in Appendix C. The method that is mostly used is temperature control and the prevention standing still water, and is the focus of this project.

This method means in practice that certain tap points in a building need to be flushed and checked on temperature every week. Kiwa Compliance, a company specialised in safety and quality marks, was consulted to gather more information about this way of prevention. There are two scenario’s that make it necessary to perform a flushing of a tap point:

- A tap point is not or barely used
- A tap point is at the end of the water pipe network

For these tap points one of the following requirements need to be met:

- The tap point needs to run until the water reaches a constant temperature. From that moment the tap point needs to run for two more minutes. In a big building this can take up to 10 minutes. This needs to be done weekly.
- The pipe part that connects the tap point with the nearest junction in the pipe network needs to be refreshed at least three times a week. This is the case when a flow is detected and the temperature corresponds with the temperature of the water entering the building (cold water) or the temperature the boiler is set to (warm water).

Employees from Octo and expert Tim Schmidt

(Appendix D) from Rentokil Hygiene were consulted to gather information about the issues that are involved in this method of legionella prevention.

The method of weekly flushing as described above takes a lot of time. The logbooks are often still on paper and therefore sensitive to errors. These flushing rounds are sometimes executed by an external company, sometimes by the facility itself and sometimes a bit of both. Especially when people of the facility itself are involved confusing situations can occur (RIVM, 2012). Examples of people who are involved in this are: caretakers, cleaning staff or technical staff. They are not schooled for the job and often lack knowledge, motivation and time. This results in poorly executed prevention policy.

Schmidt states that often forms of flushing rounds are not filled in properly or not filled in at all, according to Schmidt. Places where temperature measurements need to be done are sometimes hard to reach. To save the hassle, forms for these temperature measurements are sometimes already filled in for the years to come, without actually performing the temperature measurements. On top of that, owners of facilities are not willing to report an exceeding value to the government, although it is obligated. Consequences like a bad reputation or mandatory closing may be too big to take this risk. This is one of the reasons there is no good overview of the actual numbers of legionella contaminations.

## Conclusion

Legionella is a serious thread to public health. A proper water safety plan is needed to minimise the chances of a legionellosis outbreak. These water safety plans are not always executed properly.

There is an opportunity here to create a difference in public health, by making it more convenient to execute these water safety plans. The sensor could not only take over some of the work, but also create a much better overview of actual risks of legionella contamination in buildings.

# 8. Stakeholders

In this chapter the main stakeholders of this project are discussed. These include me, OCTO, Actemium, Octo's clients and the user. Several user groups are introduced to get a better understanding in their needs.

Figure 1 shows the stakeholders of this project. The clients and users in this figure are exemplary, and showing the diversity of the clients and users of the product.

### Octo

Octo is the client for this project and the owner of the product. Octo is a company that uses IoT solutions to make buildings smarter. They use a range of sensors to measure data like building occupancy, indoor climate and air quality. This data is presented in a dashboard for building and facility managers to help them make informed decisions on facility and asset management.
Octo started with the development of the Legionella sensor after visiting an elderly home. At the moment they were inside someone was performing

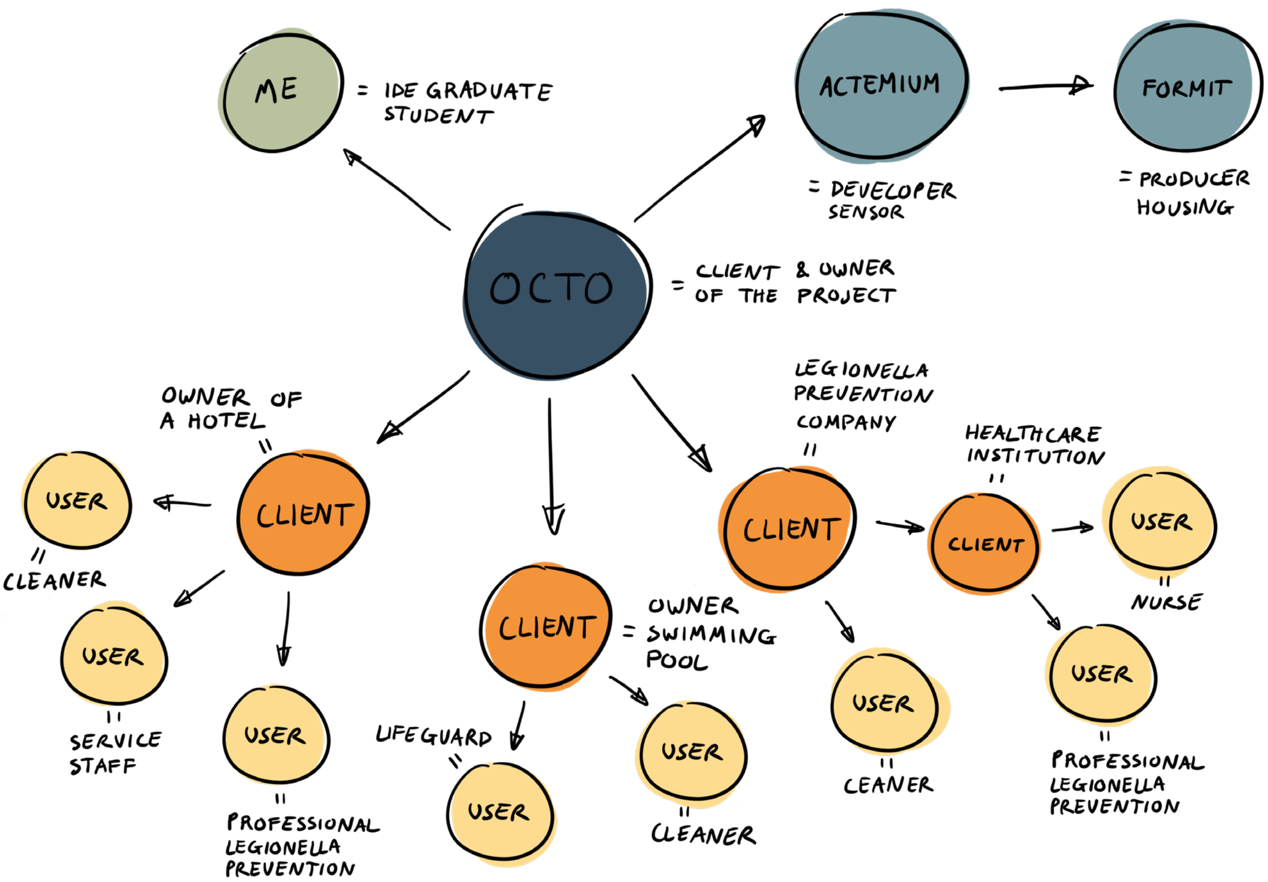



*Figure 1. Overview of the stakeholders of this project*

the Legionella prevention procedure. That is when they saw a business opportunity in facilitating tools for Legionella prevention policies.

## Actemium

The current sensor is developed and produced by Actemium. Octo decided to collaborate with Actemium because they have both the resources to develop the electronics of the sensor, as well as the facilities to produce it. For this project there has been contact with the project leader of the sensor within Actemium, Stijn Martens.

## Clients of Octo

These clients can be separated in two different categories: companies that have to deal with Legionella prevention in their own facilities and companies that are specialised in Legionella prevention. These clients can be a user as well, but not necessarily. For example, it can occur that a client is responsible for the legionella prevention of a building without being the one that actually executes it.

## User

Experts within Octo, Rentokil and Kiwa Complience were consulted to get insight in the potential user. It was concluded that the users of the product are a diverse group with different backgrounds and professions. They can vary from professionals in the field of legionella prevention to people that have these tasks next to their actual job. The users are devided in three different user groups , that are are presented on the page right. This visual includes the specific benefits the specific user group can experience from the sensor.

## Conclusion

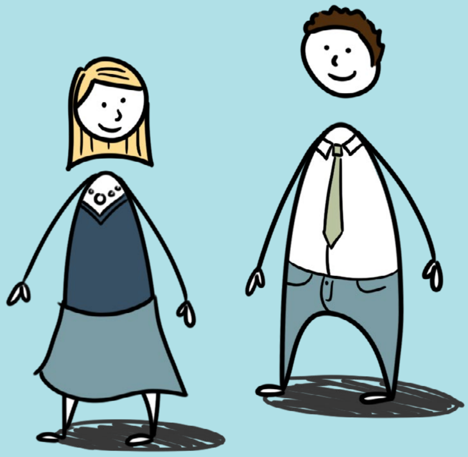
With a diverse group of users it is important to design a product that is understandable for a broad range of people. The user groups defined in this chapter will be included in the further development of the use and installation of the product.

## The different user groups of the product and their potential benefits

### Facility owners and managers

They are responsible for the execution of the water safety plans and need to make sure their buildings are legionella free.

- Have the overview of legionella risks in all buildings
- Easily report a logbook to the inspection
- Save money by reducing the time it takes
- Reduce the risks of a legionella outbreak



### Legionella prevention professionals

They are specifically tasked with the execution of water safety plans and are most of the time an employee of a specialised company.

- Be more efficient in their job, getting more buildings done in the same time
- Get more insight in what needs to be done and when
- Improve communication with their colleages and supervisors

### Professionals in other fields

They are professionals in a whole different profession and do the legionella prevention tasks on top of the tasks of their actual job. They often lack knowledge, time and motivation to do so.

- Save time to focus on their primary tasks
- Get more insight in what needs to be done
- Improve communication with their colleages and supervisors
- Reduce annoyance of unwanted tasks

# 9. Original stoppage sensor

In this chapter the current sensor of Octo will be analysed. How does it work? And what choices were made during the design? Several experts were interviewed to get a good overview of the product.

## Working principle

The stoppage sensor of Octo (Figure 2) recognises a water flow by detecting temperature differences. The sensor has two thermistors (NTC's) that are attached to the water pipes close to a water tap. One is attached to the cold water pipe, the other to the warm water pipe (see Figure 4). When a tap point is used, a change of temperature will occur. This is because water in a water pipe will cool down or heat up till it reaches the room temperature. If a tap point is used, colder (cold water pipe) or warmer (warm water pipe) water enters the pipe and a temperature change is notable. With the NTC's these differences can be measured, and the use of a tap point can be recognised. Octo has registered a patent for this use of data (Huibers, 2017).

The temperature gets measured every second. If the difference with the previous measurement is bigger then the delta threshold (in this case 0,25 °C), the sensor gets triggered. If a trigger takes place three extra data points will be registered by the sensor. With this information it is possible to analyse if the use of the tap could actually count as a flushing according to the legionella prevention legislation. If a flushing for both the cold and warm pipe is registered the tap point can be skipped in the next flushing round.

### Collected data

The sensor is connected to the internet by the LoRa network (Appendix E). Every 15 minutes the sensor

*Figure 2. The original stoppage sensor*

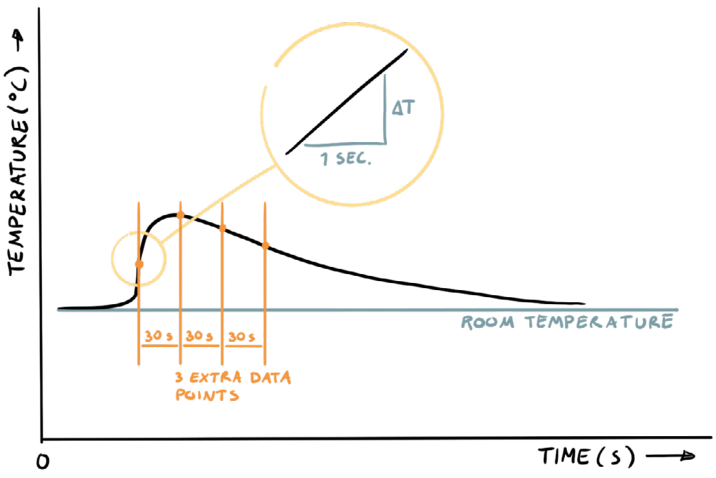



*Figure 3. Explainatory graph of the working principle*

sends the following information:

- Minimum temperature of the last 15 minutes
- Maximum temperature of the last 15 minutes
- Average temperature of the last 15 minutes
- If a trigger took place:
    - Time of the trigger
    - Temperature at that moment
    - Three extra data points (time and temperature)

This data is reachable through the online dashboard of Octo, where an overview is given of all tap points an its flushing status.This creates an overview for the user of where legionalla risks might occur and which tap points can be skipped in the next flushing round.

### Installation & use

To install the sensor the user first has to go through a few steps as described in the installation guide (Appendix F). This installation consist basically out of the following steps:

- Assembling the sensor
- Connect the sensor to the online Octo dashboard
- Place & install the gateway at location
- Place the sensor at location

The power is supplied by two lithium AA batteries. These have to be changed approximately once a year.

## Development prior to this project

The sensor has been developed by Actemium over a timespan of three years and is the third iteration. At first, the demand from Octo to Actemium was to develop a sensor that could measure if there was legionella present. Soon it was found out that it was not yet possible to measure the presence of legionella bacteria in water pipes in an easy way, so other possibilities to facilitate legionella prevention were investigated.

Two time-consuming obligatory tasks that need to be done within legionella prevention plans are monitoring temperatures and preventive flushing rounds. For this reason it was decided to develop a sensor that measures the temperature and use of a water pipe.

Important for any solution is that it takes little

Figure 4. Installed stoppage sensor

energy to run. The envisioned sensor was meant to be wireless and therefore depending on batteries.

### Detecting flow

Several methods to measure flow were considered during the development of the sensor. Actemium proposed the idea to use temperature measurement to detect water flow. For the purpose of Legionella prevention it is not necessary to know the exact flow-rate, as long as flowing and stagnant water can be distinguished. Actemium developed an algorithm that can detect a flushing with the temperature data of a water pipe. In cooperation with Octo they concluded that the use of an NTC (negative temperature coefficient) was most suitable for the sensor.

### Housing

The design and production of the housing was outsourced to Formit in Valkerswaard, the Netherlands. The aesthetics and user friendliness were no priority in this stage of the design process, so not much attention was paid to it. The housing is made of POM (polyoxymethylene) and processed by CNC milling. The reason that CNC milling was chosen is the low set-up cost for small quantities, since only 100-200 pieces were produced.

The sensor is attached on a flat surface nearby with double sided tape. Another possibility is to attach it to a pipe with a zip tie (see Figure 4).

### IoT connection

The LoRa network was chosen because it is cheap to use and is widely used. The LoRa netwerk also uses little engery, what enables a long battery life.

## Conclusion

The previous development of the sensor was mainly focussed on the detection of flow. Not much attention was paid to the installation process or use of the sensor. Octo has the ambition to deliver a product to the customer that can be installed and used without any help. This is why one of the focus points of this graduation project is to create a concept for that.

# 10. Opportunities for improvement

To find the design challenges of the project, a thorough analysis of the existing product was done. The insights of this analysis were used to formulate requirements for the new design of the sensor.

## Installation of the sensor

For the preparation of some tests it was necessary to install some stoppage sensors. This experience was simultaneously used to get insights in the installation process from a user's perspective. This was done by myself. The installation guide made by Octo was used to do this (Appendix F). Unfortunately I did not manage to do it without the help of someone from Octo, what made it clear that the installation guide could use a lot of clarification and the process could use some simplification.

Insights:

- The installation guide is not user friendly and unclear. For example, the installation guide refers to two other guides to follow during the process. The guide is also made for the employees of Octo, not for an external user.
- The installation process is not easy to understand. Without experience, it is hard to figure it out by yourself.

In the paragraphs that follow, the specific problems per installation step will be discussed.

### Install LoRa gateway

A LoRa gateway needs to be installed to get a better coverage of the LoRa network at the environment you want to use a LoRa sensor. No big issues were found doing this. Though it would be nice not having to use an extra device to use the sensors.

Insight:

- Use the sensor without the use of a gateway would be more sustainable end cost-efficient. One link in the network less will also reduce the chance of problems in the whole system.

### Register sensor to the LoRa network

The sensor needs to be registered at the console of The Things Network (The Things Network Console). To do this the Sensor ID needs to be retrieved from the LoRa module, and the network ID needs to be

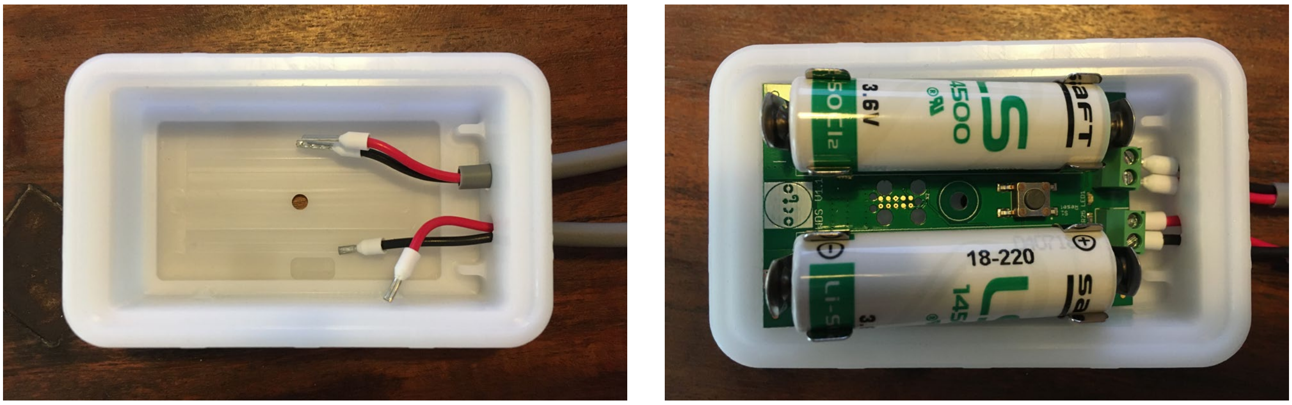



*Figure 5. Left: Cables through the holes of the housing. Right: PCB does not fit in the housing because the pins of the cables are too long.*

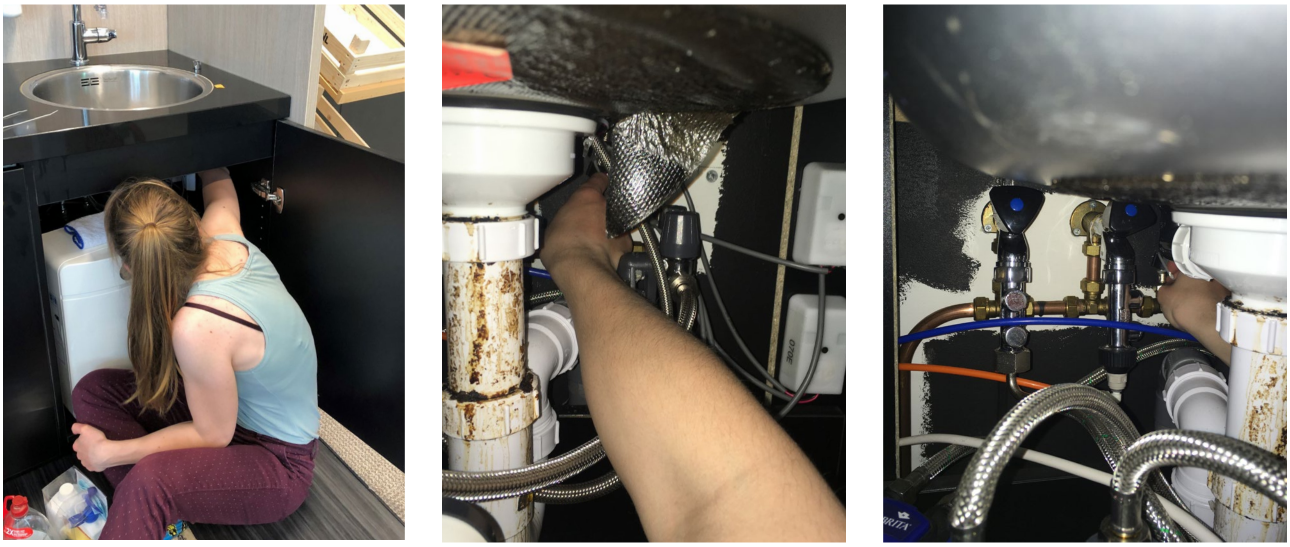


*Figure 6. Installation of the stoppage sensor at the pantry of BAM. The water pipes are sometimes hard to reach.*

retrieved from The Things Network to program in the LoRa module. After that the sensor is connected to the LoRa network. To do this, a special tool is needed to program the sensor (see Appendix F). With this step quite some help from an employee of Octo was needed. Another programming software was needed.

Insights:

- This step is not easy to understand and time consuming. It would be a big improvement if this step could be outsourced. For example by pre-programming the sensors.

### Register the sensor to the Octo dashboard

The Octo dashboard is already frequently in use by Octo and their clients, and show the results of all kinds of sensors that Octo offers. This dashboard works fine, but can be optimised for the different user groups.

- Make different interfaces for the different user groups.
- Develop a mobile application.

### Assembling the sensor

The assembly of the sensor is now done by employees of Octo. The cables of the NTC's need to be connected to the PCB. To do this, the cables have to be put through the holes of the housing (Figure 5, left). The pins at the ends of the cables are too long to fit properly in the housing (Figure 5, right) and need to be cut down.

Insights:

- The ability to assemble the electronics before putting it in the housing would be more efficient.
- The ability to assemble the cables to the PCB without using a screwdriver would save time.

### Mounting the sensor and NTC's

The mounting of the housing can be done in two ways: by sticking it with double sided tape to a surface nearby the water pipes, or by strapping it to one of the pipes with a zip-tie (Figure 4 , page 22).

There is not always much room to move. As can be seen in Figure 6, only one hand could be used to attach the clips with the NTCs to the pipes. With the flexible pipes the clips do not fit and zip ties are needed to make sure the NTCs do touch the pipe.

Insights:

- Using the zip-tie looks unprofessional and feels clumsy.
- Using double sided tape can harm the surface it sticks to, makes it impossible to translocate the housing and comes of easily.
- It would be beneficial to place the NTC's with one hand since the pipes are sometimes hard to reach.
- The clips of the NTC's only work for a small range of pipe diameters. Making the attachment of the NTC's suitalble for a bigger range of diameters would be a big improvement.

### Maintenance

No maintenance was needed in the time the sensors were tested. Therefore the experience from people from Octo was consulted to get an insight in this.

Insights:

- The battery needs to be replaced after a year of use (in worst case).
- The use of a screwdriver to open and close the housing is not convenient.
- It is sometimes hard to find back the exact spot the sensor is installed.
- It seems to happen that sensors sometimes break down because of water damage.

## Technical performance

People from Octo and Stijn Martens from Actemium were consulted to gather information about the technical performance of the sensor.

### Data collection

Soon it was found out that there were still uncertainties wether the sensor did perform good enough or not. For this reason, it was decided to perform a validation test further in the project.

Insights:

- There are still issues with the measurements of cold water pipes.
- There are differences in measured temperature for the different types of pipe (copper, plastic and flexible pipes).

### IoT connectivity

Dutch telecommunications company KPN claims to offer a nationwide covering LoRa network (KPN, n.d.). This sounds promising, but in practice it can still cause trouble connecting the sensors. Martens stated that not all areas in the Netherlands are covered equally well. Next to that, sensors that are placed indoors or installed at places with a lot of sensors are sometimes hard to reach through the network. This is why the use of LoRa gateways is needed to create better coverage.

Insights:

- Other IoT networks than LoRa are probably more suitable to use.

## Conclusion

It can be concluded there is a lot of room for improvement concerning the stoppage sensor of Octo. The technical performance and usability seem to be most critical to the succes of the product. This will be the main focus of the project as well.
All insights of this analysis were added to the List of Requirements (Appendix H).

# 11. Additional annalysis

Some additional analysis were done that turned out not to be that relevant for outcome of the project, but are still worth mentioning. Other analysis were simply too short to spend a whole chapter on them. These analysis are briefly described in this chapter and put in the Appendices.

## Existing solutions & competitors

Existing solutions in the field of legionella prevention and the potential competitors of Octo were investigated. It was concluded that there are no direct competitors that offer the same functionallity as the stoppage sensor of Octo does. Octo distinguish itself by offering a solution that is applicable without having to change anything to the pipe system.

The full analysis can be found in Appendix G.

## Context references

Due to COVID-19 measurements, it was not possible to do an on-site research on what to expect of the direct environment the sensor will be placed. To still get a better overview of this, friends and colleagues were asked to make a picture of their own sanitary. Some examples of these can be found in Appendix L. This is not entirely representative for hotels, elderly homes, etc., but at least did broaden my perspective from my own home to over 50 reference pictures.

## Life Cycle Analysis

In the original assignment, it was proposed to do a Life Cycle Analysis (LCA) to get an insight in the environmental impact of the sensor. The question was if the water and energy that would be saved would outweigh the negative impact a electronic product has.

However, at the midterm was decided that the technical performance of the sensor had more priority then the impact analysis. Since there was only limited time within this project, the LCA was taken out of the assignment.

However, already some time was spend on it, and the results of that can be found in Appendix Q.

# 12. Main drivers

With all information gathered during the analysis of this project a List of Requirements (LoR) was put together (Appendix H). In this chapter the main drivers for the continuation of this project are described.

Pugh's checklist as described in the Delft Design Guide (2013) was used to structure the list and make sure it is complete. The LoR served as a guideline throughout the rest of the design process. Though the LoR is not fixed, since the design process is a dynamic process. Opinions on what is important, realistic, etc. may change throughout the project. Requirements may also become more concrete and quantified.

The LoR was also used as a communication tool with the client, Octo, to get to an agreement on the scope and expectations of the project.

Some extra columns are build in to show if a requirement was in the scope of this graduation project.

The main drivers are:

### Reliability

The most important thing is that the sensor functions well and meets the regulations for legionella prevention. Without that, the sensor will be useless.

### Usability

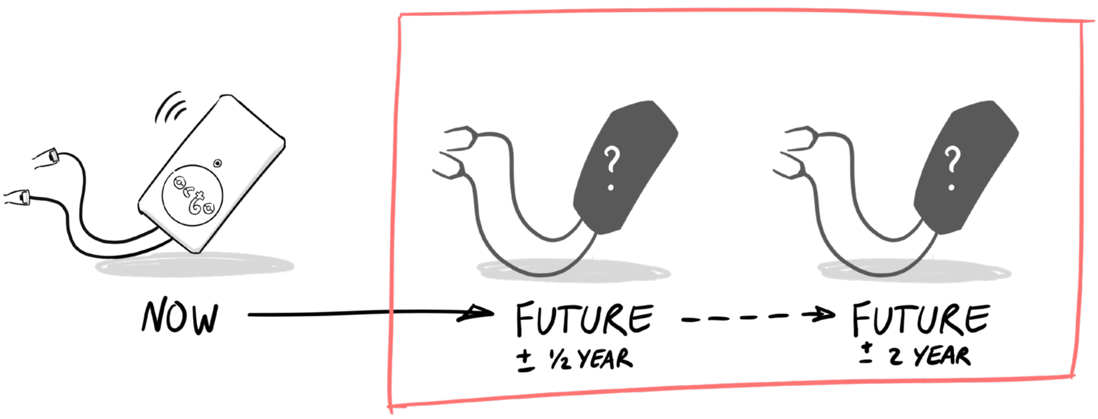
To make the user entirely independent from Octo it is important to create a product that is understandable and pleasant in its use.

### Feasibility

The first batch of products will be relatively small. For this reason it is important to specifically keep the producibility in mind. Too complex or too many parts can cause unnecessary costs that need to be avoided.

## Goals of the project

The LoR is put together in a way that there is room for a short and longer term design vision. The short term will be approximately the end of this graduation project. The longer term will be about two years from now. The product proposal at the end of this graduation project is a design that fits both scenarios. If the product is designed in a way that it can easily adapt (shape, size, etc.) Octo can bring out their product in the near future and improve their product without a lot of extra costs.



# Technical performance

# 13. Sensor data validation

During the analysis some questions arose about the performance of the sensor. To find out what problems there still were according to the functionality of the sensor, a few technical tests were done. The results of these tests were also used to give an answer to the question: does the stoppage sensor meet the requirements that are given by the Dutch government?

To get an impression on the preparations of the test, some pictures were included in Appendix I.

## Test 1: Accuracy test Octo sensor

*Do the registered flushings match the actual flushings of a tap point?*

This test was done to get more insight of the data collected by the stoppage sensors. This test was performed over a period of two weeks in my own apartment.

### Method

Two tests were done: one at the faucet of the kitchen and one at the faucet of the bathroom. At both locations two stoppage detectors were installed: one with the NTCs attached to the copper part of the pipes and one with the NTCs attached to the flexible part of the pipes.

At the kitchen a flow sensor was installed at the faucet. With an Arduino each use of the faucet was registered (Figure 7). With this flow sensor it was possible to detect if the faucet was used or not.

At the bathroom it was not possible to install a flow sensor. For this reason a analogue logbook was used to keep track of the use of the faucet.

The data of the stoppage detectors was compared to the data of the flow sensor and logbook.

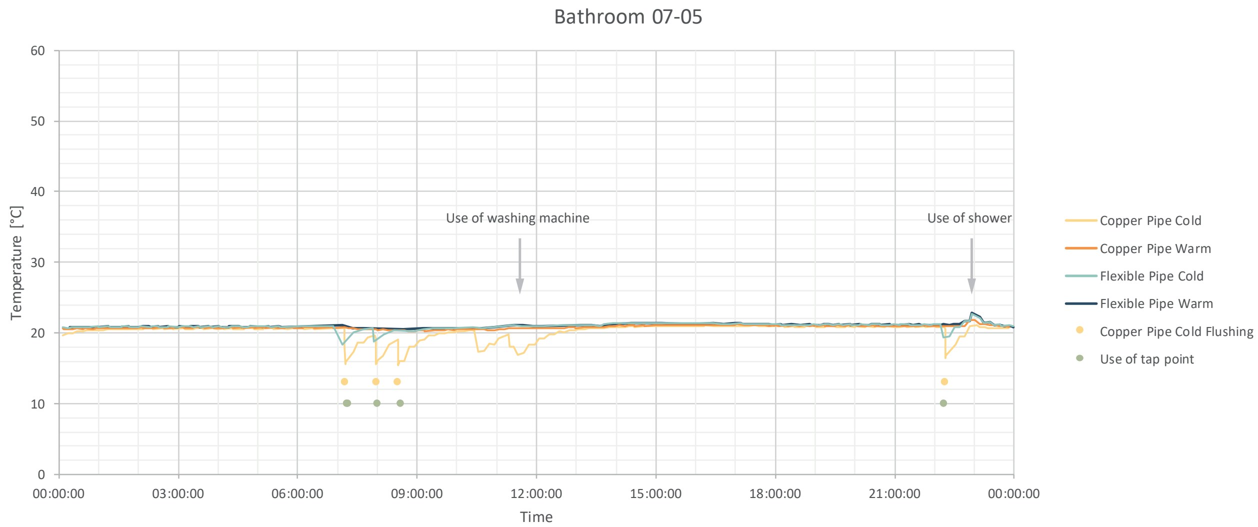
### Results

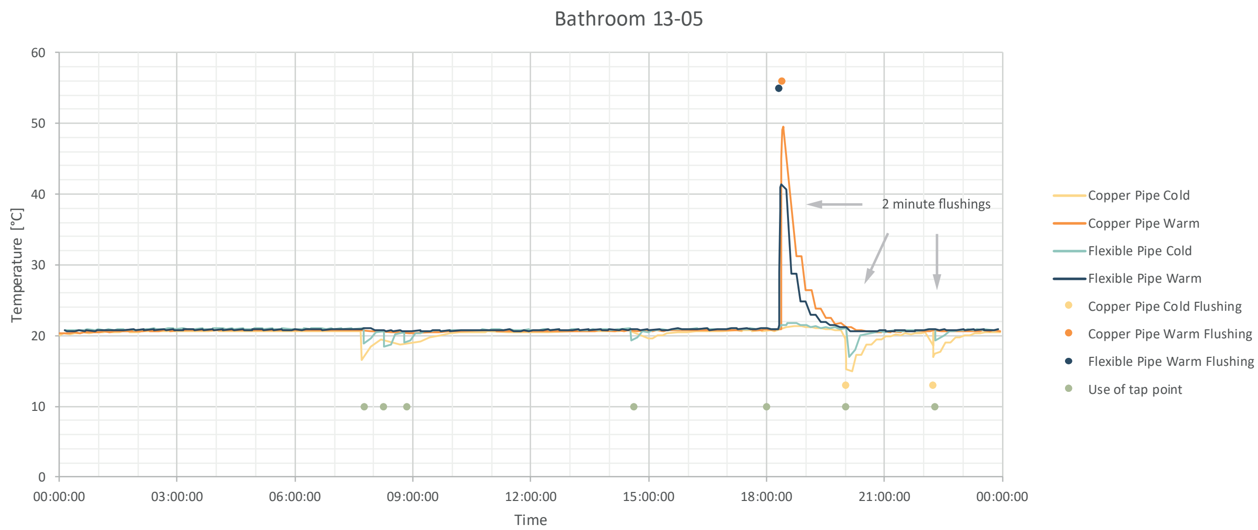
In the graphs at page 30 the most relevant results can be found. The lines show the temperature progression of the individual NTCs. The dots represent the flushing registered by the stoppage sensor. The green dots represent the times the faucet was actually used, registered by the flow sensor or logbook.

Several things stand out in these graphs. First of all, the NTCs attached to the flexible cold water pipe did not register a single flushing in the two weeks the data was collected.

At the graphs of the bathroom data two things are remarkable. As can be seen in graph Bathroom 05-07, a temperature drop around 11 o'clock and a temperature rise at 23 o'clock occurred without the tap point being used. After some more testing

*Figure 7. Test set up with flow sensor*

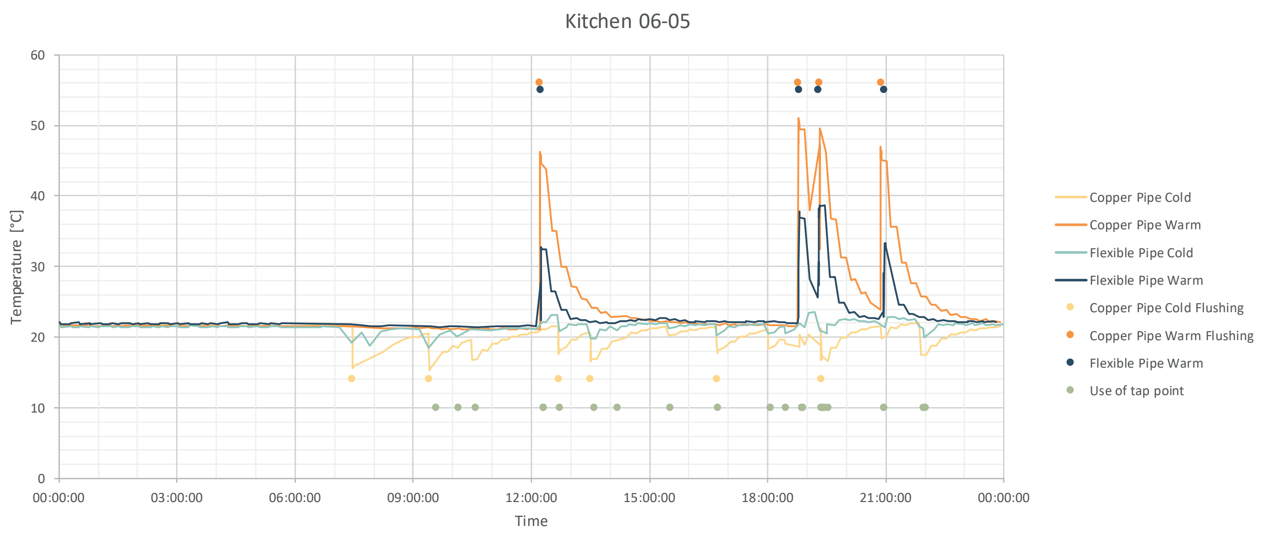


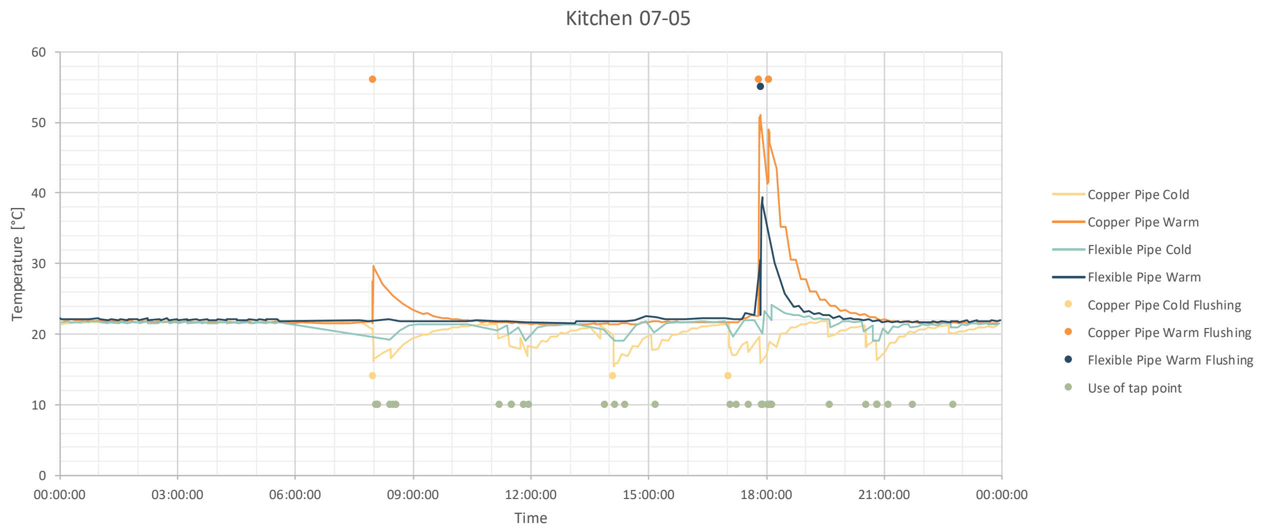




it was found out that these changes were caused by other external factors: the temperature drop by the use of the washing machine connected to the same main water pipe, the temperature rise by taking a hot shower. Neither of these influences were registered as a flushing.

Graph 'Kitchen 07-05' shows a small flaw in registering a flushing at the warm water pipe. The temperature barely reaches a temperature of 30 degrees Celsius, which by no means can be counted as a flushing according to the legionella prevention policies.

In graph 'Bathroom 07-05' a perfect performance of the stoppage sensor at the copper water pipes can be seen. Short uses of the tap point earlier on in the day are not seen as a flushing, yet the flushings of two minutes later that day are. The graph 'Kitchen 06-05' also shows good results. Though it is not possible to draw a conclusion from it, since there is no data of the extent of the use of the tap point.




## Test 2: Delta threshold settings

*Does changing the settings of the sensor improve the accuracy of the sensor?*

Before the start of this project, Octo already recognised the issues with the measurements on cold water pipes. The sensors that were used in Test 1 had a delta threshold of 0,25 °C. This threshold can be reduced, so it reacts more sensitive to the data. In this test several delta thresholds were tested. This test was done at the pantry of one of their clients, BAM FM.

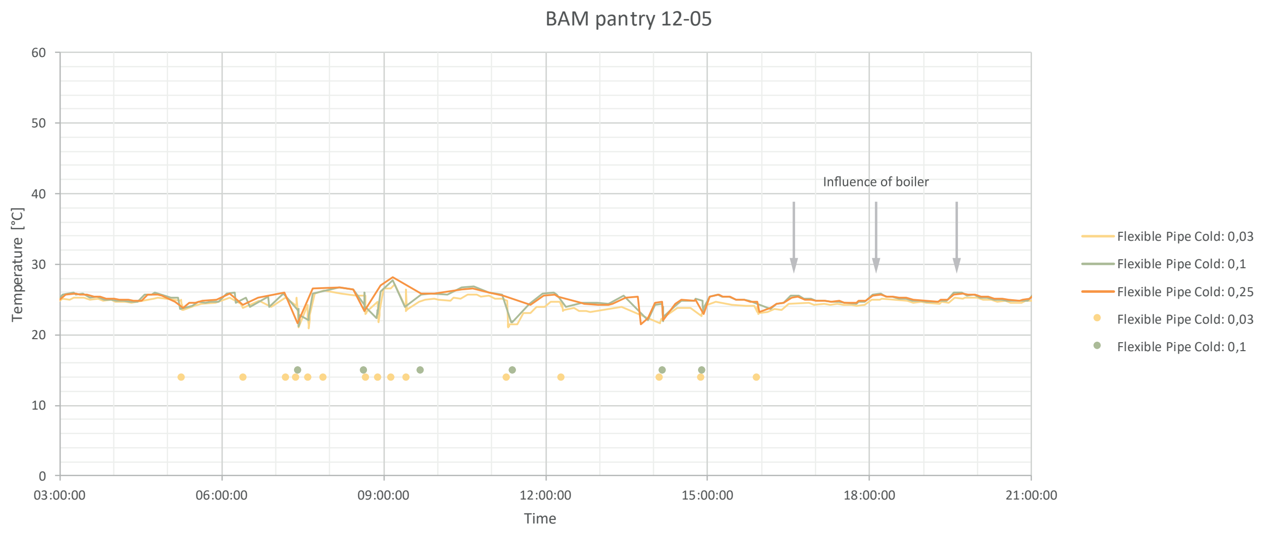
### Method

For this test the data of three sensors with different delta thresholds were compared to each other:

- 0,25 °C over a second
- 0,1 °C over a second
- 0,03 °C for three seconds in a row

Figure 8 shows the sensors being installed. As can be seen, the NTC's were attached to a flexible pipe, since no copper pipe was present to attach the sensors to. There are four sensors because

## Results delta threshold test




two sensors with a delta threshold of 0,1 °C were available.

The data was supposed to be compared with a flow sensor as well (the same set up as in test 1), but due to technical problems no data was recorded.

### Results

Since there were two sensors with a threshold of 0,1 °C only one of them was used to analyse the data. No big differences were found between the two. The data of the warm water pipes was also excluded since this test was performed to find the right settings for the cold water delta threshold.

The first thing that stands out is the wavy pattern that is easy to recognise if the tap point is not used. This is most likely caused by the boiler that was standing in the kitchen cupboard where the sensors were placed.

Again, no tap use was registered by the sensor with a delta threshold of 0,25 °C (the same result as in the previous test). Both the sensor with a delta threshold 0,1 °C and the sensor with a delta threshold of 0,03 °C did register tap use. The one with a delta threshold of 0,03 °C triggered quite some times, even though only a small temperature drop can be seen in the graphs. The delta threshold of 0,1 °C already shows a more realistic outcome.

## Test 3: Temperature progression

*How does the measured temperature progression differ with different types of water pipes?*

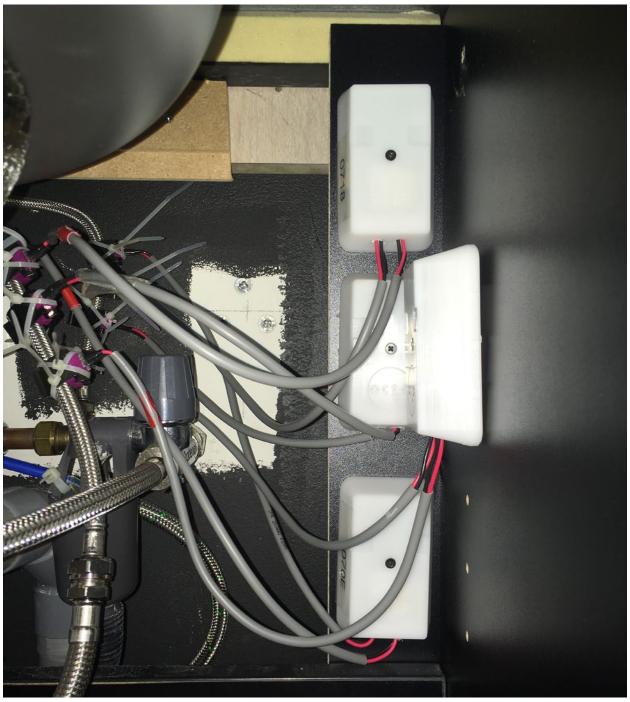
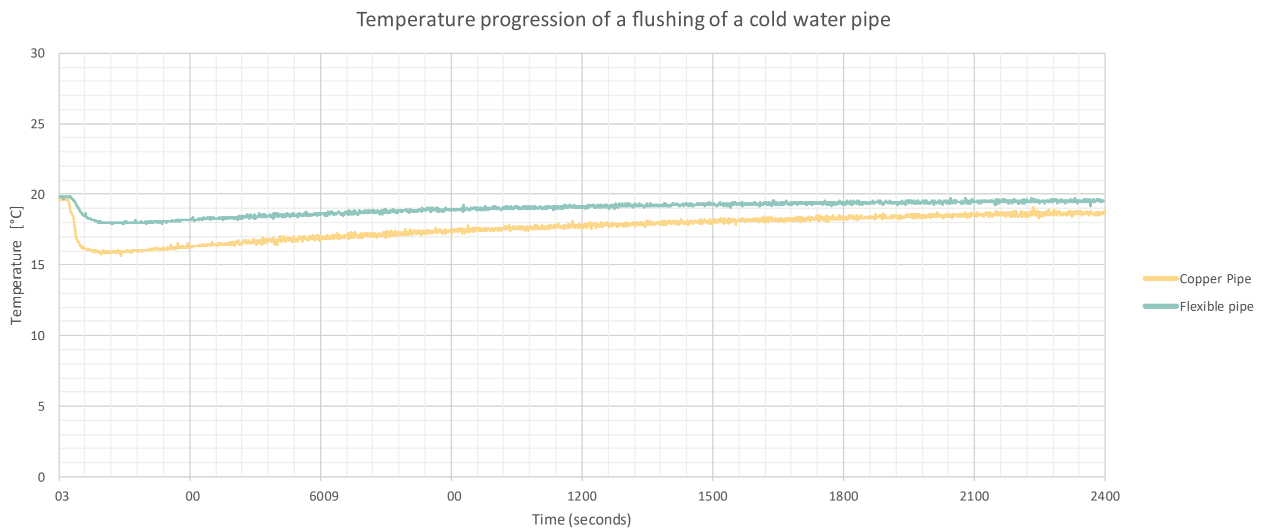


*Figure 8. Sensors installed at the pantry of BAM*

## Results temperature progression test




To get a better understanding of the temperature progression of a flushing of a cold water pipe, a third and quick test was done. Two NTC's were attached to the cold water pipe: one on the copper part and one on the flexible part. A data recording in Excel was performed to collect the data of a cold water flushing. The results of this can be seen in the graph above.

These kind of graphs can help to find the right settings for the delta threshold. What can be seen is that the measurements on the flexible pipe have a less steep temperature drop. This should be taking into account when determining the delta threshold.

## Conclusion

There are a few things that can be concluded from the data of the three tests:

1. A flushing of a flexible cold water pipe is hard to register with the stoppage sensor in its current form.
2. The registration of a flushing of a cold water pipe is not reliable enough. False positives do occur.
3. There are external factors that can influence the measured data, like a hot shower, boiler or connected water pipes.
4. The registration of a flushing of a warm water pipe has some minor flaws, but works for both materials of pipe.
5. The temperature drop (or rise) steepness differs for different water pipe types.
6. No conclusion can be made about what the right delta threshold for flexible pipes is yet:
    - A delta threshold of 0,03 °C seems to trigger too much.
    - A delta threshold of 0,1 °C gives better results on a flexible water pipe than a delta threshold of 0,25 °C.

What can be said is that it is not possible to prove the sensor registers flushings according to the dutch legislation as mentioned by Kiwa Compliance (Chapter 7).

In the next chapter possible solutions for the improvement of the stoppage sensor are discussed.

# 14. Improvements in technical performance

With the results of the perfomance tests in last chapter, possible solutions to validate the working principle were formulated in this chapter. The use of which IoT network should be used is dicussed as well.

## External influences

What needs to be thought of are the external influences on the temperature measurements. A change of room temperature (due to a boiler, hot shower, heater, etc.) will most likely not cause a trigger since there is a gradual temperature in- or decrease. On the contrary, a water flow in a pipe near a junction can cause a change in temperature and potentially a false positive flush registration (Figure 9). This can be solved through the instructions keep a minimum distance from a junction to place the NTC's. The recommendation will always be to place them as close as possible to the tap point as possible anyway.

## Solutions for validating the working principle

### Delta threshold

The delta threshold is a good start to recognise the use of a tap point, but does not make sure it is an actual flushing according to the legionella prevention regulations.

Additionally, the steepness of the temperature drop or rise differs for the different types of water pipe. A solution for this can be that there will be different delta thresholds for the different types of water pipe. In this research, only a copper and a flexible pipe were tested, and no optimal delta threshold was found yet. More research can be done to find out what the exact threshold needs to be for the different types of water pipe.

### Filter sensor output

An important thing to keep in mind is the possibility to filter the incoming sensor output at the platform of Octo. For example, the false positive of the warm

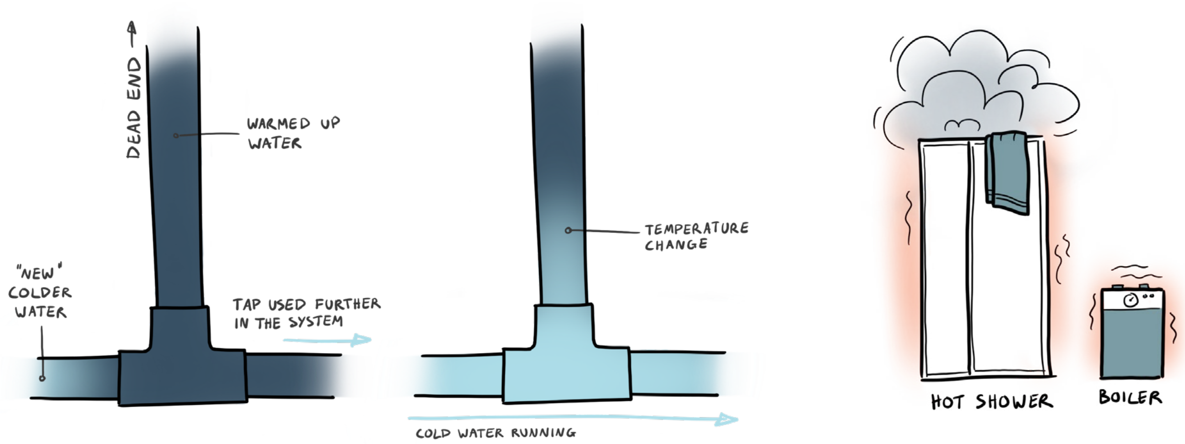



*Figure 9. External influences on temperature measurement*

water flushing in the graph 'Kitchen 07-05' can be filtered out quite easily by setting some conditionals. This could be: the water needs to reach at least 45 °C to count as a warm water flushing in a copper pipe. For a flexible pipe this should be lower, for example 35 °C.

For the cold water flushings this is a little bit harder. The fresh water coming in differs in temperature from building to building. Setting a minimum temperature would not work in this case. This can be seen in the graphs as well: in my own apartment the temperature measured at a flexible pipe during a flushing drops from 20 °C to 18 °C, while the temperature of the pantry of BAM FM never dropped below 20 °C. What could be interesting to look into is once the sensor is triggered by the delta threshold, another requirement can be used: the difference in temperature between the mean temperature (the room temperature) and the lowest temperature during the use of a tap point needs to be bigger than (for example) 1,5 °C (flexible pipe) or 4,5 °C (copper pipe). In Figure 10 this is visualised, including the formula that comes with it.

## Reference sensor

The use of a reference sensor in each building could make it possible to prove the stoppage sensor meets the requirements of the legionella prevention legislation. At the point were the water enters the building a sensor gets installed (Figure 12). This sensor will be used as a reference point for all the other sensors in the building. Does the water at a tap point reach the same temperature as the water that comes in? Than this tap use could be counted as a flushing. This is visualised in Figure 11.

The same sensor can be used for this purpose, but the data comming in will be processed differently at the Octo platform.

## Changing the rules

The use of this type of sensor is a new development in the field of legionella prevention. The regulations are based on the techniques that are used now, and that is a weekly temperature measurement and flushing round. With the stoppage sensor it can be proven that a tap point is used, for example, twenty times a week. Is that enough to conclude the tap

IF ($\Delta T_1 \geq$ *Delta threshold* AND $\Delta T_2 \leq$ *Minimum temperature difference*)

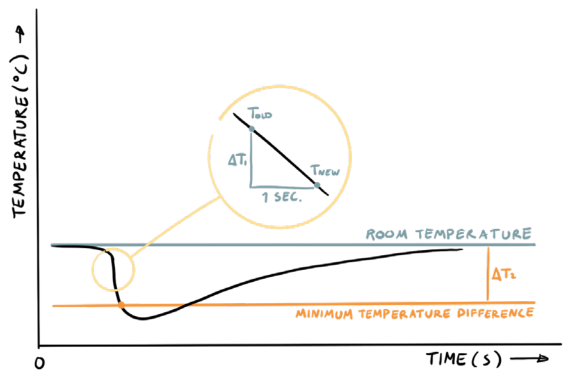



*Figure 10. Minimum temperature difference method*

IF ($\Delta T_1 \geq$ *Delta threshold* AND T $\leq$ *Temperature water entering the building*)

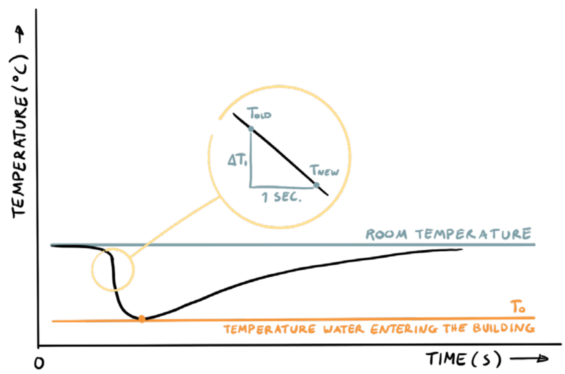



*Figure 11. Reference sensor method*

point is used often enough to be excluded from the flushing round that week?

There is an opportunity here for Octo to start the discussion with certified companies whether it is sufficient to proof a tap point is frequently used to eliminate it form the flushing round.

## Use of other IoT network

Stijn Martens of Actemium noted that it could be interesting to investigate other IoT networks than the LoRa network. The choice to go for the LoRa network was made three years prior to this project, and other IoT networks being developed in the past years. Other techniques could apply better to this project than the LoRa network.

To make the sensor future proof it would be wise to reconsider the choice to use the LoRa network. The use of a gateway makes the system more complex for the user to install. Extra components in the IoT chain could also create more room for errors.

Benefits for using a different network could also make it possible to do software updates remotely.

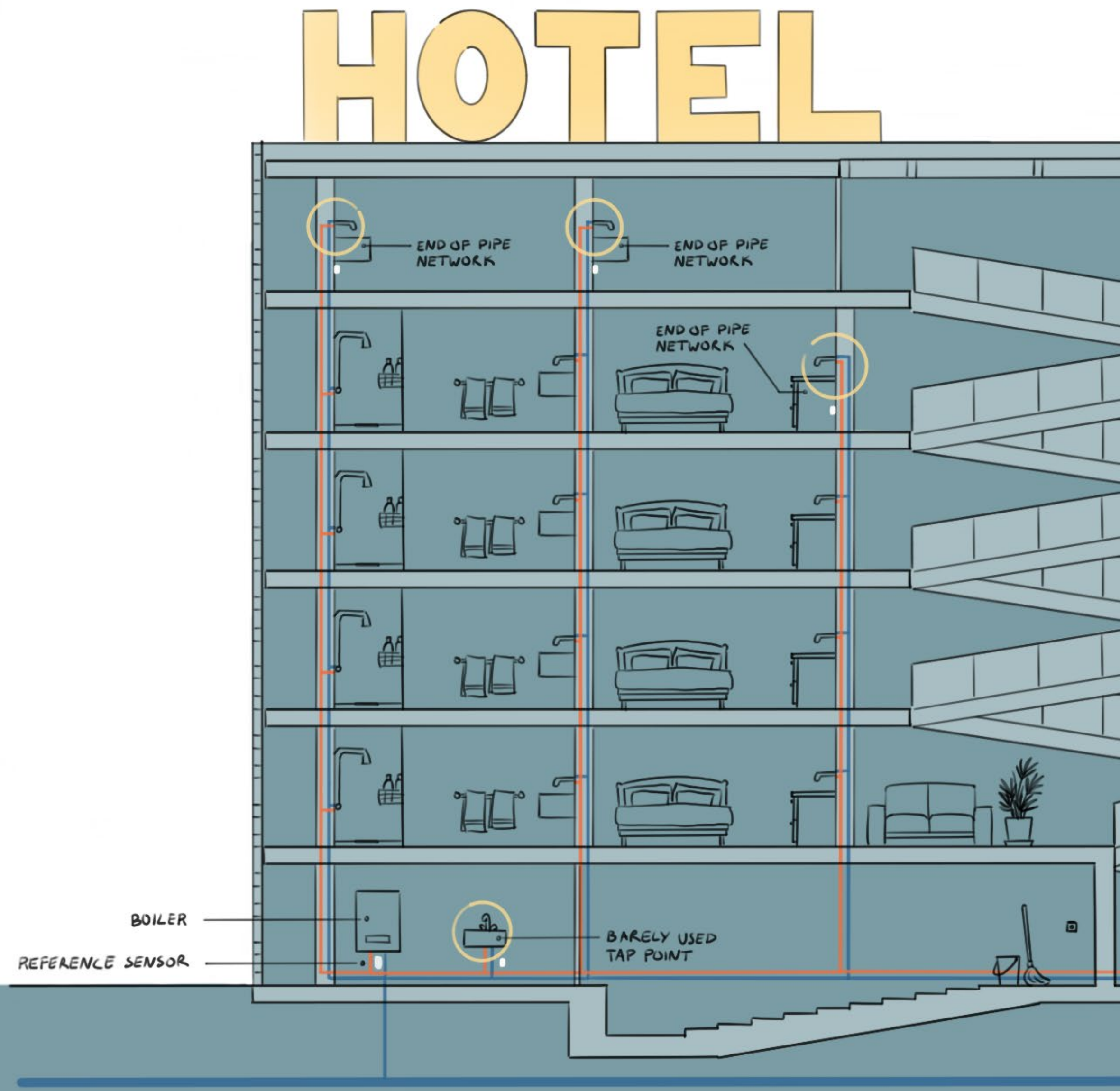


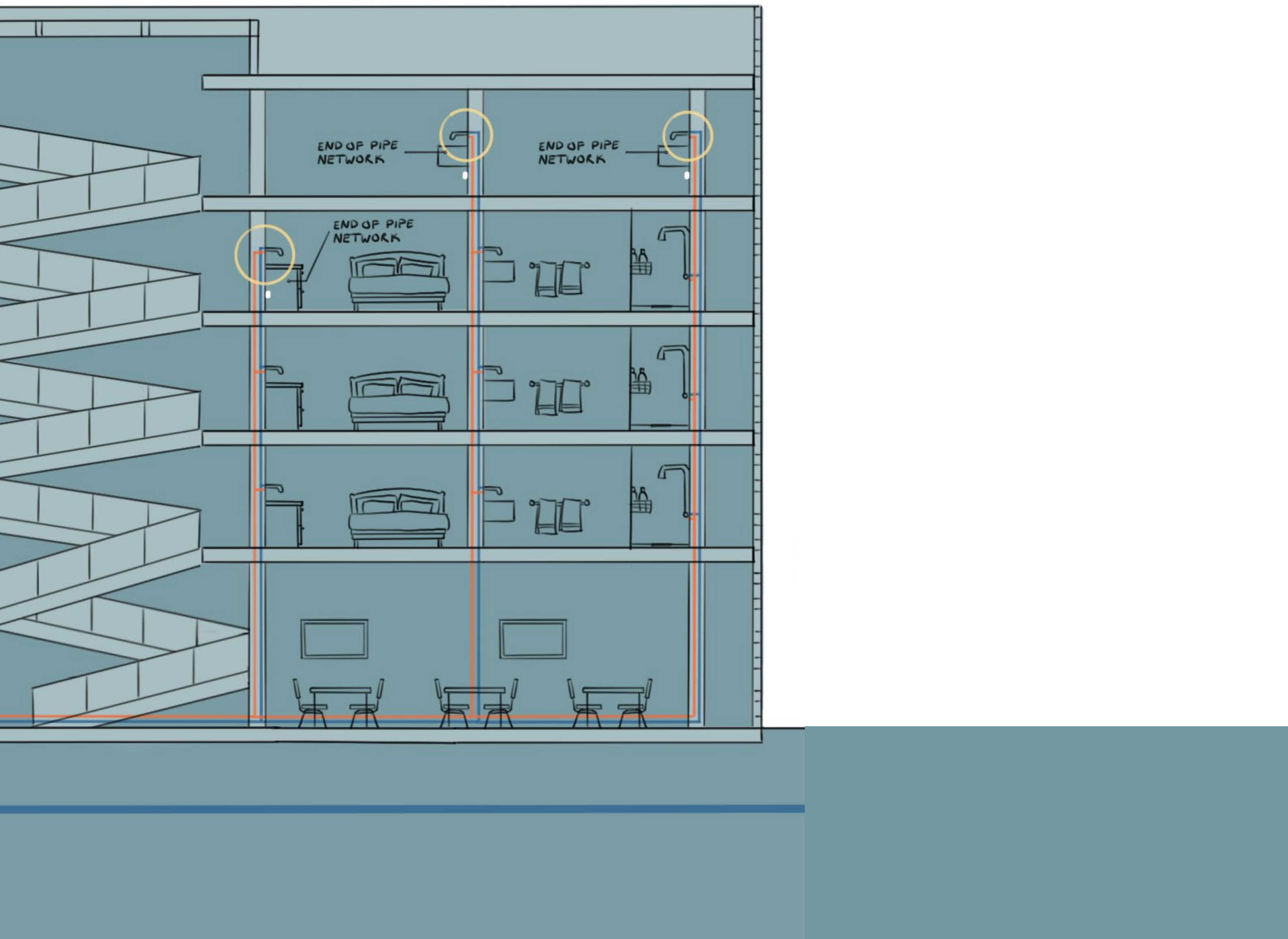

*Figure 12. Example of reference sensor placement*

This would make the sensor more future proof.

The advice Martens would be to use the Narrowband IoT network (NB-IoT). NB-IoT uses the radio access network, which means that it uses the already existing cell towers of the GSM network. With this network no gateways are needed. It is also safer to send data since the radio access network is not free to use and therefore protected. With this sensor it is also possible for the sensor to receive data, which means that it would be possible to perform software updates remotely.

## Conclusion

As said before, there is an opportunity for Octo to start the discussion about the rules that apply for the legionella prevention. These rules are based on old prevention methods and therefore not representative for the method that Octo introduces. Until then, it is recommended to make use of a reference sensor, in combination with a delta threshold that recognises the use of a tap point.



# Design Phase

With the insights from the analysis the design phase was started. Although all parts of the design problem are interconnected with each other, three sub-problems were defined: the installation and use of the product, the attachment of the NTC's to the water pipe and the housing of the PCB. As the physical product is part of the installation process and use, it made sense to start with having a vision for this process first.

# 15. Installation & use

The use of the physical product is limited to the installation of the sensor. After which, except from the replacement of batteries, no interaction with the physical product takes place. This chapter will discuss the installation of the physical sensor and the use of the (digital) product after the installation.

## Installation process

The concept for the installation process was created by combining insights of the analysis and ideas from a brainwriting session within Octo. Actemium was consulted to validate the ideas on feasibility.

As formulated in the List of Requirements (Appendix H), the installation process and use should meet the following requirements:

- The sensor should provide feedback to the user wether it is on and/or connected.
- The user should be able to install the sensor within 10 minutes.
- The user should be able to install the sensor without the help of Octo.

### Brainwriting session

A brainwriting session was organised to generate more ideas about the installation process of the sensor. Several people within Octo whom are involved with the installation or development of the sensor joined the session. In Appendix J, the setup of this (online) brainwriting session is explained, including a summary of the outcome.

## Installation process concept

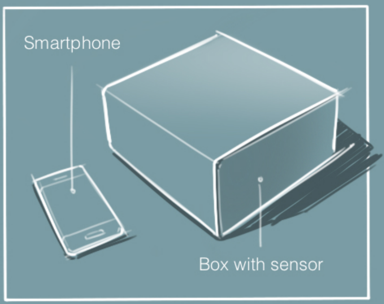
A storyboard (see page 40) was created to visualise the envisioned installation process.

### Packaging

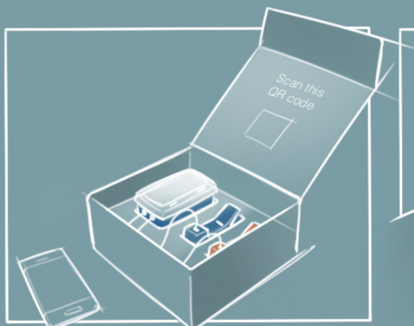
Figure 13 shows the imagined packaging design of the product. The packaging contains the sensor, batteries and a QR code. This QR code leads the user to the download page of the Octo legionella


*Figure 13. Concept for packaging design*

## Storyboard of the installation

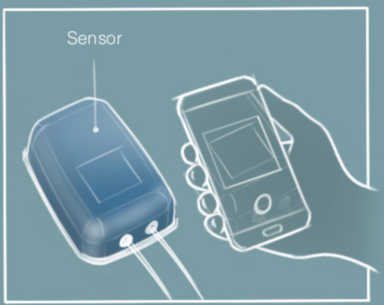



Needed to install the sensor: a smartphone with connection to the internet and the box with the sensor



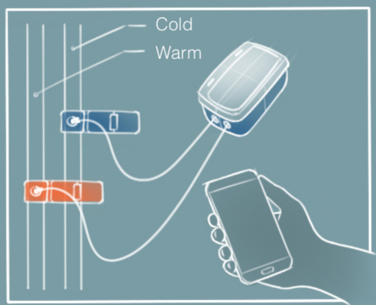

Scan the QR at the lid of the box: install the application on the phone


Log in or create an account. Select: add new sensor.

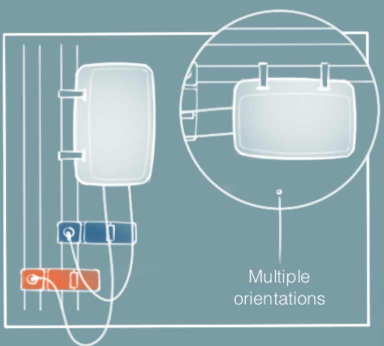



Scan the QR code on the backside of the sensor you.


Add a description of the building, room & specific location in the room.



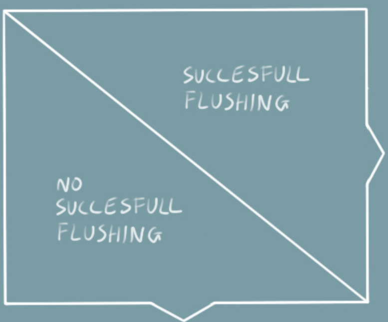

Put the temperature clamps to the correct pipes. (Red on the warm water pipe, blue on the cold. As close as possible to the faucet.)

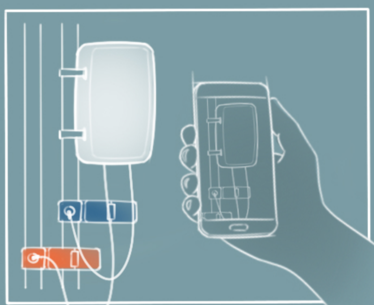



Attatch the sensor housing to one of the pipes.


Run the test flushing for the cold water.


Wait for the app to analise the test flushings. Repeat this step for the warm water.



Make a picture of the installed sensor, the place of the sensor ánd the surroundings.


Congratulations! The sensor is now installed succesfully.


Follow the trouble shooter in the app. Then, run the test flushing again.

*Figure 14. Storyboard of the installation of the sensor*

app. If the user already installed the app, they can directly open the app on their phone.

### Octo legionella app

The user logs in or creates an account. They can now select “Add sensor” to start the installation process. Now a step by step installation program starts in the app.

### Registration of the sensor

First is asked to scan the QR code on the back of the sensor housing. This automatically registeres the sensor to the platform of Octo.

### Placement of the sensor

After the sensor is scanned the app shows how to attach the NTCs and sensor housing to the water pipes. The NTCs are colour coded to make clear on what pipe the NTCs need to go.

### Registration of the location of the sensor

During the installation steps the user is obligated to ad a description and pictures of the location of the sensor. All this data is automatically send to the Octo platform. This should help to locate the sensor if maintenance is needed.

### Test flushing

To check if the NTC’s are attached in a right way to the pipes, a test flushing will be done. The application asks the user to perform a flushing for both the cold and the warm water. This includes a timer that shows the user when to stop flushing. The application checks the data, if it registeres a flushing, the installation is successful!

### Trouble shooting

If the test flushing was unsuccessful a trouble shooting program starts within the application. This is a step by step approach to check what did go

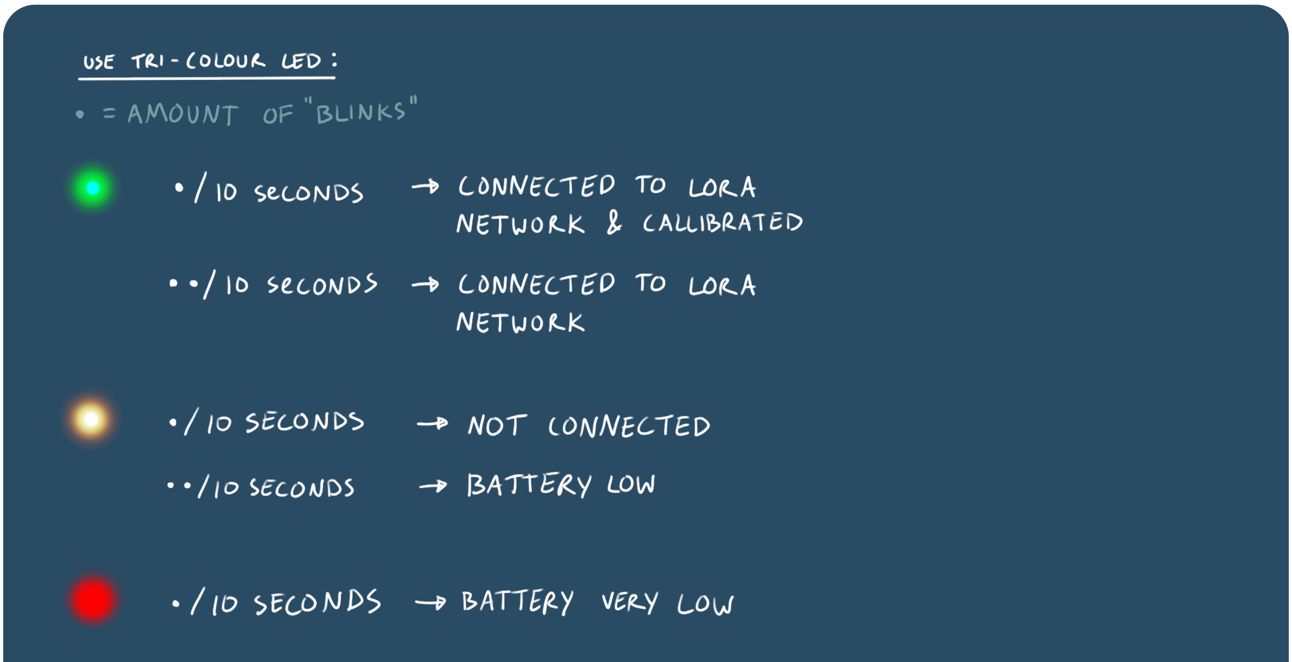



*Figure 15. Envisioned colour coding of the LED feedback*

wrong. For example, the NTC for cold water could have been attached to the warm water pipe.

### Feedback LED

To provide feedback to the user about the state of the sensor a LED will be implemented. This will give the user information whether the sensor has power, is connected to the LoRa network, etc. The envisioned code/pattern of the LED can be found in Figure 15.

## Feasibility of the concept

Once again, Stijn Martens from Actemium was consulted to validate the ideas for the installation concept. Not only the feasibility is important, also the battery life should not be negatively influenced by adding functionality to the PCB.

### Programming of the sensor

The most important insight that came out of the installation process analyis, was the programming of the sensor to gain the sensor ID and register it to The Things Network. This was a time consuming and hard to understand task. Ideally, neither people of Octo or the customer should have to be involved in this process. According to Actemium, it is possible to pre-program this and print out a serial number, QR code, etc. Only scanning this code and adding the right location would be the only thing to be done then by the user. Implementing this step in the production process would improve the ease of installation significantly.

### Test flushing

To make sure the installation of the sensor is succesfull, a test flushing step could be interesting to implement. According to Martens this is definitely possible. However, the exact execution should be sorted out.

### LED

The LED should only blink once in a while because of energy efficiency.

## General use

Apart from the installation process, the user will not have a lot to do with the physical product, but will interact with it through the dashboard and mobile app of Octo. As mentioned before, there are several user groups. These groups have different needs and the dashboard and app should respond to that. On page 43, an overview of the different user groups is shown, including the specific functionalities they need or might want.

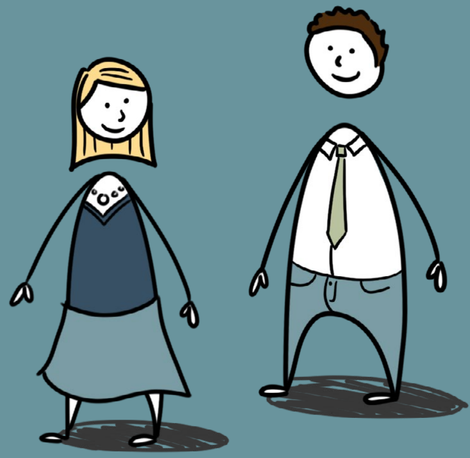
### Time indication

The data of the sensor and data of the performed tasks (flushing the tap points) can be used to predict the duration of future  tasks that need to be done. An algorithm can be developed which calculates the time that future tasks will take and what would be their optimal order.
For the legionella prevention professionals, it could even be possible to make a schedule of what order the buildings could be serviced. This way the workweek of a legionella prevention professional can be as efficient as possible.

## Specific functionalities of the Octo dashboard per user group

### Facility owners and managers

- Ability to export a report with all logbook data that is needed to hand over to the inspection
- An overview of all buildings and the status of the tasks to be done
- Notifications of when legionella tasks are not adequately executed
- Notifications of a possible legionella risk detection



### Legionella prevention professionals

- An overview of all buildings in their portfolio and the status of the tasks to be done
- An overview of the tasks that need to be done and when
- An indication of how much time the tasks take
- An optimised work schedule on which order the buildings can be serviced best

### Professionals in other fields

- Only the crucial information required to perform the tasks
- An overview of the tasks that needs to be done and when
- An indication of how much time the tasks take

# 16. NTC attachment

As explained in chapter 10, some room for improvement was found on the attachment of the NTCs. The clip included by the manufacterer of the NTC only fits a small range of pipes. The clip also could be improved on usability, since it can be hard to attach it using only one hand. An iterative design approach was used to generate a solution for this.

As formulated in the LoR (Appendix H), the NTC attachment should meet the following requirements:

- The design is suitable for a low quantity production, which implies the design should be relatively simple.
- The NTC attachment should be suitable for multiple pipe diameters.
- No changes to the water pipes can be made while installing the sensor.
- The NTC's should be able to be placed with only one hand.
- The aesthetics should fit the brand of Octo, and the design should look reliable and non-disturbing (whishes).

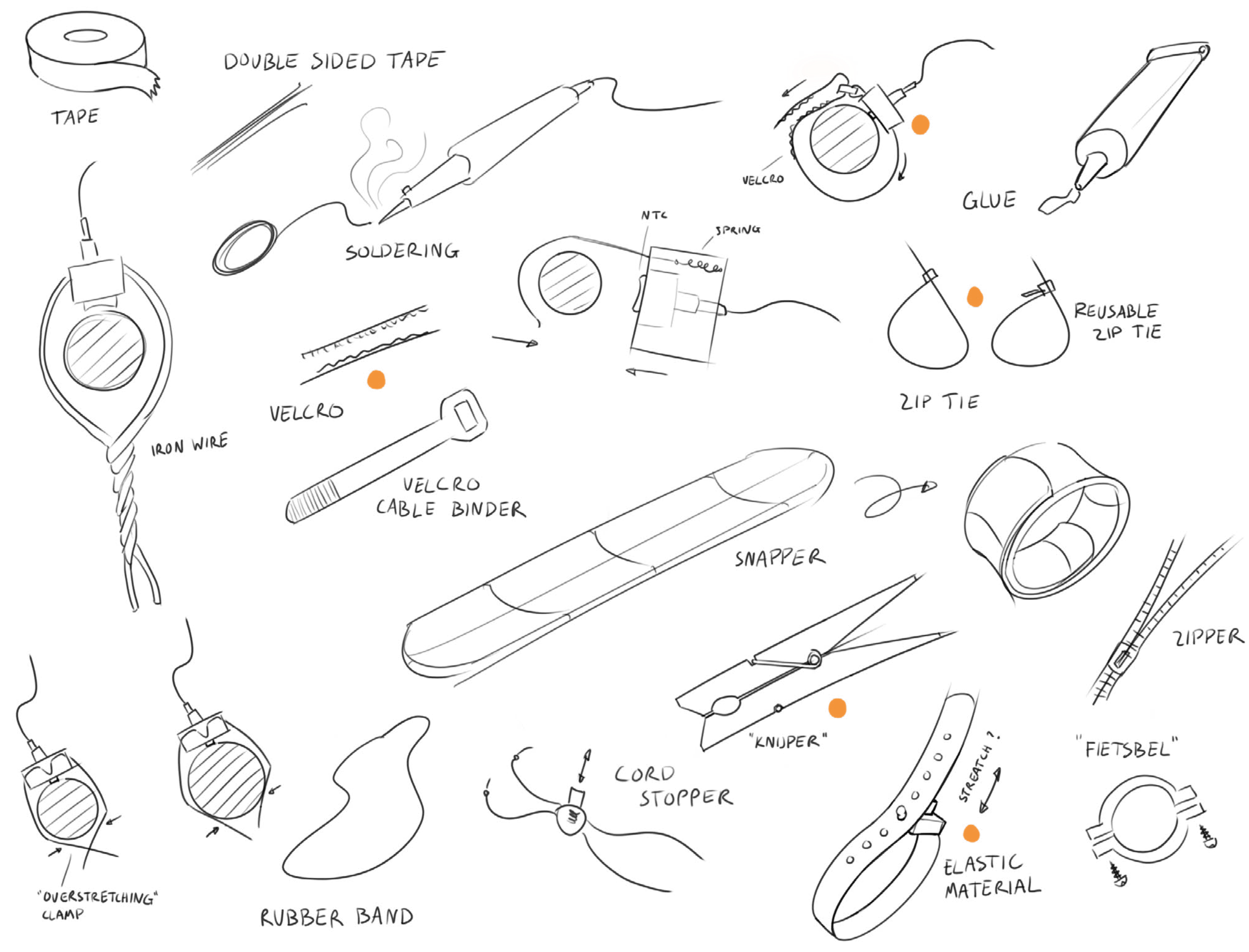



Figure 16. Ideation sketches for the NTC attachment

*Figure 17. All prototypes for the NTC attachment*

At first a brief desktop study (Appendix K) was done to see if there were other NTCs on the market suitable for this purpose. According to Octo, several alternatives were already tried and the current used NTC did work best. For this reason it was decided to stick with the current NTC and improve the way of the attachment.

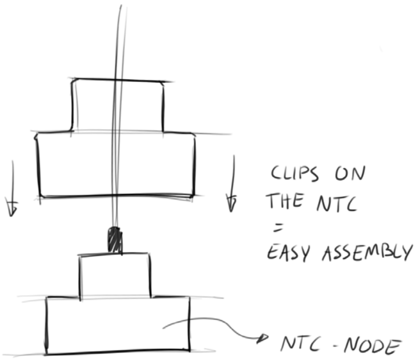



*Figure 18. Clip-on idea*

## Ideation sketching

Early on in the ideation phase, the idea was thought of to replace the cap of the NTC node with a cap that clicks on the NTC (Figure 18). How this looks like in practice can be seen in the prototypes in Figure 19; 3D printed parts are put on top of the NTC module (purple). The shape of the NTC makes this easy to do. Next to this, explorative sketching was used to generate possible solutions to fix something to a pipe (Figure 16). Promising ideas were marked with an orange dot and investigated further.

## Explorative prototyping

Quick prototypes were modelled using Solidworks and 3D printed. Several materials like zip-ties, elastic bands and velcro were tested out. This process involved many models and many iterations (Figure 17). The different concepts can be seen

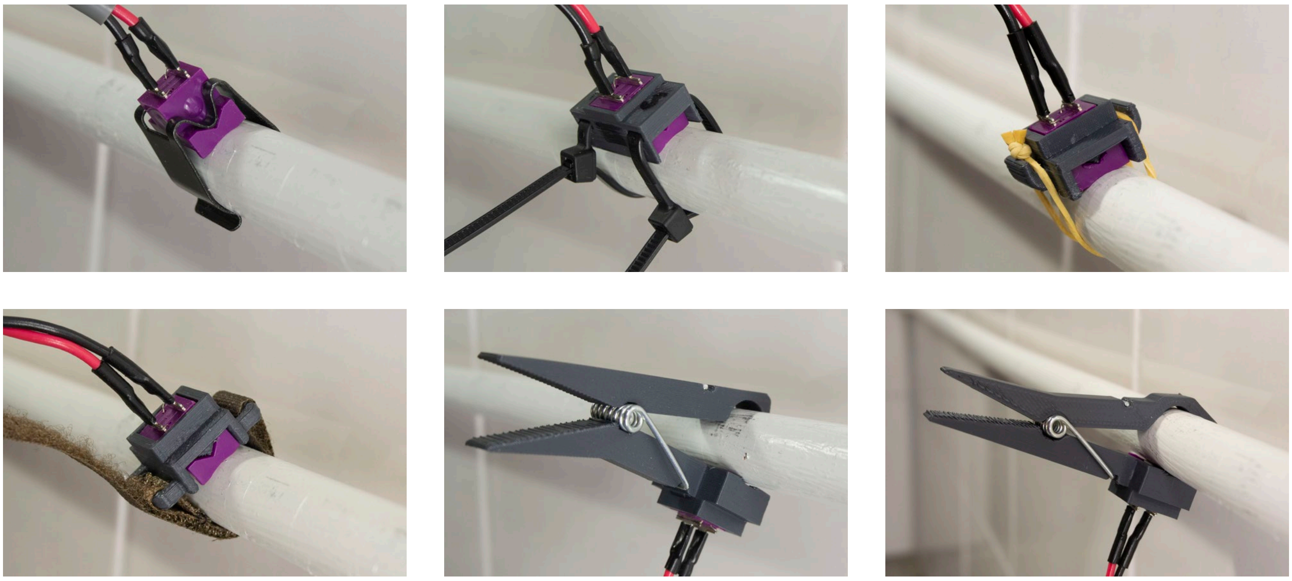


*Figure 19. Prototypes for the NTC attachment (f.l.t.r.): Metal clip (original), zip ties, elastic band, velcro, clamp (two iterations).*

in Figure 19. The concept with the velcro seemed promising, and was investigated a little bit further. Though, it was hard to attach the velcro concept using only one hand, as can be seen in Figure 20. This is why a fourth concept was tested; a clamp based on a clothes pin. With the clamp concept it was possible to attach the NTC to a pipe with the use of one hand (Figure 21). An iteration of this clamp was made, since it was nog applicable for multiple diameters yet.

## Multi-diameter clamp

With use of the drawing tools of Solidworks, the optimal shape for the clamp was found (Figure 23). With this shape it is possible to use the clamp on pipes of 9-10, 15-16 and 20-22 mm. These dimensions are the standard dimensions that are used in The Netherlands. With the original solution, a different clip for each dimension is needed (one for 9-10, one for 15-16 and one for 20-22 mm).
The first version of the multi-diameter clamp concept could easily slip off the pipe (Figure 22).

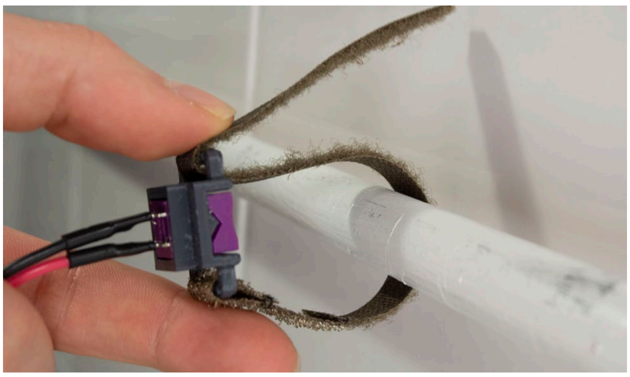


*Figure 20. Test the velcro concept with one hand*

*Figure 21. Test the clamp concept with one hand*

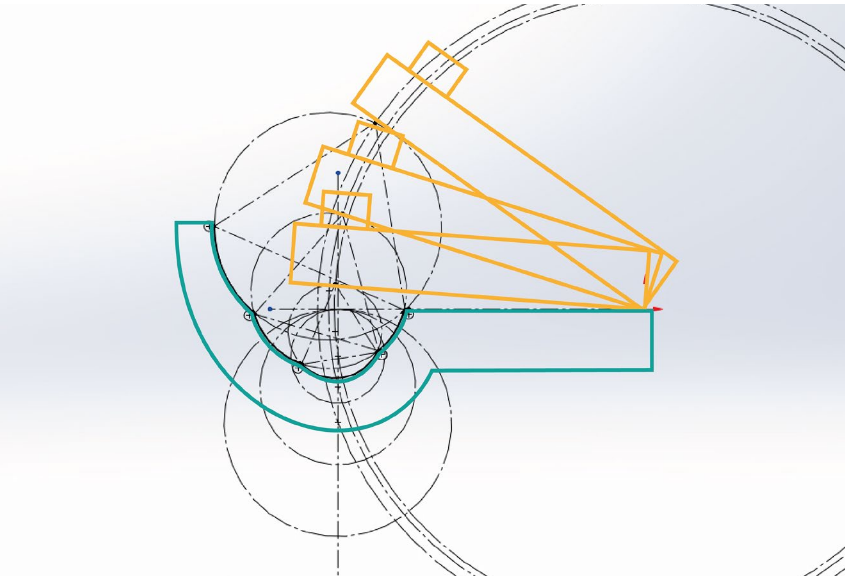


*Figure 23. Finding the right shape and dimensions for a multi-diameter clamp shape*

The drawing tools of Solidworks where used once again, now to make sure the pipe is supported at three points that form a nearly equilateral triangle (it was not possible to form a perfect equilateral triangle). This way the clamping is supported optimally and the chances of slipping are reduced to the minimum (Figure 24).

## Concept choice

The Weighted Objectives Method as described in the Delft Design Guide (2012) was used to validate the concepts (Figure 25). The requirements of the LoR were used as criteria, with the addition of 'durability'.

The weigth and given score were defined by consulting Octo on what is important, and the feedback they gave on the concepts. The wishes were scored lower than the requirements.

The clamp concept has by far the highest score, even without weighting the criteria. The clamp concept is easy to install, producible, durable due the use of a steel spring and fits the right range of

*Figure 22. Clamp almost slipping off*

*Figure 24. Improved clamp concept*

| Concept | Weight | Metal Clip | Zip Tie | Velcro | Elastic | Clamp |
|---|---|---|---|---|---|---|
| Multi diameter | 30 | 1 | 4 | 3 | 3 | 4 |
| Producability | 25 | 4 | 4 | 3 | 4 | 4 |
| Ease of installation | 25 | 3 | 1 | 3 | 1 | 4 |
| Durability | 10 | 4 | 3 | 3 | 2 | 4 |
| Aesthetics | 10 | 2 | 1 | 2 | 2 | 3 |
| | 100 | 265 | 285 | 290 | 255 | 390 |

*Figure 25. Weighted Objectives Method to validate the NTC attachment concepts*

pipe diameters. This is why the clamp concept was chosen.

## Fine-tuning prototyping

More prototypes were made to fine-tune the clamp concept, mostly focussing on the aesthetics and producibility.

In the first clamp prototype, the spring of a normal clothes pin was used. This was material that was readily available and used to test the working principle of a clamp. Other possibilities were explored to see if there were better solutions with the same working principle.

Since the clothes pin springs are not easily available as stock parts, several regular torsion springs were ordered to test out. A quick prototype was made to test if the use of these torsion springs was beneficial (Figure 26). The big disadvantage of this type of spring turned out was the need for an axis, while the clothes pin spring functions as its own axis.

It was concluded that the use of a clothes pin spring was actually very suitable for this project. There is no need of extra parts, a relatively simple injection mould can be used and it is easy to assemble. This is very benificial for a product with a small batch size. A custom made spring is needed, but the costs did turn out not to be that high (see the cost price calculation in Appendix O).

An additional prototype was made, using the spring of a wider clothes pin (Figure 27). Because of the width of this clamp the attachment was more stable. This was chosen to be the final sotution.

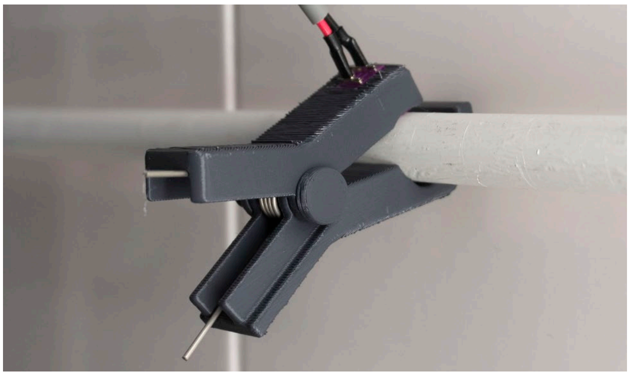


*Figure 26. Clamp concept with stock part spring*

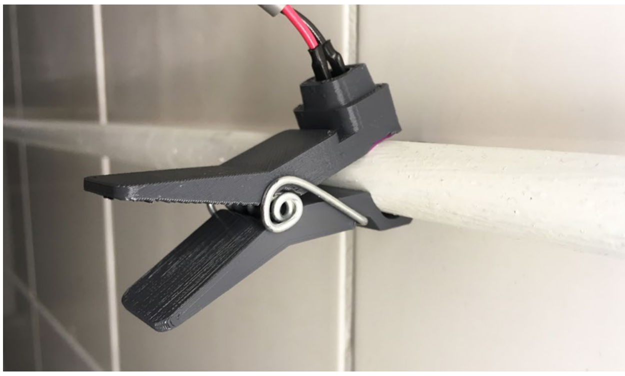


*Figure 27. Clamp concept with wider spring*

# 17. Sensor housing

The housing of the original sensor was very basic. Not much attention was paid to it previously, since it was not the focus of the development phase the sensor was in. However, there was room for improvement concerning usability and aesthetics.

One of the challenges was to find an elegant and practical way to install the sensor housing. The housing should be placed nearby the place where the NTCs are attached to the pipes, since it is limited by the length of the cables. Other options, like mounting it for example to a wall or cupboard, make it almost impossible to avoid permanent changes to the direct invironment of the sensor. This is why the possibility to mount the housing to a pipe was added to the List of Requirements.


Figure 28. Ideation sketches for the housing (attachment methods)

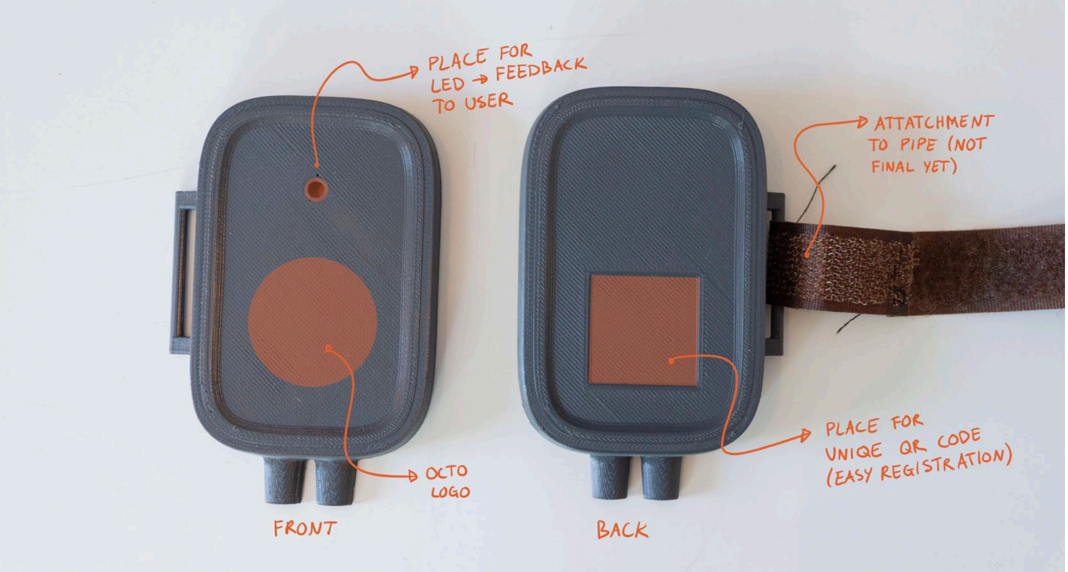



*Figure 29. Ideas on how to implement elements of the installation process*

In the LoR (Appendix H) other requirements were formulated concerning the housing of the sensor:

- The design is suitable for a low quantity production, which implies the design should be relatively simple.
- No changes can be made to the environment by installing the sensor.
- The housing should be water resistant.
- The housing should be attachable to any pipe diameter.
- The housing should be attachable to horizontal and vertical water pipes.
- The housing should be able to install using one hand (whish).
- The aesthetics should fit the brand of Octo, and the design should look reliable and non-disturbing (whishes).

The concept of the installation process, as formulated in chapter 15, was also used as a guidance for the details of the housing concept. An example of this can be seen in Figure 29.

## Ideation of the housing

Explorative sketching was used to generate ideas a for the attachment of the housing (Figure 28). Ideas where selected on producibility and versatility (is the housing applicable in multiple orientations and on multiple diameters) to explore further. The other requirements could be met in a later stadium of the design process.

The selected ideas can be divided into two main concepts: the first with two external NTCs (as the original design of the sensor is), and the other in which one of the NTCs integrated in the housing. Both were explored further. More pictures of the prototyping process can be found in Appendix N.

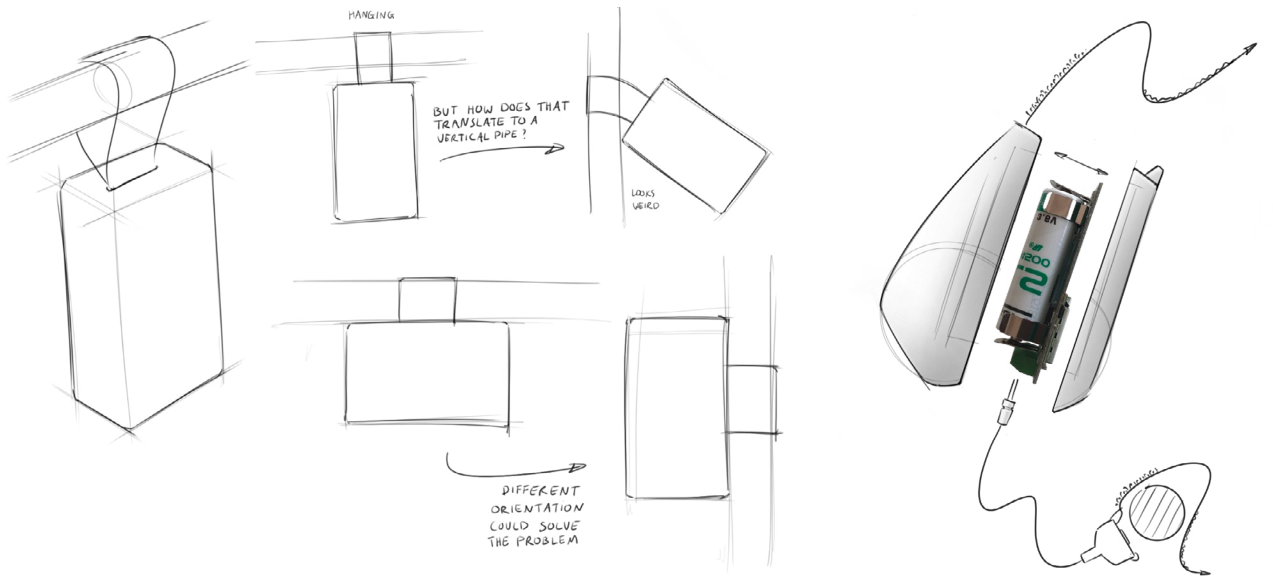



*Figure 30. Sketches of concept 1*

## Concept 1: Two external NTC's

The first concept sticks to the original lay-out of the sensor: the housing with the PCB in it and two cables with NTCs coming out. The main benefit of this design is the relatively simple shape, what makes the design easy to produce and make water resistant.

It seems better to make the attachment on the long side of the housing, as can be seen in Figure 30. This will make the fixation more stable and reduces the cantilever of the weight.

At this stage velcro was used to test the attachement (Figure 31), however this method was changed later on.

*Figure 31. Prototypes of concept 1*

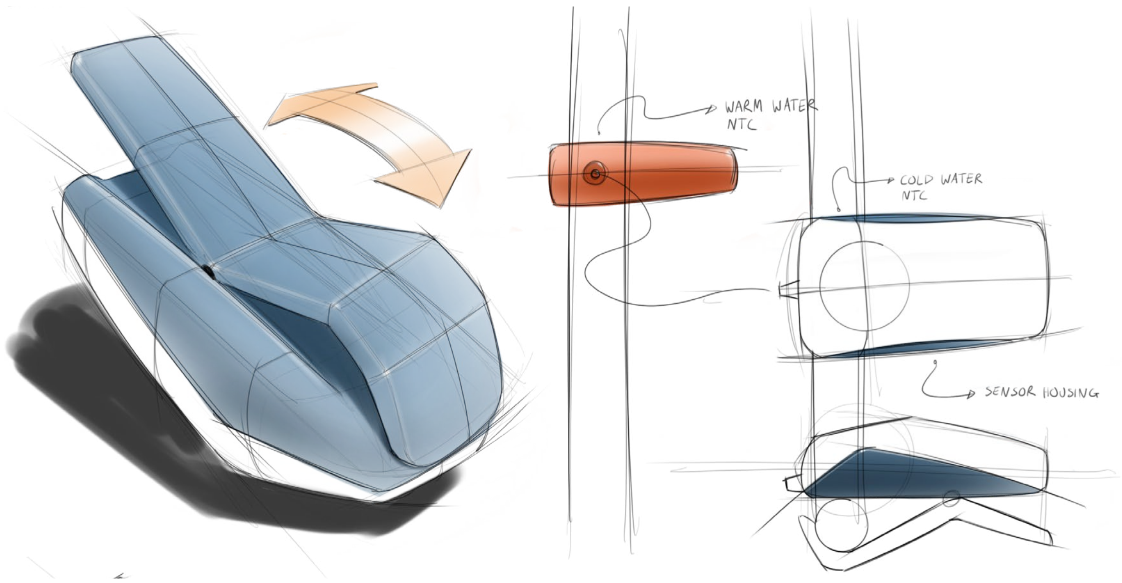



*Figure 32. Sketches of concept 2*

## Concept 2: One integrated NTC

In the second concept, the cold water NTC is integrated in the housing (Figure 32). This reduces the amount of actions that is needed for the physical installation, as the housing no longer needs to be fixated seperately. It also reduces the amount of parts.

The first prototype of concept 2 (Figure 33, right) did not properly stay on the pipe. Therefore, a second prototype (Figure 33, left) was made to see if this could be improved. A stronger and wider spring was used, which imediately showed a significant improvent. As can be seen, the housing now stays in its place without the tendacy to turn down.

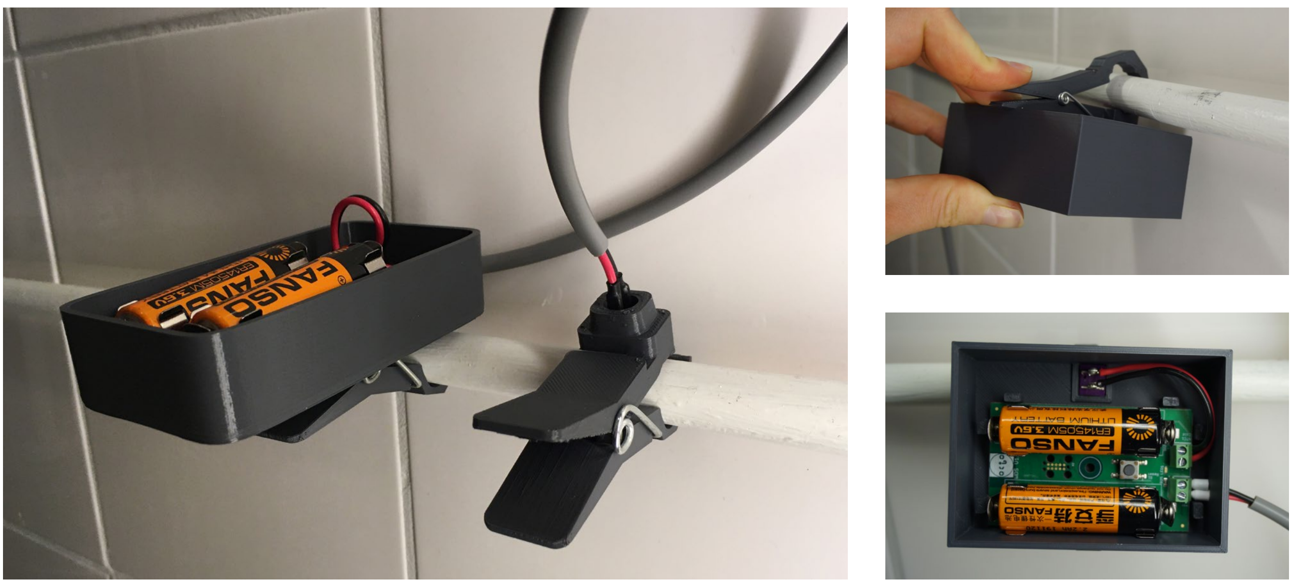



*Figure 33. Prototypes of concept 2*

| Concept | Weight | Concept 1 | Concept 2 |
|---|---|---|---|
| Producability | 30 | 4 | 3 |
| Versitality | 25 | 4 | 3 |
| Ease to get water resistant | 25 | 4 | 2 |
| Ease of installation | 10 | 3 | 4 |
| Aesthetics | 10 | 2 | 4 |
| Total | 100 | 370 | 295 |

*Figure 35. Weighted Objectives Method to validate the housing concepts*

## Concept choice

Again, the Weighted Objectives Method as described in the Delft Design Guide (2012) was used to validate the concepts (Figure 35). The requirements were used as criteria, and the versitality combines the requirements on orientation and pipe dimensions.

The weigth and given score were defined by consulting Octo on what is important, and the feedback they gave on the concepts. The whises were scored lower than the requirements.

Concept 2 scores lower on versitility than concept 1, because the NTC with the housing will take extra space on the water pipe. This could obstruct the flexibility in placement of the NTCs. For example, sometimes insulation material would need to be cut away to place the NTCs.

Concept 1 scores lower on aesthetics the way of attachment is less elagant than just using two clamps.

As can be seen in Figure 35, concept 1 has the highest score. For this reason was was chosen for concept 1: the housing with two external NTCs.

## Finetuning

In the first versions of the concept velcro was used to attach the housing to a water pipe. Finding the right lenght for the velcro was somewhat anoying, because it needed to be long enough to fit all diameters of pipe. However, the longer the velcro got the longer the “rest piece” got if the pipe diameter is small (see Figure 31 , page 52). This looks clumsy and could even invite people to touch


*Figure 34. Prototypes of the final concept*

it, even when they should not do that.

There were also some concerns about the durability and sturdiness of the velcro. It also adds another part to the list that needs to be manufactured seperately, what would increase the costs.

For that reason, the idea of using of a zip tie was back on the table. A zip tie makes it possible to attach the sensor housing to any diameter of pipe and  a lot of different features nearby as well. It is also something that is  cheap and widely available.

Another benefit is that it is less likely the sensor would be taken away by somebody. The zip tie functions as a semi-permanent attachment, without harming the direct environment of the sensor.

In Figure 36 a sketch of the final concept is shown. It also includes ideas on how to make the housing water resistant. In the next chapters the details of the final product will be discussed.

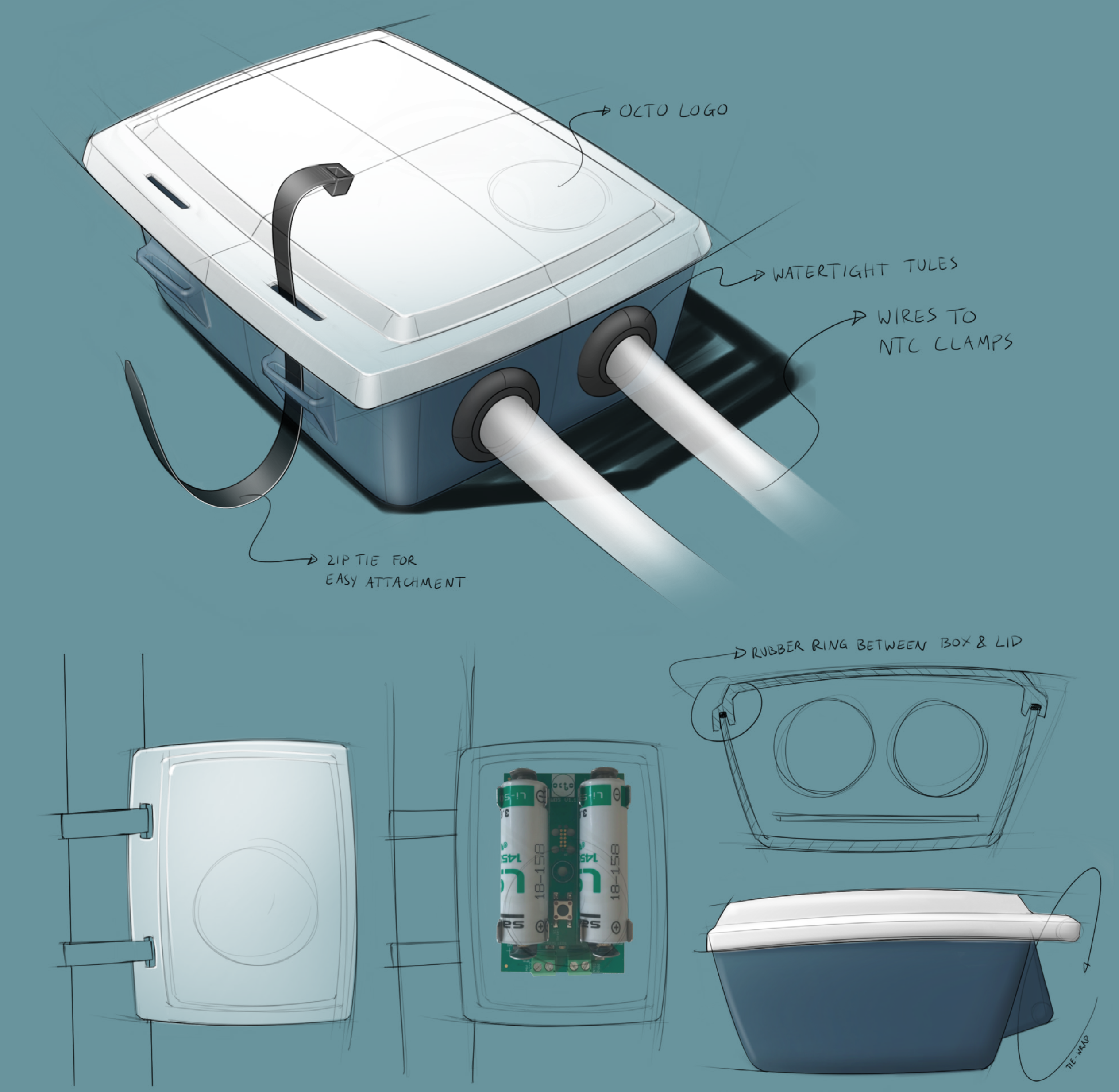



*Figure 36.   Final housing concept sketch*

# 18. Product proposal

The concepts of the installation process, NTC attachment and housing were combined to create the final product proposal. At this page the main characteristics of the design are highlighted.

## Sensor

- The NTCs can be installed using only one hand, and are coulour coded: blue for the cold water pipe, red for the warm water pipe.
- The housing of the sensor is designed in a way that it can be implemented right away, but is also future proof. No changes to the original PCB need to be made to fit the housing.
- The Housing can be attached to a pipe with the use of zip ties.
- The use of reference sensor to validate the data from the sensors comming in is recommended. The same sensor can be used, but the data will be processed differently.

## Dashboard and app

The sensor output is accessable through the dashboard of Octo. In addition to that, a mobile application will be developed. This app contains a step-by-step installation guide and simultaniously shows the status of the tasks that need to be done. The interface and functions of the dashboard and app will differ for the different user groups, to provide the optimal user experience for each user.

## Next generation(s)

As long as the dimensions of the PCB do not change, the design of the housing keeps usable. Even if the dimensions change a little bit, minor changes need to be made to the ribs of the housing.

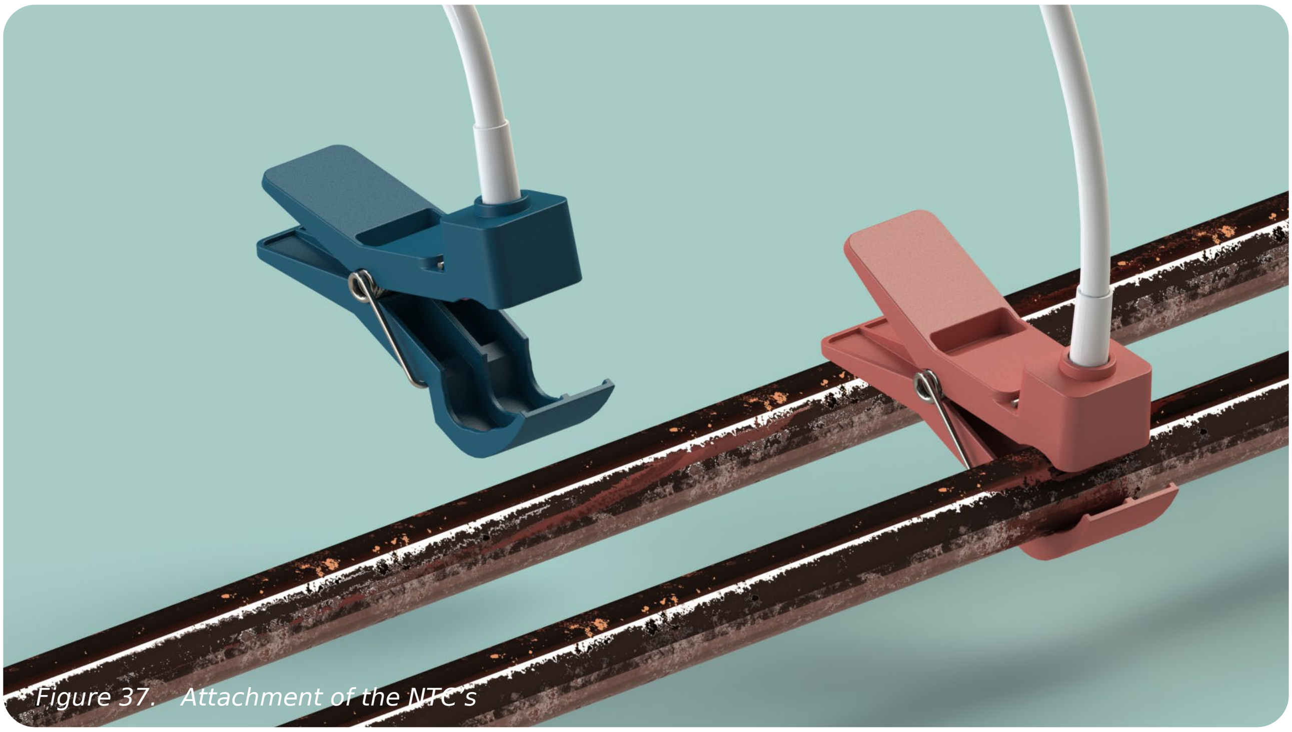


*Figure 37. Attachment of the NTC's*


*Figure 38. Final product proposal*

*Figure 39. Final prototype*

# 19. Embodiment

The elaboration of the product proposal will be explained in this chapter. This includes a detailed overview of all parts and their characteristics. Multiple manufacterers and experts were consulted to gain information about production, costs and other embodiment details.

All parts of the sensor are shown in the exploded view in Figure 42. Some are custom made and some are stock parts.

Custom made parts:

- Housing: box and lid
- Clamps: top and bottom
- Clamp spring
- Rubber seal
- Sensor PCB with LoRa module

Stock parts:

- Cables incl. cable jacket and shrinking tubes
- NTCs
- Membrane grommets
- Screw (M3x25) with seal
- (Small o-ring for screw)

## Product details

### Clamps

The bottom part of the clamps is designed in a way it fits on multiple pipe diameters (Figure 40).

To make the design of the clamps suitable for injection moulding, the parts were made hollow with some ribs. The place where the axis of the spring touches the clamp needs to be smooth (Figure 43), otherwise the ribs of the clamp could get stuck in the windings of the spring. For this reason the shape is inverted at that point. The NTC is held in place by ribs that at the same time add stiffness to the design.

In the initial concept the NTC clicked in the head of

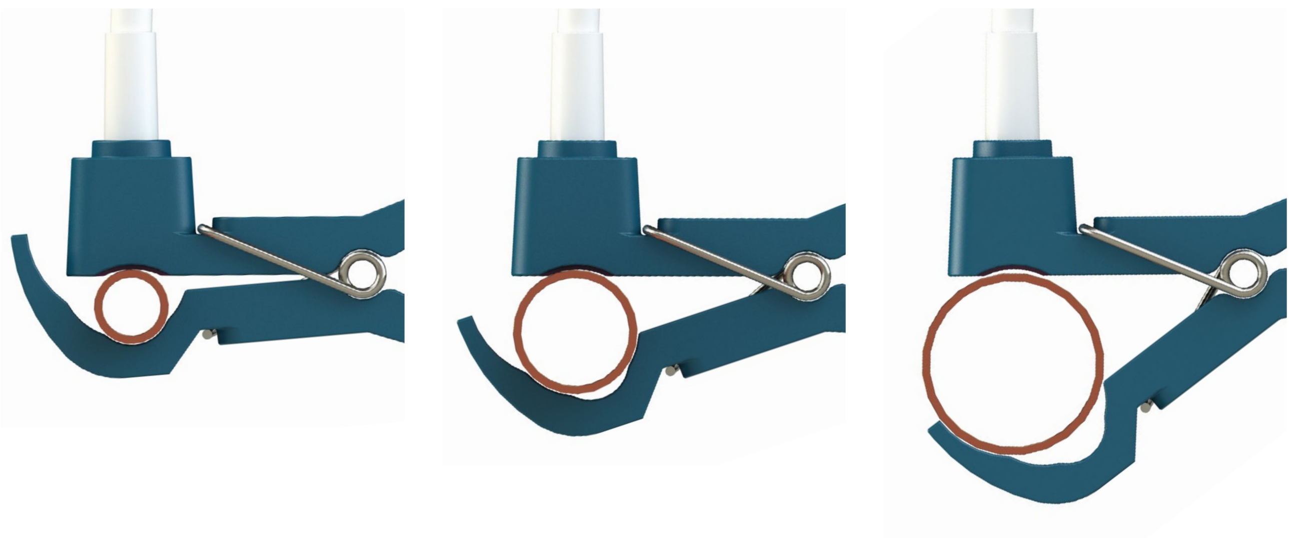


*Figure 40. Clamp fitting on multiple pipe diameters*

*Figure 41. Use of a shrinking tube to finish the design*

the clamp. Due to mould release restrictions this is not possible. This is solved by making the fit neat so it will stay in its place by clamping between the ribs.

## NTCs with cables

The cables are kept together and protected by a cable jacket. To finish the product, some extra shrinking tube will be added where the cable is connected to the NTC. Figure 41 shows what this will look like. The colours of the model are different than what the finished product will look like.

## Housing

The housing consists out of a box and lid in which the PCB is placed. The PCB is sandwiched between the box and lid, so it is fixed when the box is closed. There are holes for zip ties to fix the housing to a pipe or other nearby feature.
The holes for the cables have the size of the membrane grommets that will be used. This will also make it easier to stick the cables through the hole with the connectors already attached, since the holes will be bigger.
At the lid, a thinner part is integrated where a LED can shine through. If no LED is added to the PCB, it does not disturb the design of the lid.
A square-shaped face is added to the back of the box where a label with a QR code and other information can be placed. This is done so the sticker is always alligned and placed on a flat surface, since the back of the box is slightly curved.

## PCB

Some changes can be made to improve the functionallity of the PCB. These changes will apply for next generations of the sensor.

### LED

As mentioned before, a status LED can be added to improve the feedback to the user. In the paragraphs below these additions are described.

### Switch

Replace the button for a switch. With the switch it is possible to switch between different algorithms that are programmed on the sensor. This can be of use if it turns out different pipe materials need different threshold values for example.

### Connectors

The connectors that are now used to connect

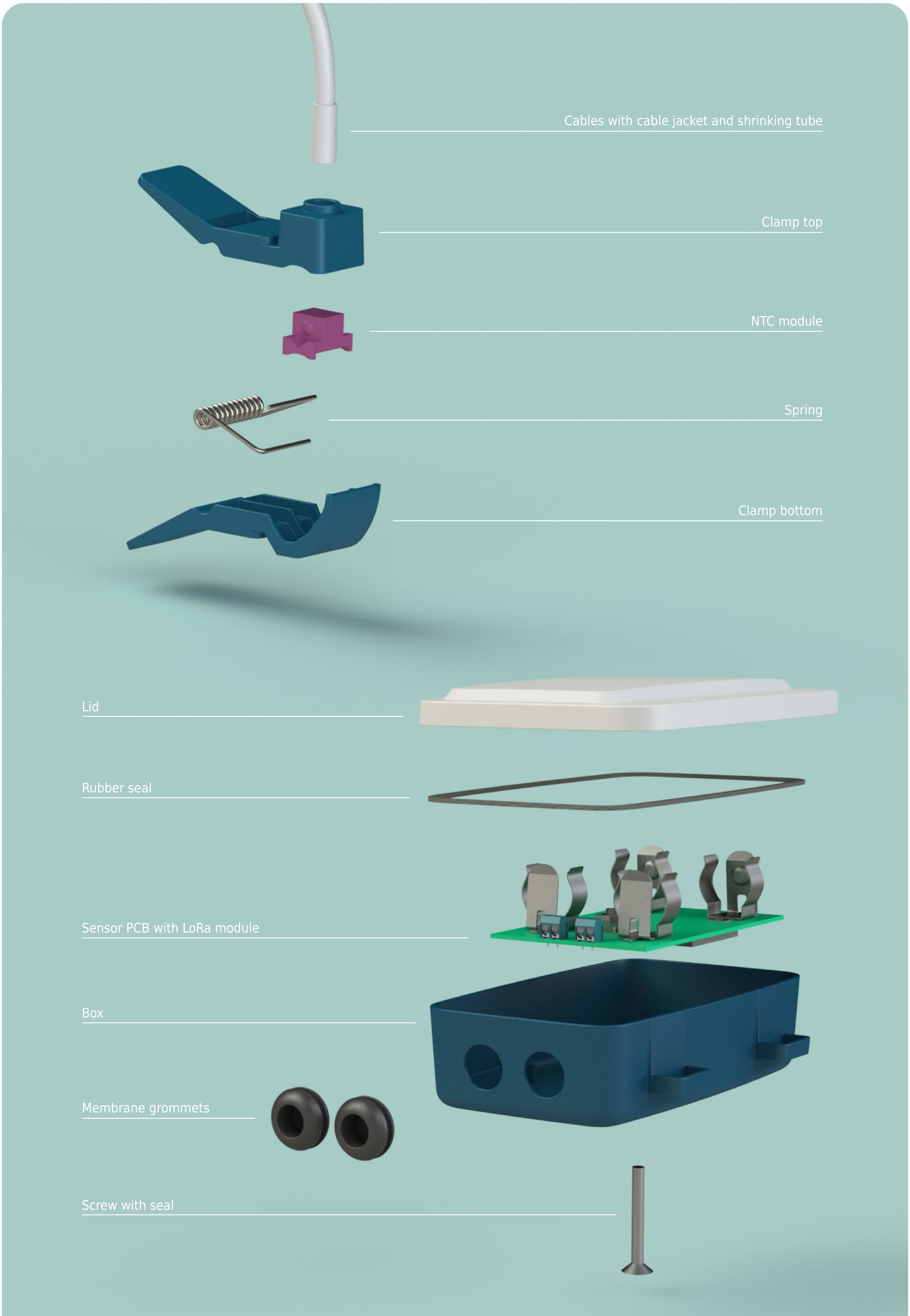



*Figure 42. Exploded view of the product*

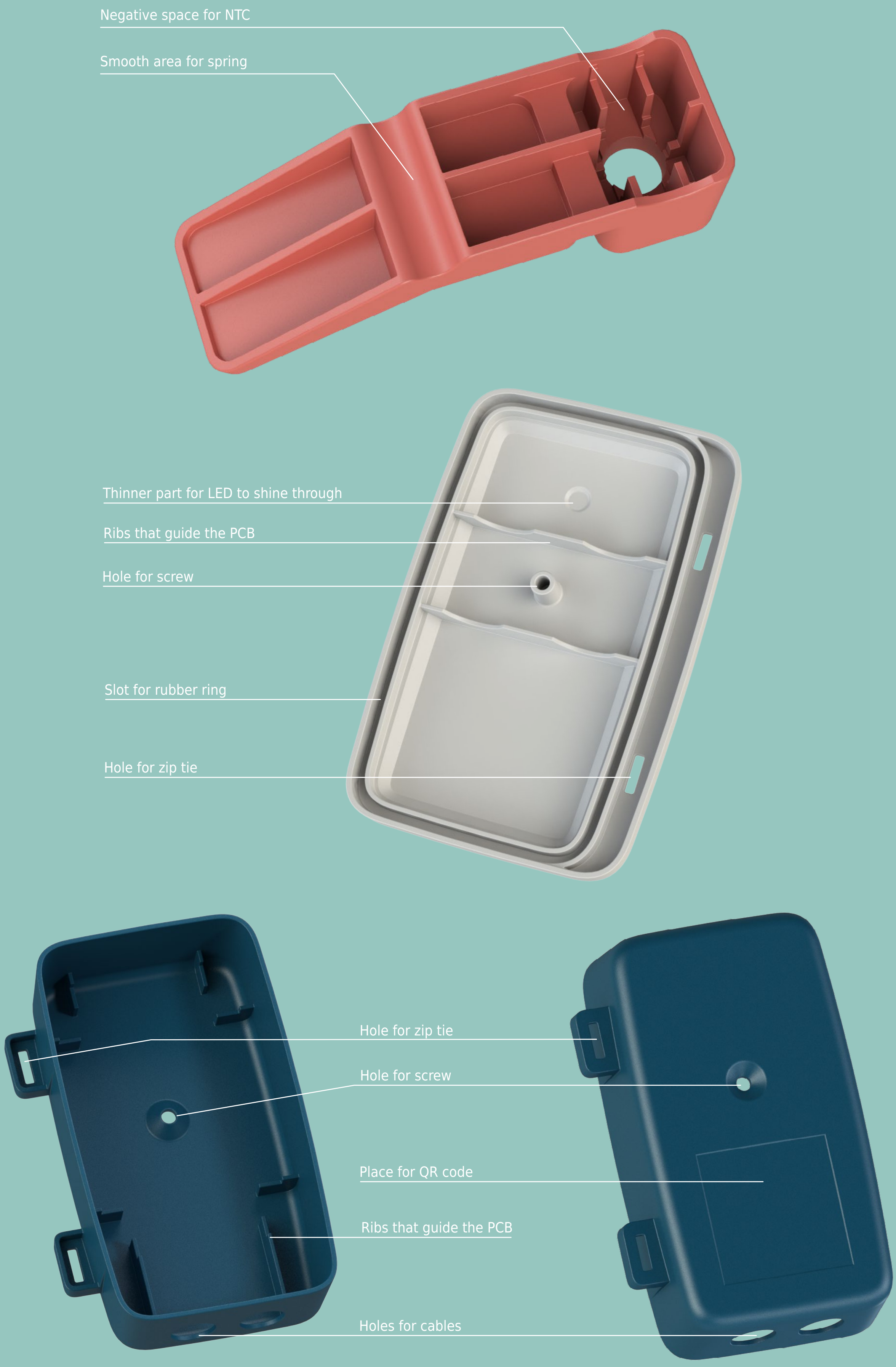



*Figure 43. Details of the injection moulded parts*

*Figure 44. Example of an membrane grommet*

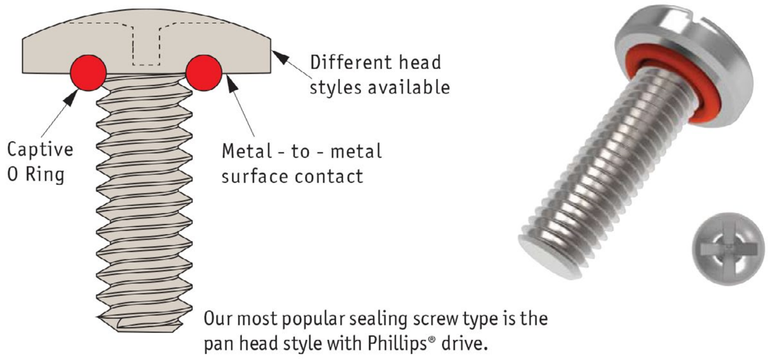



*Figure 45. A seal screw*

the NTC cables with the PCB are screw terminals. This works fine, but is not as convenient during assembly. Therefore, the advise would be to look into other connectors in which no tools are needed, for example a JST connector.

## Water resistance

In close consultation with the stakeholders within Octo, the grade of water resistance was determined. This came down to ‘splash proof’, what means that an IP34 rating is sufficient. As turnes out, there were not that many cases (about two) where the sensor broke down due to water damage. The following measures are taken to make the housing at least as water resistant as an IP34 rating:

### Seal screw

A seal screw has an integrated o-ring as can be seen in Figure 45. Alternatively, a normal screw with a small o-ring can be used.

### Membrane grommets

Membrane grommets are grommets in which the hole is closed by a membrane. The cable is pierced through the membrane, so the grommets seals around the cable tightly. An example of a cable piercing the membrane can be seen in Figure 44.

### Rubber seal

A rubber ring will be put between the lid and the box of the housing. This seal is plased in the slot of the lid, and the edge of the box will be pressed to the seal by the srew.

## Aesthetics

Although the sensor is installed at places that are mostly not visible, the aesthetics of the sensor could not be ignored. In the LoR, it was defined the aesthetics should be fitting the brand of Octo and the product should look reliable. These wishes where taken into account during the design process, but where not considered as crucial for the success of the project. The focus of this graduation project was in the first place to design a product that fulfils it function and is easy to use. Next to that, the customer will buy the product because of its function, not because of the looks.

A reliable looking product will most likely be a product that has a nice finishing. For that reason it was made sure that all ellectronics are covered. The cable jackets need to be long enough to cover hole cable length. At one end it will enter the housing through the grommets, at the other end the transition to the NTC will be covered with a shrinking tube. Changing the colours of the cable jacket and shrinking tube to white makes the design feel more modern as well. Adding proper holes for the zip ties to go through also adds to a more professional look.

### Colours

The colours that were chosen are inspired by the visual identity of Octo. The clamps are coloured in a way that the user will better understand which one needs to be placed on which water pipe. The blue one is for the cold water pipe, the orange/red one for the warm water pipe. Using red and blue in this way is the standard in a lot of countries. Additionally, research shows that the colour red is perceived warmer than blue does (Fenko, 2009). It can be expected that people will automatically assume the blue one needs to go on the cold water pipe and visa versa.

The lid will be white, so the optional LED can shine through it. Any other colour will influence the colour of the LED itself. The use of white also fits within the visual identity of Octo.

The colours are assigned as described below.

- Octo Navy - cold water clamp and housing box
- Octo Orange - warm water clamp
- White - lid, cables and shrinking tubes

## Production techniques

### Electronics production & assembly

The LoRa sensor is developed and produced by Actemium. They have production facilities where they can scale the quantities up to a production of 20.000 PCBs. This means that there is enough space for growth for Octo.

During the production the sensors will be pre-programmed and connected to the cloud of The Things Network. A QR code that corresponds to the sensor ID of the LoRa module on the PCB will be put on the back of the sensor housing.

The NTCs, including cables, cable jacket and heat shrink tubing are stockparts that are assembled at Actemium. The metal clips should be removed from the NTCs before the assembly starts.

### NTC clamp & housing production

The obvious production method for these kind of products seemed to be injection moulding. Because the quantities of the first batch will be small, 1.000 pieces, it was sorted out if it was feasible to use this technique.

3PD and Protolabs were consulted to make sure the parts are suitable for injection moulding, and to get a price indication.

P3D uses 3D printed moulds for small batches. These are cheaper to produce, but also less durable, what makes them not suitable to use for the production large quantities of parts. P3D sent a price indication for a batch of 50 pieces (what can be found in Appendix O), and suggested to move on to steel moulds if the numbers will rise. Since the price per part was quite high (about 180 Euros per sensor for all injection moulded parts), this didn't seem to be the right technique to use.

Protolabs was consulted through their online quote tool. CAD files can be uploaded and you automatically get a price indication and validation on producibility (Figure 46). This tool was very usefull to optimise the design of the parts.  Depending on the batch size, the costs of all parts of one sensor together, would cost 10-30 Euros and is way more realistic. The benefit of using injection moulding from the beginning on is that is is easily scalable to an almost infinite number of pieces, since nothing has to be changed about the design of the parts.

## Spring production

The spring needs to be custom made by a spring manufacturer. Contact was already made with Alcomex and Tevema. At first some samples need to be made to find out the right dimensions of the spring. It costs about 100 Euros to make five samples, at Alcomex as well as at Tevema. If the right dimensions are found, the production can start.

## Rubber seal production

The rubber seal that will be put in between the bottom en the lid will to be custom made as well. Rubbermagazijn was consulted to verify the dimensions were possible to cut. It did, and the advise was to use cell rubber.

## Packaging

For the packaging a cardboard box will be used. It will contain the sensor, batteries and a QR code that sends the user to the download of the Octo legionella app (as explained in chapter 15). This box can be custom made, but it is also possible to use a standard dimension box and print a design on it.

## Final assembly

The details of the assembly of the sensor were not part of the scope. Octo has mentioned that they want to make use of a sheltered workspace to

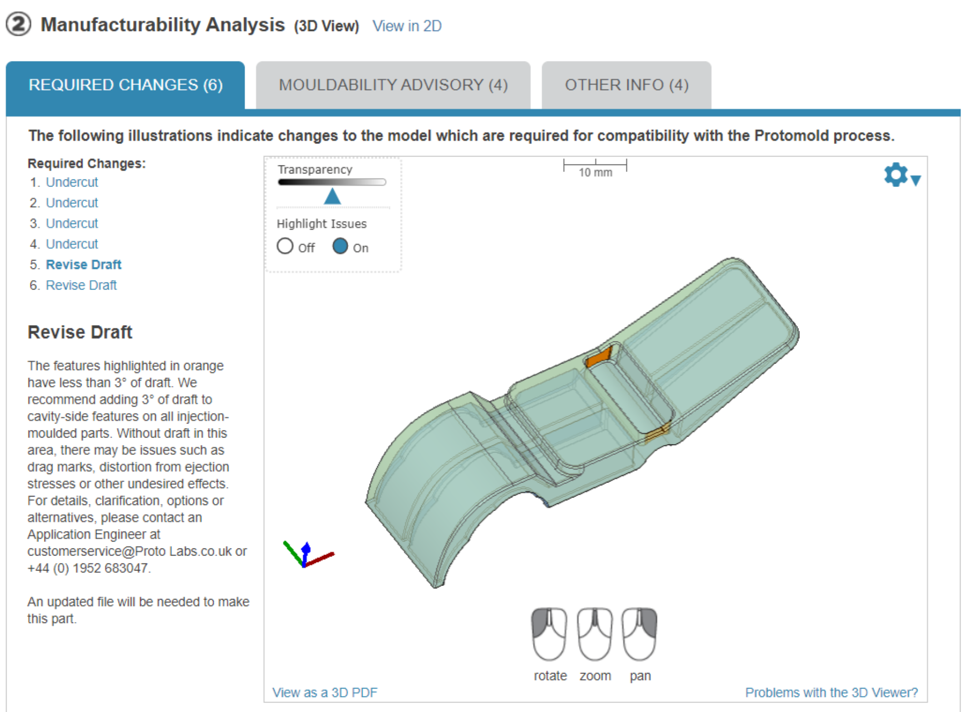



*Figure 46.  Online validation tool of Protolabs*

assemble the sensor.

## Cost price

To come up with a realistic cost price indication of the custom made parts, several companies were consulted for a price indication:

- Protolabs for injection moulding with steel moulds
- P3D for injection moulding with 3D printed moulds
- Alcomex and Tevema for custom springs
- Rubbermagazijn for custom rubber rings

Not all cost-related information was available from Octo, so the production of the PCB, assembly of the NTC and assembly in general were excluded from the calculation.
On request of Octo, a price calculation was made for batches of 1.000, 5.000 and 10.000 pieces. The full cost price calculation can be found in Appendix O.

## Dimensions

The main dimensions of the injection moulded parts can be found in Appendix P.

## The digital product

The digital product consist out of the dashboard (to use on a computer) of Octo and a mobile application. This dashboard already exists and is used for all kinds of sensors that Octo supplies to their clients. The mobile application needs to be developed yet.
As said before, the differences between the user groups ask for special attention in what is shown to the specific user groups. Customised interfaces that adapt on the user group will be beneficial for the user experience. Octo is already working on these kind of distinctions between user groups in their other (digital) products, and can continue with this approach within this project.
There is enough experience and knowledge within Octo to make this happen. The envisioned concept is described in chapter 15, and can be used as a guidance to create the optimal user experience.

# 20. Validation

In this chapter the List of Requirements (Appendix H) is used to validate the product proposal. Special attention goes to the requirements that were not met (yet). On top of that, the main drivers as described earlier in this report (chapter 12), are evaluated as well.

There were 63 requirements and whishes formulated, of which 39 were part of the scope of this graduation project. 22 of those are (presumably) met, and an additional 10 (addressed with "rec" in the LoR) are presumably met if the recommendations in this report are implemented. This leaves 7 requirements and/or whises that were not me. In the next paragraphs it is explained why. The numbers between the brackets correspond with the numbers requirements in the LoR.

## Requirements that are not met yet

### Cost price (5) & Quantity (8)

If the production of the sensor will be feasible for Octo will need to be verified with the stakeholders within Octo. It strongly depends on the size of the first batch and the investment Octo is able and willing to make. The costs for a batch of 1.000 pieces (what Octo has in mind for the first batch) seems high. If it is not feasible, other production methods need to be investigated.

### Aesthetics (11)

The aesthetics of the sensor were considered as one of the least important wishes that were included in the scope of the project. Attention was paid to the finishing of the sensor to create a more professional looking product. Colours of the housing were inspired by the visual identity of Octo. If the user experiences this as 'reliable' and 'fitting the Octo brand' is not validated, since no user tests were done.

### Installation (22)

Not all requirements concerning the installation process are validated yet. The mobile application with its step-by-step installation guide are is not further developed yet. A user test (using for example a mock-up of the app) could be done to verify the installation process is understandable to do and within a reasanable amount of time.
If the design of the app is executed well, it should be possible to meet these requirements.

## Main drivers

### Reliability

Making sure the sensor is reliable and meets all regulations was a big part of this graduation project. The performance of the sensor was tested in multiple ways (chapter 13). With the conclusions of the tests, a vision was created to improve the performance of the whole product (chapter 14). If the recommendations that are given will be implemented in the future of the development, it should be possible to meet the regulations on legionella prevention.

### Usability

The concept was created to optimise the experience of the user. Experts were consulted to get a better insight in the wishes and needs of the different user groups (chapter 8). An analysis of the installation process was done to get an overview of the improvements that could be made (chapter 10). With those insights, a vision on the installation process and use was created (chapter 15). When the development of the mobile application is done, additional user tests can be done to validate this vision.

### Feasibility

During the project, multiple experts were consulted to validate the producibility of the parts of the design (19). The product proposal is a realistic and producible design, but still a little bit too high in costs for small batch sizes (about 30 euros for only four injection moulded parts). As said before, it needs to be verified with Octo if the investments can be made.

## Conclusion

Most requirements and wishes are, with logical reasoning, likely to be met. Those that are not, presumably will, if the recommendations are implemented with the future development of the product.

# 21. Conclusion

The goal of this project was to further develop Octo's stoppage sensor, that supports the prevention of legionella risks in buildings and facilities making use of IoT systems. The two main themes during the process were the technical performance and usability of the product. The ambition of this project was to reach the end of the embodiment stage, delivering a product proposal that is nearly ready to take into production. In the following paragraphs the main conclusions of the project are discussed.

To make the product a success, the product needs to meet the legionella prevention regulations. With the use of a reference sensor, the sensor output can be validated. Smart use of data can also initiate a discussion in how the regulations can be interpreted differently. The proof that a tap point is used frequently, may be enough to conclude there is no legionella risk in that part of the water pipe system.

A vision for the installation process was created, to make the installation understandable and doable for a broad range of users. Guiding the user with a step-by-step guide through the installation process, the user is able to install the sensor without the help of Octo. The sensor itself is designed in a way that it is easy to install and easy to understand, by adding details like colour coded clamps.

The sensor is used by a diverse group of professionals. Therefore, a distinction has been made between three different user groups. The facility owners and managers, the legionella prevention professionals and professionals in other fields (like nurses, handymen, etc.). These user groups have different whishes and needs. The dashboard an mobile application that show and process the sensor output, should addapt to the specific user group, to offer the best user experience.

The product proposal is a detailed embodiment design that is easy to produce and water resistant. With some minor corrections the design should be ready to take into production. A prototype was build to demonstrate the installation of the design. This prototype can be used by Octo to communicate with their clients, making the product proposal more concrete.

# 22. Recommendations

In this chapter a summary of all important recommendations is given.

## Installation process

### Placement of the sensor

- Make sure the NTCs are not placed to close to a junction in the pipe system. This can negatively affect the measurements (Figure 9 , page 34).
- User tests need to be done to make sure the user understands the installation process and is able to perform this installation within a reasanable amount of time.

### Test flushing

- To make sure the sensor is installed properly, the implementation of a test flushing in the installation process is highly recommended.
- If the test flushing fails, it can occur that the user needs to wait for some time to let the water acclimatise to the room temperature first.

## Technical performance

- Do not take the technical performance of the sensor for granted yet. Especially on the flushing recognition in the cold water pipes some improvement needs to be done.
- Add a reference sensor to the system to verify if the water at a tap point has reached the right temperature. If that happends at least three times a week, the tap point can be excluded from the flushing round. At the moment, it seems that this is the only way to meet the standards that do apply at this moment.
- Make it possible to switch threshold values to get an optimal result for each type of pipe.
- Valdiate the technical performance of the sensor with co-operations that are specialised in legionella prevention policies.

## Dashboard and app

- Design a dashboard and app that adapt the needs of the different user groups. Not all information and functions are relevant or even appropriate to show to all users.
- Use the knowledge and skills within Octo in the field of coding to lift the dashboard and app to the next level. For example by using the data of the tasks that are performed to estimate the time tasks in the future will take. Optimise the order of tasks/buildings to make the user as efficient as possible.
- More research can be done about the whishes and needs of the different user groups.

## IoT network

- Reconsider the choice to use the LoRa network to avoid the use of a gateway and enable remote software updates. The NB-IoT network could be a good option.

## Embodiment finetuning

### Production

- The srew is now srewed right into the plastic of the screwhole of the lid. It should be discussed with the manufacturer if this is the right solution, or if it is better to insert a screwthread of some kind.
- It should be sorted out if there is need for a strain relief on the cables of the NTCs.

- The fit of the NTC clamping between the ribs of the clamp is preferably very neat. This was only tested with 3D printed parts, of which the shrinkage behavious will probably be different than in a injection moulded part. The exact dimensions should be discussed with the manufacturer.
- Some extra finetuning should take place on the parts that will be injection moulded. Attention was paid to make the designs suitable for injection moulding, but some dimensions still need to be revisioned to prevent any problems. The tool of Protolabs is very usefull for this.

### Hardware changes to PCB

- Add a LED to the PCB to improve the feedback to the user.
- Replace the screw terminals with JST connectors for a shorter and easier assembly.
- If a different IoT network will be used a different IoT module is needed.
- The button can be replaced with a switch to enable the possibility of changing between different algorithms.

### Battery life

- Increase the battery life by reducing the energy the sensor consumes. Something that has a big influence on the battery life is the frequency the LoRa module sends a data package to the cloud. This is now done every 15 minutes. The same information could be send but with a bigger time delay in between.

## Sustainability

- Add even more value to the product by proving it has a positive impact on the environment.

In the original assignment of this project this impact analysis was included. A start of a life cycle assessment was already made, which can be found in Appendix Q.

# 23. Reflection

The individuality of a graduation project can feel lonely sometimes, but with the ‘smart lock down’ , due to the COVID-19 pandemic, now it definitely did. The lack of distraction was a curse and a blessing at the same time. In a normal situation, I would have probably just filled my evenings and weekends with all kinds of plans. Now I spent a lot of those at home, with enough time to think and work on my graduation project. This actually resulted in experiencing a lot of stress, since the only thing I could think about was the pandemic and my graduation project, but without being able to actually focus on the work that needed to be done. Fortunately, as the rapid changes of the measurements of the government cooled down a bit, I noticed myself to be able to relax more as well. I managed to work through the process without any (major) delay, and I am very happy with that achievement.

Next to the corona pandemic, probably the biggest challenge within the project was to get all information about the sensor in one place. I noticed there was a lot of information and knowledge within Octo, but it was scattered between people and not much was documented. Working at home also resulted in a less optimal way of communication, certainly because I did not have the chance to get to know everyone at Octo before the lock down started. Though I believe I managed to put as much information as possible down in this report. Achieving that, this report is probably already an improvement for Octo on its own.

The progression of the project felt very slow at the beginning. I am not sure if this was because of the pandemic, or just because the analysis is not my favourite part of a project. The answer lays probably in between. As soon as I can start with testing and designing within a project I am gaining momentum. I love sketching, prototyping, testing and finding smart, practical solutions. This is why I had a lot of fun designing the clamps. With the design of the housing I experienced some struggles since I found it hard to make a decision on which concept was best. At the end I managed to make smart use of the weighted criteria method and made sure that I could substantiate my choice.

When I found out the sensor did not function properly yet I freaked out a little bit. I did not want to work on a product that I did not believe was feasible. However, the decision to dive into the technical performance of the sensor was the right one. I actually did not bother about the fact that I had to eliminate the sustainability part out of the assignment, since I am a practical oriented designer that likes to work on the technical aspect of a product. Although the sensor is not there yet, there is a lot more insight in what can be done to make it a successful product.

Although I enjoyed working on the project, I am happy it is (almost) done. I cannot wait to work on projects in a team again. The corona pandemic makes the future a little bit more uncertain then it normally is, but I have faith I will find my way to a job I like.

# 24. Acknowledgements


### Supervisory team

I would like to thank Ruud, Erik and Koen to guide me through the process, keep me on my toes and supporting me when needed.

### Octo

Thanks to Octo for the opportunity to work on a project that is relevant and novel. It is really impressive to see what you can do with 'just' data. Special thanks to Tara, who helped me keeping structured by having a weekly (digital) meeting, allowing me to think out loud and discuss minor details that you would normally discuss in front of a coffee machine.

### Mom and dad

Well, without them I wouldn't even be here. Right? Thanks for being a listening ear, especially when I felt anxious about the whole corona situation.

### Maikel

Thanks for letting me being my chaotic self and letting me take over the house with my project(s) (as I always do...). Thanks for being a listening ear. And last but not least, thanks for finding a job, it really helped having a "colleague" at the "office".

### The breakfast party

Thanks for starting the days together in a time our social lives collapsed.

### Max

Thanks for all the support, especially in the last few weeks.

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## Images

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Figure 48: https://vakbladLegionella.nl/Legionelladossier-tekent-integrale-samenwerkingsovereenkomst-met-unica/

Figure 49: https://www.aquaassistance.nl/producten/intelligente-spoelautomaten/

Figure 50: https://Legionelladossier.nl/clipr/

# Appendices

# Appendix A. Original assignment

DESIGN FOR our future

TU Delft

## IDE Master Graduation

### Project team, Procedural checks and personal Project brief

This document contains the agreements made between student and supervisory team about the student's IDE Master Graduation Project. This document can also include the involvement of an external organisation, however, it does not cover any legal employment relationship that the student and the client (might) agree upon. Next to that, this document facilitates the required procedural checks. In this document:

- The student defines the team, what he/she is going to do/deliver and how that will come about.
- SSC E&SA (Shared Service Center, Education & Student Affairs) reports on the student's registration and study progress.
- IDE's Board of Examiners confirms if the student is allowed to start the Graduation Project.

**USE ADOBE ACROBAT READER TO OPEN, EDIT AND SAVE THIS DOCUMENT**

Download again and reopen in case you tried other software, such as Preview (Mac) or a webbrowser.

**STUDENT DATA & MASTER PROGRAMME**

Save this form according the format "IDE Master Graduation Project Brief_familyname_firstname_studentnumber_dd-mm-yyyy". Complete all blue parts of the form and include the approved Project Brief in your Graduation Report as Appendix 1 !

family name: Verduijn

initials: IN given name: Irene

student number: 4283414

Your master programme (only select the options that apply to you):

IDE master(s): (★) IPD ( ) DfI ( ) SPD

2nd non-IDE master:

individual programme: (give date of approval)

honours programme: ( ) Honours Programme Master

specialisation / annotation: ( ) Medisign

( ) Tech. in Sustainable Design

( ) Entrepeneurship

**SUPERVISORY TEAM ****

Fill in the required data for the supervisory team members. Please check the instructions on the right !

** chair: Ruud van Heur dept. / section: ID - AED

** mentor: Erik Thomassen dept. / section: DE - PAD

2nd mentor: Koen Bogers

organisation: Octo Facility Management B.V.

city: Den Haag country: Nederland

comments (optional)

Chair should request the IDE Board of Examiners for approval of a non-IDE mentor, including a motivation letter and c.v..

Second mentor only applies in case the assignment is hosted by an external organisation.

Ensure a heterogeneous team. In case you wish to include two team members from the same section, please explain why.

IDE TU Delft - E&SA Department /// Graduation project brief & study overview /// 2018-01 v30 Page 1 of 7

## Procedural Checks - IDE Master Graduation

### APPROVAL PROJECT BRIEF
To be filled in by the chair of the supervisory team.

chair Ruud van Heur date 05 - 03 - 2020 signature

### CHECK STUDY PROGRESS
To be filled in by the SSC E&SA (Shared Service Center, Education & Student Affairs), after approval of the project brief by the Chair.
The study progress will be checked for a 2nd time just before the green light meeting.

Master electives no. of EC accumulated in total: 44 EC

Of which, taking the conditional requirements into account, can be part of the exam programme 30 EC

List of electives obtained before the third semester without approval of the BoE

YES all 1[st] year master courses passed

NO missing 1[st] year master courses are:

name date 20-3-2020 signature CB

### FORMAL APPROVAL GRADUATION PROJECT
To be filled in by the Board of Examiners of IDE TU Delft. Please check the supervisory team and study the parts of the brief marked **.
Next, please assess, (dis)approve and sign this Project Brief, by using the criteria below.

- Does the project fit within the (MSc)-programme of the student (taking into account, if described, the activities done next to the obligatory MSc specific courses)?
- Is the level of the project challenging enough for a MSc IDE graduating student?
- Is the project expected to be doable within 100 working days/20 weeks ?
- Does the composition of the supervisory team comply with the regulations and fit the assignment ?

Content: ✓ APPROVED NOT APPROVED

Procedure: ✓ APPROVED NOT APPROVED

comments

name Monique von Morgen date 30-3-2020 signature MvM



Initials & Name IN Verduijn Student number 4283414

Title of Project Development of an IoT sensor facilitating legionella prevention

# Development of an IoT sensor facilitating legionella prevention

project title

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

start date 20 - 02 - 2020 14 - 07 - 2020 end date

## INTRODUCTION **

Please describe, the context of your project, and address the main stakeholders (interests) within this context in a concise yet complete manner. Who are involved, what do they value and how do they currently operate within the given context? What are the main opportunities and limitations you are currently aware of (cultural- and social norms, resources (time, money,...), technology, ...).

The company
Octo Facility Management B.V. uses IoT solutions to make buildings smarter. They use a range of sensors to measure data like building occupancy, indoor climate and air quality. This data is presented in a dashboard for building and facility managers to help them make informed decisions on facility and asset management.

Octo has set the goal to have the opportunity to offer products that can be bought, installed and used without the help of Octo. With that, Octo can distinguish itself from competitors by making building managers more independent in solving problems. The sensor for legionella prevention is a good first step in this, since legionella is a common known problem within buildings.

The problem - facilitating legionella prevention
Legionella is a group of bacteria that can cause legionellosis. This is a generic name for different types of infection caused by legionella bacteria. There is a pneumonic (lung infection) form, Legionnaires' disease, that causes serious lung infections, and a non-pneumonic form, Pontiac disease. Legionnaires' disease can be fatal for certain groups, like elderly people and people with a poor health. Pontiac disease is considered to be not fatal. (WHO, 2018)

The bacteria are often present in normal, tap water, but can grow when the water has a temperature between 20 and 50 degrees Celsius. This is when the quantities of bacteria get for humans. Infection with legionella happens when the bacteria come into contact with the lungs. Spreading mainly occurs by breathing in contaminated (vaporised) water. Contamination is not transferable to other people and people can not get infected by drinking contaminated water.

In the Netherlands, it is by law obligated to practise an active legionella prevention policy for certain facilities, like hospitals, swimming pools, hotels and campsites. (RIVM, 2019) Legionella prevention is one of the responsibilities of facility management of a large building or facility. Water points that are not used frequently need to be flushed to prevent legionella from developing. This is often done without any insight into the actual use of taps throughout the building. This leads to a lot of unnecessary flushing, wasting a lot of water.

This prevention policy is still done by hand. This means a person has to go by every tap in a facility to run it for some time, check a box and go to the next tap, and repeat this whole process every week. This process takes a lot of time and water and is sensitive to errors.

Octo came up with the idea to develop a sensor that handles a big part of this process by eliminating taps that already have been flushed. This sensor makes use of a IoT system and is connected to a dashboard. This device has the potential to save these facilities a lot of water, time and money.

Main stakeholders for this project will be the company, Octo, their clients and the final user: facility managers of big buildings. A part of the research will be done on these stakeholders. Who are they and what do they need from the product? What is the problem they need to be solved?

space available for images / figures on next page

introduction (continued): space for images

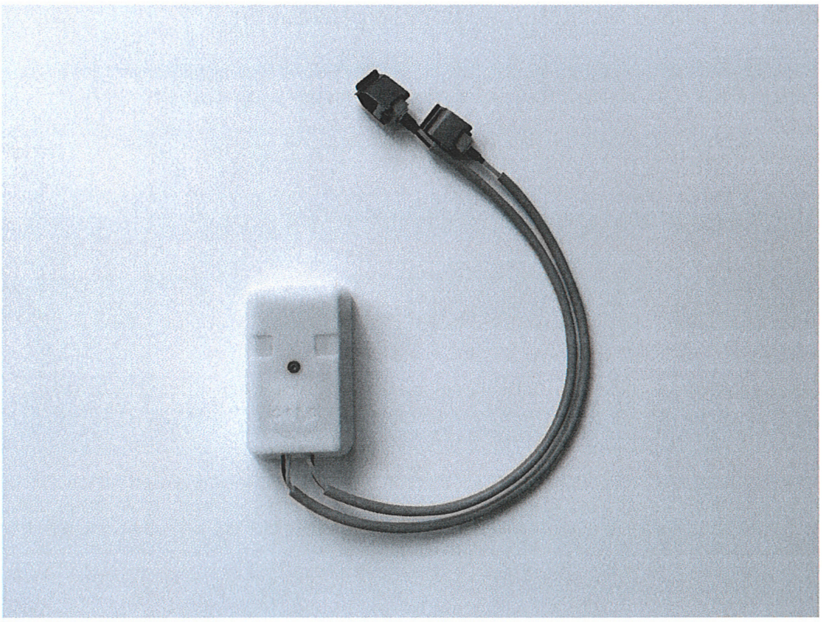


image / figure 1: Current legionella prevention sensor by Octo

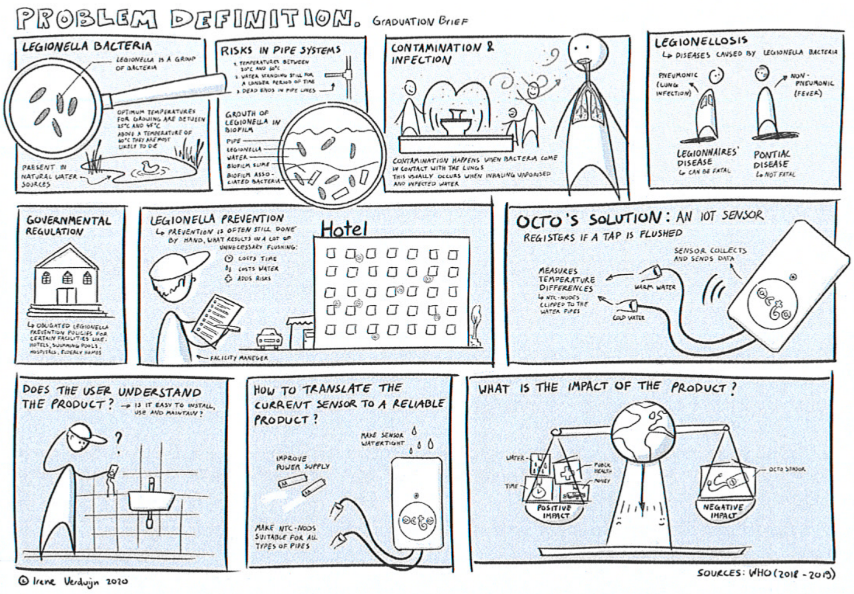



image / figure 2: Problem definition visual



Initials & Name IN Verduijn Student number 4283414

Title of Project Development of an IoT sensor facilitating legionella prevention

## PROBLEM DEFINITION **

Limit and define the scope and solution space of your project to one that is manageable within one Master Graduation Project of 30 EC (= 20 full time weeks or 100 working days) and clearly indicate what issue(s) should be addressed in this project.

Functionality: The sensor works by measuring peaks of temperatures in the water pipes near tap points and can recognise if there has been a flushing or not (according to the regulations). This method works quite well for the warm water pipes, but still misses flushing registrations on the cold water pipes. Other problems are that the clamps with the thermistors do work for copper pipes, but not for pipes made out of materials other than copper, the sensor is not water tight yet and that the lifespan is no longer than the battery life (approximately a year). Questions: How can be made sure the legionella sensor is a reliable and sustainable device that autonomously collects and sends correct data of the flushing? How can be made sure the legionella sensor is applicable on all types of pipes and in all possible environments?

Environmental impact: The use of the sensor will prevent unnecessary flushing and waste of water. It will also save time when not all tap points have to be flushed because a part of them is eliminated already. On the long term, the investment of the sensors and IoT system can pay themselves back. The saving of water also has a positive impact on the environment. It would be interesting to see what the positive and negative impact of this solution is on the environment and if it can be used when advertising the product. Question: What is the (environmental) impact of the sensor, and do the water safety and savings in water, time and money weigh up to the (negative) environmental impact of the device itself?

Usability: At this moment, Octo has to provide a lot of support in the sales, implementation and usage of the sensor. The goal of Octo is to make this a product that can be bought and taken in use by the customer without interference of Octo. Question: How does the sensor/product look like when it is easy to install, use and maintain for the user and provides all data and analysis the customer needs?

## ASSIGNMENT **

State in 2 or 3 sentences what you are going to research, design, create and / or generate, that will solve (part of) the issue(s) pointed out in "problem definition". Then illustrate this assignment by indicating what kind of solution you expect and / or aim to deliver, for instance: a product, a product-service combination, a strategy illustrated through product or product-service combination ideas, ... . In case of a Specialisation and/or Annotation, make sure the assignment reflects this/these.

The goal of this assignment is to (further) develop a sensor that will help prevent legionella risks in buildings and facilities making use of IoT systems. This sensor should be easy to install, use and maintain the customer himself. Research will be done about the functionality, environmental impact and usability.

To describe the stage of the deliverables I used the ID cards of the Loughborough Design School: https://www.lboro.ac.uk/media/wwwlboroacuk/external/content/schoolsanddepartments/designschool/downloads/id-cards%20(1).pdf

A user and usage research will be done to find out what challenges and problems need to be solved to make the installation, use and maintenance as easy as possible. Next to this the negative and positive (environmental) impact of the product will be assessed and compared to each other, in order to advise Octo and their customers.

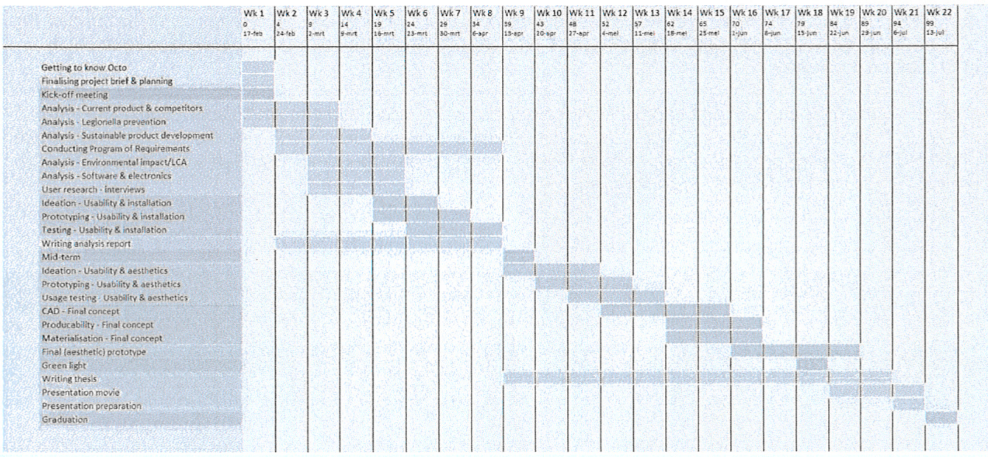
The ambition for this project is to reach the end of the 'embodiment' stage of product development. Best would be to enter the 'detail' phase as well. This means that at the end of the project, there will be a fully working prototype/demonstrator that as close to the final product as possible. To fulfil this ambition producibility and aesthetics need to be addressed during the project as well.

Things that will be out of the scope: Design of mobile application & business model

## PLANNING AND APPROACH **

Include a Gantt Chart (replace the example below - more examples can be found in Manual 2) that shows the different phases of your project, deliverables you have in mind, meetings, and how you plan to spend your time. Please note that all activities should fit within the given net time of 30 EC = 20 full time weeks or 100 working days, and your planning should include a kick-off meeting, mid-term meeting, green light meeting and graduation ceremony. Illustrate your Gantt Chart by, for instance, explaining your approach, and please indicate periods of part-time activities and/or periods of not spending time on your graduation project, if any, for instance because of holidays or parallel activities.

start date 20 - 2 - 2020 | 14 - 7 - 2020 end date




I will not take any holidays, except for national holidays and the friday after Ascension Day (5 days in total). Starting halfway the first week and finishing halfway the last week makes it a total of 22 weeks, but 100 working days.



Initials & Name IN Verduijn Student number 4283414

Title of Project Development of an IoT sensor facilitating legionella prevention

## MOTIVATION AND PERSONAL AMBITIONS

Explain why you set up this project, what competences you want to prove and learn. For example: acquired competences from your MSc programme, the elective semester, extra-curricular activities (etc.) and point out the competences you have yet developed. Optionally, describe which personal learning ambitions you explicitly want to address in this project, on top of the learning objectives of the Graduation Project, such as: in depth knowledge a on specific subject, broadening your competences or experimenting with a specific tool and/or methodology, ... . Stick to no more than five ambitions.

What I want to show:

Last semester I did an internship at the design agency VanBerlo. During the internship I learned a lot about what it takes to be a designer, and what skills are useful in this profession. I also found out that I really enjoyed working there, and that I would like to have a job at a design agency after graduation. With my graduation project I want to show that I have the potential to become a design engineer. This project suits my ambitions because I want to show my technical skills as an engineer, but also my sense of form as a designer. I believe I can deliver a detailed product proposal that works properly, fits the user and is aesthetical pleasing.

What I want to learn & improve:

Doing interviews
For the ergonomic research I am planning on doing interviews. I have never done an in depth interview, and I would like to dive into this more and use this during my research. I would like to take some time to do some reading about how to conduct an interview properly.

Sustainability
I find sustainability a topic that should not be neglected during the design process. I would like to invest what the possibilities for this product are to make it at sustainable as possible, within the restrictions it has. I already gained some knowledge in sustainable design during my studies, but I think I can broaden my knowledge more.

## FINAL COMMENTS

In case your project brief needs final comments, please add any information you think is relevant.

# Appendix B. Additional information about legionella

## Legionellosis

People cannot get infected by drinking contaminated water. Though, if a person coughs or chokes it can happen contaminated water ends up in the lungs. Legionella is not transferable from person to person. (WHO, 2018; RIVM, 2019)

Pontiac fever is self-limiting, so no treatment is needed and patients will recover by themselves. For Legionnaires' disease this is not the case. No vaccine is available, and treatment is done by antibiotic (WHO, 2018). Research shows that a fast response is highly beneficial for the recover-rate (Lettinga, 2002).

## The Netherlands

One of the biggest outbreaks in history took place in The Netherlands. In 1999, an infected whirlpool at a flower show in Bovenkarspel caused a lot of people to get sick, some of whom died. Sources give contradicting numbers, but the number of cases would have been around 188 (den Boer, 2002) with at least 28 deaths (den Boer, 2000). A lot of people who did not die from the disease got permanent health issues. Another major outbreak took place in 2006 caused by a wet cooling tower in Amsterdam. 30 people got infected of whom 2 died (van den Hoek, 2006).

## Increasing number of cases

In several studies an increase of legionella cases has been reported. In the USA, the annual number of reported Legionella cases increased with a factor of almost 4,5 (Rubin, 2018). Figure 47 shows a doubling in cases in the past ten years in the Netherlands. The peak in 2010 can possibly be explained by an exceptional wet and hot summer (NOS, 2017).

According to the National (USA) Academies of Sciences, Engineering and Medicine (2019) the increasing numbers are possibly caused by a higher amount of people having health vulnerabilities (like elderly people) and more and more people living in cities. Also, it is becoming easier to test for legionellosis so more cases are reported with an increased number as a result.

A correlation has been found between heavy rainfall and an increasing number of Legionellosis cases (Hicks, 2007). This is possibly because of puddles of water, where water easily heats up and there is no water flow. There are also presumptions that climate change has a positive effect on legionella growth.

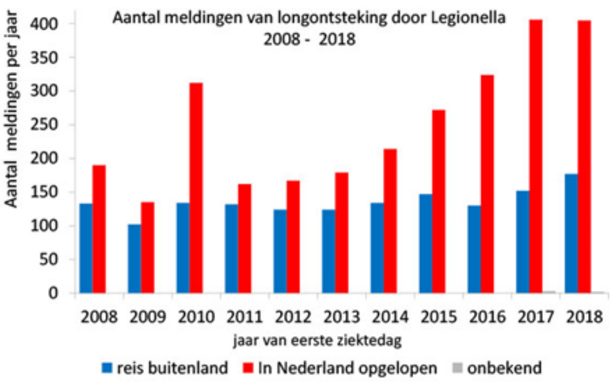



*Figure 47. The number of reported cases of legionnaires' disease (RIVM, 2018)*

# Appendix C. Legionella prevention methods

There are several methods to control or eliminate the presence Legionella bacteria in artificial water systems. These are the categories as described by the RIVM (2012). Every method has its benefits and disadvantages. A research of the RIVM (2012) shows that temperature control is used the most in the Netherlands. The sensor of Octo is also operating in this form of prevention.

### Temperature control

Temperature control is a very effective way of keeping the bacteria from growing or even killing them:

- Keeping cold water pipes below 20°C to prevent grow
- Keeping warm water pipes above 50°C to prevent grow
- Heating the water to a temperature above 60°C once in a while to kill the bacteria

### Chemical control

There are several chemicals that can be added to the water in the water system to kill bacteria (WHO, 2007). Some of these chemicals are effective in killing bacteria, but often harm the water safety in general. Other chemicals are not that harmful, but less effective. Chlorine dioxide is a commonly used additive to disinfect swimming pools and in lower concentrations also drinking water. A lot of countries ad chlorine dioxide to the mains water system. One of the disadvantages is the taste of chlorine, which can cause people to avoid drinking water from the mains network. In the Netherlands no or neglectable amounts chlorine are used, in contrast to a lot of other countries (Vitens, 2018).

### Physical control

It is possible to filter out the bacteria by using a physical filter or UV light. These are effective techniques but only work at the point of use. They can be used as a gatekeeper (UV light and filter) or installed at an outlet (filter). They do not prevent already existing biofilm from expanding. Filters also need to be replaced regularly (WHO, 2017), which makes it costly to use.

### Electrochemical control

With this method copper and silver ions are added to the water that react with the bacteria and biofilm. Big advantages are that this technique not only kills the bacteria, but also destroys the biofilm. In the Netherlands this technique is only allowed in certain circumstances, if proven that other measures did not prevent Legionella grow (ILF, 2012). What should be said is that this method only works when there are points of stagnant water in the system, otherwise the ions will not reach all parts of it (RIVM, 2012).

# Appendix D. Interview Tim Schmidt from Rentokil

Tim Schmidt from Rentokil Hygiene was consulted to gather more information and insights about Legionella prevention in practice. Schmidt and Dirk Huibers (CEO of Octo) met at a business fair.

Rentokil Hygiene is a company operating in the Netherlands that, among other things, is specialised in Legionella prevention. The company can help facilities from doing risk analysis of the pipe systems to carrying out the actual Legionella prevention. They make use of the Clip'R sensors of Legionella Dossier. The sensor uses temperature to recognise if a sensor is flushed.

For a priority facility it is obligated to have a water safety plan. To draw this plan, a risk analysis of the pipe system is done. Critical parts of the system are addressed, and only those parts need to be flushed. In a building with 100 taps, about 20 taps will need to be flushed (20 %). There are two ways to do this flushing:

- The tap is put fully open for two minutes. After two minutes, it is allowed to assume that the whole pipe is flushed, according to the regulations of the Netherlands.
- The temperature is measured until there is a constant temperature. This method saves about 40% of water in comparison with running a tap for two minutes, according to Schmidt.

This flushing needs to take place once a week. On top of that the temperatures of assigned parts of the pipe system need to be measured every month. In big buildings it is usual to have a warm water circulation system. This systems pumps around warm water to make sure tap points far from the heating system have warm water in reasonable time. The pipes of these systems are often located in floors or ceilings. Because these kind of systems are a risk as for Legionella contamination these pipes need to be measured as well. Because of the places these pipes are located measuring temperature can be a hustle.

People who do the Legionella prevention rounds are often people that have Legionella prevention as a side task. These could be for example people from technical service or even caretakers in healthcare institution. They are not educated to do these tasks and it is added to their regular task package.

Schmidt tells that in practice Legionella prevention is not executed well. The people that are tasked to do so lack knowledge, willingness, time and sense of urgency. This results in poorly executed prevention rounds. Flushing rounds are skipped or done in a hurry. Temperature measurements are often filled in months prior to the actual date, in order to skip the measurement round for the upcoming months. Forms are almost never filled in properly, he says.

There is a reporting obligation for facilities if numbers of Legionella bacteria exceed the legally permitted quantity after a sample test is done. In order to bad publicity this is often not done. The actual numbers of dangerous quantities in pipe systems of those facilities are therefore missing. This means there is no overview of the actual risk of these poorly executed water safety plans. Schmidt claims that hardly five percent of the cases are reported.

He also warned for a big increase in Legionella outbreaks after the corona crisis. A lot of buildings are closed during the crisis, and therefore taps not used.

# Appendix E. Introduction to IoT

The internet of things (IoT) is the principle of connecting all ‘things’ to the internet. ‘Things’ is used in the broadest definition of the word, it can indicate anything that is in the world around us. These things are not only connected to the internet, but are also able to communicate with each other through the internet. This technology offers big opportunities in automating and optimising our lives and industries. (McClelland, 2020)

In practice this means that there are lots of devices with sensors in our environment that collect data. This data is processed for the user and converted into actions. These actions could set other devices to work or notify the user.

## LoRa network

The sensor of Octo makes use of the LoRa network to connect to the internet. LoRa stands for ‘long range’ and is a low power wide area network (LPWAN) technology that is designed for IoT networks. The idea of LPWAN networks is that a big amount of sensors spread over a wide area are connected to one system. A LoRa network consists out of sensors that send data to LoRa gateways which are connected to the internet. These gateways can have a range of ten kilometres and is most of the time powered by mains power. A well-implemented LoRa sensors can last for over two years without having to replace batteries. (Radovici, 2017)

To organise the LoRa network, there is the LoRa Alliance that manages the network and protocol, the LoRaWAN specification. The definition from the LoRa Alliance for LoRaWAN is: “The LoRaWAN® specification is a Low Power, Wide Area (LPWA) networking protocol designed to wirelessly connect battery operated ‘things’ to the internet in regional, national or global networks, and targets key Internet of Things (IoT) requirements such as bi-directional communication, end-to-end security, mobility and localization services.” (LoRa Alliance, 2020)

A LoRa network operates in an open frequency. This means that it is not needed to have a licence to send data, in contrast to other frequencies like a phone network. These free to use frequencies are called Industrial Scientific Medical (ISM) frequencies and are different for each continent. The disadvantage of an open frequency is that there is a lot of interference since everyone can use it. This can make it harder to receive the correct data in crowded areas. (Radovici, 2017)

Other networks that use open frequencies are for example Bluetooth and Wi-Fi. These two examples are local area networks (LAN). With a LAN it is possible to send a big amount of data, but over a relatively small range. Sending these data also uses a lot more energy. This means in practice that the ‘things’ in the network needs to be connected to the mains power because it will run out of battery quickly. The big advantage of a LPWAN is the ability to transmit data over a small area with a small amount of energy needed.

# Appendix F. Installation guide

## Benodigdheden

- Legionella Sensor
- TEKTELIC Kona Micro IoT LoRaWAN Gateway
- Teltonika RUT240 4G Router
- 3.6V Lithium AA Batterij (2,0 per sensor)
- Water thermometer
- Programmeer Tools
- Netwerkkabel
- Plattegronden/sensorplan van gebouw
- Schroevendraaier: Kruis- en platkop
- Schaar
- Dubbelzijdig tape
- Kabelbinders of tyraps
- Sofware: Tera Term (https://tera-term.nl.softonic.com/)

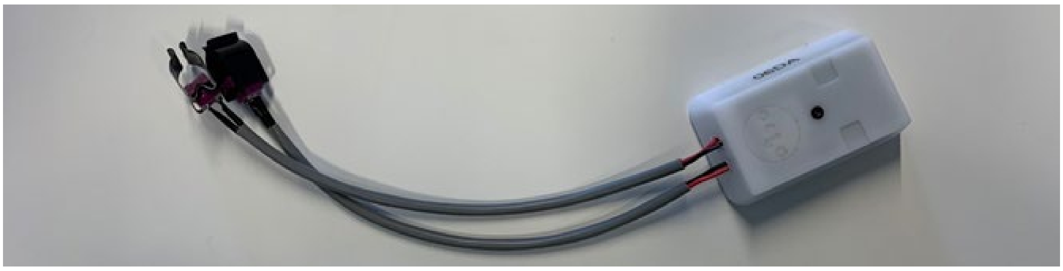
## Voorbereiding op Kantoor (Hardware)

1. Open https://octooffice.sharepoint.com/:x:/s/activeprojects/snUvvnHYABjVqapFWIB4nsdmYf0GdKtQ?e=chpgDM, kopieer het bestand en vul deze in.
2. Verzamel de onderstaande stukken:

*1.1 Legionella Printplaat*

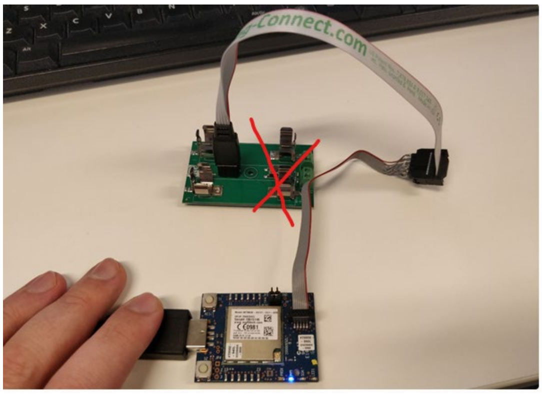
*1.2. Legionella Case*

*1.3.*



*2.1 Legionella Sensor*

3. Bevestig de bovenstaande stukken aan elkaar als 2.1 Legionella Sensor.
4. Verzamel de onderstaande Programmeer Tools;

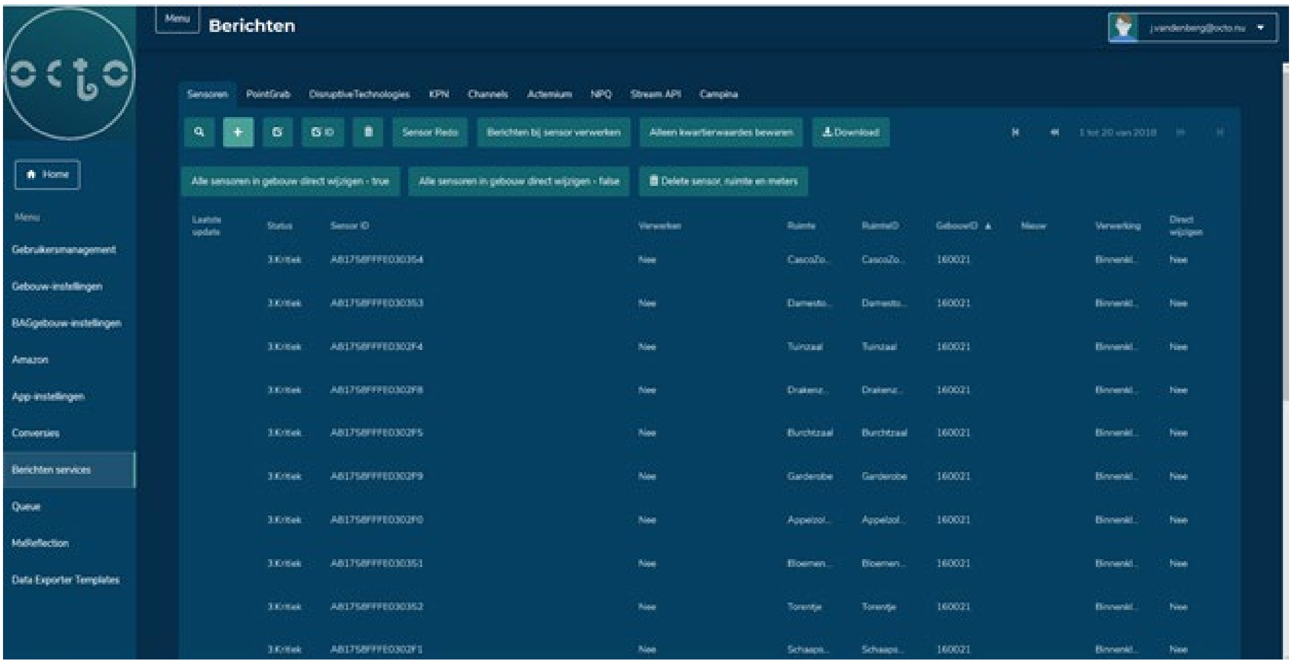



*3.1 xDot development board*

5. Volg de stappen in Slite voor de installatie en configuratie van de sensor: https://octo.slite.com/api/s/note/GvCL38jHMNUuN3aVP8ekUR/3-Legionella-Sensor
6. Configureer de TEKTELIC Kona Micro IoT LoRaWAN Gateway
   - Volg de stappen in Slite voor de installatie en configuratie van de Gateway: https://octo.slite.com/app/channels/fq1aLXUCay/notes/M4hAeC8eDI
7. Gebruik je een Teltonika RUT240 4G Router?
   - Ja, voorzie de 4G Router van een Simkaart, stroom en een internet verbinding (LAN-poort) tussen de Gateway en de 4G Router.
   - Nee, voorzie de gateway van Wi-Fi of via een ethernet kabel in een ethernet poort

## Voorbereiding op Kantoor (Software)

8. Ga naar https://octo.mendixcloud.com/ en log in als administrator.
9. Voeg bij Berichten Services de Legionella Sensor aan een gebouw toe.





10. Voeg de Legionella Sensor toe met een interval van 15 minuten, Sensor ID (Device EUI) en RuimteID (Project_#_#). Functie wordt meestal buiten beschouwing gelaten.
11. Sla de toegevoegde sensoren op door op de Diskette Icoon te drukken.
12. Controleer bij Gebouw-instellingen of de Legionella Sensoren zijn toegevoegd aan het gebouw en of ze werken.

## Installatie op Locatie

13. Installeer de TEKTELIC Kona Micro IoT LoRaWAN Gateway
    - Voorzie de gateway van stroom.
    - Voorzie de gateway van internet, door een ethernet kabel in een bestaand ethernet port of door een Teltonika RUT240 4G Router.
14. Bevestig de Legionella Sensor in de ruimte op de aangegeven locatie.
15. Verbind de koude voeler aan de koud-waterleiding.
16. Verbind de warme voeler aan de warm-waterleiding.
17. Plak de Legionella Sensor vast met het dubbelzijdig tape.
18. Controleer of de Legionella Sensor data verstuurd, via DBeaver of https://octo.mendixcloud.com/

## Afwijkingen op Locatie

- Leidingen kunnen zich boven een (systeem) plafond bevinden, verplaatst dan een systeemplafond plaat.
- De doorsnede van de waterleidingen kan te groot zijn, verwijder dan de clip van de voeler.
- De doorsnede van de waterleidingen kan te klein zijn, gebruik kabelbinders of tyraps.

## Tips/tricks

- Een Legionella Sensor is voorzien van een koude- en warmte meter.
- Op de Legionella Printplaat wordt de hot en cold connectie aangegeven.
- Plak een rood plakbank om de warmte geleider.
- Bevestig de geleiders zo strak mogelijk om de waterleidingen. Zit de voeler niet strak genoeg om de leiding heen, gebruik dan kabelbinders of tyraps.
- Bevestig de geleiders zo dicht mogelijk bij het tappunt van de waterleidingen.
- Elektrische kraan boilers kunnen storing in de data veroorzaken.

# Appendix G. Existing solutions & competitors

In this chapter existing solutions and competitors of Octo are discussed. The scope of this analysis are solutions that deal with the temperature control and periodic flushing method. Other methods like chemical and physical control are considered not to be relevant for this analysis.

## Analog logbook with manual temperature registration

One of the methods that is still used is an analogue logbook. Someone goes by every tap that needs to be flushed and performs a flushing according to the water safety plan. The results are written down in a paper logbook.

- Time consuming
- Error sensitive
- No data of tap point use: unnecessary flushing
- No automated flushing

## Digital logbook with manual temperature registration

There are several temperature sensors on the market that measure temperature and are connected to a device (mostly a smart-phone) by Bluetooth. The temperature sensor is put under a running tap and the device notifies the user if the flushing is done. These sensors automatically register the temperature and flushing to a database. An example of such a Bluetooth sensor is the one from Legionella Dossier (Figure 48).

+ Automated database
- No data of tap use: unnecessary flushing
- No automated flushing

## Digital logbook with automated temperature registration

There are several companies that use temperature sensors to monitor the temperatures in water systems. These sensors take care of the obligated temperature log of the system. An example of this kind of sensor is the temperature sensor of Aqua Assistance (Figure 49). This company offers this product in combination with an automated flushing system (see "Automatic flushing systems).

+ Automated database
+ Temperature log
- No data of tap use: unnecessary flushing
- No automated flushing

## Digital logbook with automated flushing registration

There are several possible ways to register flow. Though it seems that the only method to do this on the market is the use of temperature data. This is also the method the sensor of Octo uses.

Legionella Dossier is the closest competitor to Octo. Their Clip'R (Figure 50) is a sensor that uses a similar flow detection method as the sensor of Octo. The big difference is that it only measures the temperature once a quarter of an hour. This is insufficient for cold water pipes because of the

*Figure 48. Bluetooth temperature sensor of Legionella Dossier*

small temperature differences are not measurable then.

They offer a total package with a dashboard that automatically logs taps that have been flushed and taps that still need to be flushed by hand.

+ Easy to install
+ Temperature log
+ Data of tap use
+ No unnecessary flushing
- No automated flushing
- Measures only one pipe

## Automatic flushing systems

### Automatic flushing by-pass

Aqua Assistance also offers an automated flushing system, that is attached to the pipe through a bypass between the supply and drain pipes. This valve opens at a certain time frequency to flush the pipe. With this system there is no information of the actual flushing of the tap. The system is mostly used in combination with their temperature sensor.

+ Automatic flushing
- No data of tap use: unnecessary flushing
- Hassle to install: changes to the pipes need to be made

### Automatic flushing taps

Some facilities are equipped with automatic or electric driven tap points. Some of these systems automatically perform a flushing if a tap is not used for a certain time period.

These kind of systems are often used in new-build facilities that make use of sensor-automated tap points like showers and faucets.

+ Automatic flushing
+ No unnecessary flushing
+ Temperature log
- Taps need power supply
- Need to replace the whole tap

## Conclusion

Automatic flushing systems always involve change of the pipe system or replacement of the whole tap. This makes these systems less suitable for older/ already build buildings. Octo distinguish itself by offering a solution that is applicable without having to change anything to the pipe system.

The Clip'R of Legionella Dossier can be considered as Octo's only and biggest competitor in the field of Legionella prevention.  Other solutions do not solve the same problems. However, the Clip'R can only be used for one pipe although a lot of taps are connected to cold and water pipe lines. These pipes both need to be flushed and thus measured to exclude the tap.

*Figure 49. LoRa temperature sensor (left) and flushing system of Aqua Assistance*

*Figure 50. Clip'R of Legionella Dossier*

# Appendix H. List of Requirements

| | | | | |
|---|---|---|---|---|
| Number of requirements | 63 | | | |
| Within scope | 39 | D = Demand | Must be met, otherwise product fails |
| Met | 22 | R = Requirement | Must be met, but product can work without (but goal not met) |
| Reccomendations | 10 | W = Wish | Increasees quality of the product when achieved as much as possibl |

| Main category | Sub category | N | Type | Description/details | Scope | Met | Source/comment |
|---|---|---|---|---|---|---|---|
| 1. Performance | 1.1 Measurement | 1.1.1 | D | The product should be able to detect a flushing in a warm water pipe | Yes | Yes | Otherwise the sensor does not fulfil its basic function |
| | | 1.1.2 | D | The product should be able to detect a flushing in a cold water pipe | Yes | Rec | Otherwise the sensor does not fulfil its basic function |
| | | 1.1.3 | R | The detection of flushings should work on every standard pipe material (Copper, PVC, PP, PER and PEX) | Yes | Rec | https://www.habitos.be/nl/bouwen-verbouwen/sanitairspecialist-welke-materialen-voor-de-waterleiding-5667 |
| | 1.2 Connectivity | 1.2.1 | W | The sensor should be able to connect with an IoT network without the use of an gateway | Yes | Rec | This is desirable to reduce complexity and improve |
| | | 1.2.2 | W | Sending data should cost as little energy as possible | No | n/a | Basic principle of LRWAN, extends battery life |
| 2. Environment | 2.1 Water tightness | 2.1.1 | D | The sensor should be water resistant with an rating of at least IP34 | Yes | Yes | https://www.gwp.co.uk/guides/ip-ratings-explained/ |
| | 2.2 Temperature | 2.2.1 | D | The sensor should withstand temperatures between 0°C and 60°C | No | n/a | Temperatures the water (and thus pipes) can possibly get up to at least 60°C. |
| 3. Life in service | 3.1 Use intensity | 3.1.1 | D | The product should be in use constantly | Yes | Yes | Sensor is constantly measuring temperature |
| | 3.2 Life span | 3.2.1 | R | The sensor should last for at least five years | No | n/a | The sensor should be worth the investment in costs and environmental impact |
| 4. Maintenance | 4.1 Maintenance | 4.1.1 | R | The sensor should not need maintenance for at least a year | Yes | Yes | Cannot be validated during this project, but needs to be taken into account |
| | | 4.1.2 | R | The location of the sensor should be known after installation | Yes | Yes | Otherwise the sensor is untraceable for maintenance |
| | 4.2 Battery life | 4.2.1 | W | The power supply of the sensor should last for at least two years | No | n/a | This is the standard for IoT sensors |
| | 4.3 Software | 4.3.1 | W | It should be possible to perform software updates of the sensor remotely | Yes | Rec | This is not possible with the LoRa network, but is with other IoT networks |
| 5. Target product cost | 5.1 Cost price | 5.1.1 | W | The cost price should be €50 or less | Yes | n/a | Whish from Octo |
| | 5.2 Business model | 5.1.1 | R | The dashboard is a service purchase, what is paid monthly/yearly | No | n/a | How Octo currently offers their products to clients |
| | | 5.2.1 | R | The sensor should be available as a service | No | n/a | Requirement from Octo |
| 6. Transport | - | | | | | | |
| 7. Packaging | 7.1 Instructions | 7.1.1 | R | The packaging should include instructions how to install, place and use the product | Yes | Yes | This will improve the usability of the product |
| | 7.2 Physical requirements | 7.2.1 | W | The package should protect the sensor (from falling from 1m height) | No | n/a | It is not desirable that the sensor breaks during transport |
| 8. Quantity | 8.1 Batch size | 8.1.1 | R | The first batch size of the sensor will be a 1.000 pieces | Yes | n/a | Requirement from Octo |
| | | 8.1.2 | W | The production of the sensor should be scalable to mass-production | Yes | Yes | Requirement from Octo |
| 9. Production facilities | 9.1 Production | 9.1.1 | R | Production facilities should be suitable for a batch of 1000 products | Yes | Yes | Requirement from Octo |
| | | 9.1.2 | R | The entire production is outsourced | Yes | Yes | Octo does not own any production facility (yet) |
| | 9.2 Assembly | 9.2.1 | | Assembly of PCB is done by Actemium (max. of 20.000) | | | Not really a requirement |
| | | 9.2.2 | W | Assembly of the sensor is done by a sheltered workshop | No | n/a | Whish from Octo |
| 10. Size and weight | 10.1 Size | 10.1.1 | D | The housing of the sensor should fit the already developed PCB | Yes | Yes | Requirement from Octo |
| | | 10.1.2 | R | The housing of the sensor, if attached to a pipe, should fit all standard sizes of pipes | Yes | Yes | This should be investigated during ideation https://www.habitos.be/nl/bouwen-verbouwen/sanitairspecialist-welke-materialen-voor-de-waterleiding-5667 |
| | | 10.1.3 | W | The NTCs should take as less as possible space on a water pipe | Yes | Yes | Surroundings of the pipe may obstruct the placement of the NTCs |
| | 10.2 Weight | 10.2.1 | R | The sensor should not weight over a 0,20 kg incl. batteries | Yes | Yes | Current sensor is about 0,150 kg |
| 11. Aesthetic, appearance and finish | 11.1 Aesthetics physical product | 11.1.1 | W | The aesthetics of the sensor should fit the brand of Octo | Yes | n/a | This is one of the first physical products of Octo |
| | | 11.1.2 | W | The sensor should look "reliable" | Yes | n/a | The more professional it looks, the more faith (new) clients will have in the product |
| | 11.2 Aesthetics digital product | 11.2.1 | W | The aesthetics of the dashboard should fit the brand of Octo | No | n/a | The product is part of the already existing services of Octo |
| 12. Materials | 12.1 Materials | 12.1.1 | W | Materials should be as little harmful for the environment as possible | No | n/a | In my opinion this should always be part of a design process |
| | | 12.1.2 | W | The material of the housing should be sustainable enough to last at least x (10?) years | No | n/a | The housing could be used for multiple life spans |
| 13. Product life span | 13.1 Future proof | 13.1.1 | W | The sensor should be able to be updated during the time the sensor is on the market | Yes | Rec | Software could be updated and housing parts could fit new versions of electronics etc. |
| | | 13.2.1 | W | The dashboard should be kept up to date regularly | No | n/a | This is standard for IT developers |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **14. Standards, rules and regulations** | 14.1 Regulations | 14.1 | D | The product should be conform to the "Drinkwaterbesluit" of the Dutch government | Yes | Rec | https://wetten.overheid.nl/BWBR0030111/2018-07-01 |
| **15. Ergonomics** | 15.1 Sensor ergonomics | 15.1.1 | W | The product should provide feedback if the power is on | Yes | Yes | Would improve usability |
| | | 15.1.2 | W | The product should provide feedback if the sensor is connected | Yes | Yes | Would improve usability |
| | 15.2 Dashboard ergonomics | 15.2.1 | R | The dashboard should be understandable for someone without prior knowledge | No | n/a | Would improve usability |
| | | 15.2.2 | W | The dashboard should adapt on the needs of the different user groups | Yes | Rec | In the anlysis the different user groups are explained |
| **16. Reliability** | | 16.1.1 | D | The product should not communicate a false positive | Yes | Rec | False positives of the sensor should be filtered out by the post processing of the cloud |
| **17. Storage** | 17.1 Storage | 17.1.1 | D | The sensor should be stored moisture free | No | n/a | To prevent breakage before use |
| | | 17.1.2 | D | The sensor should be stored ESD (electrostatic discharge) free | No | n/a | To prevent breakage before use |
| **18. Testing** | 18.1 Water tightness | 18.1.1 | W | The sensor should pass a water tightness test | No | n/a | https://www.gwp.co.uk/guides/ip-ratings-explained/ |
| | 18.2 Reliability | 18.2.1 | D | The product should be tested on reliability | Yes | Rec | This should be sorted out by Octo |
| **19. Safety** | 19.1 Safety | 19.1.1 | D | The sensor should not be able to physically harm the user | Yes | Yes | Presumably not a big issue in this project |
| | 19.2 Data safety | 19.2.1 | R | Data collected by the sensor should be inaccessible for third parties | No | n/a | This should be sorted out by Octo |
| **20. Societal and political implications** | 20.1 Impact | 20.1.1 | W | The product should have a positive environmental impact | No | n/a | Use of an LCA |
| | | 20.1.2 | W | The product should have a positive impact on public health | Yes | Yes | This is the core goal of the project |
| | | 20.1.3 | W | The product should be cost saving for the client | No | n/a | Could become a challenge to make an acurate estimation |
| **21. Product liability** | 21.1 Liability | 21.1.1 | | *Who is liable? (Or who should be?)* | No | n/a | Something Octo should think about |
| **22. Installation and initiation of use** | 22.1 Installation | 22.1.1 | R | The user should be able to install and place the product within 10 minutes | Yes | n/a | Placing the sensors plus execute a test flushing. If needed, trouble shooting |
| | | 22.1.2 | R | No changes to the water pipes can be made to install the sensor. | Yes | Yes | |
| | | 22.1.3 | R | The housing should be attachable to any size of water pipe | Yes | Yes | |
| | | 22.1.4 | R | The housing should be attachable to horizontal and vertical oriented water pipes | Yes | Yes | |
| | | 22.1.5 | R | The NTCs should be applicable on all standard pipe sizes (roughly 9, 12, 15 and 22) | Yes | Yes | https://www.habitos.be/nl/bouwen-verbouwen/sanitairspecialist-welke-materialen-voor-de-waterleiding-5667 |
| | | 22.1.6 | R | The attachment of the NTCs should be able to do with one hand | Yes | Yes | |
| | | 22.1.7 | W | The user should be able to install and place the product without any support from Octo | Yes | Rec | Wish from Octo |
| | | 22.1.8 | W | The user should be able to understand the installation within 10 minutes | Yes | n/a | The instructions should be that clear and the installation be that simple |
| | | 22.1.9 | W | The installation of the housing should be able to do with one hand | Yes | No | The desired place of the sensor is sometimes hard to reach |
| **23. Reuse, recycling** | 23.1 Reuse | 23.1.1 | W | The housing can be reused for a second life cycle (with new components) | No | n/a | Part of sustainable design |
| | 23.2 Recycling | 23.2.1 | W | The materials of the housing should be recycled | No | n/a | Part of sustainable design |
| | | 23.2.2 | W | The materials of the electronics should be collected separately and be recycled | No | n/a | Part of sustainable design |

# Appendix I. Test process

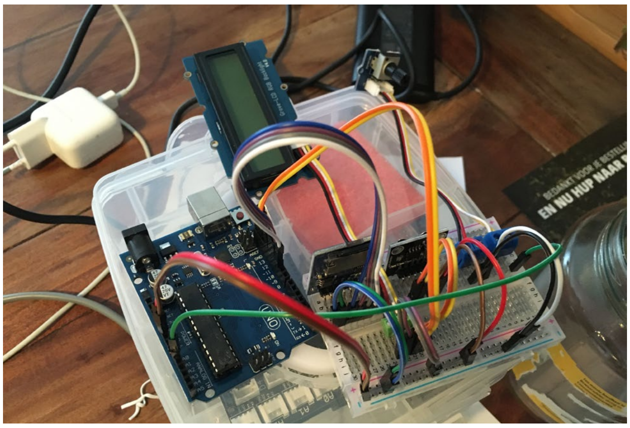


Figure 51. Arduino prototyping


Figure 52. Using excel data stream

Figure 53. Leakage by installing a flow sensor

Figure 54. Testing the flow meter

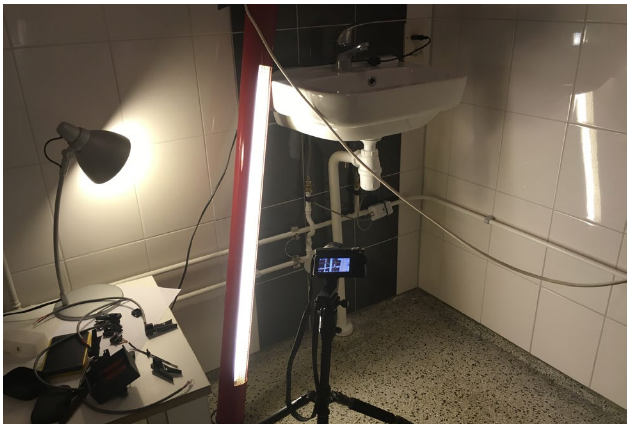


Figure 55. Photo studio in the bathroom

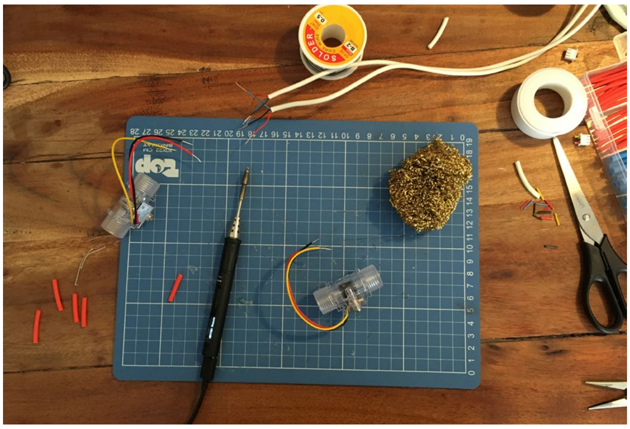


Figure 56. Home office

Figure 57. Flow sensor test at home

# Appendix J. Brainwriting session

Due to the COVID-19 crisis it was not possible to host a brainstorm session with people being physically present. This asked for some creativity in making it possible to do a session online.

For this reason was chosen to use the method of brainwriting. This was easy to translate to a digital version.

An Excel file was created (Figure 58) to facilitate the session. Each participant started in their own tab and wrote down their ideas for the questen that was stated in that specific tab. After four minutes the participants were asked to go to the next tab, etc. They were able to see the ideas of the previous participants and were able to build on those ideas.

## Outcome of brainwriting session

### Bevestiging – methodes

- Knijper
- Sugru plakmateriaal
- Tie-wrap
- Magnetische bevestiging: Snap-on systeem
- Elastische klem die de voeler automatisch aantrekt
- Klitteband
- Sterk dubbelzijdig tape, zodat de NTC niet verschuift tijdens installatie
- De voeler in een soort spiraal van veerstaal verwerken die zichzelf oprolt om de leiding heen
- De kant die op de leiding zit plakkerig maken zodat de ntc niet verschuift tijdens installatie
- Elastiek
- Schroefsluiting
- Tie-wrap
- De sensor met een flexibele verende klem aan de leiding bevestigen

### Bevestiging – eisen

- Het met één hand kunnen doen.
- Dat de bevestiging niet afhankelijk is van de diameter van de buis.

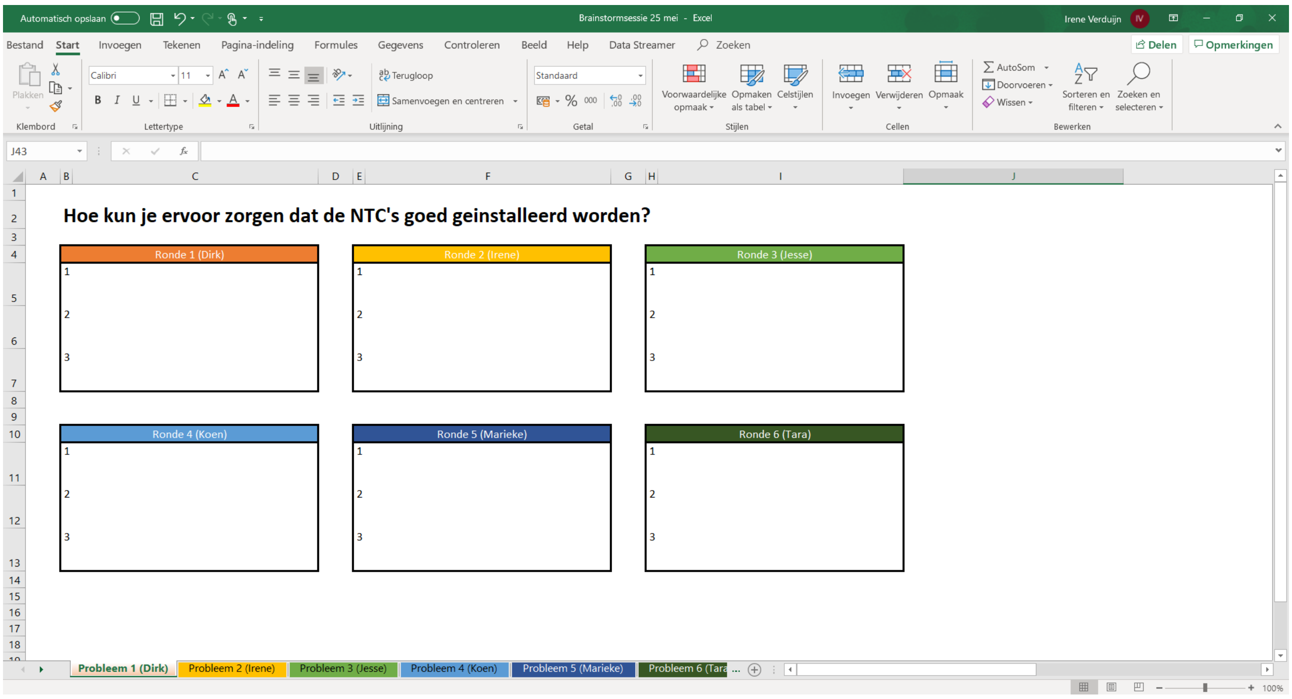



*Figure 58. Set up of brainwriting session*

- Verschillende maten bijleveren. Een “passer” toevoegen waarmee de diameter opgemeten. kan worden en zo de juiste clip gebruikt kan worden.
- De NTC zo vormgeven dat die een foute installatie onmogelijk maakt.
- Er mag geen materiaal relaxatie/moeheid optreden over tijd.

## Behuizing

- Veranderen van de behuizing naar een klik systeem zodat er geen schroevendraaier en dergelijke nodig zijn.

## Use cues

- Verschil warme voeler en koude voeler gemakkelijk zichtbaar maken
    - Andere kleur (rood/blauw)
    - Tekst
    - Klem
    - Andere vorm
- De installatie van de ntc’s logisch maken. Het moet in één oogopslag duidelijk zijn wat de bedoeling is.

## Installatie-instructies

- Stap voor stap instructies (IKEA stijl)
    - Incl. aandachtspunten
    - Benodigd gereedschap
    - Onderdelen
    - Veelgemaakte fouten
    - FAQ
    - Debug-flowchart

Instructiefilmpjes

- Ook onjuiste installatie laten zien
- Youtube/OCTO website/OCTO platform
- Mobiele applicatie met stap voor stap instructies
    - Bij succesvol uitvoeren stap ga je automatisch door naar volgende stap in de app/platform

## Feedback installatie

- Lampjes
- Geluid
- Feedback in een app
    - Proefspoeling
    - Als het fout is: wat zou er dan mis kunnen zijn? Tips & trics
    - Resultaten van het verschil tussen te verwachten en gemeten data laten zien
- Achteraf: Communiceren met de desbetreffende partij over hoe het is uitgevoerd en checken of de data binnenkomt
- Een geijkte referentie sensor meenemen. Adhv die sensor controleer je vervolgens of de sensor juist geïnstalleerd is.

## Registratie/aanmelding van de sensor

- Alles door Octo laten registreren.
    - Locatie bij installatie aangeven
    - Octo ontvangt lijst met sensor id’s van leverancier en kan dit in het platform laden.
- Gebruiker hoeft alleen nog maar op een knop te drukken
    - Sensor van te voren toevoegen aan het Octo en ttn platform bij een specifieke gebruiker. Installateur kan dat met een knop in drukken de sensor naar voren halen die hij aan het installeren is (zoals bij de disruptive sensoren) dan naam toevoegen en aan het juiste gebouw toevoegen
- Een usb kabel meeleveren waarmee je via

een computer of telefoon instellingen kan wijzigen
- Vanuit Actemium de sensoren voorgeprogrammeerd laten leveren. Elke sensor wordt standaard aangemeld met zijn eigen key.
- Sensor laten registreren en assembleren door een derde partij.
- Sensor met smartphone koppelen
    - Bluetooth
    - NFC
    - QR
    - RFID
    - Barcode
    - Code overtypen

## Locatie registreren

- Gebruik maken van GPS locatie
    - Van smartphone (GPS stamp)
    - Van sensor zelf
- Sensor bij installatie moeten aangeven op de plattegrond van het gebouw
    - 2D
    - 3D
- Verplicht een foto moeten toevoegen
    - Sensor zelf (Micro)
    - Wastafel
    - Ruimte
    - Verdieping
- Logische opzet voor de benaming van de sensor
- Gateways (3) gebruiken om te lokaliseren waar de sensor zich bevindt.
- Bij elke sensor een routebeschrijving naar de leiding toe vanaf de hoofdleiding waar het water het gebouw in komt (hoe doen loodgieters dit?)

## Controle voor een correcte installatie

- Het doen van een testspoeling
    - Controleren of de goede NTC op de goede leiding zit door de kraan te laten lopen
    - Het verloop van de eerste spoeling vergelijken met het verwachte verloop
    - Door naar de volgende stap als de spoeling goed is.
    - Vanuit de app de gebruiker een spoelpatroon laten uitvoeren en dat naast de data leggen die de sensor meet.
    - Een testspoeling doen met warm water: de sensor brandt een groen lampje als de sensor voor warm inderdaad op de warme leiding zit en andersom.
    - Via het platform de huidige informatie van de sensor doorgeven als deze geïnstalleerd wordt.
- Checklist waarbij de belangrijkste dingen voorkomen:
    - Kan de NTC makkelijk bewegen?
    - Zit er geen ruimte tussen de NTC en de leiding.
    - Kan je de draad van de NTC heen en weer bewegen?
- Controle doormiddel van een foto
    - Uploaden zodat deze door iemand van Octo bekeken kan worden
    - De applicatie herkent (middels beeldherkenning) of de sensor goed geïnstalleerd zit en geeft een go of no-go.
- Andere sensor als ijkpunt nemen
    - Flow sensor
    - Legionella sensor
- Controle door het meten van de temperatuur

van het water.

- Sensoren of andere indicatoren in het bevestigingsmechanisme plaatsen die meten of die goed gemonteerd is.

### Opleiding

- Installateurs opleiden
- De eerste keer een Octo installateur mee voor uitleg

### Out of the box

- Van tevoren op basis van een foto van de te bevestigen leiding een instructie mee sturen en de voelers hierop aanpassen
- Voorbeelden van goede installaties delen op social media
- Bij elke sensor een qr code leveren die in de buurt van de sensorid gehangen moet worden en gescand kan worden om meer informatie over de sensor te tonen.
- Door ergens op de locatie zelf een klein herkenningspunt (sticker) te plaatsen [als de sensor bijv. boven het plafond zit]

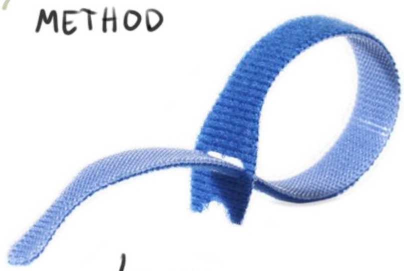
# Appendix K. NTC exploration

OPTIONS:

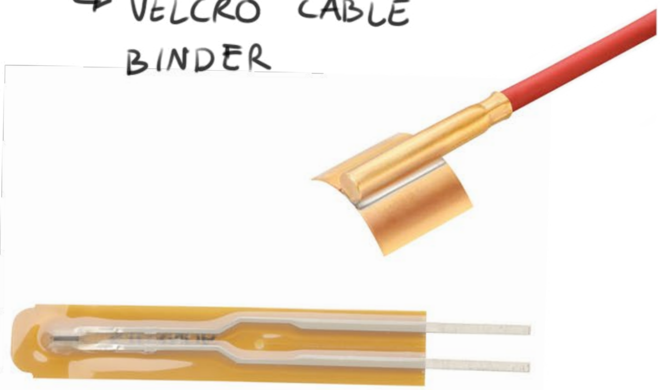
1. MULTIPLE CLIPS IN PACKAGING
2. CHANGE CLIP/FASTENING CONCEPT
3. CHANGE NTC
4. CHANGE MEASUREMENT METHOD

CLIP-ON NTC
USED BY CLIP'R?

METAL ZIPTIE



VELCRO CABLE BINDER



"FLEXIBLE" NTC

VELCRO TIE

ALREADY TRIED BY OCTO
= WHY WAS THIS NOT FEASABLE?

# Appendix L. Context references

# Appendix M. NTC prototyping

## Original clip

- \+ Attaches well to the pipe
- \+ Doable with one hand
- \+ Reusable
- \+ Durable
- \- Not suitable for multiple diameters
- \- Makes scratches on the pipe surface
- \- Looks unprofessional

## NTC Concept 1: Zip-ties

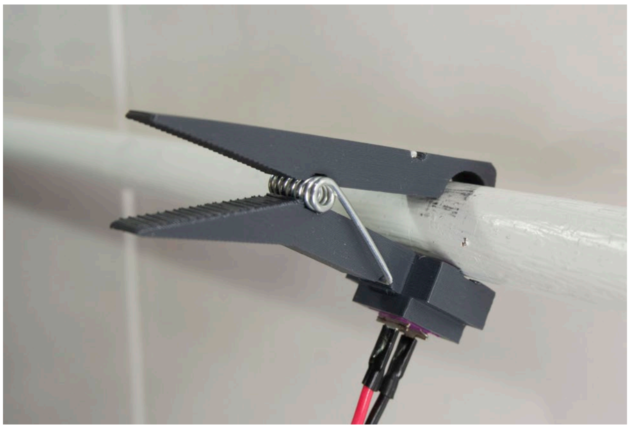
- \+ Attaches well to the pipe
- \+ Suitable for multiple diameters
- \+ Reusable (with new zip-ties)
- \+ Durablew
- \- Not doable with one hand
- \- Looks unprofessional

## NTC Concept 2: Velcro

- \+ Attaches well to the pipe
- \+ Suitable for multiple diameters
- \+ Reusable
- \- Durability is questionable
- \- Not doable with one hand

## NTC Concept 3: Elastic material

+ Attaches well to the pipe
+ Suitable for multiple pipe diameters
+ Reusable
- Limited in pipe diameters
- Durability is questionable
- Not doable with one hand

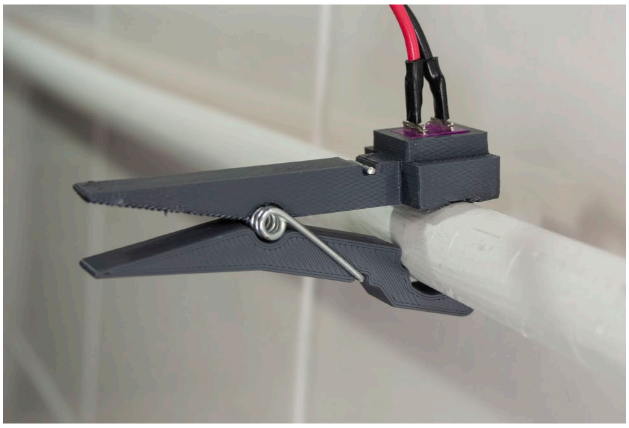


## NTC Concept 4.1: Clamp

+ Attaches well to the pipe
+ Reusable
+ Doable with one hand
+ Durable
- Not suitable for multiple diameters

## NTC Concept 4.2: Multi-diameter clamp

+ Attaches well to the pipe
+ Reusable
+ Suitable for multiple pipe diameters
+ Doable with one hand
+ Durable
- Chance to slip off pipes with bigger pipe diameters

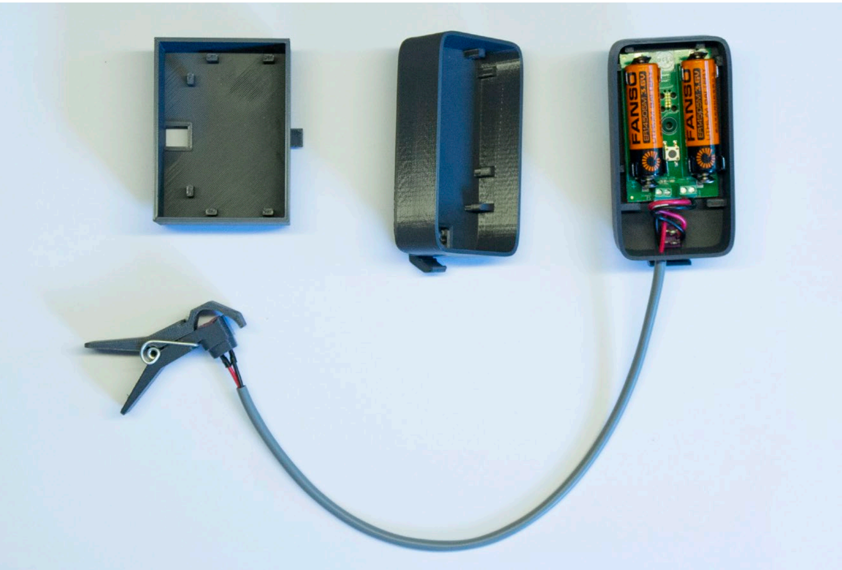


## NTC Concept 4.3: Multi-diameter clamp

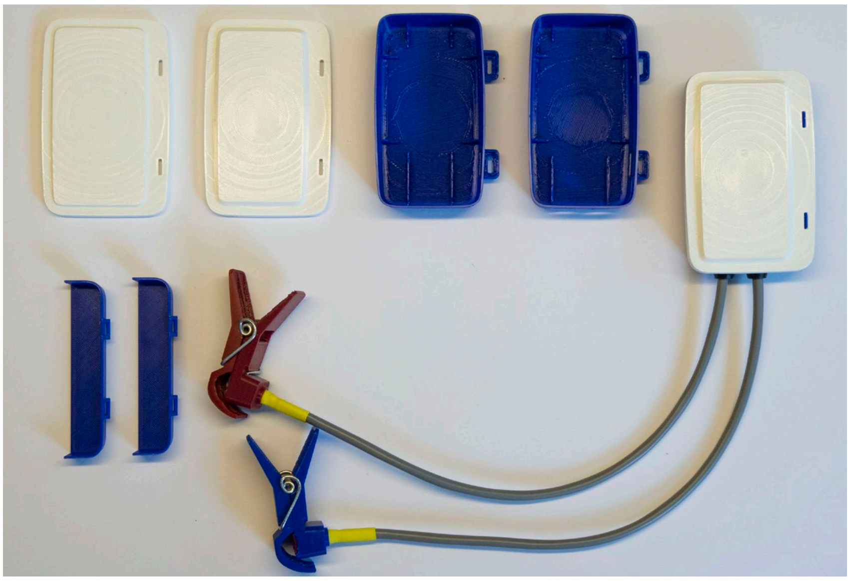
+ Attaches well to the pipe
+ Reusable
+ Suitable for multiple pipe diameters
+ Doable with one hand
+ Durable
+ Reduced chance to slip off the pipe

# Appendix N. Housing prototyping

Concept 1



Concept 2



Final concept

# Appendix O. Cost price calculation

| P3D | Injection Molding | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 3D printed moulds | | | | | 50 Pieces | | Total | € 193,51 |
| | | | | | | 3D printed moulds | | Excl. Batteries | € 186,51 |
| Part | Specs | Material | # | Tool costs | Start-up costs | Quantity | Piece price excl. tool | Piece price | Total price |
| Assembly total | | | | | | | | | |
| Housing | Top | ABS | 1 | € 1.500,00 | € 109,00 | 50 | € 10,00 | € 42,18 | € 42,18 |
| | Bottom | ABS | 1 | € 1.500,00 | € 109,00 | 50 | € 10,00 | € 42,18 | € 42,18 |
| NTC clamp | Top | ABS | 2 | € 1.300,00 | € 109,00 | 100 | € 10,00 | € 24,09 | € 48,18 |
| | Bottom | ABS | 2 | € 1.300,00 | € 109,00 | 100 | € 10,00 | € 24,09 | € 48,18 |
| Sring | Custom made | Steel | 2 | € - | € 100,00 | 100 | € 0,18 | € 1,18 | € 2,36 |
| Screw (seal screw) | M4x20 | Steel | 1 | € - | € - | 50 | € 0,19 | € 0,19 | € 0,19 |
| Rubber ring | Custom made | | 1 | € - | € - | 50 | € 0,65 | € 0,65 | € 0,65 |
| Diafragma tule | 12.5x1.5 | PVC | 2 | € - | € - | 100 | € 0,50 | € 0,50 | € 0,99 |
| PCB | Incl. assembly | | 1 | € - | € - | 50 | € - | € - | € - |
| NTC | Incl. assembly | | 2 | € - | € - | 100 | € - | € - | € - |
| Packaging | Cardboard box, incl. logo | | 1 | € - | € - | 50 | € 1,60 | € 1,60 | € 1,60 |
| Batteries | | | 2 | € - | € - | 100 | € 3,50 | € 3,50 | € 7,00 |

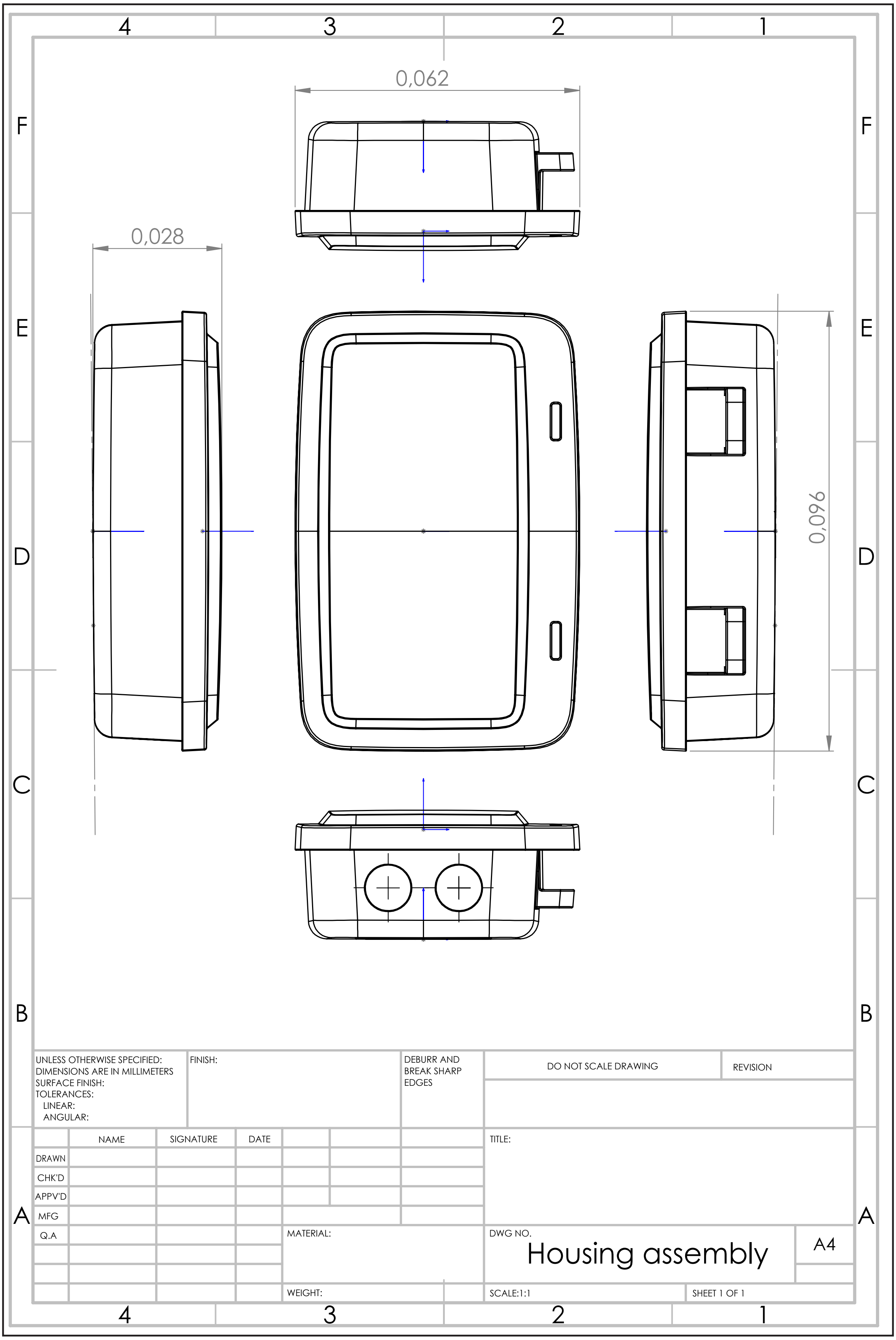
| | Source |
|---|---|
| Housing | Price indication from P3D |
| | Price indication from P3D |
| NTC clamp | Price indication from P3D |
| | Price indication from P3D |
| Sring | Price indication from Alcomex en Tevema |
| Screw (seal screw) | https://www.rvspaleis.nl/bouten/kruisgleuf/din-965/din-965-[-]-a2-[-]-m4/965-2-4x25_1 |
| Rubber ring | Price indication from Rubbermagazijn |
| Diafragma tule | http://www.ijzerwaren.nl/shop/?product=tuledia12515 |
| PCB | |
| NTC | https://nl.mouser.com/ProductDetail/Amphenol-Advanced-Sensors/JC103C3R5-13?qs=%2Fha2pyFadujE5EW91428HgWfaSelnU6ZHhCav0mmkJhmjh3D35CeBQ%3D%3D |
| Packaging | https://www.doosopmaat.nl/bestellen |
| Batteries | https://www.batterijenland.nl/saft-ls14500-lithium-aa-36v |

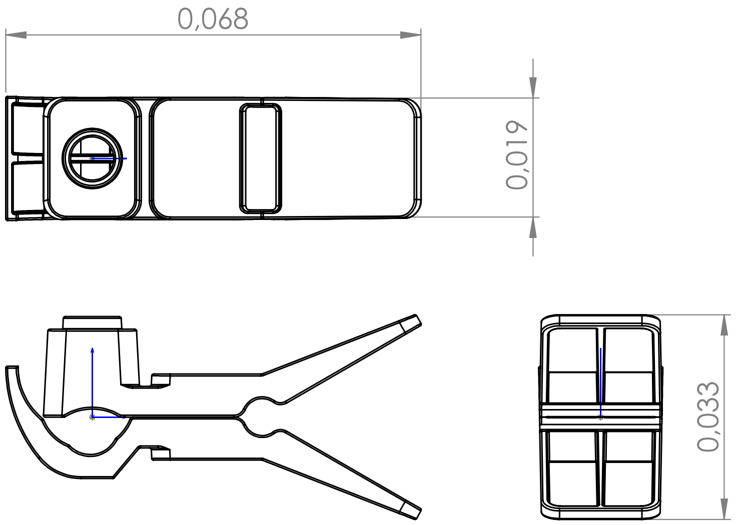
Protolabs Injection Molding

| | Steel moulds | | | | | 1000 Pieces | | Total | € 39,64 | 5000 Pieces | | Total | € 22,29 | 10000 Pieces | | Total | € 20,41 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Excl. Batteries | € 32,64 | | | Excl. Batteries | € 15,29 | | | Excl. Batteries | € 13,41 |
| Part | Specs | Material | # | Tool costs | Start-up costs | Quantity | Piece price excl. tool | Piece price | Total price | Quantity | Piece price excl. tool | Piece price | Total price | Quantity | Piece price excl. tool | Piece price total | Total price |
| Assembly total | | | | | | | | | | | | | | | | | |
| Housing | Top | ABS | 1 | € 4.000,00 | € 500,00 | 1000 | € 2,00 | € 6,50 | € 6,50 | 5000 | € 1,45 | € 2,35 | € 2,35 | 10000 | € 1,45 | € 1,90 | € 1,90 |
| | Bottom | ABS | 1 | € 4.750,00 | € 500,00 | 1000 | € 2,00 | € 7,25 | € 7,25 | 5000 | € 1,50 | € 2,55 | € 2,55 | 10000 | € 1,45 | € 1,98 | € 1,98 |
| NTC clamp | Top | ABS | 2 | € 3.000,00 | € 500,00 | 2000 | € 2,00 | € 3,75 | € 7,50 | 10000 | € 1,30 | € 1,65 | € 3,30 | 20000 | € 1,30 | € 1,48 | € 2,95 |
| | Bottom | ABS | 2 | € 3.000,00 | € 500,00 | 2000 | € 2,00 | € 3,75 | € 7,50 | 10000 | € 1,30 | € 1,65 | € 3,30 | 20000 | € 1,30 | € 1,48 | € 2,95 |
| Sring | Custom made | Steel | 2 | € - | € 100,00 | 2000 | € 0,18 | € 0,23 | € 0,46 | 10000 | € 0,18 | € 0,19 | € 0,38 | 20000 | € 0,18 | € 0,19 | € 0,37 |
| Screw (seal screw) | M4x20 | Steel | 1 | € - | € - | 1000 | € 0,19 | € 0,19 | € 0,19 | 5000 | € 0,19 | € 0,19 | € 0,19 | 10000 | € 0,19 | € 0,19 | € 0,19 |
| Rubber ring | Custom made | | 1 | € - | € - | 1000 | € 0,65 | € 0,65 | € 0,65 | 5000 | € 0,65 | € 0,65 | € 0,65 | 10000 | € 0,50 | € 0,50 | € 0,50 |
| Diafragma tule | 12.5x1.5 | PVC | 2 | € - | € - | 2000 | € 0,50 | € 0,50 | € 0,99 | 10000 | € 0,50 | € 0,50 | € 0,99 | 20000 | € 0,50 | € 0,50 | € 0,99 |
| PCB | Incl. assembly | | 1 | € - | € - | 1000 | € - | € - | € - | 5000 | € - | € - | € - | 10000 | € - | € - | € - |
| NTC | Incl. assembly | | 2 | € - | € - | 2000 | € - | € - | € - | 10000 | € - | € - | € - | 20000 | € - | € - | € - |
| Packaging | Cardboard box, incl. logo | | 1 | € - | € - | 1000 | € 1,60 | € 1,60 | € 1,60 | 5000 | € 1,58 | € 1,58 | € 1,58 | 10000 | € 1,58 | € 1,58 | € 1,58 |
| Batteries | | | 2 | € - | € - | 2000 | € 3,50 | € 3,50 | € 7,00 | 10000 | € 3,50 | € 3,50 | € 7,00 | 20000 | € 3,50 | € 3,50 | € 7,00 |

| | Source |
|---|---|
| Housing | http://www.protomold.co.uk/ProtoQuote.aspx?p=596927tq6e |
| | http://www.protomold.co.uk/ProtoQuote.aspx?p=596959h2in&c=1&fa=PM-T1&fb=PM-F0&sq=25&d=15&m=19&q=10000&View=3D#PartAdvisorySection |
| NTC clamp | http://www.protomold.co.uk/ProtoQuote.aspx?p=5963734j3s |
| | http://www.protomold.co.uk/ProtoQuote.aspx?p=596374zk7t |
| Sring | Price indication from Alcomex en Tevema |
| Screw (seal screw) | https://www.rvspaleis.nl/bouten/kruisgleuf/din-965/din-965-[-]-a2-[-]-m4/965-2-4x25_1 |
| Rubber ring | Price indication from Rubbermagazijn |
| Diafragma tule | http://www.ijzerwaren.nl/shop/?product=tuledia12515 |
| PCB | Developed and produced by Actemium |
| NTC | https://nl.mouser.com/ProductDetail/Amphenol-Advanced-Sensors/JC103C3R5-13?qs=%2Fha2pyFadujE5EW91428HgWfaSelnU6ZHhCav0mmkJhmjh3D35CeBQ%3D%3D https://www.digikey.nl/product-detail/en/ar |
| Packaging | https://www.doosopmaat.nl/bestellen |
| Batteries | https://www.batterijenland.nl/saft-ls14500-lithium-aa-36v |

# Appendix P. Dimensions






UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBURR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

| | NAME | SIGNATURE | DATE |
|---|---|---|---|
| DRAWN | | | |
| CHK'D | | | |
| APPV'D | | | |
| MFG | | | |
| Q.A | | | |

TITLE:

MATERIAL:

WEIGHT:

DWG NO.

# Assembly NTC Clamp

A4

SCALE:1:1

SHEET 1 OF 1

# Appendix Q. Life Cycle Assessment

A first setup of the Life Cycle Assessment (LCA) was made.

## Life Cycle Assessment

To validate the environmental impact of the sensor a LCA has been done. 'A practical guide to LCA for students, designers and managers' by Joost G. Vogtländer (2017) is used as a guideline.

### Scope and goal

The goal of this LCA is to find out what the environmental impact of the sensor is and if it is preferable to the manual Legionella prevention. Two scenarios will be compared with each other:

- Manual Legionella prevention
- Legionella prevention using the existing Octo Legionella sensor

After that, a new design of the Octo Legionella sensor will be developed. During the design process sustainability will be taken into account, as well as Life Cycle Design. This is where a third scenario is added to the analysis:

- Legionella prevention using the new Octo Legionella sensor

Comparing these scenarios should create insight in the environmental impact of the sensor. Is it more sustainable to practice Legionella prevention the manual way, or is it better to make use of sensors in an IoT network? This LCA will not take into account the potential benefits in the field of public health or finance.

### System, Functional Unit (FU) and System Boundaries

The three scenarios are characterised as services. The sensor is off course a physical product, but still part of a service system, where Octo facilitates the processing of data via their dashboard. Whether the sensor is owned by the customer or somehow leased from Octo is neglectable for this analysis.

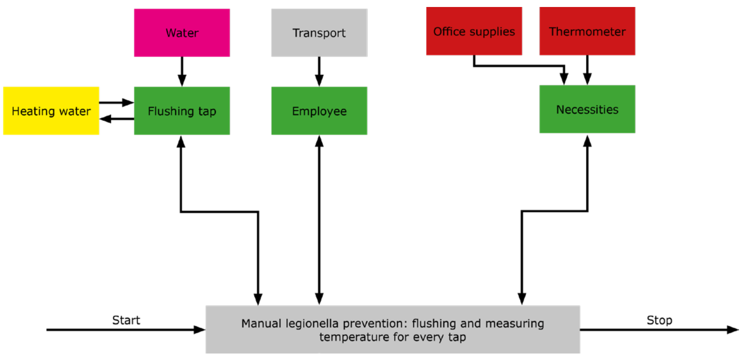



*Figure 59. System boundaries of manual Legionella prevention*

The Functional Unit for this LCA is formulated as following:

*"Active Legionella prevention of a water tap, per year, including preventive flushing and temperature monitoring."*

With this FU it is possible to compare the two scenarios with each other: one without a physical product and the other including a physical product.

What is included in the system of manual legionella prevention (Figure 59):

- Water flushing (incl. temperature)
- Measure/document supplies: thermometer, timer, pen, paper, etc.
- Personnel

What is included in the system with using the existing Octo Legionella sensor (Figure 60):

- Legionella sensor
- Production
- Use
- Maintenance

## Discussion

The exact numbers of some variables are hard to define. Therefore some well substantiated estimations need to be done.

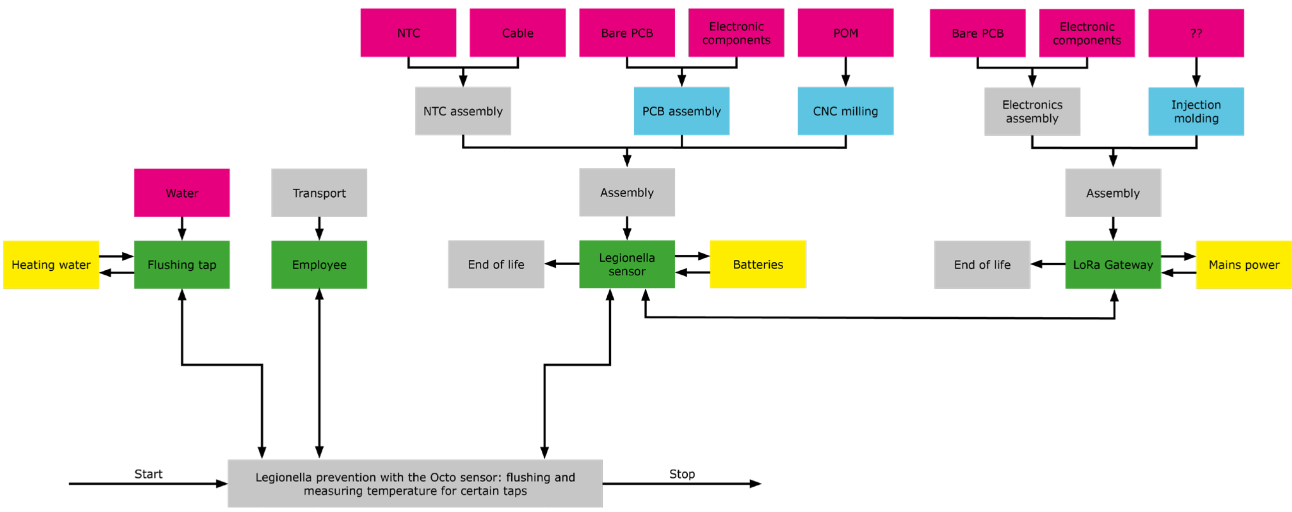



*Figure 60. System boundaries of Legionella prevention with the Octo sensor*