JULY 2018

DEVELOPMENT OF A DIY AND CONSUMER READY SMART RAINWATER BUFFER

BACHELOR THESIS CREATIVE TECHNOLOGY

JEROEN WATERINK

Supervisor:
ir. ing. R.G.A. Bults
Critical Observer:
ir. J. Scholten

FACULTY OF ELECTRICAL ENGINEERING, MATHEMATICS & COMPUTER SCIENCE
UNIVERSITY OF TWENTE.

ABSTRACT

Climate change and urbanization are two inevitable increasing challenges that cities have to deal with. The increasing amount of people migrating to the cities and the effects of climate change can cause problems that influence the quality of life in the cities. One of these problems is heavy rainfall. One of the cities dealing with this is the city of Enschede. Because of the way the city of Enschede is build it cannot handle heavy rainfall very well, resulting in flooding of streets and basements. In order to deal with this problem, the concept of the Smart Rainwater Buffer was ideated. Which is a smart rainwater buffering system which can be installed and connected to the roofs of the inhabitants of Enschede. The system buffers water during rainfall and makes sure it has enough capacity for the next rain shower. The rainwater can be used locally, promoting to waste less drinking water. By installing large numbers of these buffers, it is possible to reduce the strain on the sewage system during rainfall, preventing flooding issues.

This bachelor thesis describes the process of developing a DIY and consumer ready Smart Rainwater Buffer. A literature research on Design for DIY was conducted to design the system to be easy to assemble by the user. Next to that research was conducted on data communication technologies for smart city IoT and fluid level measurement techniques. Several concepts were ideated, from which one concept was chosen by the stakeholders. This final concept was used to build a prototype of the DIY and consumer ready Smart Rainwater Buffer. The prototype incorporates a newly designed sensor module suitable for most rainwater barrels. The complete system was designed to be as robust, reliable, and user friendly as possible. The evaluation of the prototype showed that it is ready to be tested in a pilot project with inhabitants of the city of Enschede.

ACKNOWLEDGEMENTS

There are several people who I would like to explicitly thank for their help and support during this project. First of all, I would like to thank my supervisor Richard Bults and my critical observer Hans Scholten for their supervision and guidance throughout this project. Furthermore, I would also like to thank Hendrik-Jan Teekens from the municipality of Enschede for his useful input in the design process of this project.

Moreover, I would like to thank my team members from the Smart Rainwater Buffer team for their dedication and pleasant cooperation during this project.

CONTENTS

LIST OF ABBREVIATIONS

AirT	Air Temperature monitoring
API	Application Programming Interface
CTDP	Creative Technology Design Process
DIY	Do It Yourself
DP	Differential-Pressure
IoT	Internet of Things
LPWAN	Low Power Wireless Area Network
OTA	Over-The-Air
SRB	Smart Rainwater Buffer
UI	User Interface
US	Ultrasonic
WLAN	Wireless Local Area Network
WPAN	Wireless Personal Area Network

LIST OF FIGURES

1. INTRODUCTION

1.1 Problem

Climate change and urbanization are two inevitable increasing challenges that cities have to deal with. The increasing amount of people migrating to the cities and the effects of climate change can cause problems that influence the quality of life in the cities. Problems like air pollution, increasing temperatures and extreme rainfall are becoming increasingly harder to deal with. One of the problems that arises is the flooding of streets. Because of all the concrete and asphalt the overall water runoff volume of the infrastructure is simply not high enough anymore [1].

Cities in the Netherlands have to adapt to these circumstances. In order to ensure and improve the quality of living in the city, more and more cities start to solve these challenges using technology. They want to become Smart Cities, by the use of smart algorithms, sensor networks, and cloud computing [2].

One of these cities is Enschede [3]. With nearly 160.000 inhabitants [4] the municipality Enschede is the biggest municipality of the province Overijssel. Due to urbanization the city kept expanding. Resulting in interference with the natural water management of the area. Location wise Enschede is not located conveniently for water management. Enschede is built on a hill with a height difference of 44 meters between the highest and the lowest point of the city [5] (see figure 1). In periods of heavy rainfall storm water flows downhill into the city. The water runoff volume of the infrastructure in the city is not high enough causing local flooding problems.

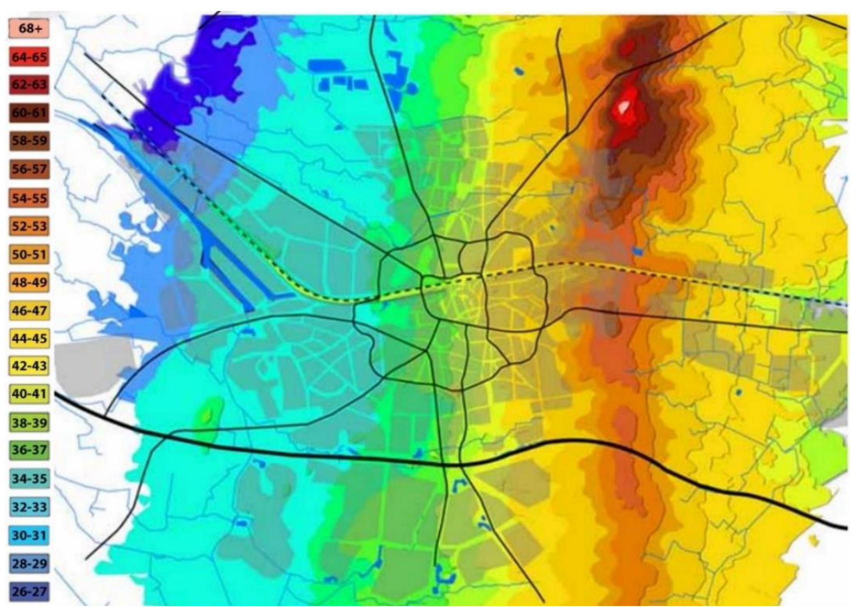


Figure 1: Height map of Enschede: from high to low; from NAP + 68 m to NAP + 24 m, 44 m difference in altitude. Source: Gemeente Enschede, Water in Enschede: feiten, cijfers en trends, 2012

Together with the waterboard Vechtstromen [6] and the University of Twente [7], the municipality Enschede started the Climate Adaptive City Enschede project [7]. The goal of the project is to let the city of Enschede adapt to climate changes. One of the parts of the Climate Adaptive City Enschede project and this graduation project is the development of the Smart Rainwater Buffer (SRB). The concept of the SRB is a smart rainwater buffer that act on the weather predictions for rainfall. The system collects rainwater during rainfall and releases the buffered water prior to predicted rainfall, resulting in less strain on the sewage system during the critical times of heavy rainfall. The SRB is in development for over a year now and is ready to be redesigned for the use by early adopters.

1.2 Goal

The goal of the project is to redesign the SRB for the use by early adopters[1]. Which means that the system needs to be designed for a Do It Yourself (DIY) and needs to be consumer ready. At the end of the project there should be a working prototype of the redesigned SRB. Which should be able to be produced in large quantities of 20 to 50 units, ready to be installed by the early adopters.

To reach the goal of a redesigned DIY and customer ready SRB the project is split into two parts. The first part being the redesign of the technical side of the system. The Second part being the design of a Do It Yourself (DIY) system. This graduation project will focus on the redesign of the technical part of the SRB and the design for DIY, but no on the design of the actual DIY.

To reach the beter understand the goal of this graduation project there first needs to be a clear definition of "DIY" and "consumer ready" in the context of this research. For this research DIY is seen as "design for DIY", the developed solution should be designed to be compatible to be used as a DIY project. The design of the DIY project including instructions will not be part of this research. It is also important to define what is meant with "consumer ready" in the context of this research. For this research a consumer ready SRB will be seen as a product that can be used without the need of having technical knowledge about the system. It must work reliably and contains all needed functionalities. After the setup of the system the system must not require any technical maintenance.

Based on the previous presented problem statement and project goal the main focus of this thesis will be:

"How to develop a DIY and consumer ready Smart Rainwater Buffer for deployment in the city of Enschede?"

[1] Based on the innovation theory of rogers, early adopters can be seen as the pioneers of consumers. An early adapter is someone who starts using a certain product before it is used by the masses [53].

1.3 Report outline

The outline of this report is as follows. Chapter 2, the background analysis, starts with background information on water management and climate adaptation in Enschede. Furthermore, an overview is given on the previous research that has been done on the SRB. The remainder of this chapter contains Literature research on design for DIY and a state of the art. Chapter 3 describes the methods and techniques that are used in this project. Chapter 4, the ideation chapter, identifies the stakeholders and their requirements. Several concepts were created from which one was chosen by the stakeholders. Chapter 5, the specification, uses the final concept of the previous chapter as input to specify the functionality of the system. Chapter 6 deals with the realization of the prototype and all the research that was done to create the prototype. Chapter 7 contains the evaluation of the prototype and chapter 8 features the conclusion and further recommendations for the project.

2. STATE OF THE ART

This chapter starts with background information on water management and climate adaptation in Enschede. Furthermore, an overview is given on the previous research that has been done on the SRB. Then, a literature review on design for DIY is conducted, as well as a review of related research on smart rainwater buffers. Finally, the chapter is concluded by evaluation the relevance of the research question.

2.1 Background information

2.1.1 History of water management in Enschede

Before the early 1850's the water management of Enschede was not influenced much by its inhabitants. The water mainly followed its natural course. The hardened surfaces were very limited making it easy for storm water to infiltrate into the ground. Around 1930 the textile industry started expanding. This resulted in that the groundwater level got lower because the textile factories used large amounts of groundwater. With the growth of the industry also workers' districts were required. This resulted in that Enschede grew further on the lower side of the hill because the originally wet spots were now dried up (see figure 2).

Nowadays the textile industry has completely disappeared from Enschede, causing the ground water levels to rise again. The rising of the groundwater level caused lots of problems, for example basements that leak water or streets that flood because the water doesn't get absorbed enough in the ground. Next to the groundwater problem, climate change also results in more and extreme rainfall. Making the strain on the sewage system of Enschede too high. The overall water runoff volume of the infrastructure is simply not high enough anymore to keep the water out of the city [5].

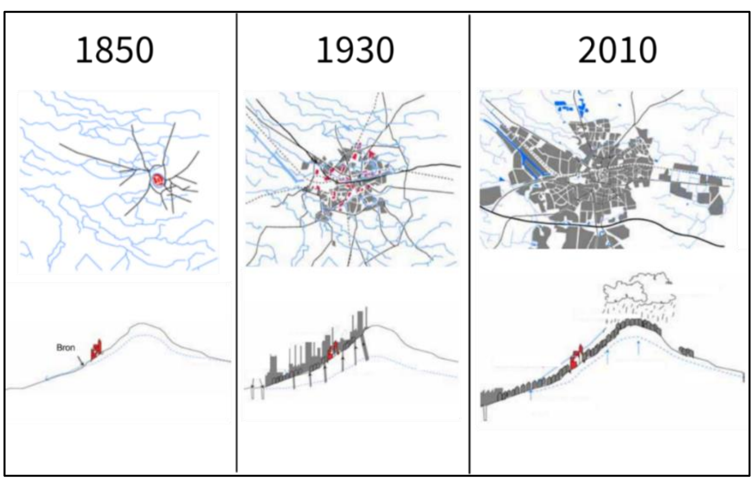


Figure 2: History of Enschede and water management, Source: Gemeente Enschede

2.1.2 Climate adaptive Enschede

To deal with the challenges that arise from climate change, the municipality of Enschede and the University of Twente started the Climate Adaptive City project. The goal of this project is to let the city of Enschede adapt to particular aspects of climate change. At the moment the project consists of two parts: 1) the Smart Rainwater Buffer, and 2) Air Temperature monitoring (AirT). Both will use one central data repository for data storage. There will also be a monitoring dashboard available, displaying the status of the SRB and AirT system. The project was started in the beginning of 2017 with research on the Smart Rainwater Buffer. Two prototypes were developed. In Q2 and Q3 of 2018 five prototypes will be used for a pre-pilot. In the pre-pilot five innovators will be testing and co-developing the system. In Q4 there is a pilot test planned this pilot test will make use of the to be redesigned SRB. This pilot will include approximately 10 SRB systems [8].

The redesign of the SRB will take place in Q1 and Q2 of 2018. As stated before the redesign of the SRB consists out of two parts. The first part being the redesign of the technical side of the system. The second part being the design of a Do It Yourself (DIY). This research will focus on the technical part, but there will be a close collaboration with the other part, mainly on the redesign of physical components of the system.

Additionally, there will be a collaboration with the researchers responsible for the data repository, AirT, interface design and awareness. The SRB systems will be connected to the main data repository just like the AirT systems and the monitoring dashboard. The data repository will store and process the data gathered from the SRB and AirT systems.

2.1.3 Expert opinion

As an extension on the background analysis a small interview was conducted with Hendrik Jan Teekens, water management designer at the municipality of Enschede. Teekens confirmed the findings in the background analysis section on the water management of Enschede. He pointed out that the main problems are ground water problems. In case of large scale problems like the flooding of streets, the municipality will take responsibility. But smaller problems that only affect a few households are the responsibility of the home owners themselves. In this case an SRB could work not only beneficial for the strain on the sewage system but it would also be directly beneficial for the owners.

2.2 Previous research

The Smart Rainwater Buffer was ideated in 2016 at a creathon organized by the University of Twente in collaboration with the waterboard Vechtstromen and the municipality Enschede [9]. In 2017 this idea was developed further in three graduation projects of the university. The two graduates Steeghs [10] and Rindt [11] translated the idea into a product concept while graduate Vetter [12] also worked on a version of the SRB. In 2018 a fourth graduate student, Defize [13], investigated the possible barriers to introduce a Smart Rainwater Buffer in Enschede. Early 2018, Groeneveld [14] continued the research on the fluid level measurement technique of the prototype.

In 2017 Vetter [12] did research on the Smart Rainwater Buffer. The focus of his research was centered around finding a solution to reduce the strain on the sewage system of Enschede during rain fall. He listed requirement that the potential solution should have. During his ideation phase he concluded together with the client, municipality of Enschede, that the Smart Rainwater Buffer concept has the most potential. Further in his research he proposed a setup using water fences, because this solution takes up the least amount of space in a typical city backyard and this solution is modular. The water fences are easy to connect to each other which allows the system to be modular and usable in small and large scale. The final stage of his research was also to make a prototype.

During the development of the prototype and the evaluation of his research Vetter made the following, relevant to this current research, recommendations. One of his recommendations is to use a different type of ultrasonic sensor for fluid level measuring. The HC-SR04 used in his prototype is very sensitive to small disruptions. One other recommendation proposed by the client, the municipality of Enschede, is to implement the functionality to automatically discharge the water in the buffer into the garden. Because in the summer the water level in the soil in Enschede are too low. The client also proposed automatic discharge if the water in the buffer has a risk of developing the legionella bacteria, caused by long term high water temperatures. Vetter also recommended to equip the Smart Rainwater buffers with a rain meter. Using the data of a rain meter and other rain meters in the area to predict in what direction a rain cloud is going. Vetter also proposed a display on the Smart Rainwater Buffer to inform the user about the state of the system. During his research Vetter also concluded that a ball valve is the best option for a valve to empty the buffer. Because this type of valve works best for narrow pipes, and this valve can still work if the water is a bit dirty. Finally, Vetter recommended to research other option than Wi-Fi as network connection in order to lower the dependency on the system owners own Wi-Fi network. He proposed researching the use of a LoRa network [12].

Steeghs [10] and Rindt [11] both did research on converting the idea of the Smart Rainwater Buffer in to a feasible and realistic concept. They first listed the requirements for the system and end users. Then they used these requirements to build a first prototype. The prototype consisted of a working smart rain barrel and a web interface.

One of the recommendations of their research that is relevant to this research is to use more accurate sensors. In the first prototype flow sensors were used but these are only accurate when used with a minimal water pressure. Another recommendation is to not only use Buienradar [15] for the rainfall predictions but also use the data of weather stations in the area. Using the weather station data to predict in what direction a rain cloud is going. They also recommended to add a temperature sensor to the system. Hence, the system can act on temperature changes like freezing or long term high temperatures which increase the risk for legionella in the buffered water. The final recommendation was that the system should be designed to be implemented in different buffers of different sizes, allowing for flexibility and applications in different situations. One thing that stood out in all the prototypes of Steeghs, Rindt, and Vetter is that all prototypes need a 230-volt power source, meaning that they need a physical wall socket outside the house at the location of the SRB.

In 2018 Defize [13] also did research on the Smart Rainwater Buffer but this research was mostly focused on investigating the possible barriers to introduce a Smart Rainwater Buffer in Enschede. Some interesting conclusions were drawn from his research. One of these conclusions is that sustainability is the main motivation of the people interested in the SRB. Defize also recommends using a SRB DIY kit for the tests with early adopters. This is because his research showed that there are strong preferences and rejections for certain buffer designs. Because of this the final product should be customizable to personal preferences. He claims that customers should have the option to purchase a DIY-kit, with optional buffer designs and optional installation service. He also proposed the idea of making a separate “smart module”. He envisions a solution that a rainwater buffer can be made smart with a separate module that can be attached to an existing or new buffer. The remainder of his research is more on the societal aspects of the project but not relevant for the scope of this research.

In early 2018 Groeneveld [14] was the last person to research the SRB. His research was focused on a sensing technique to automatically determine the capacity of the SRB. During his research he used an ultrasonic sensor to measure the distance between the top of the buffer and the surface of the fluid in the buffer. He found out that the ultrasonic sensor gets more accurate if instead of one ultrasonic wave, a burst of multiple waves is used to calculate the fluid level in the buffer. The average distance calculation of the burst is more accurate than a measurement using only one ultrasonic wave. Groeneveld also concluded that when using an ultrasonic sensor in a closed barrel, there will be echo’s which will be received as noise by the sensor. He recommended the use of an algorithm that can filter the noise. He also recommends looking into different sensing techniques for fluid level measurement [14].

Conclusion
What can be concluded from the previous research is that there is more research needed in finding reliable measurement methods. In a consumer ready product, it is very important that the system works consistently meaning that reliable measurements are a must. What also can be concluded is that it is important that the system can autonomously handle indirect effects of the weather. Like the increased risk of legionella and the freezing of the water inside the barrel. Another point to research is making the system modular and suitable for a DIY product. Furthermore, it can be concluded that there is a need to research possible other weather prediction sources than Buienradar, and the use of local rain meters to predict the direction of rain clouds. Also, the dependency on the SRB owners' home network might be an unreliability and it is worth researching other wireless data communication technologies (e.g. LoRa).

One thing that also stand out is that both prototypes need a 230-volt power source, meaning that they need a physical wall socket outside the house at the location of the SRB. One could imagine that not all future users have a 230v power plug at the potential location of the Smart Rainwater Buffer. Therefore, it is worth researching if the power supply could also be a battery with a small solar panel for example.

2.4 Literature research

This section a literature review that focuses on Design for DIY. This part contains an overview on key aspects that are important to take into account when designing a self-assembly product.

2.4.1 Design for DIY

As stated before, for this research DIY is seen as "Design for DIY" the developed solution should be compatible to be used in a DIY project in other words a self-assembly product in the sense that the user self assembles the product. The design of the DIY project including instructions will not be part of this research. In order to develop a product to be DIY compatible it is important to know what aspects are important to take into account.

Self-assembly products are becoming more and more popular, for this reason Richardson [16] conducted a survey in the UK to identify the problems that can occur during self-assembly. He reports that 52% of the respondents claimed that they assembled a self-assembly product in the last 2 years. 67% of these respondents reported that they experienced some difficulties during assembly. 13% of the respondents damaged the parts during assembly and 7.8% reported that they injured them self during assembly. What can be concluded from these findings is that customers clearly have problems with self-assembly products. The most important thing is that self-assembly products must not be too difficult to assemble, because this might lead to frustrations, damaging of the product or even injuries [16].

In a onetime assembly process technical skills and experience do not play a significant role. Richardson [17] claims that even if an assembler is experienced, it is still very likely that the person will just work from the provided procedural assembly instructions. This is because self-assembly products are mostly a one-time thing and are not repeated again.

Rules on design for assembly

Richardson [17] shows that consumer self-assembly products have some comparable aspects with product line assembly in factories. For product line assembly the method Design for Assembly (DFA) is applied. Chan, Wysk, and Wang [18] translated the DFA rules so they can also be applied on self-assembly products. They specify the following rules for DFA:

1. **Reduce the total number of parts** – In general reducing the amount of parts results in lower costs and lower assembly difficulty. It reduces the level of intensity of all activities related to the product. The use of one-piece structures is encouraged.
2. **Design a modular system** – A modular design is recommended in order to simplify manufacturing. A modular design allows for an easier assembly, testing, inspection, redesigning and maintenance.
3. **Use standard components** – When developing a system for self-assembly always try to use as much as possible standard components. Standard components are cheaper than custom components and they are widely available. Another benefit of standard components is being less dependent on one specific supplier because standard components can be delivered by many suppliers.
4. **Design parts to be multi-functional** – Parts that are multi-functional reduce the amount of parts. This rule is also beneficial for rule 1. An example is a part that acts as a structural and also as an electric conductive part.
5. **Design parts for multi-use** – If multiple different products are being developed than try to let these products use the same parts. These parts can have the same or a different function. This results in a more uniform design an creates a standard for the complete product line, making it easier to upgrade or combine different products.
6. **Design for ease of fabrication** – Use parts that do not require extra work by the person assembling the system. For example, avoid operations like painting, polishing and finishing.
7. **Avoid separate fasteners** – Fasteners like screws and glue should be avoided. They require more effort in assembly and the chances for errors during assembly are higher. If fasteners should be uses than some guidelines need to be followed. First minimize the number and variation, second use standard components as much as possible, finally avoid screws that are too

long or too small. Take into account the motor abilities of the person who will assemble the system.

8. **Minimize assembly directions** – Try to design the system in a way that all parts can be assembled from only one direction. The best direction is to assemble parts from above in a vertical direction, because than the effect of gravity has the most positive effect on assembly.
9. **Maximize compliance** – Try to design parts to be robust, making sure they don't break during assembly. Avoid the use of fragile parts or add spare parts of things that can easily brake. Also make insertion unambiguous, design parts to have a guiding surface.
10. **Minimize handling** – Handling is the positioning, orienting and fixing of a part. In order to facilitate orientation, the use of symmetrical parts is strongly recommended. If this for some reason is not possible than asymmetry should be exaggerated to avoid possible failures. External guidelines like arrows can help with the orientation of a part. Also, when designing the product try to minimalize the material waste also for the packaging.

Although these guidelines are clear and useful for the DIY compatibility of the SRB, some more information is still needed on the specifics of the complexity of self-assembly products. Richardson et al. [19] studied the factors that cause complexity during assembly. They approached this with the use of methods that origin from the cognitive psychology research field. In their research they created a framework that can be used to evaluate the complexity and difficulty of self-assembly products. Of course, assembly instructions are also very important for in the process of self-assembly, but this is outside of the scope of this research.

Evaluating assembly complexity

In order to design an easy to assemble product is needed to understand what exactly makes assembly complex. As Richards [17] states, complexity is linked to a task and affects the difficulty of that task. Richardson et al. [19] uses physical characteristics called "task variables" to identify tasks that influence assembly complexity. These task variables are related to the nature of the task, required mental effort and the cognitive load of the task. Richardson et al. [19] created a model to link cognitive load to assembly complexity and difficulty. This model uses task variables to score the difficulty of the assembly process (for details see Richardson et al. [19]). The task variables that were found in his research that affect assembly complexity are given below.

Symmetrical planes - This factor has the most influence on the complexity of assembly. Richardson et al. [19] found out that a decrease in symmetry is related to an increase in assembly complexity and thinking time. The orientation of parts should be kept as easy as possible. This can be done by including clues like arrows. This helps people orientate and rotate parts in the correct direction. Just like Chan et al.

[18], Richardson et al. [19] also concluded that parts should preferably be symmetrical shaped and in case of asymmetry than this should be exaggerated.

Novel assemblies – This factor is the second important factor that influences complexity. Novel assemblies can be measured as the number of unique assemblies in an assembly step, in other words the variety of parts per assembly step. The higher the number of parts in an assembly step, the higher the difficulty level.

Selections – This task variable measures the amount of parts available to choose from. The research by Madan, Bramorski and Sundarraj [20] also concludes this. They point out that difficulty can be reduced by packaging components into bags following the order of assembly. They also found out that too many bags made the task difficult again, so it is really important that the amount of parts and bags is balanced.

Fastening points – Fastening points provide clues for the placement of parts. An increase in the amount of fastening points results in more possibilities for part positioning. For this reason, an increase in fastening points leads to a higher difficulty and higher chance of errors.

Fastenings – A large amount of fastenings can lead to the perception that the assembly will be difficult, although this doesn't have to be the case. Also, the number of fastenings increases the amount of fastening points, so both should be kept at a minimum.

Parts – As pointed out before in the rules for DFA, the amount of parts should be kept at a minimum.

Conclusion

The relationship between assembly tasks and assembly difficulty is now better understood. Now there is a clear overview of aspects that influence the complexity of a self-assembly product that can be applied to design for DIY. It can be concluded that the SRB can be made DIY compatible if the aspects and rules that are mentioned above are taken in to account for the design of the SRB.

2.5 Related Research

This section contains an overview both of already existing products or projects with the same goals and functionalities of the SRB and alternative projects focused on urban rainwater buffering. Finally, this section also contains an expert opinion on rain barrels.

2.5.1 Similar projects

Slimme regenton [21] - Waterschap Amstel Gooi en Vecht & Studio Bas Sala

De "Slimme regenton" (English: The smart rain barrel) is a project from Waterschap Amstel Gooi en Vecht in cooperation with Design Studio Bas Sala. Together they developed a consumer-friendly smart rain barrel meant for at home use. They used an ordinary rain barrel and upgraded it with a small internet connected computer, sensors and an electronically controlled valve. The computer uses the sensors to measure the amount of water in the barrel and controls the valve to empty the barrel in to the city's sewage system. The onboard computer has an internet connection that checks the rain forecast and if needed empties the rain barrel before the rain falls, to unstress the sewage system during rain fall.

The philosophy from Waterschap Amstel Gooi en Vecht is that this kind of micromanagement of the stress on the sewage system during rainfall can be effective if this smart rain barrel is applied in large quantities. See figure 3 for an impression of the system.

Figure 3: De slimme regenton. Source: Bas Sala

RainGrid [22] [23] - RainGrid & RiverSides

RainGrid is a rainwater barrel designed to collect storm water during rain fall and release it at times the sewage system is less stressed in order to prevent flooding. This product was also used in case studies on smart rain barrels, more on this later on in this section. The RainGrid has a modular design and can be easily installed by following an installation guide. The basic version of the RainGrid doesn't contain any electronics.

Content of the basic RainGrid [24]:

- 500 L/132 gal. capacity rain cistern
- Rainwater diverter system
- ¾-Inch brass mini-ball valve with ¾-inch hose thread
- Drain plug
- 200-micron Nitex mesh filter

The basic RainGrid comes with a diverter system, which basically is a hand-controlled valve that can be used to bypass the rain barrel and directly divert the rainwater to the sewage. This diverter system is meant for a shutdown of the system during periods that it is likely to freeze. See figure 4 and 5 for an impression of the RainGrid barrel and diverter system. The system also contains a filter which prevents any debris from entering the barrel and prevents the outlet of becoming clogged. The emptying of the rain barrel is not automated on the basic version of the RainGrid. This should be done by the owner itself. The company uses a catchphrase in order to remind people to do this; "*After a rain, it's time to drain!"*.

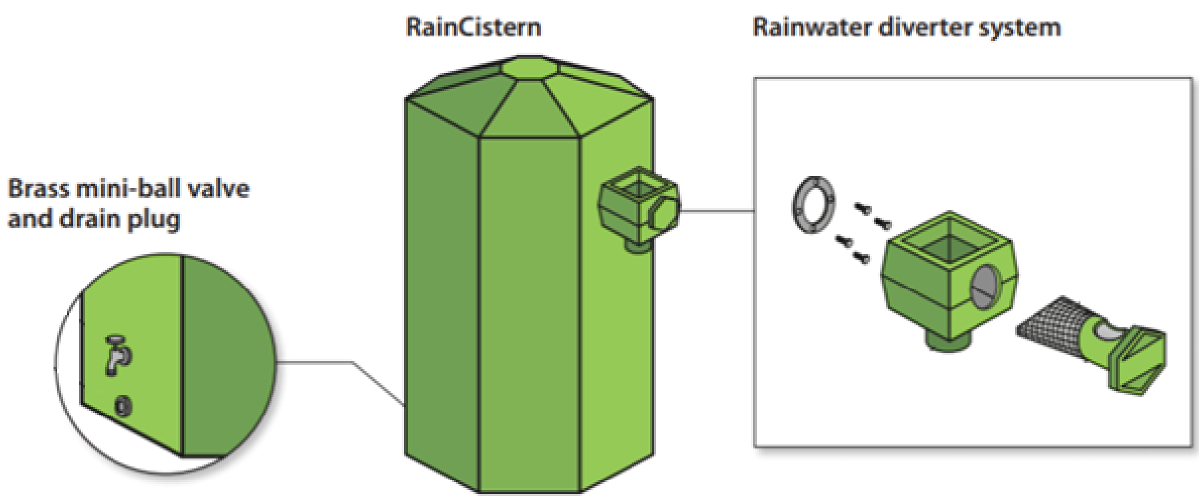


Figure 4: RainGrid basic version modules/parts. Source: RainGrid installation manual

Figure 5: RainGrid basic version installed. Source: RainGrid official website

The RainGrid also can be upgraded with the RainGrid controller. This extension module of the basic RainGrid system adds an internet connected control unit to the system together with a water temperature sensor, Ultrasonic sensor and electric valve. This allows the setup to drain automatically and monitor the system via a web interface.

Every RainGrid controller has an individual network address which is monitored real time to get its current storage volume. A data server combines local weather predictions for the next 5 days with the available storage data of the rain barrels. When the predictions are greater than the available storage that is currently available than the barrel is automatically drained to ensure enough storage.

Technical details:

- The control unit has an ZigBee radio inside that communicates with a gateway inside the house that is connected to the internet. (Figure 6)
- The used gateway is an TP-Link router with a ZigBee radio integrated and running the latest version of OpenWRT.
- Data is pulled every 15 minutes.
- 5 day local weather prediction.
- The barrels are made of 50% recycled MDPE, to lower the environmental impact. Including division system ($ 299)
- Ultrasonic sensor at the top that is used for water level measuring.
- Temperature sensor at the bottom to check the micro climate inside the rain barrel.
- 5v electronic valve,
- Online dashboard (shows current capacity, button to open/close valve, shows forecast, shows micro climate status) (Figure 7)
- Battery power, solar charged. (Figure 6)

Figure 6: RainGrid controller installed. Source: RiverSides official website

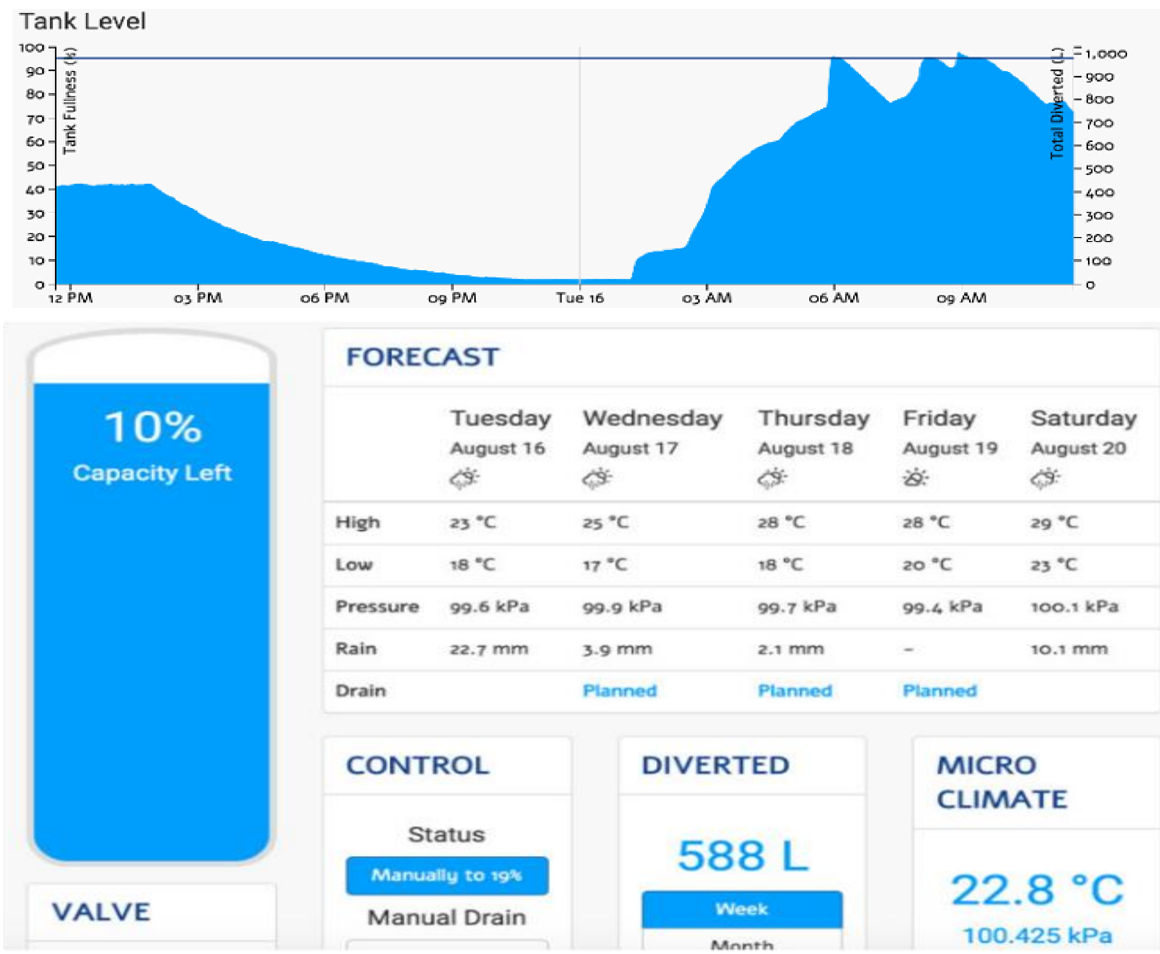


Figure 7: RainGrid dashboard web interface. Source: RiverSides official website

Case studies RainGrid – RiverSides

The non-profit environmental group RiverSides is the group that created the RainGrid. In 2013 one member of the group continued with the project in a spin off commercial company called RainGrid, which sells the RainGrid product. While the others from the RiverSides group kept developing and researching the smart rain barrel. In 2017 the Riverside group released a detailed report (Automated rain barrels: residential case studies) on their pilot project, containing five case studies.

Here follows a summary of the important facts that were found during these case studies.

One of the important lessons learned during the case studies is to help remind the owner to clean the filter. Because if the filter is clogged than the water will not enter the barrel resulting in corrupt measurements. Their recommendation is to schedule filter maintenance on the online dashboard. Also filter notifications to the householder would be useful.

Another finding was that rain reduces the signal strength of the ZigBee radio on the barrel. This resulted in that there was no communication possible during a rain shower, which is one of the most critical moments for data gathering. Another problem that arises from this problem was that their prototype didn't cache data, meaning that when the connection is lost the flow data will still be collected but will not be saved. Their recommendation was to ensure the connectivity of controller with the modem, while taking into account interference and reduced range due to rain. For example, by decreasing the distance for the gateway to the controller, increasing the range of the radio, using a different type of wireless connection instead of ZigBee or using a hardwired internet connection. Also building in system capacity to cache data, preventing data loss when dealing with connectivity issues.

Their final recommendation was to consider using a completely different wireless system and internet connection that does not depend on the owner's home network structure and internet connection.

Opti [25] **-** OptiRTC

Opti is a Cloud based water management system from the American company OptiRTC. Opti uses weather forecast for adaptive control of new and existing infrastructure. Enabling facilities to proactively respond to bad weather before it even arrives. Opti makes any water buffer smart with the use of only a water level sensor, an electric valve and Opti compatible communications hardware. Opti's cloud software controls the hardware to create a simple and affordable, intelligent storm water system [26].

Opti monitors the water level and weather forecasts to actively control the discharge of water. Opti also provides an online dashboard that allows for easy monitoring and analysis of the system. See figure 8 till 10 for an impression of the system [26].

Technical details:

- Cellular modem internet connected
- Runs on Microsoft Azure cloud
- Control board is the ioBridge Web Gateway
- Runs on solar power if no other power source is available.
- Uses Ultrasonic sensor for level measurements.
- Measure outflow
- Uses solenoid coil valve
- Equipped with liquid level switch to prevent overflow in case of Level measurement failure.

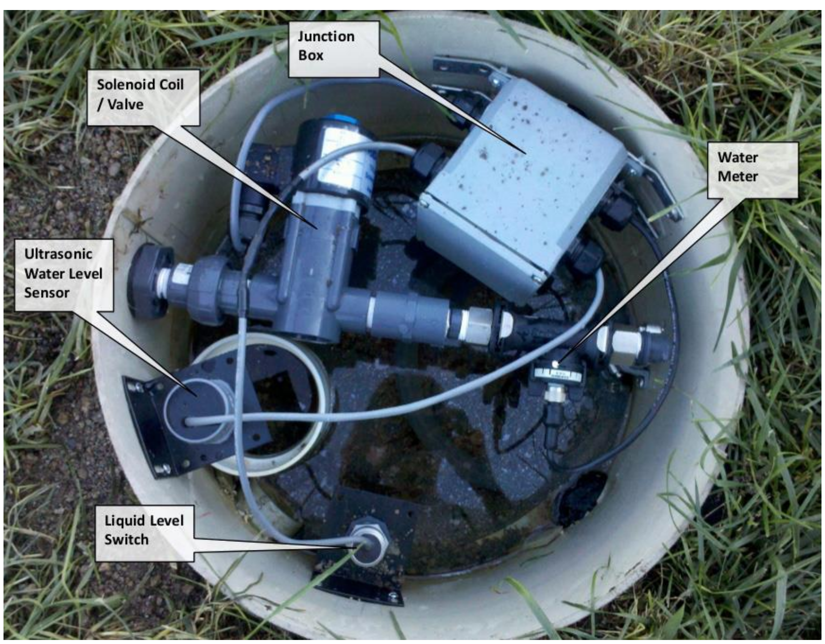


Figure 8: Opti installed system. Source: Marcus Quigley, CEO OptiRTC

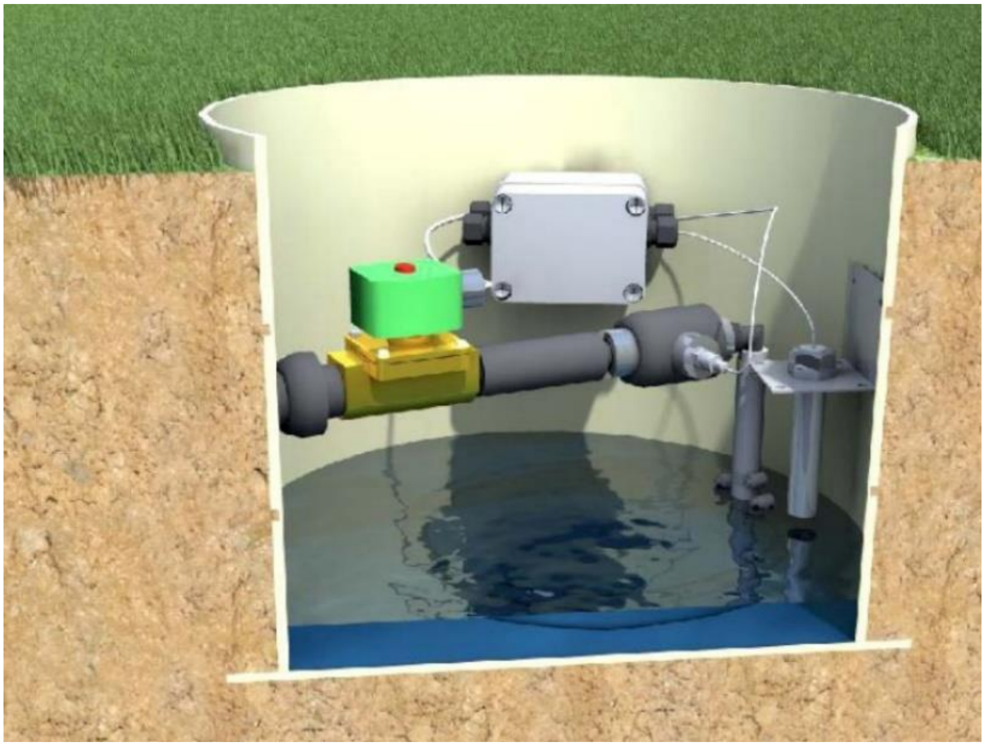


Figure 9: Opti system 3d model. Source: Marcus Quigley, CEO OptiRTC

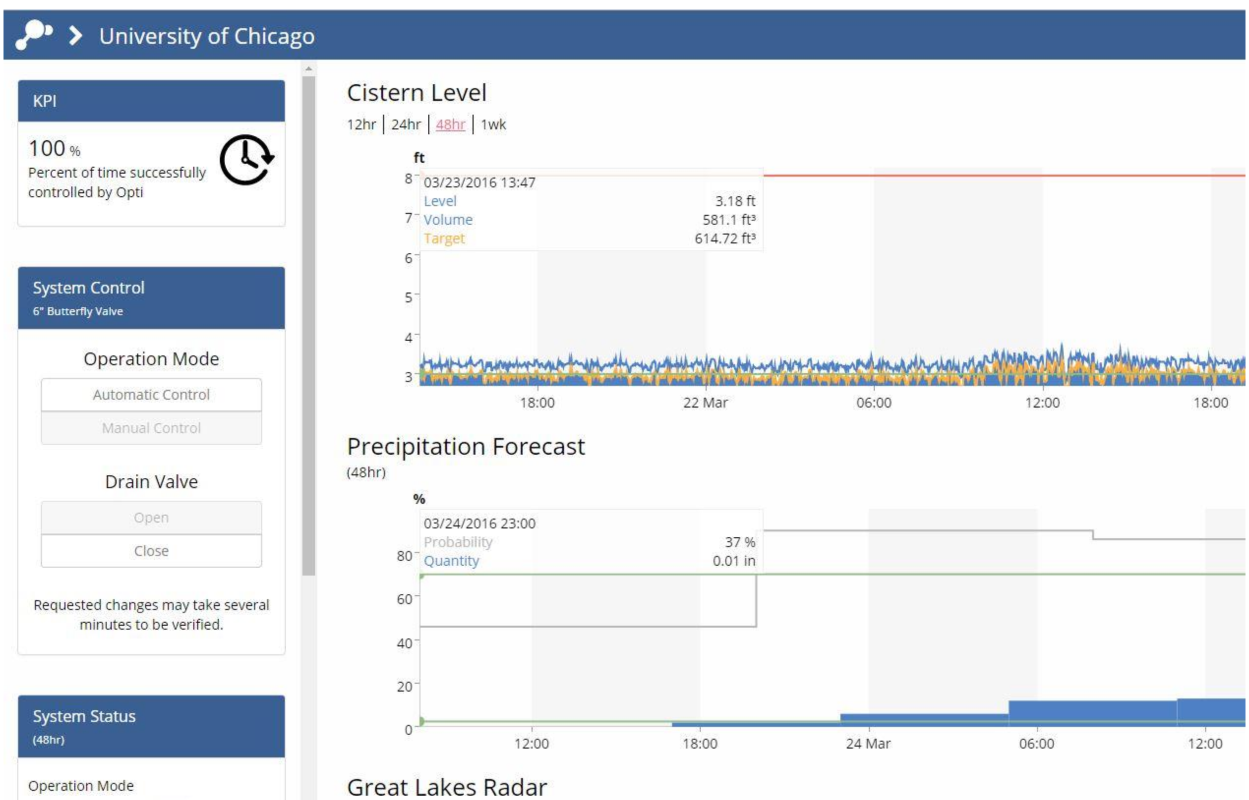


Figure 10: Opti dashboard. Source: Marcus Quigley, CEO OptiRTC

Loxone rain water harvesting project [27] **–** Loxone

Loxone is a UK based company that develops and sells high end professional smart home appliances. The products of Loxone are more expensive than regular IoT smart devices and are meant for professionally installed smart homes.

On their blog they posted an article about smart rainwater harvesting using the company's products. In their blog post they describe how they added their products to an underground water buffer with a pump connected to it. They use their own Loxone ultrasound sensor to measure the fluid level. One of their connected switches is used to control the outlet pump in combination with their developed Miniserver. The Miniserver gets the data from the ultrasonic sensor and drains the barrel if the water level gets above a certain threshold. See figure 11 for an impression of the system [28].

Since Loxone sells their products online, it is possible to make a cost estimation. The estimation is only of the Loxone technology needed and does not included the buffer and pump.

Cost estimation:

- Loxone Ultrasonic Sensor 0-10V € 258,68
- Loxone Miniserver € 511,45
- Loxone Smart Socket Air € 71,78

Total cost: € +/- 840 ,- (exclusive shipping costs)

Figure 11: Loxone Rain water harvesting project. Source: Loxone

Smart Rainwater Management System [29] **-** OTA-Analytics

OTA-Analytics develop the Smart Rainwater Management System. The system is meant for preventing flooding and reducing sewage spills. This is done by reusing and releasing rainwater. The system collects rain water during rainfall and then stores it for later re-use in for example toilets and green spaces. The buffer automatically empties prior to storms. This is done with the use of weather prediction data. This way the system maximizes its storage capacity to prevent flooding and lowers the strain on the sewage system [30].

The system uses Lora for network connectivity, making the system energy efficient. If no direct power source is available than the system is powered on a solar charged battery. See figure 12 for an impression of the system.

Figure 12: OTA-Analytics Smart Rainwater Management System installed. Source: OTA-Analytics

2.5.2 Alternative water buffering solutions

The following solutions are not a smart rainwater buffer in the sense of automatically draining water before rainfall, but these concepts are still interesting to the project because of their innovative techniques of urban rainwater buffering.

Graf underground rainwater harvesting systems [31] - Graf

The German company Graf developed an underground rainwater harvesting system. It collects the rainwater from the roof and stores it underground in big cisterns ranging from 1500 liters to 122.000 liters. The Graf system allows to use the water inside an outside the house, for example in the garden or to flush the toilet. Graf claims that with the use of this system 50% of drinking water can be saved per household. The system doesn't only lower the use of drinking water, but it also reduces the strain on the sewage system because almost all rainwater is used locally. See figure 13 for an impression of the system.

Figure 13: Underground rainwater harvesting system. Source: Graf

D-Raintank Modular Rainwater Storage System [32] [33] **– Atlantis**

The American company Atlantis develops modular underground storm water tanks. Modular water tanks are placed underground and can be constructed to hold any volume required. The system is built out of modular plastic cubes that are stacked together to the proper size. Finally, the built structure is wrapped in a plastic sheet and covered with earth, allowing the system to easily integrate into landscaping. The advantage of the modular water tanks compared with traditional water tanks is that this system is much more versatile. The system allows to use huge underground areas for rainwater harvesting. The modules are strong enough for vehicles parking making them also useful to place underneath a drive way. The plastic modules ship flat and the entire system can be installed completely by hand and is also assembled on-site. See figure 14 and 15 for an impression of the system.

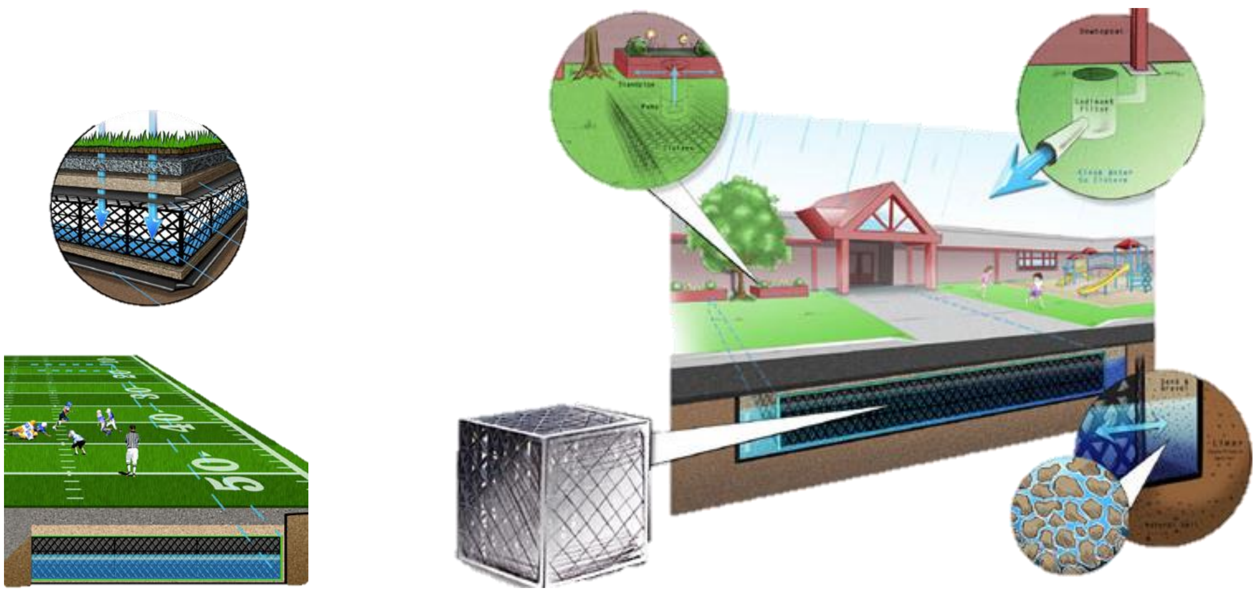


Figure 14: Modular underground storm water tank system. Source: S.A.R.G water solutions


Figure 15: Atlantis D-rain tank storm water management system. Source: Atlantis

2.5.3 Expert opinion, rain barrels

In order to redesign the SRB it is important to know the fundamentals of building a rainwater buffer. In order to get insight into this the videos from David the Good [34] and Gord Hiebert [35], two rainwater buffer experts, were used. The Good tells in the video about the most important aspects of rainwater harvesting that he has learned from his experience. Hiebert demonstrates how to build a rainwater harvesting system and what point are important to pay attention to when doing so.

Input

Make sure the water can be diverted in the winter. Frozen water expands this can damage the rain water barrel. Also, a filter should be placed at the input of the rainwater barrel. This filter keeps dirt out and prevents from mosquito breeding inside the barrel. Dirt inside the barrel can clog the output outlet, preventing the barrel to drain. Make sure the top of the barrel is closed, so dirt and mosquitoes can't bypass the filter.

Scalability

If the storage capacity of the rain barrels is too small than the system can be scaled up, simply by connecting another rain barrel to the overflow or outlet of the rain barrel.

Placement

Make sure the rain barrel is placed on a level base, this way the barrel can be drained completely, and it is also beter for water level measuring. Elevate the rain barrel for more gravitational pressure and also making it easier to put a bucket or watering can underneath the outflow.

Outflow

The diameter of the outflow of the rain barrel should not be too small otherwise it will take a long time to drain the barrel. The bigger the outflow the better.

Overflow

Also make sure the rainwater buffer has an overflow. If the water buffer is full the water should be diverted to the sewage or to another rainwater barrel.

Algae

Make sure the inside of the barrel is dark. Algae are small plants that photosynthesize, if algae form in the water than the water will turn green. In order to prevent the growth of algae you should cut off the sunlight. Without sunlight algae won't grow. Avoid using open and transparent water barrels.

2.6 Conclusion

The goal of this chapter was to get insight into the problem of flooding in the city of Enschede and to collect sufficient information to solve this problem in the remainder of the project. The research on the background information of the flooding problems in the city of Enschede created a clear understanding of the problem and its origin. It can be concluded that the SRB would be a viable solution for the problem if it would be redesigned to operate reliably all through the city. Previous research gave a clear overview of recommendations and possible improvements. The Expert opinions on rainwater barrels gave useful insight in the important aspects to take into account when developing a rainwater harvesting system.

The research on Design for DIY showed the relationship between assembly tasks and assembly difficulty. A clear overview of aspects that influence the complexity of a self-assembly products was created, and this information can be applied to develop a product that can be used in a DIY.

The state of the art research on similar projects showed that although the number of projects similar to the SRB is growing, there is no competitor for the complete concept of the SRB. The other projects are either art projects, not for the consumer market, too expensive or have a completely different goal. Because of this reason and because of the fact that still lots of research needs to be done during this project, it can be concluded that this research is still novel. The research question of: *How to develop a DIY and consumer ready Smart Rainwater Buffer for deployment in the city of Enschede?* Cannot be answered yet, but the gathered information in this chapter will be very helpful in doing so in the next phase of the project.

3. METHODS AND TECHNIQUES

This chapter describes the methods and techniques that are used during this graduation project. The methods and techniques are used to keep the research and the report structured. The main method that will be applied in this graduation project is the Creative Technology Design Process (CTDP). Next to that the used method on stakeholder identification and analysis is presented. The MoSCoW method, interviews and PACT analysis are used for requirements elicitation. Brainstorming and Interviews are used for concept generation. The black box white box method and UML diagrams are used for specification of the system.

3.1 Creative Technology Design Process

The multidisciplinary bachelor study Creative Technology has its own Design Process which is integrated in the curriculum of the study. For this reason, the Creative Technology Design Process will be the main method in this graduation project. First the Creative Technology Design Process will be explained after that the implementation of it in this project is explained. The Creative Technology Design Process is based on two design models [36]. The first being the Divergence and Convergence model of Jones [37]. This model consists of two phases, the divergence and convergence phase. A divergence phase is always followed by a convergence phase. The Divergence phase is used to open up and define the design space. This allows a broad overview of possibilities. The convergence phase is a process of reducing the design space to the point that the best solution is found. This is done using requirements and available knowledge [37]. The second model that the Creative Technology Design Process [36] is based on is the spiral model. This model allows for a process where the design steps within a phase do not have a fixed order. All the steps include a reflection phase.

The Creative Technology Design Process starts with a design question. Then four phases are used to answer this design question. The four phases are the ideation, specification, realization and evaluation phase. The goal of the Creative Technology Design process is to structure the design process, allowing for more specified steps in planning and defined feedback moments. For an overview of the original models see figure 16. During this thesis an altered version of the Creative Technology Design Process will be used (see Figure 17). The altered model limits time on the specification phase allowing for more time in the ideation and realization phase. This is important because of the limited time available for the graduation project.

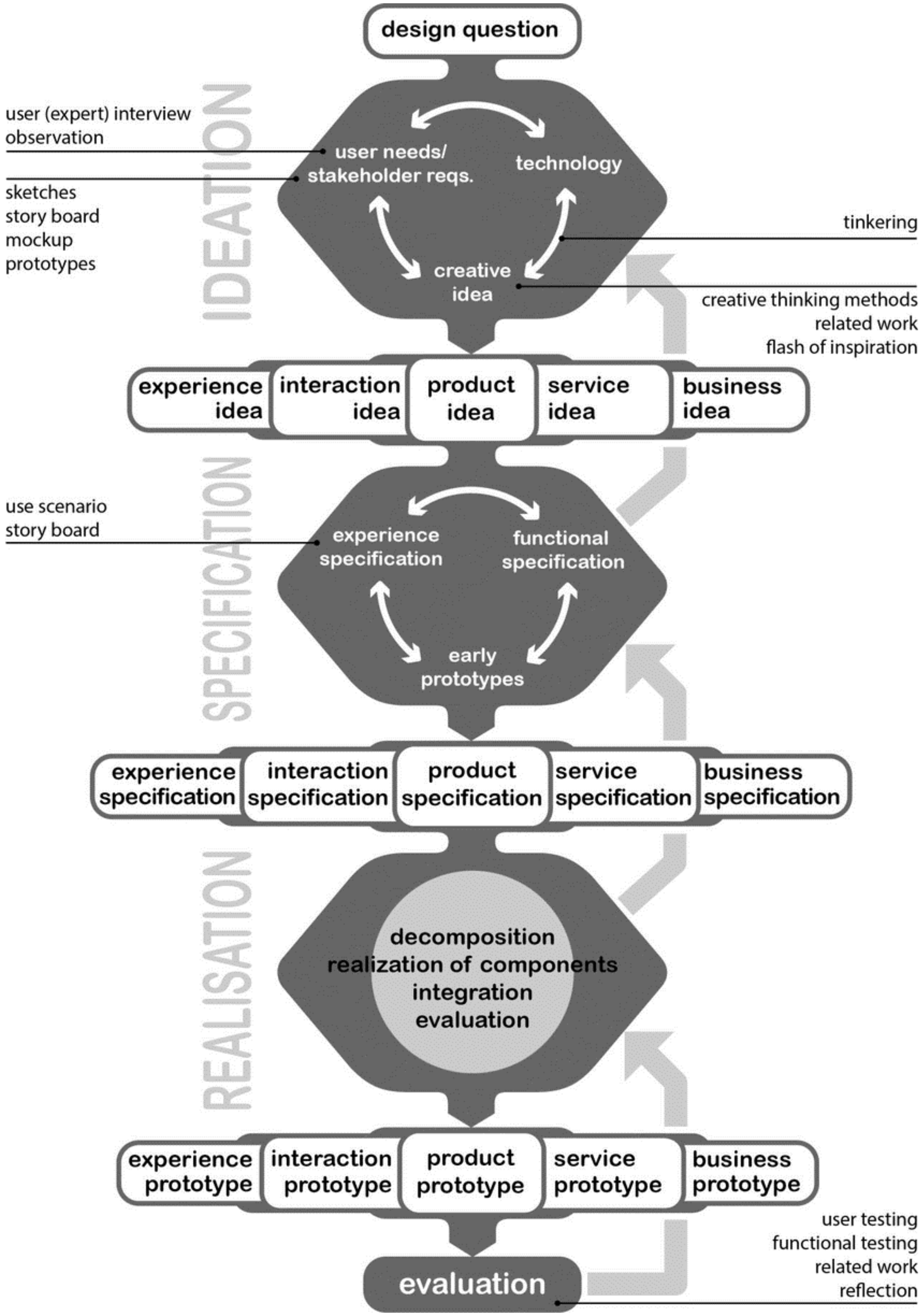


Figure 16: Creative Technology Design Process, Source: Mader and Eggink (2014)

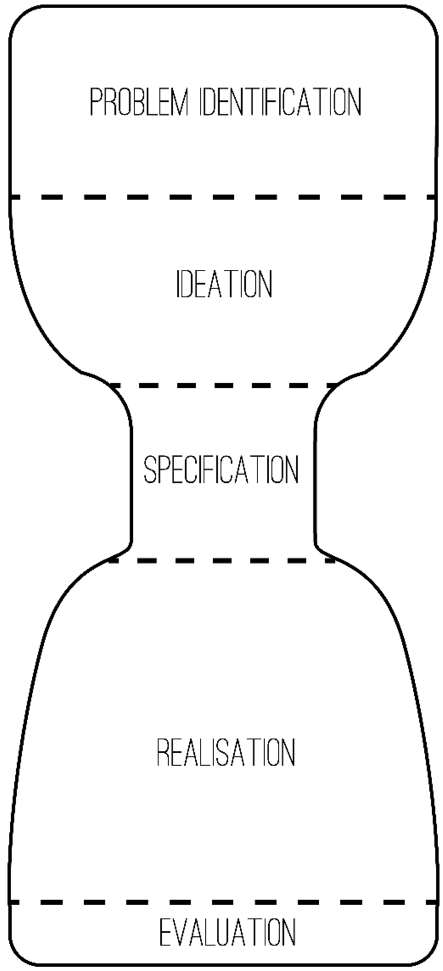


Figure 17: Time division of altered Creative Technology Design Process

3.1.1 Ideation

The main goal of this phase is to identify stakeholders, to come up with preliminary requirements and concepts. The starting point for the ideation phase is the design question originating from a product idea and order from the stakeholders together with the background research which resulted in the research question. The research question was verified in the State of the art research. Tinkering, brainstorming and the similar work found in the state of the art are used as input to come up with creative ideas. These early ideas are then evaluated with stakeholders and clients. This process is than reiterated until a useful and feasible idea is found. In these reiterations the aspects of experience, interaction, service and business model are considered and used to evaluate the concepts.

As an addition to the original CTPD, this phase will also contain a small part from the specification phase. Instead of building early prototypes in the specification phase the ideation phase is extended with the creation of high-level concepts. These high-level concepts are evaluated with the stakeholders and the output is used for requirement elicitation. The use of high-level concepts instead of early prototypes saves time and it also allows for more time for requirement elicitation and verification. Finally, the best idea is selected to be developed further in the next phase of the project.

3.1.2 Specification

The main goal of this phase is to specify the functional behavior of the to be developed product and to get a clear overview of the system and its requirements. The specification phase uses the best idea of the ideation phase as input. The original Creative Technology Design Process states that early prototypes must be used to explore the options and requirements of the product. These Early prototypes would then be evaluated, and the input would be used to create new better prototypes.

As explained in the previous section this is already incorporated in an alternative way in the ideation phase. In this graduation project the specification phase will be used to create a functional system architecture visualized with block diagrams which describe the overall system, the subsystems and the interaction between the subsystems. This gives insight in the functional behavior of the system and could result in a change of functionality or requirements if needed.

3.1.3 Realization

The goal of this phase is to build the product. The realization phase starts with the decomposition of the specifications set in the previous phases. Then the components are realized and tested. When this is done a prototype of the complete product will be build. Finally, the product is evaluated to check if it meets the requirements set in the specification phase, if needed the prototype will be altered and evaluated again until the requirements set in the specification phase are met.

3.1.4 Evaluation

The final phase, the evaluation phase, starts with functional testing, meaning that the functional requirements are tested. After that user testing is used to verify if the design indeed meets the nonfunctional requirements and facilitates the wanted user experience. Next to that the literature research done on design for DIY is used to evaluate the DIY aspect of the prototype. Software tests are used to test the logic of the system. Finally, the stakeholders are asked for feedback on the prototype.

3.2 Stakeholder Identification

Not only the end users are affected by a new product. When developing a product, it is important to have a clear overview of the people that are affected by the product and what people directly or indirectly influence the design process towards the envisioned product. Some of these people might have more influence than others, and also other specific requirements. Because of this reason it is important to perform a stakeholder analysis. Bryson [38] and Sharp [39] describe stakeholders as 'any group or individual who can affect or is affected by the achievement of the organization's objectives'.

Thompson [40] identifies 3 steps to follow in a stakeholder analysis. The first step is to identify all possible stakeholders by brainstorming. First it is important that a list of stakeholders of people who influence or are affect by the product is made, this give a clear overview of all stakeholders. The second step is to prioritize the stakeholders. This can be done using the Stakeholder power-interest matrix by Mendelow [41] . This is a tool to identify stakeholders and their power and interest in the development of the project. The final step is to identify the motivations of each stakeholder. In order to develop a product that satisfies all stakeholders it is important to know what their interest in the project is.

3.3 Requirement elicitation

When developing a product, it is important to have a clear understanding of its requirements. Requirements come from different stakeholders and have different priorities. When developing a product with in a limited time span, it can occur that there is not enough time to implement all the requirements. Hence, it is important that requirements are ranked on priorities.

3.3.1 MoSCoW

The MoSCoW method [42] is a method to categorize requirements on priorities. The method helps in getting a clear overview of the most important requirements and in what order to implement them. MoSCoW stands for 4 types of requirements: Must, Should, Could, Would. "M" stands for must have this requirement in order to succeed. "S" stands for should have this requirement if possible, the success of the project does not rely on it. "C" stands for could have this requirement, only if it does not have any effect on the implementation of other requirements. "W" stands for would like to have this requirement later, it will not be implemented during this project.

3.3.2 Functional and non-functional requirements

Requirements are divided into two categories: functional and non-functional. Functional requirements specify functions that a system must be able to perform. Functional requirements can be written down in the form of a description or in the form of a use case [43].

While functional requirements describe what a system should do, non-functional requirements specify criteria on how the system will do this. Non-functional requirements are often related to the quality or constraints of the system [43].

Once the requirements are divided into categories it makes it easier to evaluate them in the evaluation phase of the project .

3.4 Scenarios

In order to understand the usage of the to be developed product it is important to know in what context and how the product will be used. This can be done using Scenarios. In the context of this research a scenario will be defined as a description of the use of the to be developed product in a certain context to perform a specific task. The description should be sufficiently detailed, so product requirements can be derived from it [44]. A tool that can be used to identify requirements is a PACT analysis and scenario [45].

3.4.1 PACT

The PACT framework is used to create user centered scenarios and to give insight into the requirements of the system [46]. PACT stands for four key points: People, Activity, Context and Technology. These four key points are related to the use of a product by a user in a certain context [47].

This thesis uses two types of PACT analyses. The first type is based on the PACT analysis technique and format from Trulock [48]. This extensive technique uses a wide set of variables (e.g. cognitive and physical characteristics) to analyze the four key points of a PACT analysis. This approach is useful to get a good insight in the profile of potential users and requirements that they have on a product.

The second type is based on the PACT analysis technique and format of Benyon and Macaulay [46]. This technique uses PACT as a guideline to create a user centered scenario that can give interesting insights in the requirements that potential users might have on a product.

3.5 Concept generation

In order to generate as much concepts as possible it is important to use different concept generation techniques. Brainstorming is one of the techniques used in this project, but interviews and discussions are also used as tool to generate ideas [49].

3.5.1 Group brainstorming

One of the used techniques for concept generation is group brainstorming, this is a form of brainstorming where group members actively interact with each other in a verbal dialog by sharing their ideas. Group members are free to share all their ideas without direct criticism of other group members, this helps to stimulate the production of large amounts of ideas and combining different ideas [49].

3.5.2 Individual brainstorming

Next to group brainstorming individual brain storming is also used for idea generation, this is a form of brainstorming that allows an individual to generate ideas and stay more focused on the topic than in a group. The used tools for individual brainstorming are researching similar products and the use of mind maps [49].

3.6 Interviews

The interview techniques used in this thesis are all quantitative interviews. These are interviews that are semi-structured and unstructured. These interviews are more flexible than structured interviews and allow for a better insight in the interviewees' own perspectives and ideas [50]. These interviews are used for idea generation, requirement elicitation and evaluation with the stakeholders.

3.6.1 Semi-structured interviews

In a semi-structured interview, the researcher has a list of questions or topics prepared before the interview and these can be asked in any order to the interviewee. These types of interviews allow the interviewer to pick up things said by the interviewee and ask further questions in that direction while still having a guideline of questions that should be answered at the end of the interview [50].

3.6.2 Unstructured interviews

Unstructured interviews mostly only have a predefined topic and no prepared questions. The interviewer introduces the topic and the interviewee is than free to respond on it with his or her own perspective. Unstructured interviews are very similar to a normal conversation or discussion [50].

3.7 Functional system architecture

In order to describe a system and its subsystems and the interaction between the subsystems a functional system architecture can be made. This thesis uses both block diagrams modeled following the level approach, and UML activity diagrams to do this. These techniques are used in the specification phase of the project the get insight in the functional behavior of the system which is used as input to for the final requirement elicitation.

3.7.1 Level approach

In order to create an overview of the system and its functionalities, block diagrams of different abstraction levels are used to describe and visualize the overall system, the subsystems and the interaction between the subsystems. The level approach is based on the principle of black and white boxes. Black boxes don't show internal specifics and white boxes do show internal specifics of a system. Blocks in the diagram represent systems, the arrows represent interaction, together they form the functionality of the system. The Level approach starts at an abstract overview of the system and the systems it is connected to. The next levels are less abstract and look into the functionality of the main system and subsystems. See figure 18 for a graphical impression of the level approach.

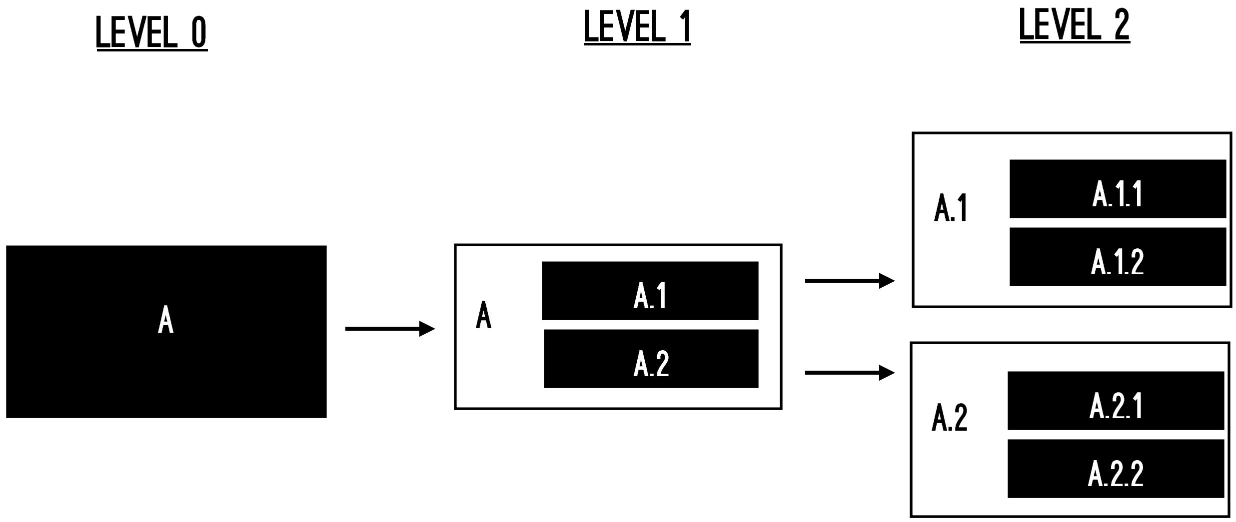


Figure 18: Level approach example of system A and sub functions

3.7.2 UML Activity Diagrams

UML Activity Diagrams are used to describe the dynamic aspects of the system. An activity diagram represents the flow from one activity to another. These types of diagrams are particularly useful to describe and visualize the inner working and functionalities of the systems logic [51].

4. IDEATION

This chapter describes the ideation phase of the project. The starting point for the ideation phase is the design question of a consumer ready and DIY smart rainwater buffer together with the research presented in the state of the art. First the stakeholder identification is presented, followed by interviews with the stakeholders to get insight in their specific requirements for the envisioned product. Next a PACT analysis is presented that was used to create a use case scenario. After that the preliminary requirements that are based on the state of the art research, stakeholder analysis, interviews and PACT analysis are presented. The remainder of this chapter contains concepts and the evaluation of these concepts. The chapter is concluded with the set of confirmed requirements based on the evaluation.

4.1 Stakeholder Identification

The stakeholders in this graduation project are identified and categorized on their roles, motivations, power and interests. Table 1 displays the identified stakeholders with their role, motivators and contact person. Figure 19 shows the power-interest matrix based on the theory of [41].

Table 1: Stakeholder identification

Stakeholder	Role(s)	Contact person	Motivator(s)
Municipality of Enschede	- Decision-maker - Legislator - Secondary user	H.J. Teekens	- Dealing with climate change / flooding - Meeting climate goals
Waterboard Vechtstromen	- Legislator - Tertiary user	J. Buitenweg	- Water management
University of Twente	- Decision-maker	R.G.A Bults	- Creating the solution for the flooding problems - Developing / delivering the perfect SRB
Early adopters in the City of Enschede	- Primary User	-	- Interest in the project - Interest in environmentally friendly solutions
Co-developer DIY	- Co-developer	S. Tunç	- Creating instructions for the DIY SRB
Co-developer Repository	- Co-developer	J. Planting	- Creating the central data repository
Co-developer User Interface	- Co-developer	T. Dortmann	- Creating the user dashboard
Early and late majority	- Potential Primary User	-	- Solving local flooding problems - Environmentally friendly aspects

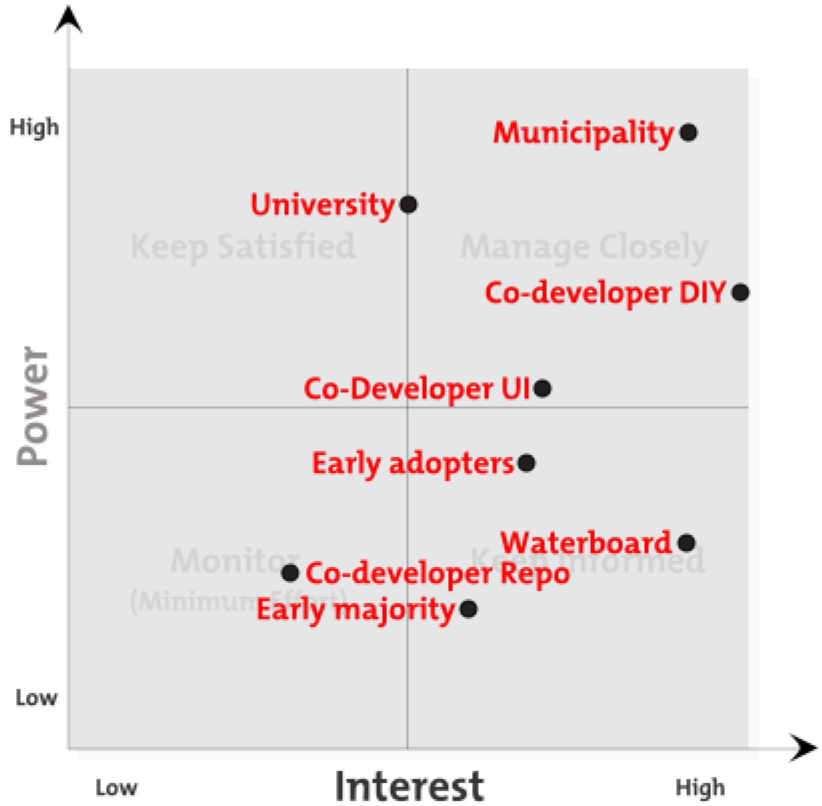


Figure 19: Power-Interest matrix based on theory of Mendelow (1991)

The stakeholder identification and power-interest matrix show that the municipality has the highest power in this project. The municipality is one of the investors and will be a secondary end user of the system. The municipality will not directly interact with the system but will have access to data collected by the system, making the municipality a secondary end user [39]. The motivations of the municipality are dealing with the flooding problems caused by climate change and meeting the climate goals [52]. It is important that the relations with the municipality are managed closely. The requirements of the municipality are very important for this project.

The university also has a lot of power over the project. At this moment they will not be explicit end users of the system, but they will be the leader in the development of the envisioned product. For these reasons it is important to keep the university satisfied. The university will play an important role in relation management, advice and decision making.

Co-developer Tunç does not have the highest power but she does have the highest interest of all stakeholders. The main goal of Tunç is to develop DIY assembly instructions for the SRB, this is only possible in close collaboration with this project. Therefore, the requirements of Tunç have a high priority.

Co-developer Planting does not have a high power and interest when it comes to the overall design of the buffering system. Planting has power and interest when it comes to the use of the central data repository. The SRB could function without the central data repository but than the other Co-developer Dortmann, who is responsible for the user interface will have a problem. Dortmann has a higher interest in the SRB than Planting because Dortmann's project depends on the SRB to send data to the central data repository. For this reason, Dortmann will have power when it comes to the measured variables, the interval of measuring and the interval of updating the data on the central data repository.

The early adopters of the SRB are the main user group for which the product will be designed for. The SRB project of Climate Adaptive Enschede follows the innovation theory of Rodgers [53]. Following this theory, the first people that use the product are called the innovators. As mentioned before the innovators of the SRB are testing and co-developing a first version of the SRB. The early adopters come after the innovators. The early adopters are the first persons who will own the redesigned consumer ready and DIY version of the SRB. After the early adopters follow the early and late majority. The early and late majority consist of the remainder of the inhabitants of the city of Enschede.

The waterboard Vechtstromen is one of the legislators and tertiary user in the project. Tertiary users are those affected by the introduction of the system, or who will influence its purchase [39]. The power of the waterboard in the project is relatively low but their interest is equally as high as the interest of the municipality, since water management is a shared responsibility between the waterboard and the municipality. The main goal of the waterboard is to indirectly benefit from the functionalities that the SRB will bring, allowing for better water management.

4.2 Interviews

Several quantitative interviews were held with the stakeholders in order to get insight in their specific requirements for the envisioned product. The interviews were all semi-structured and also functioned as brainstorming sessions.

4.2.1 Municipality

In order to get insight in the requirements for the redesigned SRB two brainstorm/interview sessions were held with the water management designer at the municipality of Enschede, Hendrik Jan Teekens. During these meetings the preliminary requirements for the redesign of the SRB were obtained. One thing that became clear in the first meeting is that the municipality wants a rain barrel as buffer. The barrel should have a capacity of minimal 200 liters or bigger depending on the roof top size and situation. The municipality wants the system to operate fully autonomous based on weather prediction data. The barrel should empty 2 hours prior rainfall because this is the maximum time needed to get water out of the sewage system. The system should preferably have a price below 250 euros.

One of the other points that was discussed is remote control by the municipality of privately owned SRB installations. The conclusion of the discussion was that at launch of the product the municipality should not have explicit control options over privately owned SRB installations. However, the systems hardware should support this, so if in the future the municipality wants water management controls, this could be realized via a software update.

Furthermore, the municipality wants to stimulate to use the collected water around the house. In some cases, it might also be beneficial for the ground water level to drain the water into the garden. This depends on the location and on the time of the year. Meaning that the buffer should only drain water in the garden if it is beneficial for the ground water levels. Also, the overflow off the buffer must put water into the garden if possible.

Also, the water quality of the buffered water was discussed. The system should autonomously guard the quality of the water. For instance, in case of an increased risk of the development of the legionary bacteria the water should automatically be drained. The barrel should also be designed to protect against mosquito breeding inside the barrel. The SRB should also have a filter.

Also, different types of SRB installations where discussed. The municipality likes the idea of a "basic" and "extended" model. The basic model being an SRB that can only drain water to the sewage and has the option to manually tap water for indoor and outdoor use. The extended version would be a basic SRB with extra output modules added to allow drainage of water into the garden or other uses.

Another point that was discussed is the installation of the buffer. The municipality prefers installation by the end users but also suggested installation by an engineer if necessary. These engineers could for instance be trained students.

In terms of system monitoring the municipality wants to focus on a personal monitoring dashboard for the user of the SRB. This dashboard should motivate the user to use water locally. The municipality also wants a public dashboard to promote the SRB. The data collected by the SRB must be handled with care and must only be use with respect for the user's privacy and conform the European GDPR.

Table 2 shows the functional and nonfunctional requirements gathered from these interviews and brainstorming sessions.

Table 2: Requirements municipality

Functional requirements	Non-Functional requirements
The barrel should empty 2 hours prior rainfall	The barrel should have a capacity of minimal 200 liters or bigger
The system could support over the air updates	There could be two versions of the system, the basic and extended version.
The system should automatically drain the water incase of risk for legionella	The system should be installable by the user self
The system must work autonomously	The collected data should be saved and transmitted in a secure way
The system must be able to drain water to the sewage system	The system should cost less than 250 euros
The system is manually drainable	The system should promote being environmentally friendly
The system must have a rainwater overflow	
The system should filter the rainwater before it enters the barrel	
The system should support an online personal monitoring dashboard	
The system could support an online public promotion dashboard	

4.2.2 Waterboard

There was also a brainstorm/interview session held with Jeroen Buitenweg, a senior policy adviser on water management and climate adaption from the waterboard Vechtstromen. Buitenweg pointed out that water management is a shared responsibility between the municipality and the waterboard. The SRB would be an interesting solution to solve flooding problems and promote local water usage. Buitenweg pointed out that he wants the system to be as simple and robust as possible. Out of his experience he learned that maintenance by user will often be forgotten, it would be wise to design the system around this. Buitenweg also pointed out that it is important that buffers that are in too wet parts of the city should never discharge the water into the gardens but directly into the sewage system.

Table 3 shows the functional and nonfunctional requirements gathered from the interview and brainstorming session.

Table 3: Requirements waterboard

Functional requirements	Non-Functional requirements
The system should only drain water into the garden if the garden is located in an area suitable for this.	The system must require low maintenance.
	The system should be durable

4.2.3 University

Out of the interviews and brainstorming sessions with Bults and Scholten, both stakeholder representatives of the university, it became clear that they want to have a consumer and DIY ready SRB that is ready to be used by the Early adopters of the SRB project. They pointed out that the system should be developed in a way that allows further development in the future of the project. The system must upload its sensor data to a central data repository. During these sessions it was also asked what they define as “consumer ready”. They responded on this that the system should be consumer ready in the extend of being universal to install. Situation specific part should not be included in the product and are the responsibility of the user him or herself. The system should work reliably, be robust and must be easy to assemble.

Table 4 shows the functional and nonfunctional requirements gathered from these interviews and brainstorming sessions.

Table 4: Requirements university

Functional requirements	Non-Functional requirements
The system must send the status information to the central data repository.	The system must be reliable
	The system must be robust
	The system must be easy to assemble

4.2.4 Co-developers

During interviews and brainstorming sessions with Co-developer Tunç, who is working on the DIY assembly instructions of the SRB, she pointed out that she is planning to use instructions that are colored. Because of this, color coding of parts on the to be developed system can be used. In order to keep the DIY tasks simple, Tunç also requests a DIY product with predefined holes for valves or other equipment. The holes could already be in the barrel or they could be easily cut out by the user during the assembly process. This is something that should be researched further in the realization phase because predefined holes limit the flexibility of placement of the SRB.

During interviews and brainstorming sessions with Co-developer Planting, who is working on the central data repository, it became clear that it is important for Planting to guard the integrity of the data. For this reason, Planting proposed the use of an Application programming interface (API) to communicate with the central data repository in order to standardize and limit the operations that the SRB can perform and secure the database in case of a security breach at the side of the SRB.

During interviews and brainstorming sessions with Co-developer Dortmann, who is working on an SRB user dashboard, it became clear that Dortmann wants access to the fluid level data and temperature of the buffered water in the SRB. He proposed that the SRB should measure this at least every 1 minute and upload the data to the server at least every 15 minutes. During the brainstorming sessions with Dortmann the installation process of the SRB was also discussed. Dortmann agreed that it would be most logical to incorporate the digital setup process of the SRB into the user dashboard. Finally, Dortmann requested that the SRB would generated planned discharges and send these to the central data repository. These planned discharges are discharges that might happen in the near future based on precipitation predictions. These planned discharges will be used in the user interface in order to give the user insight in the behavior of the system.

Table 5 shows the functional and nonfunctional requirements gathered from these interviews and brainstorming sessions.

Table 5: Requirements co-developers

Functional requirements	Non-Functional requirements
The system must send the status information to the central data repository.	The system could have predefined holes for the installation of parts in the DIY assembly process.
The system should support an online personal monitoring dashboard	The system must communicate with the central data repository via an API
The system should measure the system status every minute	The system could be setup via a web interface
The system should send the system status every 15 minutes to the central data repository	
The system should send planned discharges to the central data repository.	

4.3 Scenarios

This section contains a PACT analysis and PACT scenario. These tools help to get insight into the needs of the users while using the SRB in the city of Enschede. The source of information for this analysis and scenario originate from brainstorming sessions with the municipality, the state of the art research, statistics from CBS [4], the research of Defize [13], and the surveys from Steeghs [10] and Rindt [11].

In order to identify the user group and their needs a PACT analysis is performed in two parts: a PACT pre-analysis [48] and the actual PACT analysis [46]. The stakeholder analysis identified the early adopters as primary end-users. The PACT pre-analysis is focused on this user group and has been used to create the actual pact analysis and scenario for the early adopter.

4.3.1 PACT pre-analysis

This section contains a PACT pre-analysis for a smart rain water buffer system following the PACT analysis technique and format of Trulock [48]. This user centered approach will help understand the context the product will be used in together with requirements that come with use in that particular context. The primary user of the SRB will be the early adopter, living in Enschede. The pact pre-analysis is used to get insight in the characteristics, motives, tasks, context and used tools from the early adopter user group.

People

The user group of SRB owners will be very heterogeneous. This group contains many different types of people. In short, the users in this group could be described as the average citizen of the city of Enschede. The system will mainly be focused on adults. The cognitive abilities of users will differ a lot. Meaning that the system and the DIY assembly process should be designed for different levels of attention, learning abilities, memory and perception. There will also be diversity in the physical characteristics of the users. For example, difference in strength or physical abilities. This could also mean that the user group contains people with special needs, like wheel chair users or blind people. If the system is variable in the height of the placement or provides some sort of audible feedback than the system would also be usable by these types of users.

Enschede is also a very multicultural city, almost 30% of the inhabitants of Enschede has a migration background. The vast majority of migrants have a western background, culture wise there are no extreme differences [4]. But barriers like language, might have an influence. This is something to take into account during the development of the DIY assembly process and interface design.

The motives within the user group might also differ per user. Interests, personal values and hobbies might have a big influence in the motivation to use a smart rainwater buffer. People with the hobby of gardening might have a different motivation to use a smart rain water buffer than people who are interested in the environment and climate adaption. Another group of people might only use the smart rainwater buffer if there are financial benefits linked to the user of the SRB. Also, people in dryer parts of the city might not see the need to use a smart rain water buffer to solve problems for people in more wet parts of the city. The focus group of this project will be the early adopters. The early adopters are a subset of the user group described above, but with a bigger interest in the project.

Activities

The goals of the SRB owners can differs and also the tasks and actions. The system will mainly operate autonomously without needing any user interaction, this is uniform for all users. Although the system can work almost fully autonomous it also allows for some manually controlled actions.

The most uniform task that is applicable for all SRB users could be the cleaning of the filtering system if this is not done automatically. This will be a regular task that needs to be performed frequently. The system should remind the user to clean the filter frequently. The main task of the user will be to monitor the system performance and status. This will be done via a dashboard which is outside the scope of this graduation project and will be the responsibility of co-developer Dortmann, with a shared dependency on the central data repository of co-developer Planting. An important aspect for this graduation project with regards to system monitoring is providing the technical functionality to allow remote monitoring. Another task that might be performed by the owner is using water from the barrel for local usage. This can be done manually by tapping a certain amount of water into a for example a bucket. This means that the user should have some way to interact with the system to control the output valve. This could for instance be done with a physical button placed on the system. Local water usage could also be provided by using an extension module that allows to user to automate discharges of water into the garden. This could for instance require a one-time action of installing the extra outlet module and a setup process using the dashboard.

Context

The SRB owner can interact with the system in the digital context or in the physical context. The physical context will very likely be outside, depending on the placement of the SRB. It is assumed that most users will place the SRB outside the house. The conditions in this environment differ per time of year. The digital context also called social context will be via the dashboard which lays outside the scope of this graduation project and will be the responsibility of co-developer Dortmann .

Technologies

The main technology used is the SRB unit. The input of the system will be sensor data and prediction data but also user input. The output will also be data and the controlling of actuators like the valves. The SRB unit will communicate with a central data repository to get and to send data. The dashboard will also use the central data repository.

4.3.2 Specific PACT analysis

This section contains the PACT analysis for the most important user group: the early adoptors, based on the PACT analysis technique and format of Benyon and Macaulay [46]. This user centered approach will help understand the context the redesigned SRB will be used together with requirements that come with use in that particular context. The PACT analysis is concluded with a use case scenario of an early adaptor.

Scenario Title SRB use by early adopters		
Scenario History		
Version	*Date*	*Description*
1	08-05-2018	Discussed at GP progress meeting
1.1	10-05-2018	Modified following discussion
1.2	07-06-2018	Modified following feedback

Scenario Type
Use case scenario

Rationale
This scenario has been developed as input for the concept ideation and requirements identification for the redesign of the SRB. It is intended to provide a rich description of a general context of the use of the redesigned SRB by an early adopter. In the scope of this project an early adopter can be considered as one of the first inhabitants of Enschede that buys and uses the in this project to be develop consumer version of the SRB.

PACT analysis
<u>People</u> – 34-year-old single woman with a passion for gardening, living in a residential area in the east of Enschede. Graduated from hospitality school, currently has permanent job as waiters with an monthly income of around 1500 – 2000 euro.

<u>Activities</u> – Using the SRB to harvest rainwater to use in her own garden and to lower the change of a flooded backyard.

<u>Context</u> – Outdoor, in the garden of an terraced house in a residential area of the city of Enschede.

<u>Technology</u> – The Smart Rainwater Buffer, a system that can buffer water during rainfall in order to reduce strain on the sewage system in order to prevent flooding issues. The system will use weather prediction data to drain the necessary amount of buffered water before it starts raining. The system should allow for local water usage and supports the municipality in reducing the strain on the sewage system.

Scenario

Petra Molenaar is a 34-year-old woman who was born and raised in the city of Enschede. Petra works as a waitress at a restaurant located at the "Oude markt" in Enschede. She started working there as a teenager and has worked their ever since. Petra lives together with her dog Monty in a small cozy house in the east of Enschede. What Petra loves about her house is the big garden. Petra loves to be outside. Her biggest hobby is gardening, and she likes to grow her own vegetables. Next to her vegetables and flower beds, she also has a big lawn because Monty also needs space to play. The big disadvantage of her garden are the water problems. In the fall and winter her garden is too wet and in the spring her garden dries up to the point that her garden is completely dry in the summer. She had an irrigation system installed to keep the garden moist in the summer, but this costs her a lot of tap water which is not an environmentally friendly solution.

Petra heard that Frank from across the street has a Smart Rainwater Buffer (SRB) prototype installed in his garden, which saves him lots of tap water and also keeps his garden a little bit drier in the wet periods. Petra went over to Frank an asked him about the SRB. Frank is very enthusiastic about his SRB, in fact Frank is one of the innovators[2] of the product and showed Petra exactly how the buffer worked. Petra really liked the buffer, especially because it nicely blended in to the garden of Frank. Frank made his own wooden cover on the buffer, so it matches with his garden shed. The robustness of the system also really appealed to her. Frank modified the prototype in a way that there are no hanging wires that his dog could possibly play with and overall the system looked reliable. Frank told Petra that she could become one of the early adopter of the product, meaning that she could become one of the first few people that has the consumer version of the SRB.

Once Petra got home she decided to become an early adopter, because she really liked the concept of an SRB and she thinks it would be a very useful tool for her backyard. Petra contacted the municipality to order a SRB for her own garden. She picked an anthracite colored buffer because it matches with the color of her fence. Once the package with the Smart Rain Water buffer arrived Petra immediately assembled the DIY system using the clear assembly instructions. The employee of the municipality told her that the assembly would be easy, but she didn't expect it to be so extremely easy for real. In no time she had her SRB up and running. Petra bought the basic model of the smart rainwater buffer because at the moment she didn't had enough money to buy extension modules to connect her garden irrigation system.

Petra now uses the SRB for over a month and she loves it. When she comes home from a long day of work she goes in to her garden and waters her plants with water from the SRB. She can just press a button to fill her watering can. After a month of saving, Petra decides to buy the extension outlet module for her garden

[2] Innovators are the first users of the product [53] and in this case also co-developers, for more information see chapter 4.1

irrigation system. Together with the extension module she also got an DIY assembly manual. Before she mounted the extension module she first had to empty her buffer. After she mounted the extension module she could simply connect her irrigation system with the same connector she used for the tap water, so she did not have to change anything on her irrigation system. After she completed the installation she used the dashboard app to setup the irrigation times for her garden. She was surprised that the municipality already offered pre-programmed settings based on the ground water levels in her neighborhood.

4.4 Preliminary Requirements

As the Creative Technology design method describes the needs of the stakeholders can be used to create preliminary requirement. Based on state of the art research, interviews, stakeholder analysis and scenarios table 6 could be constructed. Table 6 shows a list of preliminary. This list is ordered in functional and non-functional requirements and following the MoSCoW method requirements (see section 3.3.2 for an explaination).

Table 6: Preliminary Requirements

Functional requirements	Non-Functional requirements
Must	
The system must be able to buffer water	The system must be durable
The system must filter the water before it enters the barrel	The system must be modular
The system must work autonomously	The system must be weather proof
The system must send the status information to the central data repository.	The system must be reliable
The system must use weather prediction data to regulate the buffer capacity	The system must require low maintenance
The system must be able to drain water to the sewage system	The system must be easy to assemble
The system must be manually drainable	The system must be secure
The system must have an rainwater overflow	The system must be designed for DIY
	The barrel must have a capacity of minimal 200 liters or bigger
	The system must be installable by the user self

Should	
The system should remind the user to clean the filter	The system should use a wireless networking technology
The system should be upgradable with extra control or sensor modules	The system should promote being environmentally friendly
The system should support an online personal monitoring dashboard	The system should be energy efficient
The system should be able to automatically drain water to the garden	The system should cost around 250 euros
The system should automatically drain the water incase of risk for legionella	The system should communicate with the central data repository via an API
The should indicate if an error occurred	
The system should only discharge water into the garden between a predefined period of time.	
The system should have a bypass module to bypass the waterflow in the winter to prevent freezing of the barrel.	
A bucket should fit underneath the manual tab	
The barrel should empty 2 hours prior rainfall	
The system should send the system status every 15 minutes to the central data repository	
The system should measure the system status every minute	
The system should send planned discharges to the central data repository.	
Could	
The system could support over the air updates	There could be two versions of the system, the basic and extended version.
	The system could have predefined holes for the installation of parts in the DIY assembly process.
	The system could be setup via a web interface
Would	
The system would support an online public promotion dashboard	

4.5 Concepts

Several concepts were created by group and individual brainstorming (see Appendix A for the results of the brainstorming sessions). All the concepts are ideated by focusing on an SRB as a solution for both the end-user, the municipality and waterboard to lower the strain on the sewage system during rainfall and therefore preventing flooding issues. Some of the presented ideas take the preliminary requirements more into account than others.

The first two concepts were created in order to find out if the stakeholders still want to solve the problem of a too high strain on the sewage system by approaching it in the same way as the previous projects focused on the problem. The previous project, as stated before in chapter 2.2, focused on a smart autonomously controlled buffering system. The first two concept are not focused on smart autonomously controlled buffering systems and will not incorporate technology. The reactions on these concepts will help understand if the stakeholders still want the same approach.

The other concepts are all based on a smart autonomously controlled buffering system. The difference in these concepts are the different types of buffering methods, buffers and other functional and nonfunctional requirements.

4.5.1 Smart Art – Rain delay

Displayed in figure 20 is a concept of a rain delaying art piece. The object will have no technology inside. The idea behind the concept is a buffer with holes in the sides of the buffer. Once the buffer gets filled the water will flow slowly through the holes reducing the amount of water per square meter per second. Instead of a large amount of water in a relatively short time this concept will spread the same amount of water over a longer period of time. This concept doesn't allow control over the buffered water and will also not be feasible for places with a too high ground water level. This object would be more suitable to be placed in a public space like a park.

Figure 20: "Gaten kaas" rain delaying art concept. Source: Sefora Tunc

4.5.2 Delay roof

Displayed in figure 21 is a concept of a rain delaying flat roof. The concept doesn't use any technology. The idea behind the concept is a narrow hole in the roof to slowly lets the water flow of the roof into the sewage system. This reduces the amount of water entering the sewage system in a small period of time. The system is very simple and only requires the narrow outlet hole and an overflow. The overflow is need in case the roof is full and cannot buffer more water. This concept doesn't allow control over the buffered water and will only be useful for flat roofs that are built to buffer water.

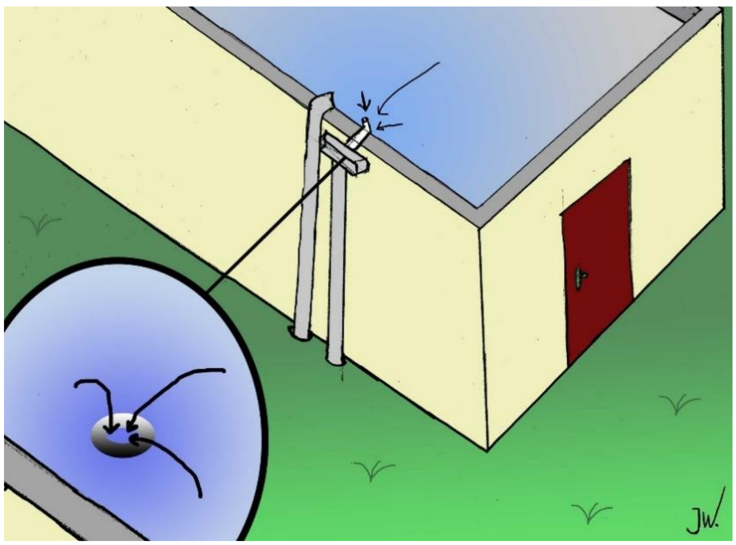


Figure 21: Rain delaying flat roof concept

4.5.3 SRB Garden Furniture

Displayed in figure 22 are some concepts of SRB garden furniture. The idea behind the concept is adding SRB modules (e.g. control module, automatic valves) to garden furniture or ornaments. For example, a planter could be used multifunctional by having flowers on top and a SRB inside. This type of SRB would fit in the context of every garden. At the outside it will not be visible that an SRB is inside. Since it is multifunctional it is also space saving, something that is important in small gardens. The limiting factor of this concept is the limited buffer size compared to other rainwater buffering solutions.

Figure 22: SRB Garden Furniture concepts. First, smart water buffering planters. Source: Sefora Tunc. Second, smart water buffering fountain. Source: Sefora Tunc. Last, smart water buffering bar table. Source: Budget Living

4.5.4 SRB flat room module

Displayed in figure 23 is the concept of the SRB flat roof module. The idea behind the concept is an SRB module that can be added to a rain pipe of a flat roof. The SRB flat roof module will be able to control the flow though the rain pipe. It does this by closing the rain pipe during rainfall to let the rainwater stay on the roof and temporally buffer it there until the raincloud has passed. Once it has stopped raining the module will open the rain pipe again allowing the water to flow into the sewage system. This system will not buffer the water for a long period of time in order to reduce the forces on the roof. In order to make sure the amount of water on the roof does not get too much an overflow needs to be installed, to drain the water after it reaches a certain level. The benefit of this system is that it is relatively simple and does not require a hard installation process. The downside of this concept is that the concept is only applicable for flat roofs that are able to store water.

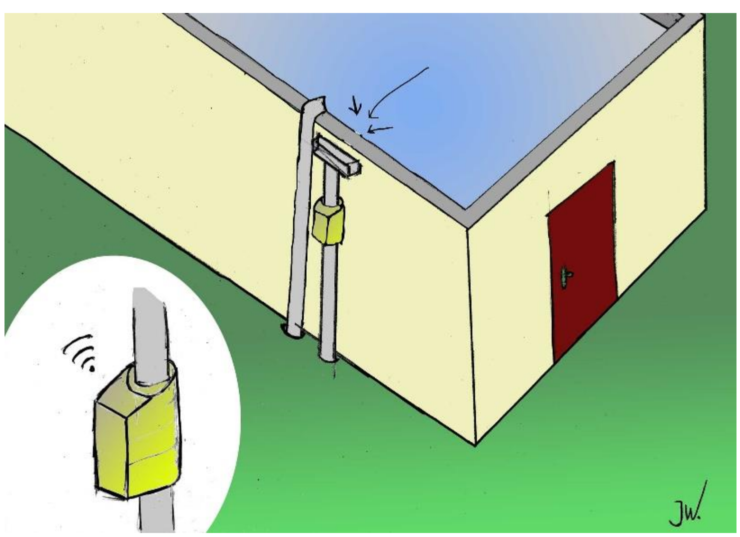


Figure 23: SRB flat roof module concept

4.5.5 SRB rain floor

Displayed in figure 24 is the concept of the SRB rain floor. The idea behind this concept is a rain buffer that is integrated in the floor of the backyard. Instead of placing tiles in the backyard one could also place a rain buffering floor. A rain buffing floor is realized by placing an open shallow buffer underneath a floor made of wooden planks. Small cracks between the planks will let the rainwater that falls onto the floor flow into the buffer. The house's rain pipes could also be connected to the buffer. Combined with a control unit and an automatically controlled valve this rain floor could function as a large capacity SRB. The SRB rain floor won't take up any space in the garden making this an interesting solution for gardens with limited space but with the need for a rainwater buffer. The downside of the concept will be the complicated installation process and the high costs.

Figure 24: Smart rain floor concept

4.5.6 Underground SRB

Displayed in figure 25 is the concept of an underground SRB. The idea behind this concept is an SRB barrel buried underground in the garden. The benefit of this concept is to ability to place a barrel with a large capacity because it will not take up any space above ground in the garden. The big downside of this concept is maintenance and installation. It will not be easy to perform maintenance on a buffer that is buried in to the ground.

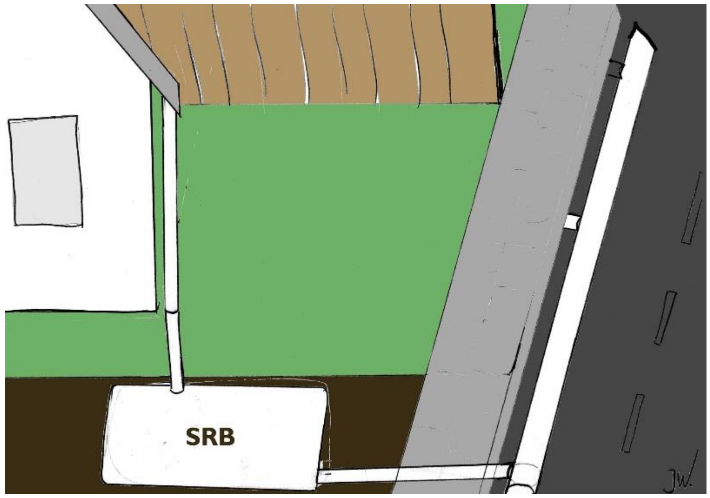


Figure 25: Underground SRB concepts

4.5.7 Rain pipe SRB

Displayed in figure 26 is the concept SRB rain pipes. The idea behind the concept is using the length and capacity of rain pipes to buffer rainwater. This solution would be very simple because it only requires one module to control the buffering and draining to the sewage system, just like the concept presented in 4.5.4. The limiting factor in this concept is the length of the rain pipes. For example, 1 meter of 80-millimeter rain pipe will only be able to store approximately 5 liters of water. Meaning that to buffer large amounts of water a long system of rain pipes is needed.

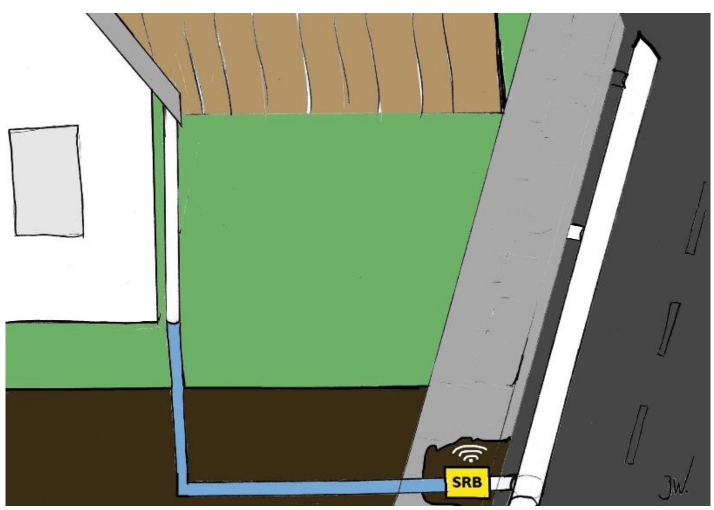


Figure 26: Rain pipe SRB concept

4.5.8 Water Fence SRB

The company Rainwinner developed the Rainwinner water fence [54] (see figure 27). This product could be part of a SRB by adding the necessary components to make this buffer smart. A water fence would not take up much space in the garden since most people already have a fence in their garden. The Rainwinner is a modular system consisting of connected modules that each have a capacity of 110 liters [54]. This makes the Rainwinner a flexible solution because the complete buffer and capacity can be altered to the specifics of the garden it will be placed in, for example 3 meters of fence could already buffer 1000 liters of water. 1 module costs approximately 190,- euros. A buffer of 330 liters would already cost 565,- euros [55].

Figure 27: Rainwinner Water Fence. Source: energienulshop

4.5.9 DIY Water Fence SRB

The previous concept of the Rainwinner water fence would be a good solution to buffer a lot of rainwater in a small garden. The big downside of the concept is the high cost. Because of this the a DIY water fence concept was ideated together with R.G.A. Bults, the stakeholder of the university and supervisor of this project. The concepts is a DIY water fence that can be build in almost any backyard in every desired size. The concept is based on steel stone cage fences (see figure 28), these fences are made by building a steel cage from concrete mesh and filling it with stones. Instead of filling these steel cages with stone they could also be filled with some sort of rainwater buffer. This could be done by making a custom “Water bag” made from industrial plastic sheeting (see figure 29). Another option might be to use pond foil this is thicker but also more expensive. In order to make the construction steady and robust some poles are needed. Concrete poles would be a good option, 2 poles are needed at the beginning and 2 at the end, so there are poles on both sides of the concrete mesh. When the water bag is filled up it will be very heavy this will result in a lot of pressure on the structure, extra poles are metal strips might be needed to reinforce the strength of the structure. See figure 30 for an impression of the concept. Using this construction and for example dimensions of 1x0.3x2 meters this would result in a buffer with a capacity of 600 liters

Ofcourse the plastic sheeting also needs to be constructed into a bag. There are several ways to do this the most simple and cheap option would be to use a roll closure (see figure 31). An other option would be to used platic welding to well the platic sheeting together. The final option would be to let these plastic water bags be produced in a factory.

The water bags would also need some type of outlet. For this the following meganism presented in figure 32 was ideated. One could use a long fitting with a flat plate and rubber ring at the end. This could be put through a round hole that is cut into the plastic sheeting. At the other side of the sheeting one could place an other rubber ring and use a large flat screw to tighten the fitting to the water bag.

Figure 28: Steel stone Cage inspiration. Source: Slegers Sierbestrating

Figure 29: Industrial Plastic Sheeting. Source: Brokers Kunststoffen

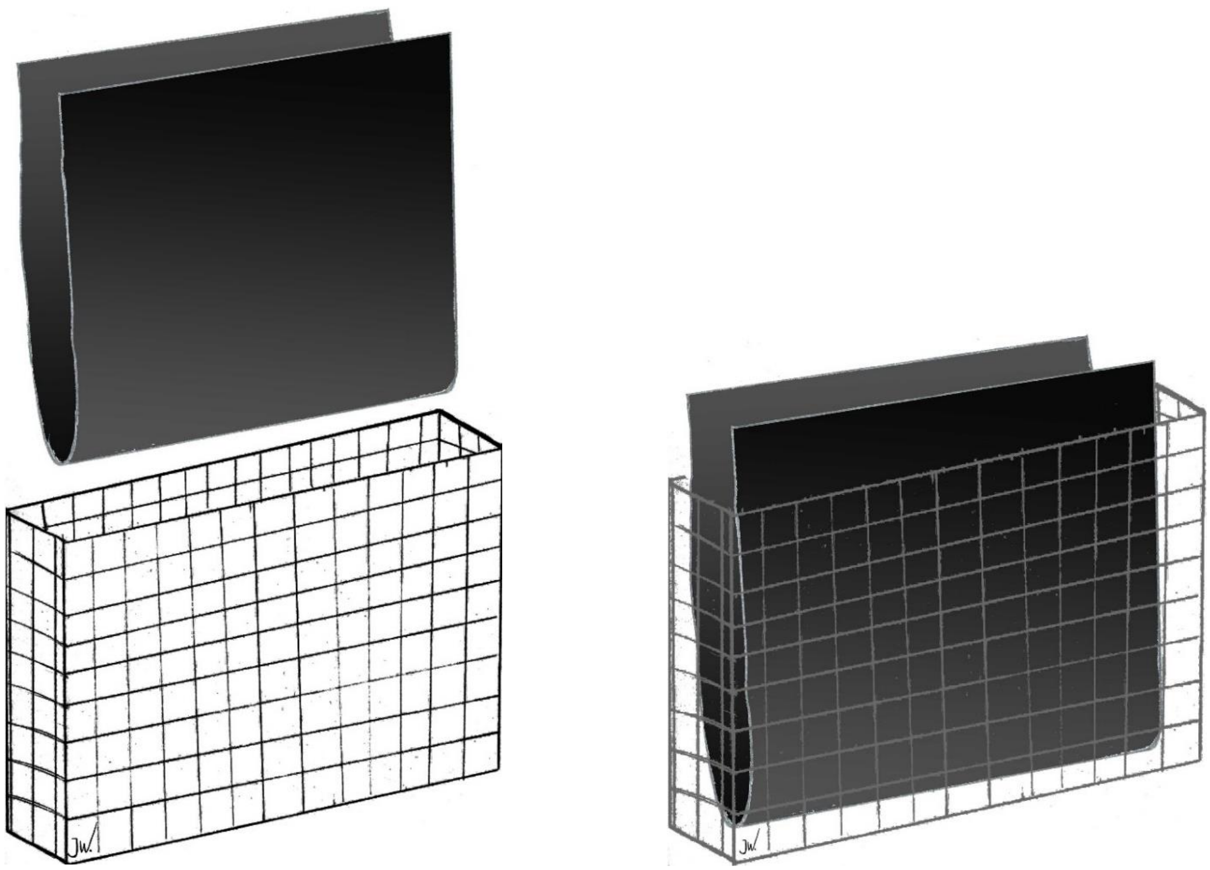


Figure 30: DIY water fence concept

Figure 31: Roll'n snap closure technique. Source: Ortlieb

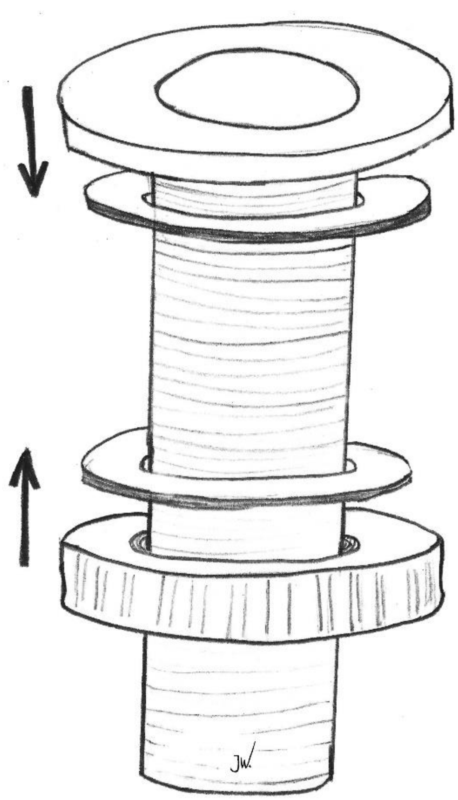


Figure 32: DIY water fence outlet concept

4.5.10 Wall mounted SRB: Small footprint large capacity

This idea is inspired by the common terraced houses (Dutch: rijtjeshuizen) in the Netherlands (see figure 33). Most of these houses have long rain pipes at the front and the back of the house with lots of empty unused space around them. The idea is to replace a part of these rain pipes and replace it with tall wall mounted rain buffers (see figure 34 and 35). The buffers will have a small footprint but will be very tall in order to provide a large buffer capacity. The buffers can have a tap at the bottom that can be used for local water usage by the residents of the house. The buffers could be equipped with the necessary components to make the buffers smart. In case the buffers will be located at the front of the house these buffers could for example easily be professionally installed by the housing associations or municipality. The power could come from a dedicated wire for SRB installations running through the street or from the meter cupboards in the houses themselves. The building guidelines in the Netherlands say the meter cupboards must be located close the entrance of the house [56], meaning that providing the SRB with power from the meter cupboard will not be a too difficult job. Because this the meter cupboard will be in the front of the house close to where the buffers would be installed.

A buffer with the dimensions of 250x60x40 cm could already buffer 600 liters of rainwater. If the entire block of houses would be equipped with these buffers on the front and the back of the house than all the rainwater that is collected by the entire roof could be buffered.

Figure 33: Common terraced houses (rijtjeshuizen) in the Netherlands. Source: ANP

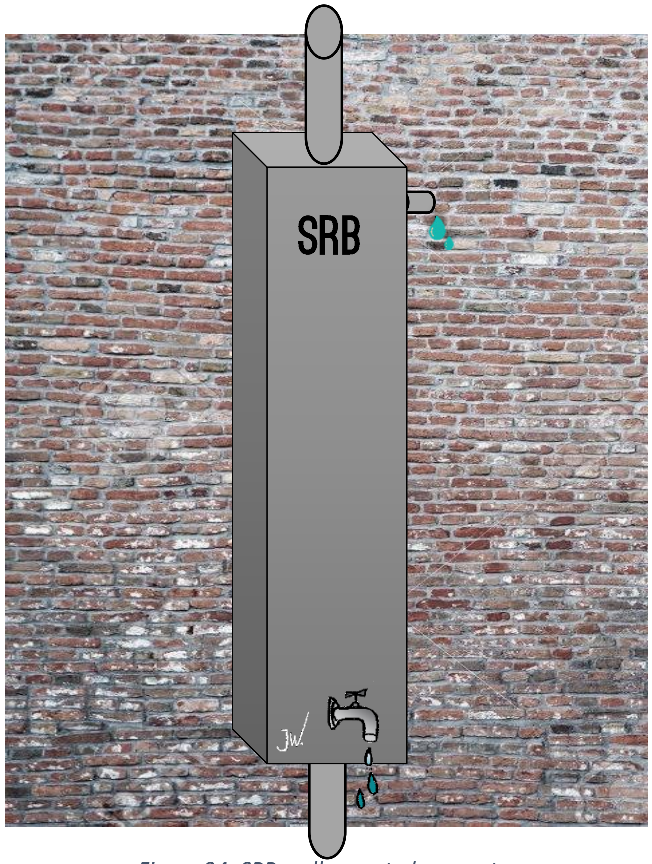


Figure 34: SRB wall mounted concept

Figure 35: Concept in context, Original image source: CBS

4.5.11 SRB DIY module

Displayed in figure 36 is the concept of an SRB DIY module. The idea behind the concept is to provide an SRB module that can be applied to any type of barrel. In other words, this allows for an SRB DIY project in which the user needs to provide his own rain barrel and the module can be added to it to make the barrel an SRB. The most important aspect behind this concept is that it only consists of two easy to install modules. The benefit of this concept is the small package size in case of shipping to customers this reduces costs since the buffer is not included. The downside of this concept is that there is no control in what barrels will be used, meaning that the modules must be compatible with different types of barrels.

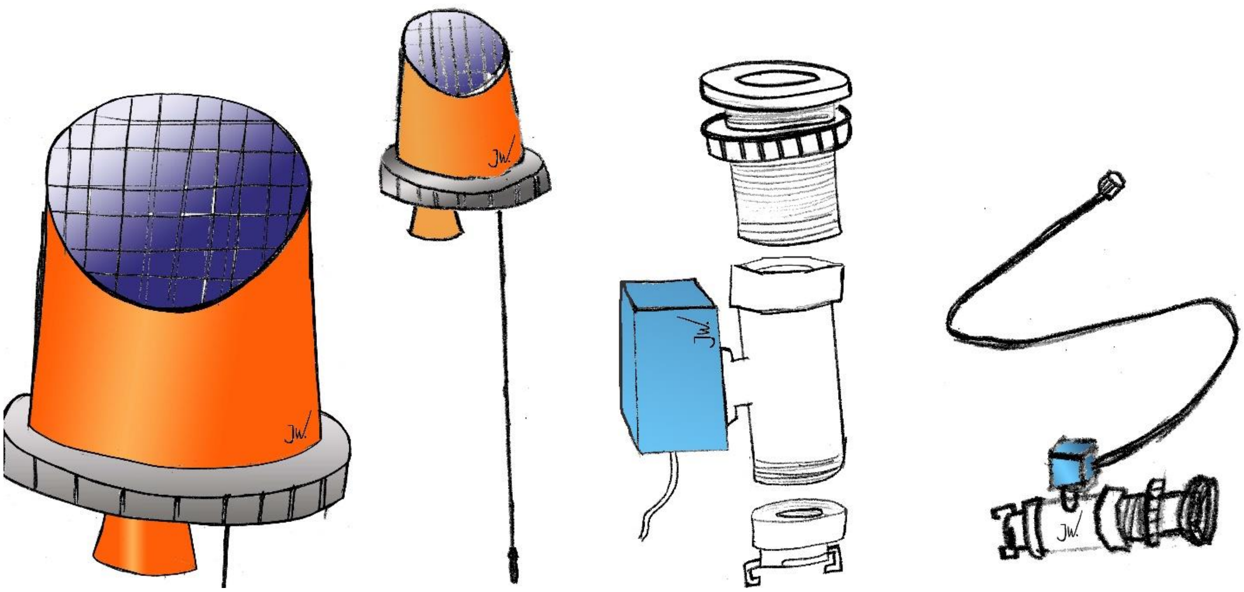


Figure 36: SRB DIY module concept, left the sensor-computing-power unit and right the valve unit

4.5.12 SRB rain barrel

Displayed in figure 37 is the concept of an SRB barrel. This concept is based on the previous prototypes of the SRB. An SRB barrel that can be placed outside in the garden and is easy to install and maintain. The benefits of this concept are that it is simple, and it can use widely available components. The system can easily be extended with extra modules and will be durable.

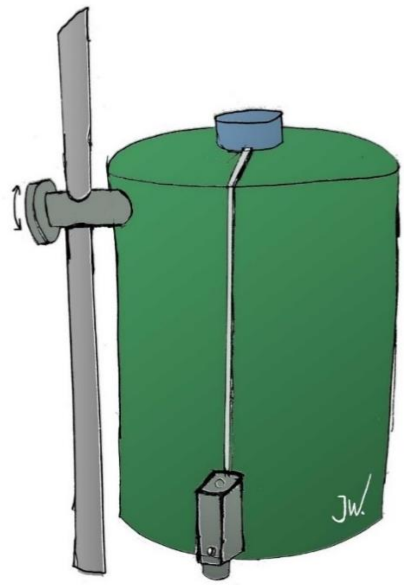


Figure 37: SRB barrel concept

4.6 Evaluation

The different concepts were presented to the municipality, university and co-developers. During the presentation of the concepts it was confirmed that the to be developed solution must be able to buffer water and that the drainage of the buffer needs to be based on the weather predictions and the freshness of the water. The municipality and the university decided to choose for the SRB barrel concept because of its simplicity, flexibility and installation process. The barrel concept must be a DIY product that can be assembled by the user of the SRB. Although the stakeholders choose for the barrel concept they also saw potential in the bring your own barrel SRB DIY module concept. They want the DIY buffer concept to be developed, but during development there should also be thought about using technologies and techniques that can be applied also for the bring your own barrel SRB DIY module. The stakeholders also made clear again that the system should communicate with the central data repository in order to provide data that suffices for the creation of an online management dashboard

After the municipality and the university agreed on the concept of the SRB barrel, the municipality and the university where interviewed on the specifics and requirements of the system. It was confirmed that the system must be modular, and the installation of the modules should not be too difficult.

Together with the municipality and the university it was decide that a the SRB should be powered by a power plug, plugged in to a wall socket (230v). Besides the safety concerns, decrease in flexibility of placement and a less environmentally friendly image it was still decided to use a power plug instead of a solar and battery combination as a power source. If a solar and battery combination would have to been used it would be very important that the power source is able to reliably deliver power to the system even in case of a long period cloudy weather when the solar power is limited. The municipality and the university pointed out that a solar and battery power system would be preferred over a power plug but in this graduation project there is not enough time to develop a completely reliable solution which is also cost effective. A solar and battery power system would be very beneficial in areas where the power grid is unreliable, but this is not the case in the Netherlands. See figure 38 for a concept of the different power sources.

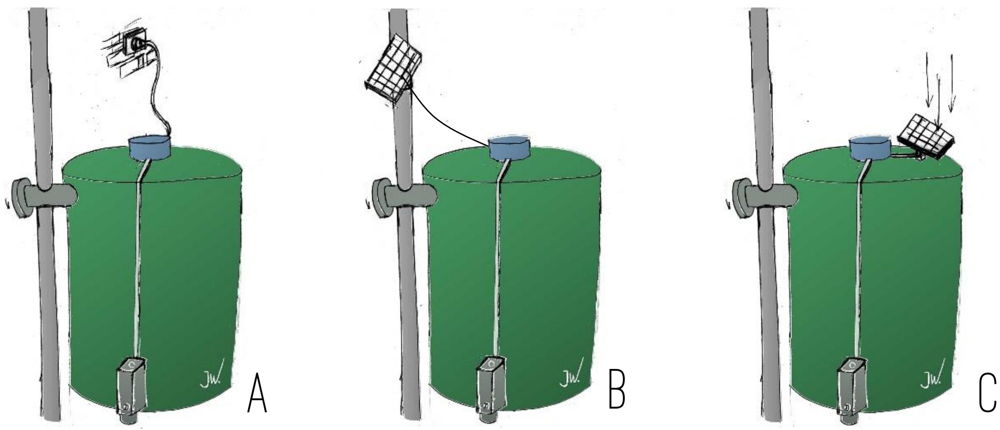


Figure 38: SRB power source options, a) a power plug, b) a fixed solar panel, c) a detachable solar panel

It was decided that either a local or a wide area wireless networking technique will be used for data communication. Both will be research in the realization phase and the most suitable technique will be chosen for the final consumer version. It was decided by the municipality and university to use a wireless communication technique because it is not common that people have a wired network connection available in their garden.

The University stated that all the rainwater should go through the system, meaning that a rain barrel filler (Dutch: vul automaat) cannot be used because this system will not divert all water into the barrel. All the available rainwater should enter the system. This makes it easier to study the performance of the system. Since a rain barrel filler cannot be used anymore there is the need for an overflow. The municipality wants that the overflow can either go into the garden or into the sewages system. This dependents on the groundwater level and the time of year. The waterboard stated that the system must be kept simple, meaning that also the overflow must be. The stakeholders agreed on the argument of the waterboard and together they agreed that the output of the overflow will be decided at installation and that people can change it later if they want to. The stakeholders didn’t like the idea of a manual 3-way valve at the overflow that can be used to quickly change between output to the sewage system to output to the garden, they belief this is the responsibility of the user to implement this themselves if they want to. The stakeholders liked the idea of notifying the users when it is advised to change the output of the overflow. The university pointed out a diverter to protect the barrel from freezing is not a must have requirement. The university made the claim that qualitative good components in contact with water will not get damaged if the temperature outside is below zero.

Both the municipality and the university agreed that the system must be robust. Two concepts of SRB barrels were presented to them (see figure 39). The first concept has the output valve and control unit on the front and the second concept has these both below the buffer. The municipality and the university agreed that the second concept with the outlet and control unit at the bottom will be the most robust. One other remark they made is that all parts should be waterproof because of the use of water and possible condensation.

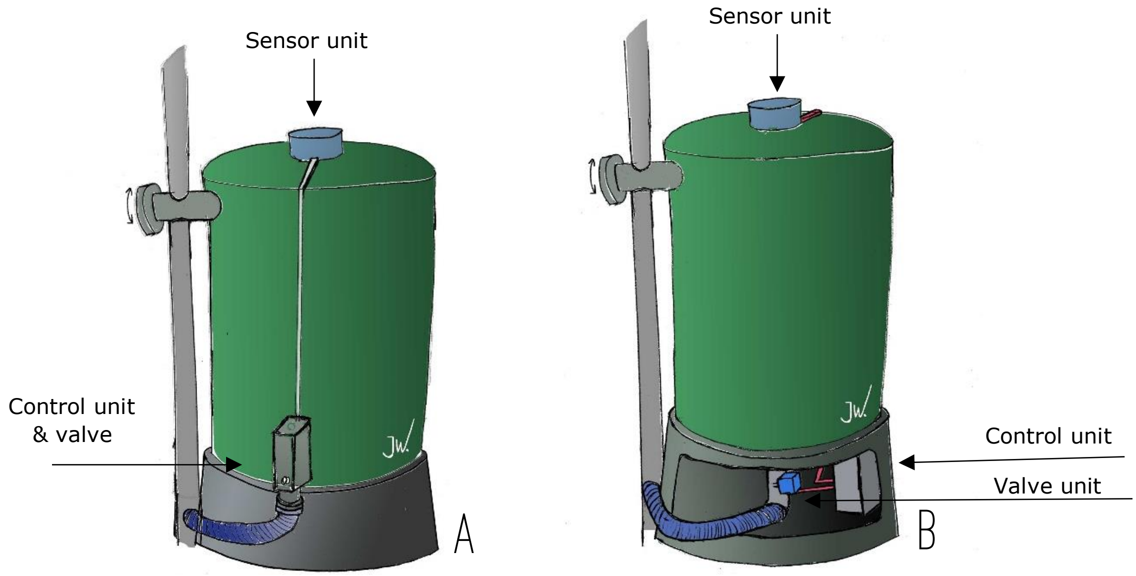


Figure 39: SRB concepts, a) control unit and valve on the front, b) control unit and valve underneath the barrel

Furthermore, the need for different types of SRB systems suggested by the research of Defize [13] were discussed. It was decided that there will be a basic and extended version of the SRB. The basic version should be upgradable with extra modules (e.g. extra output valves or water quality sensor). But for the scope of this Graduation Project the focus should be on the basic model.

The municipality wants the basic model to use weather prediction data to plan drainages before rainfall. The basic model also must be able to drain automatically to the sewage system. The output overflow must be able to be connected to the garden or sewage system. The basic model should also allow the user to manually tap water from the system for local usage. The municipality wants a dedicated tap for manual water usage and doesn't want the automatic outlet to be used for the manual tapping of water. See figure 40 for the different concepts for manual drainage and the extended version.

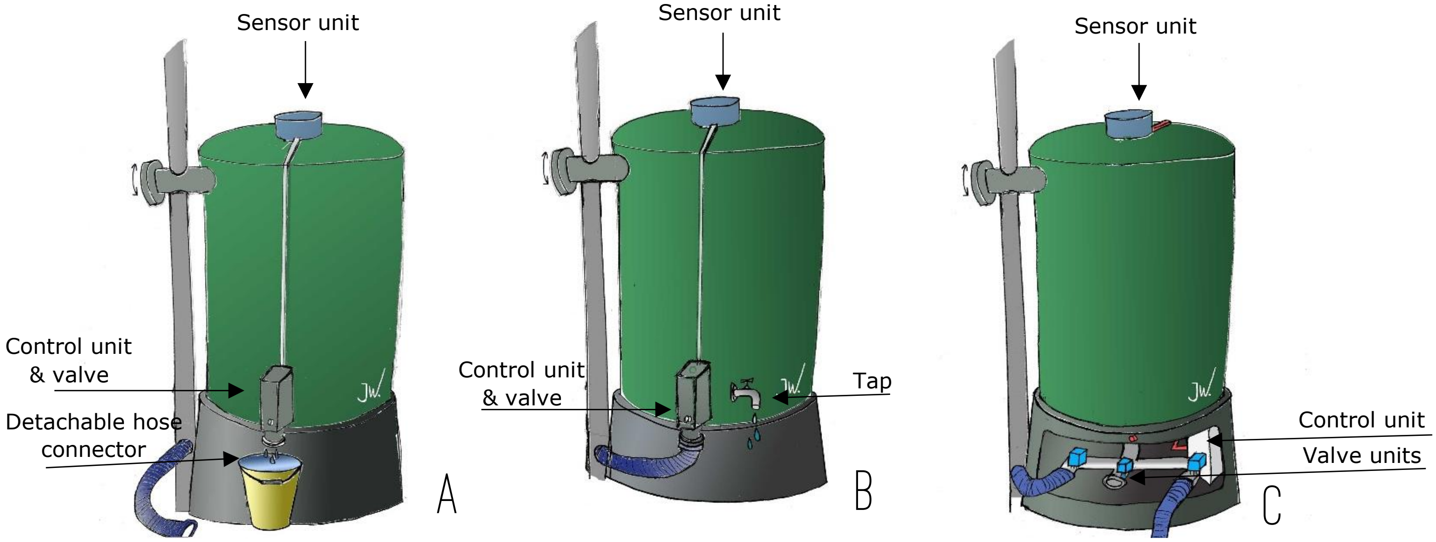


Figure 40: SRB local water usage concepts and extended version, a) no extra tap, b) extra tap, c) extended model

Finally, the municipality and co-developers confirmed that the SRB should have support for a user dashboard that allows users to monitor the system. The SRB must communicate with a central data repository that keeps track of the water level and draining of the buffer. The user interface will then get these data from the central data repository and display it to the user. Since the SRB must be a DIY product the setting up of the system must also be done by the user. In order to make this user friendly it was decided together with co-developers Planting and Dortmann to let the user setup the system via the to be developed online user interface. The setting will be stored in the data repository and will be requested by the SRB at first bootup.

4.7 Final concept

It can be concluded that the stakeholders wants an SRB that uses a barrel as buffer. This buffer must have a capacity of a least 200 liters. The system will work autonomously and will not be directly controllable via the network, only manually at the location of the buffer. The SRB uses weather prediction data in order to control the output and the capacity of the buffer. Incase it is going to rain the buffer will drain enough water based on the prediction data, this must happen 2 hours before rainfall. The buffer also monitors the water temperature in order to detect risks for legionella and will drain the water automatically if it is configured to do this. The system is powered via power plug connected to the electricity grid. The system also uses a wireless network connection. The system sends its status information to the central data repository. The system has one controlled output to the sewage system or garden and a second output for a manual valve. The valves and control unit will be at the bottom of the barrel in order to safe space and to be more robust. The system has a rainwater inlet and overflow. The cost price of the system should preferably be around 250 euros. See figure 41 for an impression of the final concept.

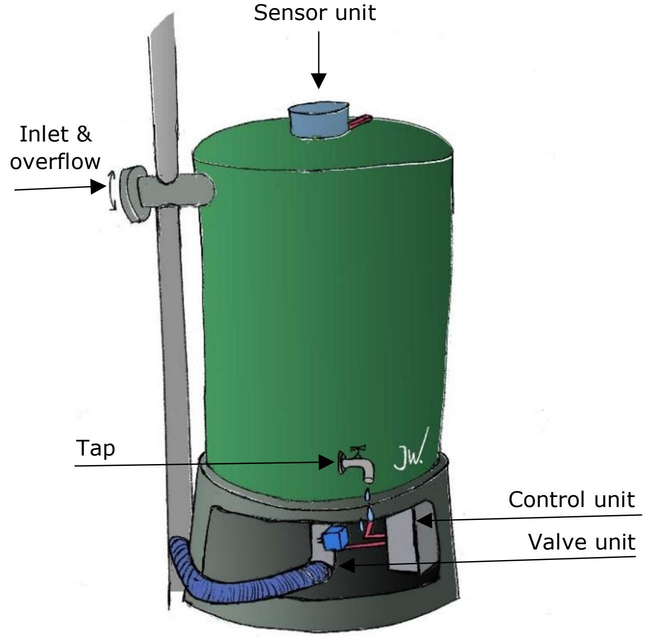


Figure 41: Final SRB concept

4.8 Evaluated preliminary requirements

Because the stakeholders evaluated the concepts and made a choice on what concept to realize, the requirements for this phase could be finalized and confirmed by the stakeholders. Table 7 below contains the final list of requirements for this phase.

Table 7: Confirmed Requirements

Functional requirements	Non-Functional requirements
Must	
The system must be able to buffer water	The system must be durable
The system must work autonomously	The system must be robust
The system must be able to drain water to the sewage system	The system must be weather proof
The system must be manually drainable	The system must be modular
The system must provide the option to connect the overflow to the garden or sewage system	The system must be reliable
The system must filter the water before it enters the barrel	The system must require low maintenance
The system must have a rainwater overflow	The system must be secure
The system must use weather prediction data to regulate the buffer capacity	The system must be easy to assemble

The system must send the status information to the central data repository	The system must be installable by the user self
The system must drain 2 hours prior rainfall	The system's capacity must be at least 200 liters
	The system must be safe to use
	The system must fit in a garden
	The system must be designed for DIY
Should	
The system should remind the user to clean the filter	The system should use a wireless networking technology
The system should indicate if an error occurred	The system should promote being environmentally friendly
The system should measure the system status every minute	The system should be energy efficient
The system should automatically drain the water in case of risk for legionella	The system should communicate with the central data repository via an API
The system should support an online personal monitoring dashboard	The complete system should cost not more than 250 euro
The system should be able to automatically drain water to the garden	The user should be able to opt out for the option to drain water in case of risks for legionella
The system should send the system status every 15 minutes to the central data repository	A bucket should fit underneath the manual tab
The system should send planned discharges to the central data repository.	The system should be upgradable with extra control or sensor modules
Could	
The system could only overflow into the garden between a predefined period of time.	The system could be independent from the user's private communication infrastructure.
The system could support over the air updates	The system could be scalable
The system bypasses the waterflow from the rain pipe in the winter to prevent freezing of the barrel	The system could be setup via a web interface
Would	
The system would support an online public promotion dashboard	There would be two versions of the system, the basic and extended version.
The system would have a self-sufficient power source (e.g. solar/battery combination)	The system would have predefined holes for the installation of parts in the DIY assembly process.
	The system would not require a software setup process by the user.

5 SPECIFICATION

This chapter describes the specification phase of the project. The starting point for the specification phase are the final concept and requirements from the ideation phase. This chapter presents a functional system architecture visualized with block diagrams and activity diagrams which describe the overall system, the subsystems and the interaction between the subsystems. Finally, the requirements are evaluated again and presented.

5.1 Functional system architecture

This section contains a description and visualization of the functional system architecture of the SRB. First an overview of the SRB and connected systems is presented. Secondly a decomposition and an activity diagram of the SRB logic are presented. Finally, specific internal functions are described.

5.1.1 Level 0: System overview

Figure 42 gives a black-box view of the complete system and connected systems. As can be seen in the figure the SRB has inputs from the outside world, water level, and temperature. Next to these two inputs the system has a connection with a precipitation prediction source. The SRB can send a request to the precipitation prediction source and then the precipitation prediction source responds with the precipitation predictions. The system is also connected to the central data repository. The SRB is able to send data (e.g. temperature and water levels over time) to the central data repository. The SRB is also able to send a request for data (e.g. configuration settings) to the central data repository. The central data repository will than respond with the requested data.

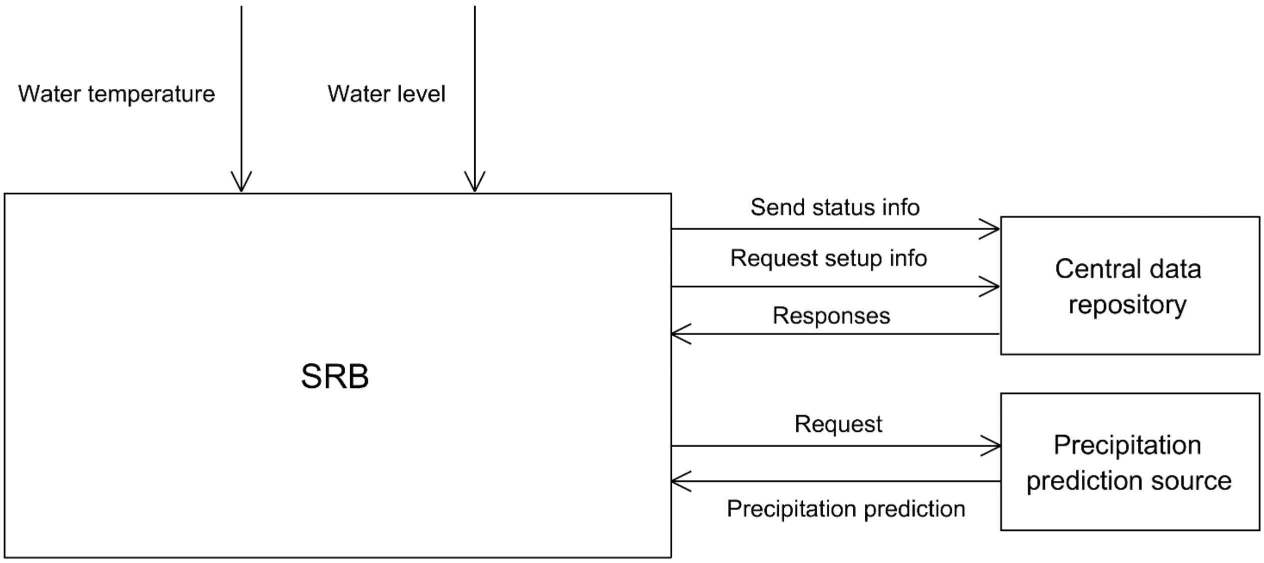


Figure 42: Overview of SRB system

5.1.2 Level 1: SRB combined functions

Figure 43 gives a first level decomposition of the SRB system, it shows the combined functions within the SRB system. The center of the system is the SRB logic. When the SRB is powered for the first time it will first request its configuration data from the central data repository. After it has received the config data it will start operating as a smart rainwater buffer. The SRB logic uses the notifications send by the job scheduler function to trigger actions. These actions are requesting the water level, requesting the water temperature and discharging an amount of water. Another function of the SRB is to periodically request precipitation predictions this is done by sending a request to the network handler. The network handler connects to the precipitation prediction source and sends the prediction data back to the SRB logic. The SRB logic analyses this data and checks if it has enough capacity left to buffer the predicted rainwater. In case there is not enough space left, the buffer will drain the needed amount water. This is done by using the drain and water level measure functions. Finally, the buffer also periodically sends the collected data to the central data repository. This is again done via the network handler. For a more detailed view of the logic of the SRB see the Activity diagram in figure 44.

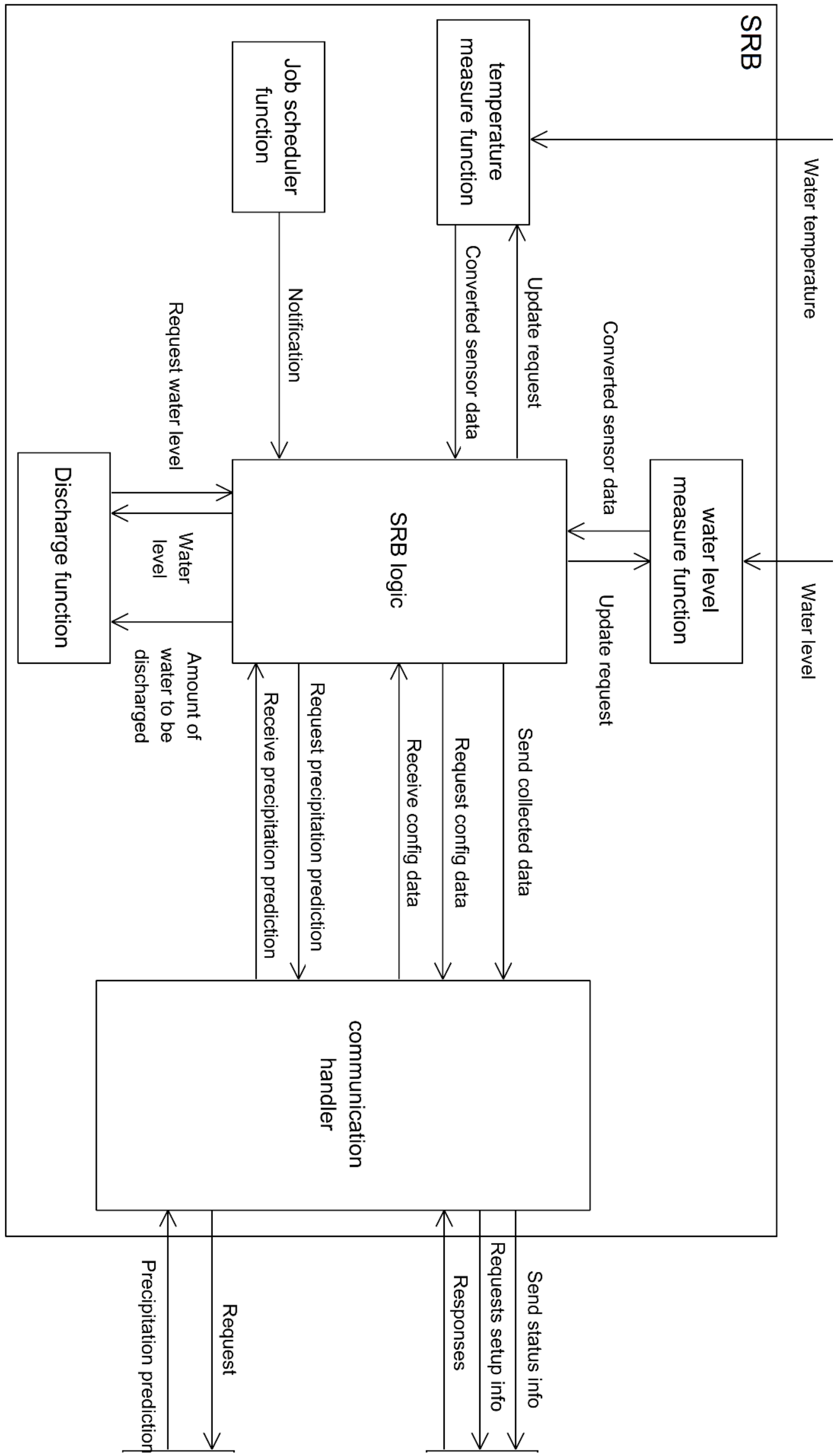


Figure 43: SRB decomposition

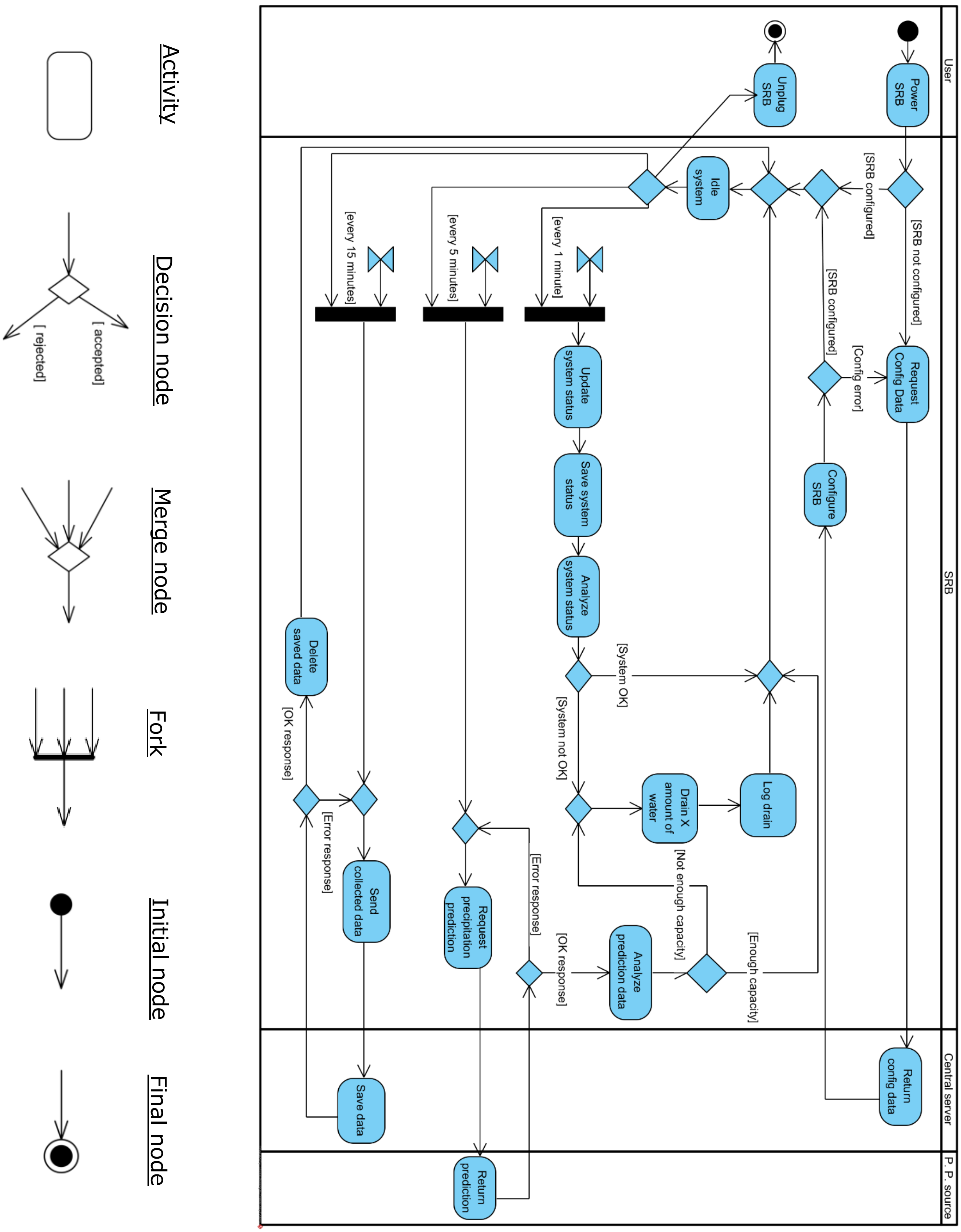


Figure 44: SRB activity diagram

5.1.3 Level 2: SRB function description

Discharge function

Figure 45 give a decomposition of the discharge function. The central function of the discharge function is the "water level control function". This function controlles the valve based on the given amount of water that needs to be drained and the current water level.

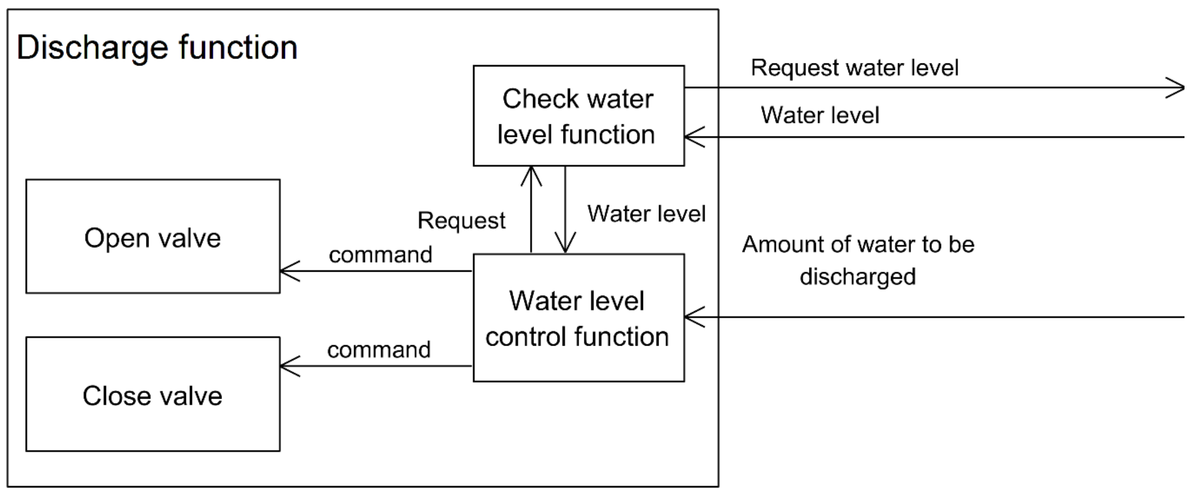


Figure 45: Decomposition of discharge function

Temperature measure function

Figure 46 gives a decomposition of the temperature measure function. The SRB logic can request a status update from this function. This request is handled by the "sensor data converter function" which sends a pull request to the "get temperature sensor data function". The "get temperature sensor data function" returns the raw sensor data. This data is converted and send to the SRB logic by the "sensor data convert function"

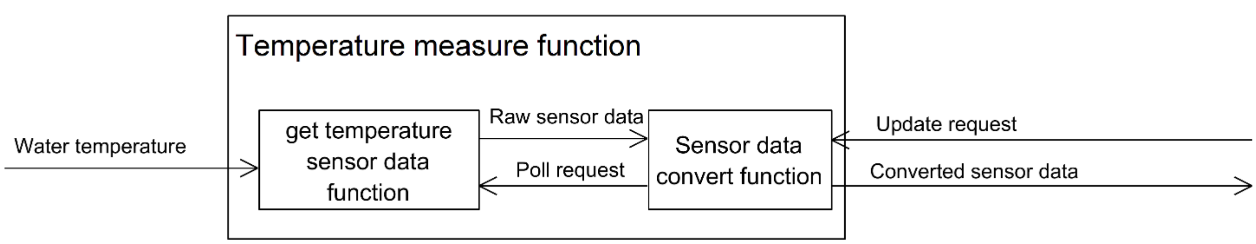


Figure 46: Decomposition of temperature measure function

Water level measure function

Figure 47 gives a decomposition of the water level measure function. The SRB logic can request a status update from this function. This request is handled by the "sensor data converter function" which sends a pull request to the "get water level sensor data function". The "get water level sensor data function" returns the raw sensor data. This data is converted and send to the SRB logic by the "sensor data convert function"

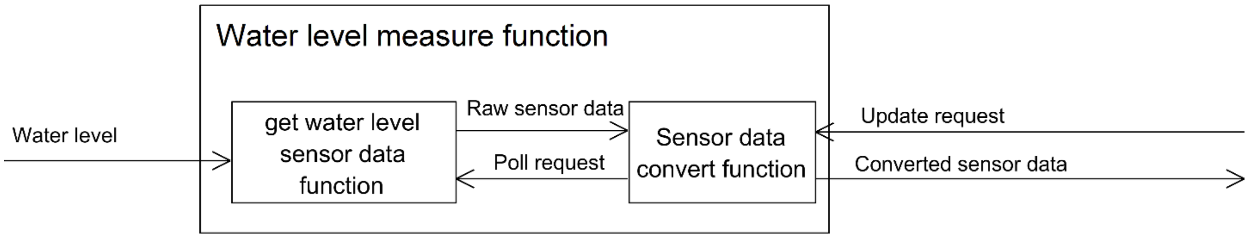


Figure 47: Decomposition of water level measure function

5.2 Final Requirements

The functional system architecture resulted in additional functional requirements these are added to the list with requirements than now is finalized. See table 8 for the finalized list of requirements.

Table 8: Final requirements

Functional requirements	Non-Functional requirements
Must	
The system must be able to buffer water	The system must be durable
The system must work autonomously	The system must be robust
The system must be able to measure the water level in the buffer	The system must be weather proof
The system must be able to drain water to the sewage system	The system must be reliable
The system must be manually drainable	The system must be secure
The system must provide the option to connect the overflow to the garden or sewage system	The system must be easy to assemble
The system must send the system status to a central data repository	The system's capacity must be at least 200 liters
The system must use weather prediction data to regulate the buffer capacity	The system must be safe to use
The system must be able to measure the water temperature in the buffer	The system must fit in a garden

The system must be able to store measurement data until it is send to the central data repository	The system must be modular
The system must drain 2 hours prior rainfall.	The system must be designed for DIY
The system must support an online personal monitoring dashboard	The system must require low maintenance
The system must send the status information to the central data repository	The system must be installable by the user self
The system must filter the water before it enters the barrel	
The system must have a rainwater overflow	
Should	
The system should remind the user to clean the filter	The system should use a wireless networking technology
The system should indicate if an error occurred	The system should promote being environmentally friendly
The system should measure the system status every minute	The system should be energy efficient
The system should send the system status every 15 minutes to the central data repository	The system should require low maintenance
The system should automatically drain the water in case of risk for legionella	The complete system should cost not more than 250 euro
The system should automatically drain in case of risk for freezing.	The user should be able to opt out for the option to drain water in case of risks for legionella
The system should be able to notify the user in case of an error.	The user should be able to opt out for the option to drain water in case of risks for freezing
The system should be able to warn the user about risk for legionella.	A bucket should fit underneath the manual tab
The system should be able to automatically drain water to the garden	The system should communicate with the central data repository via an API
The system should send planned discharges to the central data repository.	
Could	
The system could only overflow into the garden between a predefined period of time.	The system could be independent from the user's private communication infrastructure.
The system could be configurable via the central data repository.	The system could be scalable

The system could still function for a few days if the network connection fails.	The system could be setup via a web interface in the to be developed user dashboard.
	The system should be upgradable with extra control or sensor modules
Would	
The system would support over-the-air (OTA) software updates.	There would be two versions of the system, the basic and extended version.
The system would have a self-sufficient power source (e.g. solar/battery combination)	The system would have predefined holes for the installation of parts in the DIY assembly process.
	The system would not require a software setup process by the user.

6 REALIZATION

This chapter describes the realization phase of the project. The starting point for this phase is the final concept and the functional architecture given in the chapter 4 and 5. This chapter starts off with a decomposition of the final concept. Choices for every part are made and elaborated. After that the system is divided into subsystem for which prototypes were made and tested. Finally, two complete prototypes of the SRB are presented. The first prototype is focused on proving the concept of the SRB and the second prototype is the final DIY and consumer ready prototype based on the final design and specifications.

6.0 Decomposition of final concept

Now that the system has been specified a detailed decomposition of the final concept can be given. The system will consist of a buffer with a capacity of at least 200 liters. This buffer is directly connected to a rain pipe and also has an overflow to the sewage system or garden. In order for the system to work autonomously a controller is needed. This controller uses sensors to measure the fluid level and the water quality. The controller uses these values to control an electric valve that can drain the buffer to the sewage system or to the garden of the owner. In order to compute the draining of the system prediction data is needed. This data is requested through a network interface. The used networking technology will either be a local or wide area network technology. This network interface will also be used to connect to the central data repository, to request configuration data and to send measurement and control logs. The system will be power via the electricity grid. The product must be design for DIY, the installation process must not be too complicated. Parts must have a good quality and must be easy to install. The overall price of the system should be around 250 euros. The list of the main components is listed below.

- Barrel
- Barrel base
- Network controller
- Controller
- Sensors
- Power source
- Overflow
- Input
- Input filter
- Electric output valve
- Manual tap

6.1 Components

Because the system is developed for consumers and for a DIY the system should be very robust and easy to install. The total price of the system should also stay below 250 euros. Qualitative good components are needed but should not be too expensive, for this reason more standardized components will be used, these are widely available and will also be cheaper than extraordinary components. The next sections will give an overview on the available component options and the most suited components for this system.

6.1.1 Barrels

A potential buffer must have a minimal capacity of 200 liters. The buffer must also fit in the context of a garden and must not take up too much space in the garden. The total price of the system should also stay below 250 euros. Taking into account these requirements a list of potential barrels is given in appendix B, this is a complete overview of considered barrels, pros and cons, suppliers and prices.

The main goal in selecting a barrel is finding a barrel that doesn't take up too much space but still has an as large as possible capacity. For this reasons round barrels are considered less space saving than rectangular barrels. The benefit of rectangular barrels is that they can fit in a corner and take up a bit less space. Another benefit is that is easier to place a connector on a flat surface. The downside of rectangular barrels is that a rectangularly shaped barrels are less firm than round barrels. For this reason, most rectangular buffers don't have completely flat sides, this is to reinforce the buffer. These deviations on the sides might potentially cause problems for certain measurement techniques.

Conclusion

After comparing the potential buffers, the Garantia square rain buffer is the best option. This buffer has a rectangular shape and has a capacity of 300 liters. The barrel has its own custom stand that also has space inside to place an automatic valve and computing unit. The buffer comes with a tap that is in an optimal location. If the buffer is placed on the stand it has the ideal height to place a bucket under the tap. The buffer has mostly flat sides, this makes it easy to install connectors. Finally, the buffer also has a removable lid, this is nice for installation and maintenance. The buffer including base only cost 58 euro's. See figure 48 for an impression of the buffer.

Figure 48: Garantia Rain buffer. Source: Garantia

6.1.2 Filtering

Because it was chosen to connect the rain pipe directly to the rain barrel there is a change that leaves, and other types of debris end up in the barrel. The expert opinions on rain barrels [34] [35] strongly recommend using a filter. A filter doesn't only prevent debris from entering the barrel but also prevents mosquitoes from entering the barrel. On the other hand, the case studies from riversides [22] showed that user are very likely to forget cleaning the filter, resulting in flooding issues and potentially damage to the roofs.

There are several options when it comes to filtering the most save option is using a downspout filter (Dutch: bladscheider). This device (figure 49) simply filters leaves out of the water before they can enter the buffer. A downspout filter requires very low maintenance and it not likely to get clogged. The disadvantage is that is a relatively coarse filter, meaning that it will not filter out the smaller debris and also doesn't prevent mosquitoes from entering the buffer.

Figure 49: Downspout filter. Source: Hornbach

A second option would be to already filter the water before it leaves the gutter. This could be done using a leaf guard (Dutch: Bladbolrooster) (figure 50). This is the most simple and cheap solution. The leaf guard can be place in the gutter where the pipe is connected to the gutter. This will prevent leaves from entering the drain pipe. The downside of this solutions is that it is relatively coarse filtering, meaning that it will not filter out the smaller debris and also doesn't prevent mosquitoes from entering the buffer. Another disadvantage is that all the leaves will stay in the gutter, this should be cleaned occasionally, meaning that one would have to go up to the gutter and remove the leaves from the gutter.

Figure 50: Leaf guard. Source: Hornbach

A third option would be to bring the leaf guard down to the buffer. The filter guard could also be placed at the place where the drain pipe is connected to the barrel. The advantage would be that now the leaves won't stay in the gutter but at the input of the buffer. The disadvantage is still the risk of clogging is the user forgets to clean out the buffer input. It also doesn't prevent fine debris and mosquitoes for entering the barrel. See figure 51 for an impression of the solution.

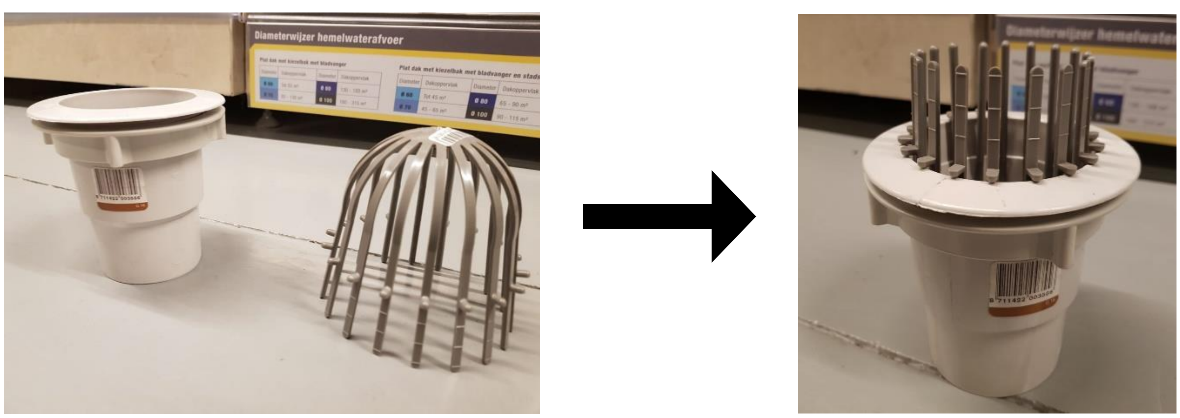


Figure 51: Filter guard in barrel input connector

The final option would be to use some kind of screen or fine mesh that prevents leaves and other debris from entering the buffer. Currently there doesn't exist a pre-made solution for rain barrels using screen or mesh but it could be easily self-made. Nylon filter mesh (figure 52) is sold on roles and can be easily made into a custom filter sock. This filter sock can be used to filter out fine and coarse debris and also prevents mosquitoes from entering the barrel. Figure 53 shows two concepts using a filter sock. The disadvantage of using a filter sock is that it can get clogged, resulting in flooding issues and potentially roof damage. This could be prevented by using a large filter sock and regularly cleaning or changing the filter sock.

Figure 52: Nylon filter mesh. Source: Wildkamp

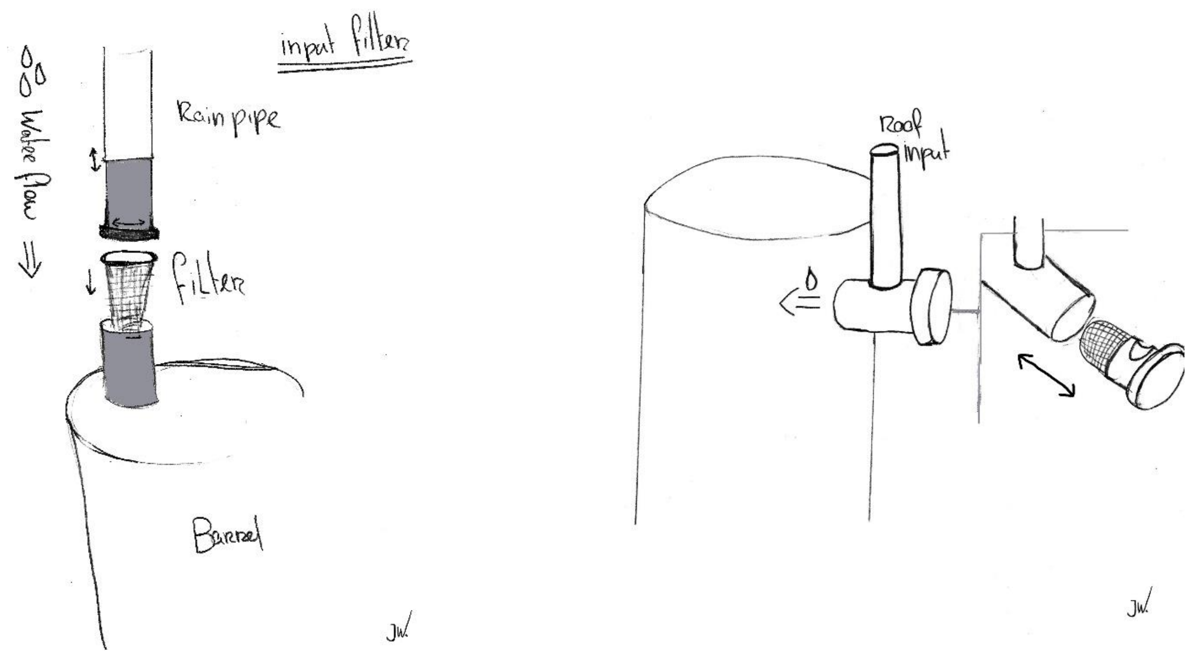


Figure 53: Filter mesh concepts

Conclusion

After evaluating the concepts with the stakeholders, it was decided that the filter sock will be used as filtering solution. This solution meets the requirements of the municipality to filter the water as much as possible. The filter sock also prevents mosquitos from entering the barrel.

6.1.3 Input, overflow, and output

When it comes down to selecting the type of input for the SRB it comes down to two options. 1) using a rain barrel filler or 2) using a direct input from the rain pipe into the buffer. Since the stakeholders decided that all water should go into to the system only option 2 is left. Since expert options also advice that the buffer is completely closed except for inputs and output the only option is to use a connector that connects the rain pipe to the rain buffer.

There doesn’t exist a pre-made solution to connect a rain pipe to a rain barrel, but this can easily be made using a simple downspout-gutter connector and a rubber ring (see figure 54). The same solution could also be used for the overflow. The user can simply connect a rain pipe to the connector and divert it to where ever the user wants.

Figure 54: downspout-gutter connector and a rubber ring. Source: Wildkamp

The output of the valve should be able to connect to valve. There exist a pre-made solution for this, a skin fitting (see figure 55).

Figure 55: Skin fitting. Source: Wildkamp

6.1.4 Valves

Before selecting a valve, it is important to set some requirements for a potential valve. The first requirement is that the valve must be of good quality and must work reliably. Secondly the valve must have an IP rating of at least IP-54. It is important that the valve is dust protected and splashing water proof because the valve will be used outdoors. The valve must also be cost-efficient because there is a limited budget for the SRB, 100 euro would be the maximum, based on the other expenses that need to be made. Finally, the valve must be controllable electrically and preferable operate on a low voltage, if possible even as low as possible in order to limit energy consumption.

Based on these requirements market research showed that there are only two types of valves that meet these requirements, magnetic solenoid valves and ball valves. Solenoid valves are the most cost effective but have the disadvantage of being sensitive to debris in the water. Since the water quality cannot be guaranteed this valve would not be the most reliable option. The most reliable option is the ball valve. A ball valve can perform better in dirty water and is available in many different sizes. The downside of electric ball valves is that they are not widely used and that there are not a lot of suppliers. Because of this reason the price of ball valves in the Netherlands is relatively high. This might be a problem because the budget for the complete SRB is limited, especially in the future if SRB's with multiple valve are considered.

Research showed that there are also foreign suppliers that can deliver potentially better valves for a fraction of the price of a locally purchased valve. Based on the specifications the price/quality ratio of electric ball valves from foreign suppliers is better than the price/quality ratio of locally purchased valves. A potential downside for the foreign purchased valves it the delivery time. The average delivery time is two weeks for a foreign purchased valve and only a few days for a locally purchased valve. Because this graduation project is executed in a limited time span the delivery time might be too long. But for commercial use this doesn't have to be a problem because one could just order a large amount of these valves in advance. A final concern might be the warranty. It is assumed that warranty of a foreign purchased valve is not as good as the warranty of a locally purchased valve. But on the other hand, the warranty of the foreign purchased valve is also less important because the price is substantially lower than the price of locally purchased valve and it might even be easier and cost effective to just replace a broken valve with a new one instead of getting warranty from a supplier.

Research showed that in the Netherlands there is one supplier that supplies motorized valves below 100 euros. This is the supplier "JP Fluid Control" who sells products via magneetventielshop.nl. the cheapest option is the 67 euro, 12v, ½ inch, IP-54 electric valve (see figure 56). This is a relatively small valve, bigger valves become costlier.

It was found that the foreign suppliers have a bigger product range with lower prices. The AliExpress[3] platform was used to get insight in these suppliers. It was found that CWX is the most promising supplier. Their products are not only sold under their Chinese brand but also under the other international brands U.S Solid, BACOENG, and Misol. CWX has a product range of valves ranging from diameter DN8 to DN32, voltage 5v to 24v, and a price range from 9 to 17 euro's. All valves are rated IP-65 and can handle a maximum pressure of 10 bar. For more extensive specifications see appendix F. For an impression of the valve see figure 57.

Figure 56: JP Fluid Control 12v 1/2-inch valve. Source: JP Fluid Control

Figure 57: CWX 5v 1-1/4-inch valve. Source: CWX

It was decided to test the CWX valves in order to check if they meet the quality requirements for the locally available valves. The test of the CWX valves can be found in appendix G.

conclusion
After performing the tests, it can be concluded that CWX valves will be used for the product. The valve is reliable and has better specification than the more expensive JP Fluid Control valves. The CWX valves are not only much cheaper but are also available in a 5 volt version, which is an ideal voltage for affordable solar power systems.

6.1.5 Controller

The controller of the system will be a Raspberry Pi. This controller is energy and cost efficient, easy to program, and has embedded support for networking. The Raspberry Pi also has the needed GPIO pin for connecting sensors and actuators. The Raspberry Pi is chosen over an Arduino because a Raspberry Pi is more powerful and has better support for networking.

[3] On foreign websites it's important that the correct search query is used. The best search query for AliExpress is "motorized ball valve". If a valve with a certain working voltage is required simply add "5v" or "12v" at the end of the search query.

6.1.6 Network connection

In order to find the best networking solution a literature research was performed. This section contains a literature review that focuses on suitable data communication technologies for the SRB. IoT devices can generally make use of two types of communication technologies: short range and long-range technologies [57]. In order to determine what data communication technology of what type is best suited for the SRB two literature reviews were performed and presented below. Both literature reviews are based on the requirements of the SRB to allow 2-way communication, and to be energy efficient. Finally, the pros and cons of using a short or long-range technology in an urban area is presented.

6.1.6.1 Long range data communication technologies

The main objective of this literature review is to provide an overview of long range data communication technologies that are used or can be used in creating a Smart city and are suited to be used for the SRB. A useful data communication technology for the SRB has the preliminary requirements of being energy efficient and being able to both send and receive data. The SRB should also be controllable over the network.

The first section of this literature review focuses on what key aspects are important for IoT networks in urban areas. The second part touches upon the data communication technologies that are most suitable to use in urban areas. In this part, an overview of different data communication technologies is presented together with their advantages and disadvantages. The final part contains a comparison on what data communication technologies best to use for what type of Smart City systems.

Key aspects of Smart City IoT networks

There are four main key aspects when it comes to IoT networks in cities. In all the studied papers published in the last three years all researchers agree that these aspects are the most important for urban IoT networks. Some authors give explanation on the importance of these key aspects and others only simply state them. The first key aspect is low device cost. Ericsson [58] states that it is important that the IoT devices have a low cost because it is a key enabler for, wider accessibility, large volume applications, enabling lots of new use cases. Raza, Kulkarni, and Sooriyabandara [59] also look at this aspect from another point of view, namely the cost of the required infrastructure. It is important to consider what it will cost to bring the infrastructure in place in order to provide connection to the low-cost devices.

The second key aspect is long battery life. Raza, Kulkarni, and Sooriyabandara [59] point out that communication operations consume more energy than processing operations. For this reason, it is crucial that the energy consumption for communication operations is as low as possible. Zhai [60] and Marais, Malekian, and Abu-Mahfouz [61] both highlight the importance of this aspect by noting that IoT devices that are placed all over the city will probably not all have an unlimited power source available. If this is the case than the only option is to equip the devices with a battery or super capacitor that can last long or can be recharged on the place of deployment.

The third key aspect is a long communication range. Especially in public areas like cities it is not convenient to place lots of receivers all through the city. It is more convenient to have a few central points that have a very large range. This minimizes the needed infrastructure which also minimizes the need of maintenance and investment cost of the infrastructure [62].

The fourth and last key aspect is scalability. As Bibri [63] points out, IoT is becoming more affordable and accessible and the amount of IoT devices will keep increasing. Especially for the purposes of big data analysis large amounts of data are required. Data that needs to be collected by as many nodes as possible. As Song et al. [62] state together with the previous key aspect of long range, there should only be a few long-range base stations. Because of this given requirement it is important that these base stations support large amounts of connected devices.

Low Power Wide Area Networks

The best networking technologies for urban IoT networks are Low Power Wide Area Networks (LPWAN). Wireless networks for IoT purposes can be divided into two categories. The first category is short-range transmission technologies and the second category is long-range transmission technologies [64]. The category that fits the needs of Smart City IoT networks is long-range transmission technologies. Within this category lay the Low Power Wide Area Networks (LPWAN). As the name implies, these types of networks are energy efficient and have a large range, providing connectivity to devices in a large area.

In literature (Vejlgaard et al. [65]; Song et al. [62]; Adelantado et al. [66]) the opinions are divided on what the most suitable LPWAN technology is for Smart city IoT. This is especially the case in the papers published after 2016. In 2016 the 3rd generation partnership project (3GPP), a global body for telecommunication standards, released the LTE Advanced protocol that standardized a protocol called Narrowband IoT (NB-IoT). This protocol made the use of the cellular licensed frequency networks very suitable for low power, long range IoT network solutions. Before the standardization of NB-IoT the cellular network did not really have an energy efficient enough networking technology that could compete with other network solutions for low power IoT devices [67]. Before NB-IoT got announced the only cellular networking technology available that more or less satisfied the key aspects was LTE-M, but one may state that this networking technology does not meet the requirement of low power and scalability [68].

The other suitable technologies for Smart City IoT networks all use the unlicensed spectrum for operation. As Li et al. [57] point out, in this spectrum everyone is allowed to operate following some country depended restrictions. There are not only divided opinions on licensed and unlicensed bands but also on network technologies in the unlicensed band. Because the licensed band only recently got support for low power, long range networks there were already multiple technologies developed in the unlicensed band. The two most promising and adapted technologies found in literature (e.g., Adelantado et al. [66]; Raza et al. [59]) are LoRa and SigFox. Now that there is a clear understanding on the status of LPWAN technologies it can be concluded that the two networking technologies that operate in the licensed band: NB-IoT and LTE-M, and also the two in the unlicensed band: LoRa and SigFox are the most suitable to use in urban areas.

NB-IoT

NB-IoT is the most recently developed networking technology that is widely adopted and suitable for urban IoT networks. As Song et al. [62] outline NB-IoT is a networking technology that is an evolution of LTE (4G), one of the most adopted cellular network technologies. The technology was standardized by the 3GPP in 2016, with the goal to provide wide coverage for a large amount of low-power, low-cost IoT devices. Because the technology is built upon LTE, currently the most widely adopted cellular networking technology, NB-IoT operates in the licensed spectrum and it has the advantage of being very flexible in deployment. As Li et al. [57] point out NB-IoT relies on the already in place cellular infrastructure, therefore no big investments are needed to deploy NB-IoT. NB-IoT can be deployed in 3 different modes: The NB-IoT carrier can be deployed within the LTE carrier, in the LTE guard band, or operate stand-alone. Zhai [60] adds to this that the flexibility of NB-IoT and the reuse of already in place base stations allows NB-IoT to be deployed fast and easy and therefore also at a low cost. Li et al. [57] also claim that the big advantages of NB-IoT is its guaranteed coverage indoor and maximum range up to 35 kilometers. They also point out that the disadvantage of NB-IoT is its latency. The maximum latency of NB-IoT is 10 seconds therefore the technology cannot be used for latency-sensitive applications.

LTE-M

Before NB-IoT was standardized by the 3GPP the only cellular networking technology available that more or less satisfies the key aspects for urban IoT was LTE-M. For the usage of LTE-M it really depends on what particular urban IoT application it is used for in order to decide if it meets all the requirements of an urban IoT solution [68]. LTE-M is a protocol on top of the LTE protocol, this makes the deployment of LTE-M simple and easy. LTE-M is compatible with the already in place LTE infrastructure, so the network operators will only have to update their systems' software [69]. LTE-M is a cellular networking technology therefore it operates in the licensed spectrum. As Yang et al. [68] point out the scalability and energy efficiency of LTE-M are questionable. This is because LTE-M uses a wider band than NB-IoT and it supports higher data rates. The higher data rates can in some applications be an advantage, but the disadvantage is the higher energy consumption. Another advantage of LTE-M is that its latency is small enough to provide a connection to latency-sensitive applications.

LoRa

The most adapted LPWAN in the unlicensed spectrum is LoRa. Because LoRa operates in the unlicensed spectrum it is open to everyone, therefore everyone is allowed to deploy a LoRa network [62]. Augustin, Yi, Clausen, and Townsley [70] point out that the LoRa technology consist of two parts. The LoRa physical layer and the LoRaWAN networking protocol. The LoRa physical layer uses a Chirp Spread Spectrum radio modulation technique, this technique is proprietary technology from Semtech. The LoRaWAN networking protocol, enables large amounts of LoRa equipped devices to connect with a gateway. As Adelantado et al. [66] describes, LoRa operates with a low power consumption, that could allow around 10 years of battery lifetime. LoRa modules are relatively cheap and have a low data rate but a long communication range, which in urban areas lays between 2 to 5 km and around 15 km in suburban areas. A LoRaWAN network is organized in a star-of-start topology. In this configuration gateways relay messages between end-nodes and an internet connected network server. The connection between the gateway and end devices is wireless. The connection between the gateway and the server goes via IP over Ethernet or Cellular. The communication is bidirectional but the use of only uplink communication from end device to gateway is preferred, because of duty cycle restrictions of gateways. LoRaWAN supports three classes of devices Classes A, B and C. Each class has different capabilities. The classes differ in power consumption and duty cycle, as explained in the following [66]. As they also point out in the research on the limits of LoRa is that LoRa has some constraints. Because LoRa operates in the unlicensed spectrum its key constraint is the regulation on maximum duty cycle, which is in Europe only 1 percent, limiting the maximum transmission time per day. Because of this constrained the downlink messages to an end-node negatively influence the capacity of the network because gateways also need to operate following the regulations. Finally, LoRa could also experience a capacity decrease because of the uncoordinated deployment of gateways or other networking technologies operating on the same frequency.

SigFox

Another leading networking technology that also operates in the unlicensed spectrum is SigFox. As Adelantado et al. [66] point out, SigFox is considered less open and less flexible than LoRa. As described by Bonavolontà et al. [71], SigFox uses Ultra-narrowband technology meaning that only a very narrow portion of the spectrum is used. Because of this the effect of noise is minimized and the hardware of end nodes becomes less complicated, but the required gateways are therefore more complicated and expensive. Because of the proprietary design of SigFox, the technology is also very energy efficient. Just like LoRa, SigFox biggest constrains are the duty cycle regulation and noise in the unlicensed spectrum from other devices. The SigFox public network has country wide coverage in the Netherlands [72]. To use the network, the end node must be compliant with the closed SigFox protocol and a payed subscription per end node is required. This subscription is offered by exclusive local partners of SigFox. These partners are responsible for maintaining the local network infrastructure.

Comparison

When it comes down to selecting the best suited technology it all depends on what type of IoT solution it will be used for. SigFox and LoRa are suitable networking technologies for data acquisitioning while NB-IoT and LTE-M are more suitable for the combination of data acquisitioning and control actions. Augustin et al. [70] state that SigFox can be a good choice for data acquisitioning IoT and less for command-and-control purposes. Adelantado et al. [66] claim that LoRa would be a better solution for data acquisitioning. Because Lora is considerd more open and flexible, giving the developer the opertunity to make more efficient IoT solutions without to many restrictions when it comes to the networking technology. Bonavolontà et al. [71] add to this that the benefit of LoRa above SigFox is that for the use of LoRa networks there is no restriction to a fixed provider and payed subscription. When using LoRa there is a choice in using a network by a provider or setting up a privately-owned network. In terms of power consumption there is not much of a difference, both technologies require very low power.

On the other hand, Cano and Iborra [69] claim that other technologies in the licensed spectrum are not only a better option for the use of data acquisitioning but also for providing control options. They state that LoRa and SigFox are not reliable and flexible enough compared to NB-IoT and LTE-M. Because LoRa and SigFox operate in the unlicensed spectrum they have the constrained of obeying the strict duty cycle regulations and they are more likely to experience errors by interference from other technologies in the unlicensed spectrum, this is especially the case for the LoRa protocol. Ericsson [58] adds to this that SigFox and LoRa are patented standards, in both cases only one manufacture has the exclusive right on the chip design. Mobile operators and some companies that are developing IoT solutions do not like this because they do not want to be dependent on just one party.

Yang et al. [68] claim that when it comes to the most flexible technology in terms of use cases, NB-IoT is the best solution based on the four key aspects of LPWAN. NB-IoT is less restricted than SigFox and LoRa, it has a higher data rate, is more scalable and still has a low power consumption. Compared with LTE-M, NB-IoT is more energy efficient and has a much larger coverage, while LTE-M facilitates a higher data rate and lower latency. Zhai [60] points out that both LTE-M and NB-IoT can reuse already in place base stations making the deployment of these technologies fast and easy and therefore also at a low cost. LoRa and SigFox require a new infrastructure. But the infrastructure for these technologies is significantly cheaper than the infrastructure for the cellular technologies. So, in case no infrastructure is in place, LoRa and SigFox would be cheaper to deploy, with LoRa being the cheapest solution. An overview of the comparison between the technologies is presented in table 9.

Table 9: *Comparison of LPWAN's, based on European frequency standards*

	LoRa	**SigFox**	**NB-IoT**	**LTE-M**
Spectrum	Unlicensed 868 MHz	Unlicensed 868 MHz	Licensed 800-2600 MHz	Licensed 800-2600 MHz
Range (km)	15 – 45 rural 3 – 8 urban	30 - 50 rural 3- 10 urban	< 35	2-5
Data rate	0.3-50 kb/s	Uplink: < 0.1 kb/s Downlink: < 0.6 kb/s	Uplink: < 250 kb/s Downlink: < 230 kb/s	1 Mb/s
Message size	-	12 bytes up 8 bytes down	-	-
Max number of messages per day	Depends on message size	140 up 4 down	Depends on data plan	Depends on data plan
Latency	Average 2 s	< 30 s	< 10 s	< 10 ms
Relative power consumption	low	low	medium	high
Relative Scalability	medium	low	high	high
Limiting factors	low data rate	low data rate	latency insensitive	relatively high power consumption

Sources: Li et al. [57]; Augustin et al. [70]; Al-Sarawi et al. [73]; Cano and Iborra [69]

Conclusion

The purpose of this literature review was to provide an overview of the data communication technologies that can be used in creating a Smart city and especially are suited to be used for the SRB. By getting insight in the key aspects of such a data communication technology, an overview of the four most promising or mostly used technologies could be created. Different criteria were used to benchmark the four selected technologies, to get insight in what technology fits what type of Smart City IoT solution. The main finding of this literature review is that there is not one specific LPWAN networking technology suited for all Smart City IoT solutions. The four found key aspects for Smart City IoT showed that LPWAN technologies are the most suitable for Smart City IoT. Using these four found key aspects, four most suitable LPWAN technologies were selected. A choice for a data communication technology depends on the specific requirements of the IoT solution. It was found that there can be made a distinction on most suitable data communication technology for Smart City IoT based on the requirements of only data acquisitioning or a combination of data acquisitioning and control actions.

Based on the requirements for a potentially useful data communication technology for the SRB it can be concluded that two of the found technologies are suitable for the SRB. NB-IoT and LTE-M meet the requirements for the use on the SRB. This is because these data communication technologies can facilitate a large enough message size and a bidirectional communication. NB-IoT would be the best option since it has the lowest power consumption of the two. For other Smart IoT solutions it completely depends on the requirements of the solution to select the right data communication technology.

Despite that the findings of this research can give a guideline in selecting a suitable data communication technology for Smart City IoT, some critical remarks should be made. This research did not explicitly take into account the availability and providers of the proposed data communication technologies for a specific area. In some cases, it might be more beneficial or mandatory to use already in place networks than having to setup a new network, this could bring other factors like subscription costs that could influence the choice for a suitable data communication technology. Therefore, further research in appendix C of this report presents research on the status of the four found networking technologies in their practical use. Looking at availability and providers of the networks in the Netherlands and the cost of required network modules that are needed for the IoT solution.

6.1.6.2 Short Range data communication technologies

Next to long range data communication technologies it would also be possible to use a short-range data communication technology for the SRB. With the use of a short-range data communication technology the system needs a local gateway to connect to, in case of the SRB this gateway would be placed inside the private ethernet network of the SRB owner. This gateway can relay messages between the SRB and the Internet. The Goal of this literature review is to provide an overview of short range data communication technologies that are used or can be used in IoT applications and are suited to be used for the SRB. A useful data communication technology for the SRB has the preliminary requirements of being energy efficient and being able to both send and receive data. The SRB should also be controllable over the network.

The first section of this literature review focuses on what types of short range data communication technologies are suitable for the SRB. The second part provides an overview of the different suitable data communication technologies. The last part contains a comparison on what data communication technologies best to use for the SRB.

Local Area Networks

The most suitable types of short range networks for the SRB are Wireless Personal Area Networks (WPAN) and Wireless Local Area Networks (WLAN). As Rahman [74] points out these networks should have a range between 20 to 100 meters. This range would be large enough for the SRB since the SRB is likely to be placed close to a house with a gateway inside. As found in literature [57] [62] [73] there are four short range networking technologies that currently dominate the IoT market. These technologies are ZigBee, Wi-Fi, BLE, and Z-Wave. The technologies differ in key aspects for implementation, for example in energy efficiency or data rate.

ZigBee

The Zigbee protocol is created by the ZigBee alliance based on the standardized low power wireless communication standard IEEE 802.15.4. The goal of ZigBee is to provide a small sized personal area network at a low cost and low power consumption [73]. As Li et al [57] notes, because of its low deployment cost and its low power consumption the technology is widely adopted to IoT solutions. As they also point out, ZigBee operates in the unlicensed spectrum. But because it operates in the unlicensed spectrum it shares this spectrum with other appliances, so it is more likely to experience interference. As Ahmad et al. [75] point out ZigBee is based on master/slave and facilitates two-way communication between devices. Zigbee also facilitates the functionality of confirming that messages were received, this makes ZigBee a reliable networking solution. Overall ZigBee is considered to be a good solution for the use in in-home IoT devices.

Wi-Fi

Wi-Fi is a high-speed wireless internet technology. Currently this network is available in almost all households in the Netherlands and if not, it is easy and cheap to setup. Wi-Fi is designed to provide a secure, high-speed and reliable communication. The data rate of Wi-Fi is higher than the most WPAN networks. The coverage of Wi-Fi reaches up to 100 meters, depends on conditions like interference and obstacles. As Chen and Han [76] point out Wi-Fi works via an ip based protocol this is an advantage when comunicating with the internet. The downside of Wi-Fi is its high power consumption, because of this it is not suitable for many IoT devices [57]. Another disadvantage pointed out by Song et al. [62] is that Wi-Fi also operates in the unlicensed spectrum, meaning there is a higher chance of interference. Especially in urban densely populated area’s the range of Wi-Fi is strongly influenced by other Wi-Fi networks in that area. This could be a problem for the SRB, since the SRB will also be placed in densely populated areas.

BLE

Bluetooth low energy (BLE) also known as Bluetooth smart is a protocol that is very suitable for IoT solutions. BLE was designed for low latency, low power, low bandwidth and short-range IoT applications. The benefits of BLE compared to classic Bluetooth are a lower setup time, support for an unlimited number of nodes in a star network topology and most important a lower power consumption [73]. As Rahman [74] describes BLE also works via the Master/Slave principal, and also facilitates two-way communication. As he also points out, BLE has support for internet connectivity, this is beneficial if the slave device wants to communicate with the internet. Just like the other technologies BLE also operates in the unlicensed spectrum.

Z-Wave

Z-Wave is designed to be a low power protocol for IoT communication, especially for smart home appliances. The technology facilitates the sending and receiving of relatively small packages at low data rates. For this reason, Z-Wave is only suitable for sending small messages like control commands. Z-Wave supports two types of devices, controller and slave devices. The slave devices are limited in the way that they are unable to initiate messages. Slave devices can only reply and execute commands that are being send by a controller device. For this reason, slave devices have a very low cost [73]. This would be a problem because the SRB (slave) needs to functionality of being able to initiate messages. If Z-Wave would be used for the SRB, then the gateway (master) should periodically initiate communication with the SRB (slave). As Li et al. [57] point out, Z-Wave also operates in the unlicensed spectrum, but on a much lower frequency than the technologies mentioned above. Z-Wave operates on a frequency where it must obey to European duty cycle restrictions of 1%, for this reason the number of messages and message size is limited per day. Z-Wave is low power, reliable and low-cost therefor it is widely used in smart home and other IoT appliances.

Comparison

When comparing the four above mentioned network technologies it clearly shows that there is a trade of between power consumption and data rate. As Al-Sarawi [73] pointes out the low data rate and master slave implementation of Z-Wave make the technology mostly useful for control operations and not for transferring large amounts of data. Z-Wave has the lowest power consumption, but it has some constraints, therefore it is not useful for the SRB.

Zigbee has a higher data rate than Z-Wave and still a respectively low power consumption but is limited in range. The data rate of ZigBee is still relatively low compared with the other technologies. But if data rate and limited range are not important for the IoT application than ZigBee would be a good choice [75]. In case of the SRB, ZigBee would be a good option, but only of the distance between the gateway and the SRB is not too big.

If a higher data rate is required at roughly the same power consumption than BLE should be a good choice. The data rate of BLE is much higher than the data rates of Z-Wave and ZigBee. This technology would be a good choice for the SRB, but to use BLE a gateway is required. This is also the case for ZigBee and Z-Wave. The advantage of Wi-Fi is that most people already have a Wi-Fi network, so no extra gateway is needed. Wi-Fi also has the advantage of having a very high data rate, but this comes at the price of a very high-power consumption. If Wi-Fi would be used for the SRB than a large power source is needed and the SRB will probably not be able to run on a solar charged battery. The disadvantage of all technologies is that they all operate in the unlicensed spectrum a therefor have a higher change for interference. An overview of the comparison the technologies is presented in table 10.

Table 10: Comparison of WLAN's, based on European frequency standards

	Zigbee	BLE	Wi-Fi	Z-Wave
Frequency bands	2.4 GHz Unlicensed spectrum	2.4 GHz Unlicensed spectrum	2.4 GHz or 5 GHz Unlicensed spectrum	868 MHz Unlicensed spectrum
Range	10-50 m	100 m	100 m	30-100 m
Data rate	< 171.2 kbps	< 1 Mbps	> 10 Mbps	< 40 kbps
Latency	15 ms	3 - 6 ms	3.2 – 17 ms	100 ms
Relative power consumption	Low	Low	Highest	Lowest
Limiting factors	Short range	Unlicensed spectrum	High energy consumption	Low data rate

Sources: Song et al. [62]; Al-Sarawi etal. [73]; Li et al. [57]

Conclusion

The Goal of this literature review was to provide an overview of short range data communication technologies that are used or can be used in IoT applications and are suited to be used for the SRB. The networking technologies should meet the requirements set for the SRB. The goal of this research was reached by getting insight in the most used and suitable IoT data communication technologies. After the comparison of the four data communication technologies one data communication technology could be selected to be most suitable for the SRB. This data communication technology is BLE. BLE meets the requirements of low power and two-way communication. BLE has a large range and provides the option to use the IPv6 protocol, making it easily to create a gateway to the internet. If the range would not be an important factor than ZigBee would also be a good option for the SRB. It is reliable and also meets the preliminary requirements. Wi-Fi does not meet the requirement of being energy efficient, but the advantage of Wi-Fi is that no extra gateways need to be install because there is a high change that these are already in place. So, incase low power would not be a requirement than Wi-Fi would be the most suitable option. Despite that the finding in this literature review can provide a guideline in selecting a suitable short range data communication technique, some critical remarks should be made. This literature research is based on theoretical value's and specification of the techniques. Only in practice it can become sure if the chosen solution indeed is the most optimal in a given environment. Factors like interference and attenuation can differ per situation and location therefore practical experiments should to be conducted if one of these technologies is chosen to be used on the SRB.

6.1.6.3 Short vs Long range

Now that there is a clear overview of both short and long range wireless data communication technologies they can be compared. As Song et al. [62] point out short range wireless data communication technologies like Wi-Fi and ZigBee are very suitable for small scale personal area networks. Wi-Fi has a high data rate a low latency, but high power consumption. Zigbee is the opposite, it has a low data rate, but is also very low power. The long range technology NB-IoT lays in between the two data communication technologies when looking only at the data rate but NB-IoT has a much larger range and can handle more connections than Wi-Fi and ZigBee.

LPWAN technologies like NB-IoT are more consumer friendly. As Song et al. [62] and Li et al. [57] point out, the use of short range wireless networks like Wi-Fi and ZigBee also comes with a high chance of unexpected failures because of the widely used communication environments. This challenges the end users who lack patience and specific knowledge. The advantage of NB-IoT is that it provides a city-scale network for IoT devices without any particular configurations on the gateway or having to setup a new gateway. NB-IoT makes adding devices to the network a simpler task, the entire process can be completed without the need for expert knowledge.

As Li et al. [57] point out in their research, NB-IoT is the best choice for IoT devices like the SRB. NB-IoT is very reliable since it is operating on top of the operators' existing cellular networks on licensed bands which are significantly more reliable than unlicensed solutions. The NB-IoT protocol supports repeating transmissions of data to enhance the reliability of transmission. The security of NB-IoT is also better than all the other proposed solutions in this report. This is because NB-IoT relies on the security of the cellular networks, whose security mechanisms are based on a physical subscriber identification module (SIM) attached to the device. Next to the high reliability and security, NB-IoT also has a high scalability, flexibility and availability.

The downside of NB-IoT is the dependency of the user on the operators. Operators ask a monthly fee for their services and this price could for some user maybe be too high. Than a BLE network would be a better alternative, a short-range networking technology. If short range technologies were to be used for the SRB this would mean that a gateway would have to be placed at the owner's house, being the bridge between the SRB and the internet. The benefits of short range wireless technologies on the SRB would be the low power consumption and relatively high data rates. The downsides of the use of short range wireless technologies for the SRB are the dependency on the SRB owners' private network and the limited distance between the placement of the barrel and the gateway. If long range wireless communication technologies would be used for the SRB, then the SRB could connect to a centralized gateway that provides connection to multiple SRB installations in the area. The benefits would be the independency of the SRB owners' network and the simplicity of the system, the home owner doesn't have to install a gateway. The downside of long range wireless communication in this scenario would be the limited data rate because the power consumption needs to be low. Below follows a list of pros and cons based on the use of the two different networking technologies on the SRB.

Short Range	Long Range
Pros	Pros
• Lower power consumption (not always) • Not depending on carriers and payed data plans • Less restrictions • Higher data rates	• Low power (only at low data rates) • Not dependent on SRB owner's private network • No network configuration at placement required • Less hardware required (no gateway) • Less installation required by owner
Cons	Cons
• Dependent on home owner's private network • Network configuration at placement required • More hardware required • More installation required by owner • Short range of gateway/router • Disturbance of gateway/router	• Lower data rate • Not always free to use • Can be dependent on carrier • More restrictions

6.1.6.4 Final choice

After evaluating the findings on data communication technologies and looking at the list of available networks in Enschede (see appendix C), the stakeholders indicated that they prefer the Long-Range data communication technology NB-IoT over the Short-range data communication technology Wi-Fi. Taking into account the current state of NB-IoT there is a chance that NB-IoT will not work flawless. For this reason, two versions of the SRB will be developed in parallel, one version with NB-IoT and one version that used the local Wi-Fi network of the SRB owner.

The hardware costs for NB-IoT are relatively high at this moment in time. A Raspberry Pi NB-IoT shield cost 90 euro. But it is expected that the prices will drop in the near future when NB-IoT becomes more mainstream [58]. The hardware for a Wi-Fi connection is already build in the Raspberry Pi.

6.1.7 Sensors

The system will be measuring the fluid level and the temperature. The fluid level measurements will be used as input for the smart buffering logic. The temperature measurements will be used to monitor the water quality. Both measurements will also be used by the user interface. This section will contain information on fluid level measurement techniques and the most suitable technique to use for the redesign of the SRB. Next to that this section also contains information on the most suitable temperature measurement technique and the applications of using temperature measurements in determining water quality.

6.1.7.1 Expert opinion, fluid level measurement techniques

The previous prototypes of the SRB both made use of Ultrasonic sensors to measure the fluid level in the barrel. In previous research it was found that this sensing method is not completely reliable in certain conditions. This section will list all possible and realistic technologies to measure fluid levels in the barrel of the SRB. This section is based on the web article "A Dozen Ways to Measure Fluid Level and How They Work" by expert Henry Hopper [77]. In this article Hopper gives and overview of twelve techniques that can be used to measure fluid levels. A selection was made on the usability of these techniques when used to measure the fluid level in a rainwater buffer. The relevant technologies are presented together with their advantages and disadvantages. Finally, a conclusion is drawn to determine which sensing technique is in theory the most suitable for the SRB. This depends on the important aspects of: simplicity of the sensor, variable sensing range, reliability, accuracy and relatively low price. For this section where nonscientific sources used, because of the lack of practical information on these techniques in scientific literature.

1. **Floats**

The first method is using floats. The float sensors that are used currently consist of a floating magnet and multiple read switches. The magnetic float floats on the fluid while being in a tube or connected to a pipe. The tube or pipe contain read switches which detect the float. The advantages of this measurement technique are the simplicity and low chance on errors in measurements. The sensor is also very cheap. The disadvantages are the scalability and accuracy. The measurement instrument is always of a fixed length. This is not a continuous level-measuring device, meaning that it cannot discriminate level values between steps [77]. See figure 58 for an impression of the sensor.

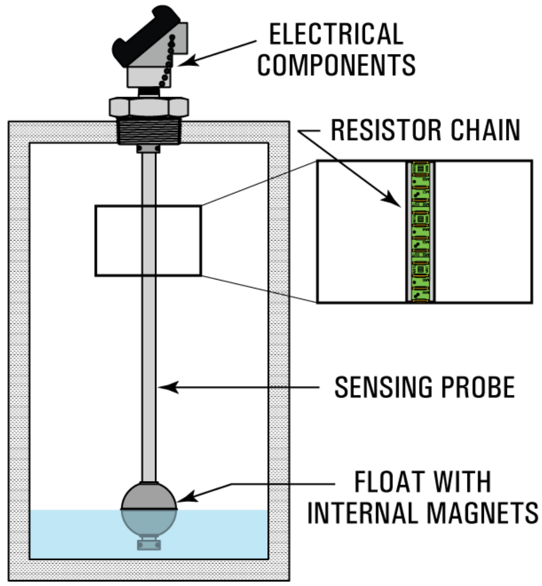


Figure 58: float sensor. Source: SWI

2. Hydrostatic Devices

In measuring fluids there are three types of hydrostatic devices. Displacers, bubblers, and differential-pressure transmitters. See figure 59 for an impression of the sensors

Displacers – These types of sensors use the Archimedes principle by continuously measuring the weight of a displacer inside the process liquid. When the liquid level increases, the displacer will become lighter to the sensor. This way the sensor can measure the fluid level. The advantage of this method is the accuracy. The disadvantage is the fixed size [78] [77].

Bubblers – This type of sensor is used for barrels that operate under atmospheric pressure. A tube is placed in the process liquid the end of the tube is located at the bottom of the barrel. Air is blown through the tube into the barrel. The pressure in the tube depends on the fluid level in the barrel, this pressure is measured [77]. The advantage of this technique is the simple design and construction. The disadvantage is the complicated calibration process [79].

Differential-pressure (DP) transmitters– This sensor is placed at the bottom of the fluid tank. The sensor measures the pressure that the fluid inside the tank creates on the sensor. This pressure is compared with a reference pressure (normally atmospheric pressure). The advantage of this sensing technique is the accuracy and simplicity. The disadvantage is that these sensors only work in clear liquids, this could be a problem with rainwater [80] [77].

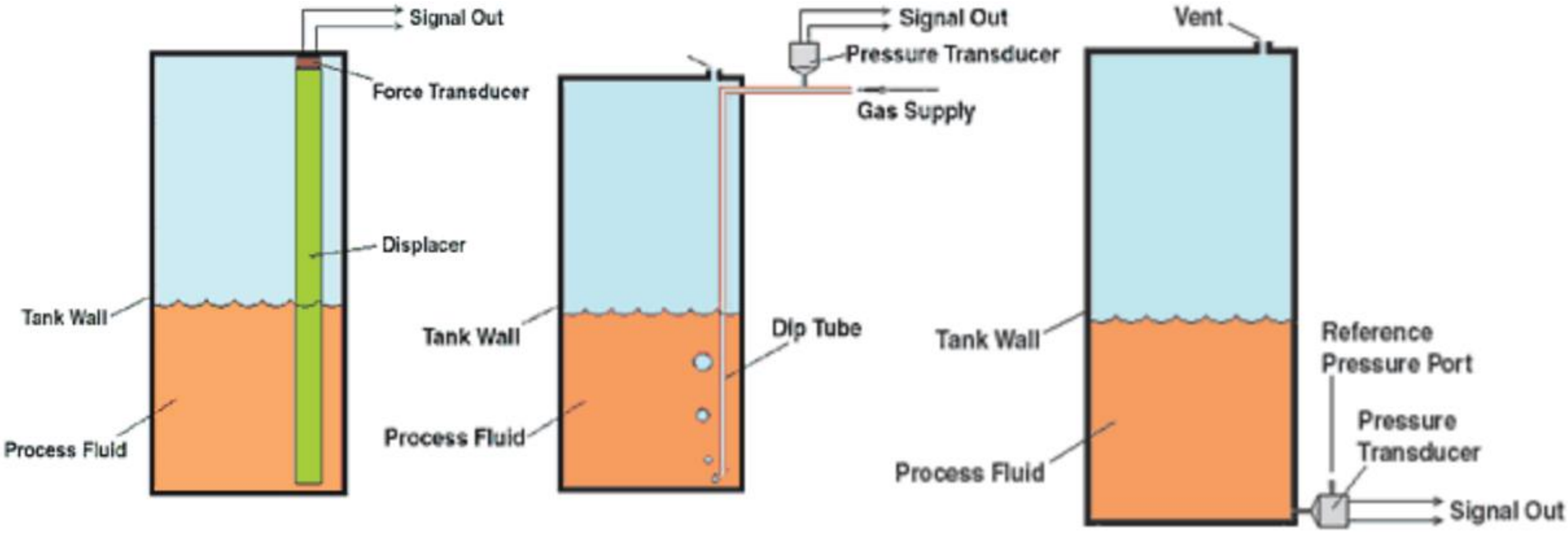


Figure 59: Displacer, Bubbler, DP sensor working principle presented respectively. Source: Henry Hopper

3. Load Cells / Stain gauges

A load cell or strain gauge are sensors that can convert a force into an electrical signal. If a load cell would be used for fluid measuring than the barrel should be specifically designed around the load cell. The support structure of the barrel should allow the barrel to put its force on the loadcell. The advantage of a load cell is that it doesn't has to be in contact with the fluid. The disadvantages are the high price, high influence from temperature or wind load. Meaning it can't be used outside easily. Also, the barrels design should be compatible with the load cell [81] [77]. See figure 60 for an impression of the sensor.

4. Capacitance Transmitters

These types of sensors make use of dielectric constants of fluids because this constant is different from air. The sensor has a transmitter connected to a rod and a reference probe that are both inside the fluid, these form the two plates of a capacitor. The capacitance between the two plates gets higher when the fluid level rises. This capacitance is measured and provides a continuous level measurement [77]. The advantage of this technology is the reliability and no moving parts. The disadvantage is the fixed range and high price. See figure 61 for an impression of the sensor.

5. Magnetostrictive level transmitter

This sensor consists of a rod with a magnetic float on it. The sensor sends a current pulse down the rod and measures the time it takes until it receives a reflected signal by the magnets in the float. The advantage of this sensor is the accuracy. The sensor is not influenced by pressure or temperature. The disadvantages are the fixed size of the rod and the high price of the sensor [77]. See figure 62 for an impression of the sensor.

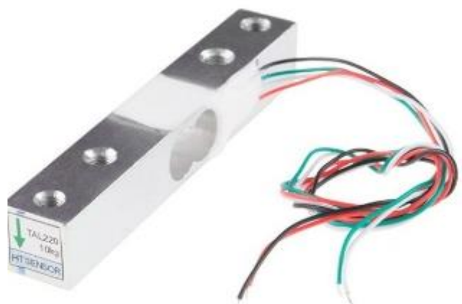


Figure 60: Load cell. Source: Kiwi electronics

Figure 61: Capacitance Transmitter. Source: Endress and Hauser

Figure 62: Magnetostrictive level transmitter. Source: Ametek

6. Ultrasonic level transmitters

An ultrasonic level sensor is placed at the top of the fluid tank. The sensor sends an ultrasonic wave down into the tank and waits for the signal to reflect on the fluid back into the sensor receiver. The sensor measures the time between sending and receiving. Using the fixed constant of the speed of sound and the temperature the distance between the water and sensor can be calculated. This distance can be used to determine the fluid level based on the size of the tank. The advantages of this sensor are its small size, low cost. The disadvantage is the noise that the sensor also detects because of reflections in the tank. See figures 63 and 64 for an impression of the sensor.

7. Radar level transmitters

Radar level sensors operate on a similar principle as ultrasonic sensors. Instead of sending out an ultrasonic signal a micro wave signal is send out. The signal is reflected on the surface of the fluid and is received by the sensor again. The advantage of this technique is that it can measure through vapor. The disadvantages are that this sensor is even more sensitive for noise cause by reflections. Also, the sensor has a high price. See figure 65 for an impression of the sensor.

Figure 63: Ultrasonic sensor
Source: Kiwi electronics

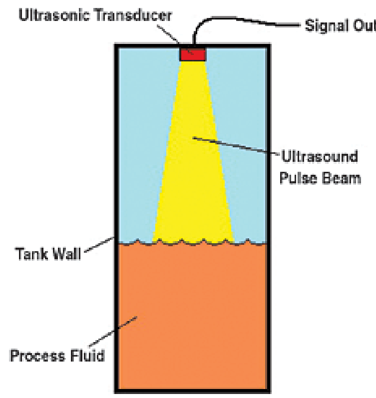


Figure 64: Ultrasonic level sensor working principle. Source: Henry Hopper

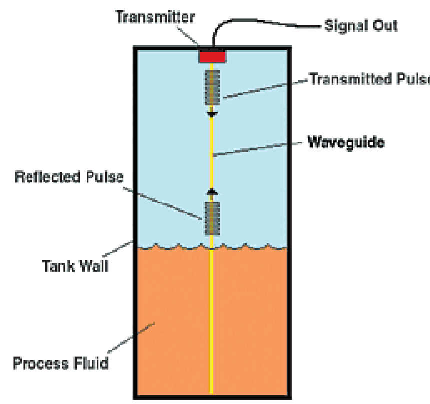


Figure 65: Radar level transmitter working principle. Source: Henry Hopper

Conclusion

Taking into account the advantages and disadvantages of the different sensing techniques. A selection of potentially useful techniques for the redesigned SRB has been made based on the aspects listed at the beginning of the section: simplicity of the sensor, variable sensing range, reliability, accuracy and low price. Based on these aspects the DP sensor and the ultrasonic sensor would be most suitable for fluid level measuring in the SRB.

Research showed that DP sensors are not widely available and also not very cost effective. For this reason, more research was done on improving ultrasonic level measurements. Ultrasonic sensors only cost between 1 and 2 euros and can be accurate enough if installed in the correct way, more on this is presented in the next section.

6.1.7.2 Improving Ultrasonic Level measurements

Previous research of Vetter [12] and Groeneveld [14] both concluded that fluid level measurements made using an ultrasonic sensor can be inaccurate because of echo's and misinterpreted signals. As Groeneveld pointed out, ultrasonic sensors have measurement deviations. This is because the sensor sends sinusoidal signals with a certain amplitude. These signals can be received at different amplitudes which result in small deviations in measurements. Because of this it is important that a measurement margin is used [14]. Next to measurement deviations, echoes are also important to take into account. As Vetter pointed out in his research, ultrasonic measurements in closed barrels need to deal with interference from echoes that arise in a closed barrel [12]. Temperature also has impact on the measuring accuracy [82]. This is because temperature influences the speed of sound. For this reason, it is important that ultrasonic measurements are analyzed with a compensation for the effect of temperature and the speed of sound. Some sensors already come with an ambient temperature sensor that can be used to compensate for this effect. Other environmental influences like humidity and air pressure both have negligible influence [82].

Even though ultrasonic measurements have to deal with these aspects, ultrasonic measurements are still a widely used technique for simple, reliable and cost-effective fluid level measuring. Research was done to get insight in the techniques used to improve ultrasonic fluid level measurements.

Echo profile filtering

The company Siemens claims to be the world leader in ultrasonic level measurement sensor [83]. Their sensors use a combination of intelligent signal processing algorithms and sensor housings. They did not publish any information on the theory behind there sensor housing, but they do provide information on their intelligent signal processing algorithms. Siemens calls their signal processing technology Sonic Intelligence and it works as follows. After the sensor sends an ultrasonic pulse it captures the echo profile of that signal. The sensor controller differentiates between true echoes, false echoes and noise. The controller analyses the received profile using software algorithms, extracting one echo from the profile as the most probable target echo [84]. The first step of the algorithm is to filter out impossible measurements. This is done by setting a predefined range. This range consist of the top and bottom of the vessel. Next to that the algorithm also looks at the previous measure level and uses this a margin for a realistic level [85]. Using this technique siemens is able to filter out false echoes caused by obstacles or the vessel its self. Next to Siemens also the company Pulsar has their own echo processing software with in theory works the same as the software of Siemens [86].

Sensor Waveguides

Next to echo profile filtering the housing/waveguide of the sensor also can have influence on the accuracy and range of the sensor. When looking at the already available level measurement sensor that use ultrasonic sensor it can be observed that the housing of the sensor is important (see figure 66 till 68). The companies that make these sensors don’t provide any information on the theory behind the waveguide. But there were some scientific sources, data sheets, and expert opinions found that explain how to design an ultrasonic sensor waveguide for a certain application.

Figure 66: US sensor with pipe waveguide. Source: Siemens

Figure 67: US sensor with horn waveguide. Source: MaxSonar

Figure 68: US sensor without waveguide. Source: MaxSonar

In order to design an ultrasonic sensor waveguide it is important to understand the principle of ultra-sonic sensing. Ultrasonic sensors use ultrasonic sound waves to measure the distance between an object and the sensor. It does this by calculating the time-of-flight (ToF) using the speed of sound. There are two types of ultrasonic sensors, sensors with a separate transmitter and receiver or a sensor with a transceiver, both work follow the same principle. The sensor sends an ultrasonic beam and measure the time until it receives an echo back from that beam. The path of sound is called the beam width. The beam width is determined by the beam angle of the sensor. Essentially the further the sound waves travel the wider the beam width and the larger the beam path (see figure 69). A large beam width means that there is a higher change that there are obstructions in the beam path. In the case of a barre this could be other sensors or the sides of the barrel. The obstacles can result in reflections of the sound wave that can cause false echoes. In order to minimize the change of false echoes it is beneficial if the beam width is a narrow as possible. This is something that can be accomplished by using waveguides [87].

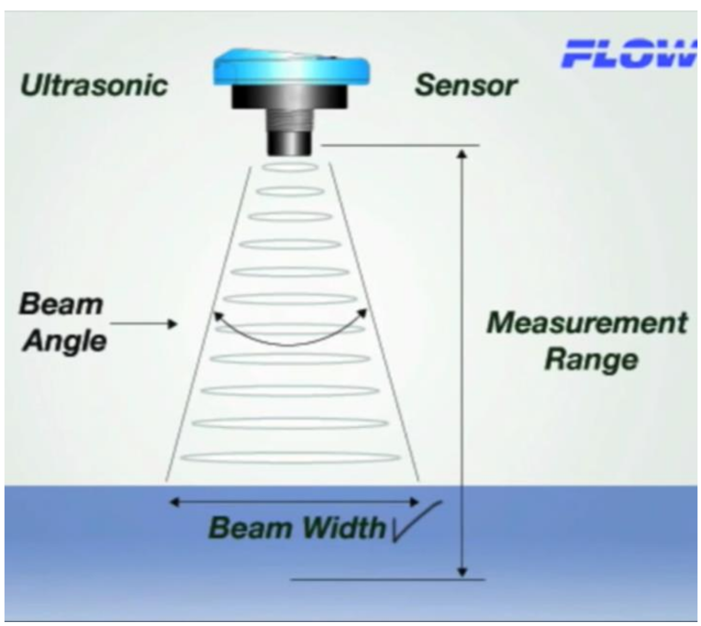
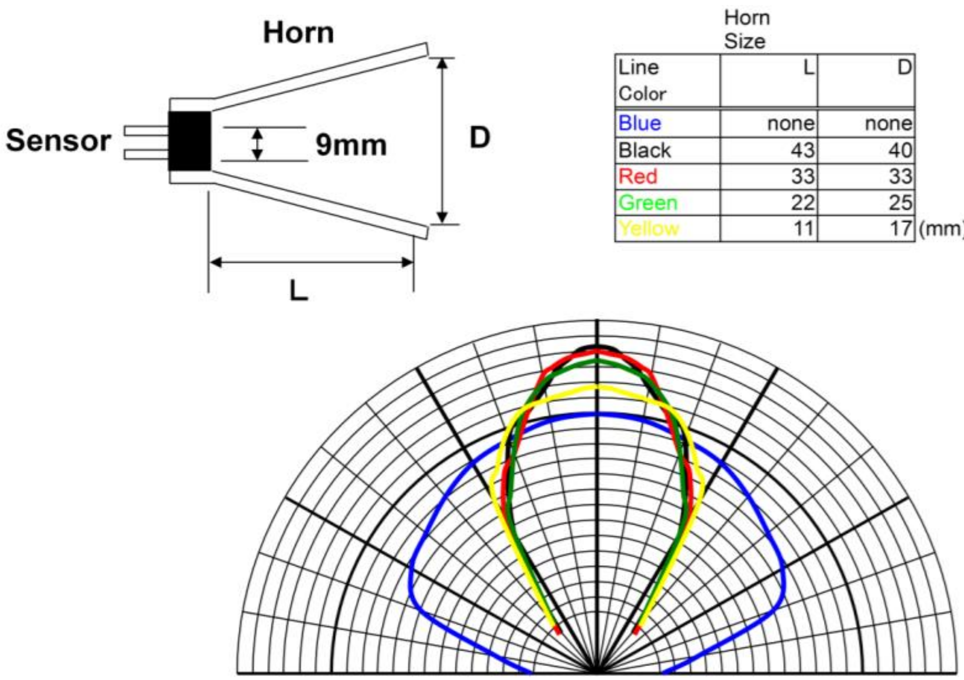


Figure 69: Ultrasonic pulse principal. Source: FlowLine

Although there is not a lot of information on waveguides available some datasheets and projects [88] were found that explain the principles of waveguides. NPX [89] and Murata [90] give a clear description on how to design an ultrasonic horn. Figure 70 displays the specification for narrowing down the ultrasonic beam for a 9 mm ultrasonic sensor.



Line Color	Horn Size L	D
Blue	none	none
Black	43	40
Red	33	33
Green	22	25
Yellow	11	17 (mm)

Figure 70: Waveguide specification. Source: Murata

Next to a horn shaped wave guide also pipe waveguides are proposed [91] [92] [93] [94] [95] [96], or a combination of both a horn wave guide and pipe waveguide [97]. There are two options when using a pipe waveguide, 1) a pipe with a length calculated using the ratio between pipe length and pipe diameter, and 2) a pipe in the full length of the barrel.

Research of Siemens [91] showed that there is a rule of thumb that can be used as a guide to design a working pipe waveguide. There needs to be a 3:1 ratio between the length of the pipe and the diameter of the pipe. Ideally the pipe nozzle should be cut at a 45-degree angle and the sides of the pipe should be smooth (see figure 71). [94] claims that a cut of 45 degrees is only necessary for pipes longer than 6 inches. [94] also points out that an air vent hole is required if the pipe is submerged in liquid. The advantages of using a pipe waveguide is that it narrows down the beam width, it blocks unwanted echoes and it can lower the temperature at the sensor face quite a bit. A pipe blocks echoes that are not perpendicular to the sensor, meaning the only the echoes directly beneath the sensor are able to reach the sensor [93].

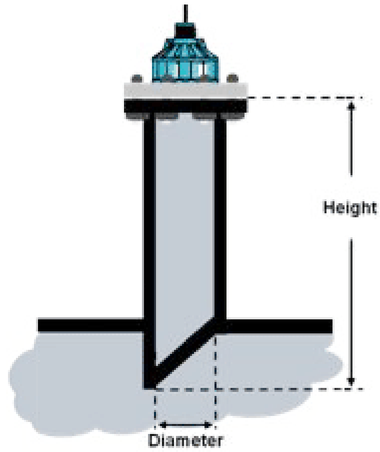


Figure 71: Siemens waveguide pipe ratio. Source: Lesman blog

Next to the previous pipe waveguide configuration there also is a pipe waveguide configuration with a pipe in the full length of the barrel it is used in. The advantage of a full-length pipe is that it separates the measurement surface from foam, turbulence, and debris. The pipe also maximizes the acoustic signal strength [92]. When making a full-length pipe wave guide it is important the pipes inner diameter is equal to or greater than the sensors beam width. [92] recommends pipes with a larger diameter. The pipe must be a seamless pipe with a smooth wall, meaning the pipe must be of one piece, so no joints between pipes can be used. The fluid must also not leave droplets on the side of the pipe, this can cause false echoes [96]. There also must be two air vent holes located just beneath the coupling with the sensor located in the sensors deadband [92]. Finally, [92] also recommends making a 45-degree cut at the end of the pipe, so there is always liquid in the pipe. The advantage of the full-length pipe waveguide is that both sensor types mentioned above can be used [95]. [97] shows in his project that a combination of a horn wave guide and a full-length pipe wave guide also can be used together. The horn wave guide can narrow down the beam width of a sensor, in order to make it useful for a full-length pipe wave guide. This makes it possible to use sensors that original would have a too wide beam width for a full-length pipe wave guide.

6.1.7.4 Temperature measuring

For temperature measuring the DS18B20 waterproof temperature sensor is used. This is a digital sensor with power supply range from 3.0V to 5.0V, and measurement range from -10 °C to +85 °C, with an accuracy of 0.5 °C. Because this is a digital sensor it is also compatible with a raspberry Pi without the use of an AD converter. See figure 72 for an impression of the sensor.

Figure 72: DS18B20 digital temperature sensor. Source: RS components

6.1.7.5 Water quality management.

As the stakeholders and previous research pointed out, it is important to guard the water quality in order to prevent risks for legionella infections for the user. Legionella is a bacterium that thrives in warm conditions between 20°C to 50°C, only a temperature above 50°C will kill the bacterium [98]. In order to get infected the contaminated water needs to be vaporized. This will be a problem if for example the user uses the water for the sprinkler system. [99] points out that the water should not be stored longer than 20 days if the water has been 20°C or higher. This is not information from a scientific source but there is no other information available on the time of legionella growth in rain barrels or growth time in general. This information will be used as a guideline for the automatic draining functionality of the buffer.

6.1.8 Power sources

This section contains literature research that focusses on the development of IoT devices with an alternative power source. The goal of this literature research is to get an overview on what combination of a networking technology, networking strategy and power source is the most suited to provide the SRB with a reliable and energy efficient network connection.

Since the SRB will be operating outside in the garden it is wise to also think about the power source of the SRB. An SRB with a plug connected to a simple wall socket might not be the most obvious solution because not all potential users might have a wall socket outside at the potential place for the SRB. If this is the case and the SRB would indeed need power via a wall socket than this could be a barrier that holds back the sales of the SRB. If users first must pay an electrician to place a waterproof wall socket outside than they might not be interested in the SRB anymore. A second concern of users with an SRB with power plug might be that they don’t consider the SRB as save, because it’s a device that deals with water and water can cause a short circuit. A final concern would be the environmentally friendly image of the SRB. An SRB is supposed to make a household more environmentally friendlier but yet another device with a power plug might not give the impression of being environmentally friendly.

Based on these concerns it is wise to look at alternative power sources. Looking at the placement of the barrel and the expected power consumption of the barrel the only suitable alternative power source is a combination of a solar panel and a battery. The SRB would not be able to run on only a solar panel because it also needs to operate in the dark. An SRB would also not be able to operate only on a battery because the battery needs to be charged after a while. That is why a combination of both would be a good solution. With this power source the placement of the SRB becomes more flexible because it doesn't need a power plug anymore. Users might also consider the device safer because it is not plugged in to the wall socket and finally the SRB will be considered more environmentally friendly. A drawback of this power source is that at the same time the SRB becomes less flexible because it needs to be placed in a spot where it can catch enough sunlight to charge the battery. This problem could for instance be solve by making the solar panel detachable from the SRB, so it can be place in a spot with more sunlight. A con of this solution is an increased complexity of the system and an increase in price. To find out if this solution is feasible literature was consulted to get insight in how to develop a solar and battery powered system that can run all day long in winter and summer.

The research of Diaz et al. [100] show that there are 3 main issues concerning long lasting power management systems for IOT modules: 1) energy harvesting, 2) energy storage, and 3) power-aware protocols. As they point out the use of energy harvesting is a requirement otherwise the requirement of long battery live and limited environmental impact cannot be satisfied. They note that solar power is one of the most applicable and accessibly energy harvesting sources for IoT solutions. There are two options concerning energy storage in IOT systems. The use of rechargeable batteries or the use of ultracapacitors. Finally, a power aware protocol is needed. As Diaz et al. [100] highlight, the radio systems of a IoT module are the main sources of energy wastage. That's why a power aware protocol is needed. In their research they propose a time slotted protocol that acts on the available charge left in the battery. The protocol also operates the radio module. It saves power by only turning the radio module on when necessary. The remainder of the time the radio is turned off which result in a lower overall power consumption leading to a longer use of one charge of a battery.

Diaz et al. [100] shows that in order to design a IoT node using an alternative power source it is important to calculate the energy demands of the system. Because a reliable design should properly balance the energy demand and supply. To balance this the energy demand of the node and the power converter need to be calculated, together with the energy delivered by the solar panel and the amount of energy that can be stored in the battery.

The research of Shi and Li [101] adds to this that it is also very important that power management of the IoT solution is designed to make optimal use of the power available. They state that the best solution for power management is not the mostly used software-controlled power management controller. But a better solution is to use a fully hardware-controlled power management solution, which relies less on the unpredictable behavior of the weather. They prove that there are 3 key aspects on which a proper power management system should suffice:

1. Make optimal use of the harvested solar energy. The system should use solar power as the preferred power if there is enough sunshine available to power the sensor node. The battery should only be used if the power of the solar panel is too low.
2. In order to extend the battery life as for as long as possible the charging of the battery should also be controlled because it is important to avoid too many charge cycles to ensure the performance of the battery.
3. The control circuit should be as simple as possible to decrease power consumption of the control unit, while still being able to perform stable and reliable.

Conclusion

It can be concluded that it is certainly possible to let the SRB run on solar power. With the use of a power aware protocol, power efficient networking technology and a properly designed power control circuit it is possible to provide a reliable power source even in long periods of rainfall. But still a few critical remarks can be made. The use of a solar and battery powered system will increase complexity and the cost of the SRB. Although a system with a power plug will be less environmentally friendly it is cheaper, and this is certainly an important aspect to keep in mind. The stakeholders also see potential in a solar powered version of the SRB but due to contains on time and resources this will not be part of this graduation project.

For these reasons the redesigned SRB will be powered with a power plug. But during the design process the aspect of a low power consumption will still be taken into account in order to prepare for a solar powered SRB in the future. This will be done by selecting parts that are energy efficient and can be powered by voltages lower than 6 volts. This is not only beneficial for a future solar powered SRB, but it will also make the power plug powered version of the SRB energy efficient.

6.1.9 Software

The software of the SRB will be written in the Python programming language. This language is compatible with the Raspberry Pi and is also preferred by the stakeholders of the University.

The software will be developed by the use of functions and combinations of functions. This makes it easy to understand and alter parts of code if needed.

Before programming the SRB is important to know where the logic of the system will be located. There are two options for this, 1) locally on the SRB, or 2) in the cloud. In order to find out what option is the most suitable for the redesign of the SRB an list with pros and cons of both options is constructed, based on the functional architecture presented in chapter 5:

Local computing	**Cloud computing**
Pros	Pros
• If the server stops working the buffers are still able to operate independently. • Less networking time required on the SRB because decisions are made locally, also saves energy. • Complete network of SRBs is less vulnerable for hacking, because every SRB needs to be updated separately.	• Logic can be updated fast and easily, every SRB will be updated at once. • Less computing on the SRB, meaning a lower power consumption on the SRB. • More beneficial for a fast updating user interface (UI), the UI doesn't have to wait on the SRB to send its status data to the sever.
Cons	Cons
• More computing locally means a higher energy consumption. • Harder to update the logic of the system, every single SRB would need to be updated separately. • Less beneficial for a fast updating user interface (UI), the UI must wait on the SRB to send its status data to the sever.	• If the server stops working all buffers will also stop working. • More networking time required on the SRB because decisions are made in cloud, also more energy consuming. • Complete network of SRBs is more vulnerable for hacking, if the server is hacked than all SRB are hacked as well.

Based on the pros and cons and the requirements from the ideation and specification phases it can be concluded that local computing would be the best option. This would be the most reliable and robust solution. The systems will be able to operate even if the central data repository is offline.

6.1.10 Data sources

In order to make smart decisions based on weather data the SRB needs a source for precipitation prediction data. Appendix D presents the research done on available weather prediction sources. The previous prototypes [10] [11] [12] [14] all used Buienradar [15] as precipitation prediction source. Buienradar provides free precipitation prediction data for the next two hours. This data is enough in order to drain the system 2 hours before rainfall but this data is not enough in order to give the user an overview of planned discharges.

From the research in appendix D it can be concluded that the data with the smallest interval can be provided by Buienradar. This data is accurate enough to divide Enschede into 24 sections. The data is only providing insight in the predictions for the next 2 hours, but the data does not contain the precipitation probability. Darksky will be the best prediction source for planned discharges. Darksky provides an API that can deliver hourly and daily predictions based on location.

In this prototype each SRB will request its own precipitation predictions even if some SRB system are located so close to each other that they have the same predictions. Once there are a lot of SRBs installed it is wise to change this by letting the central data repository collect prediction data for certain clusters of SRB systems. But for now, the central data repository will not support this.

6.2 Subsystem realization

This section contains the realization of the subsystems based on the research presented in the previous sections, and the requirements presented in the specification chapter. The realization of each subsystem is described together with the research and prototypes that led to the final version of the subsystem.

6.2.1 Valve control

As described in the components section on valves it was decided to use the CWX valves. For this prototype it was chosen to use the CWX-15 DN32 5v CR02 ball valve (figure 73). This valve has a relatively large diameter which is convenient to prevent the system from clogging. The valve also operates on 5 volts in a CR02 configuration, this the most energy efficient configuration which is beneficial if the system will be power by solar energy in a future iteration of the product. Since it was decided to use a Raspberry Pi as controller it is needed to control this valve using a relay module because the GPIO pins of the Raspberry Pi operate on 3.3 volts. See figure 74 for the CR02 configuration and figure 75 for the wiring scheme to control the valve using the raspberry pi.

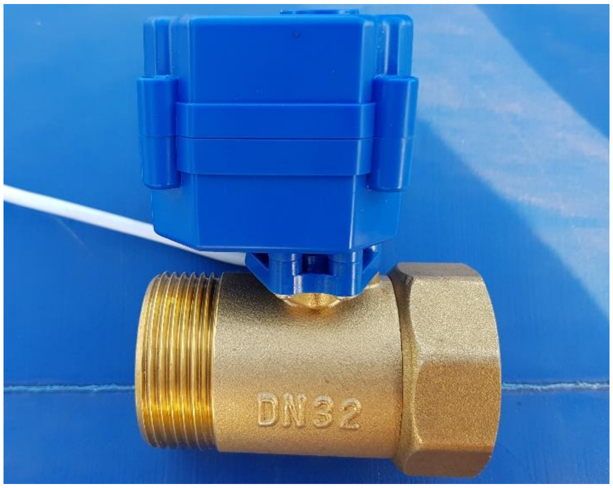


Figure 73: CWX-15 DN32 5v CR02 ball valve

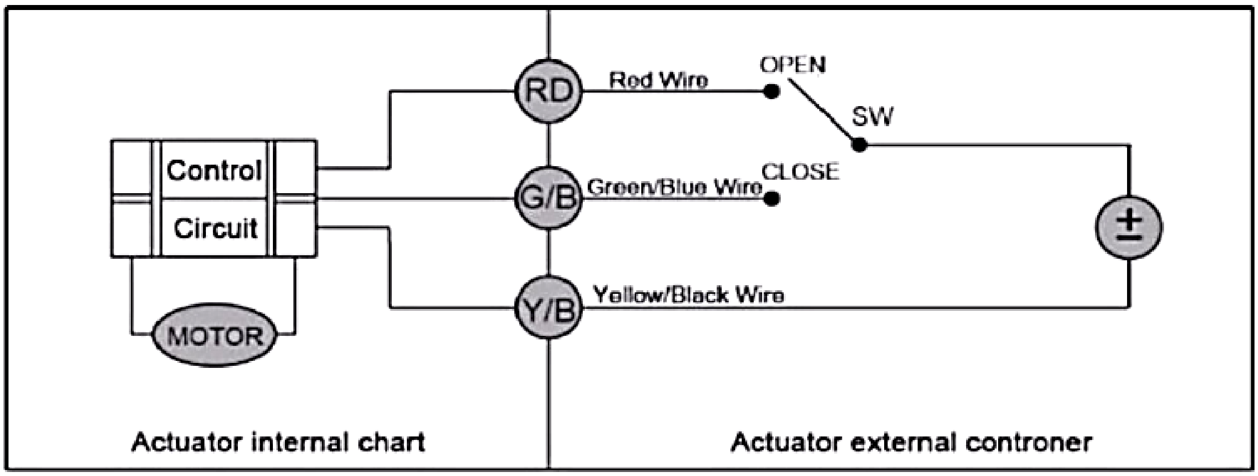


Figure 74: CR02 configuration. Source: CWX

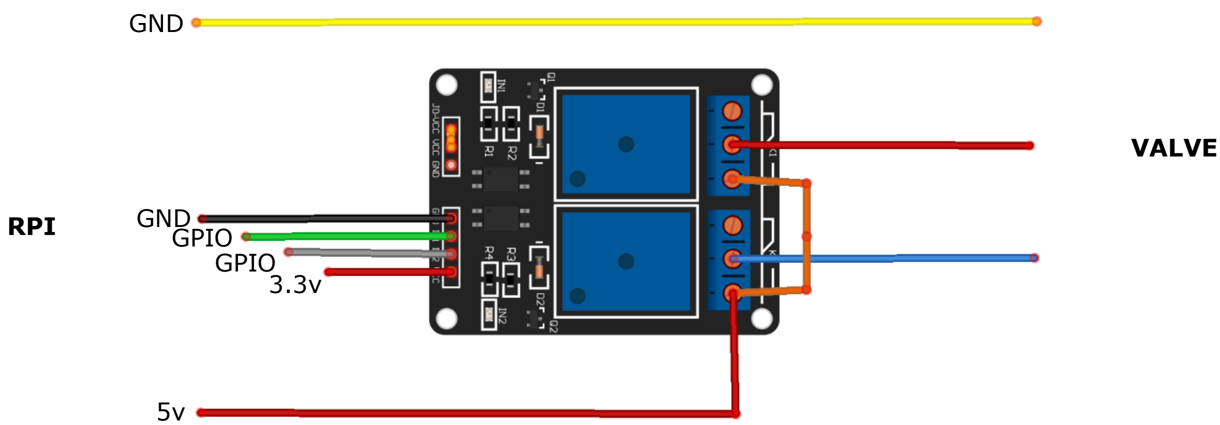


Figure 75: Valve control circuit using HL-52S V1.0 2 relay module

6.2.2 Fluid level measuring

Research in the components section on fluid level measuring sensors showed that ultrasonic sensors are the best options for fluidlevel measuring in this project. The research also showed that in somecases it might be nessiary to use wave guides in order to improve the error rate of the sensor. First a overview of suitable sensor modules was conducted. From this overview four sensors were tested. These sensors are: the US-100, hc-sr04p, JSN-SR04T-2.0, and generic 40 KHz ultrasonic transceiver unit(see figure 76-79).

Figure 76: US-100

Figure 77: HC-SR04P

Figure 78: JSN-SR04T-2.0

Figure 79: 40 KHz ultrasonic transceiver unit

US-100 and HC-SR04P

The US-100 and HC-SR04P showed almost idendical results during testing. Both sensors have a separate transducer and receiver and both have a measurement angle of 30 degrees and have a sensing range from 2 cm to 450 cm. Both sensors are compatible with the Raspberry PI. The US-100 works on a power supply ranging from 2.4V to 5.5V. The HC-SR04P works on a power supply ranging from 3.3V to 5.5V. Both sensor have a precision up to 1 mm and work with 40KHz waves. The only difference worth mentioning between the both sensor is that the US-100 has a intergrated temperature sensor that compensates for diffences the speed of sound caused by changing temperatures. Since the sensor will be used outdoor, the best option is to use the US-100 because of the natrualy occuring temperature fluctutions caused by the weather. The downside of these sensor is that they are not waterproof.

JSN-SR04T-2.0 and 40 KHz ultrasonic tranceiver

The JSN-SR04T-2.0 and 40 KHz ultrasonic tranceiver are both sensors that have a combined transducer and receiver. Both sensors can be used with the circuit board that comes with the JSN-SR04T-2.0 and both can handle a power supply ranging from 3.3V to 5.5V. The benefit of these sensors is that they are waterproof, making them usefull for outdoor usage. The sensors have a sensing range from 20 cm to 600 cm with a accurace of 1 cm and a resolution of 1 mm. When designing a sensor module it is important to take into account that the sensor has a sensing range starting at 20 cm from the sensor. Both sensors have a measurement angle of 75 degrees.

Sensor module concepts and tests

Based on the components section on improving fluid level measuring sensors serveral concepts on fluidlevel measuring using ultrasonic sensor were created.

Concept 1

The first concept that was tested is simply placing the ultrasonic sensor at the top of the barrel (see figure 80 and 81). It was found that this is only a reliable method in some barrels, depending on the shape of the barrel. In the tests it was found that all the different sensors had a higher error rate in round barrels, caused by echoes that are created inside the barrel. The rectangular barrel with flat sides that was tested had no problems with echoes and the sensor performed without any errors. But because there will be more sensors and objects inside the barrel it was decided to ideate a more realiable concept.

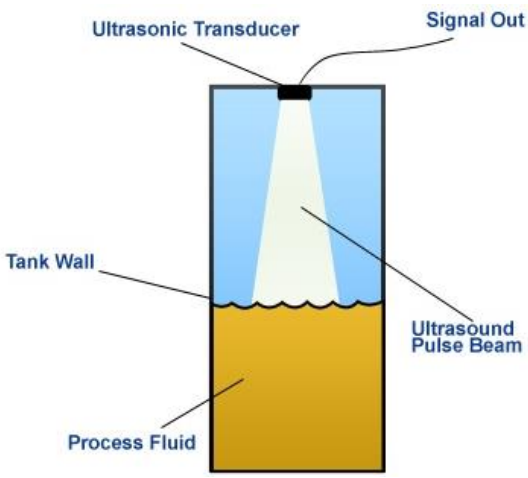


Figure 80:Fluid level measuring concept 1. Source: Chipkin Automation Systems Inc.

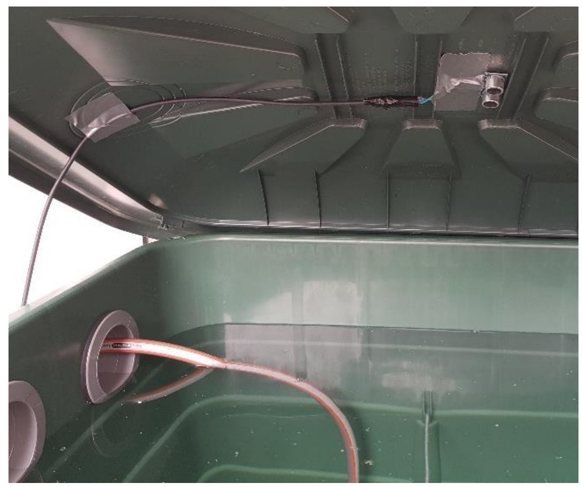


Figure 81: Concept 1 prototype: sensor on top of barrel

Concept 2

The second concept is based on the research on full lenght pipe wave guides (see figure 82 and 83). These type of waveguides isolate the sensor completely from influnces on measurement caused by the shape of the barrel and object inside the barrel, making this solution a universal solution for each rain barrel. The first prototype was constucted by using a 80 mm pipe with the same length as the barrel. The pipe was placed inside the barrel and the sensor was placed in a 3d printed mount at the top of pipe facing down into the pipe. It was found that the US-100 and HC-SR04P became more accurare and had a lower error rate when use in this setup with a pipe wave guide(see appendix H for the graphs of the measurement of the diffent sensors with and without pipe wave guide). It was found that the tranceiver based sensors (JSN-SR04T-2.0 and 40 KHz ultrasonic tranceiver) did not work inside the pipe. This is because of the bigger measurement angel. The tranceiver based sensors have a measurement angel of 75 degrees, this angle is to big to use in a pipe without creating echoes that corropt the measurements. This problem could be solved by narrowing down the measurement angle of the sensor. This can be done by using a cone shaped wave guide, as was found in the research in chapter 6.1.7.2 on improving fluid level measuring sensors.

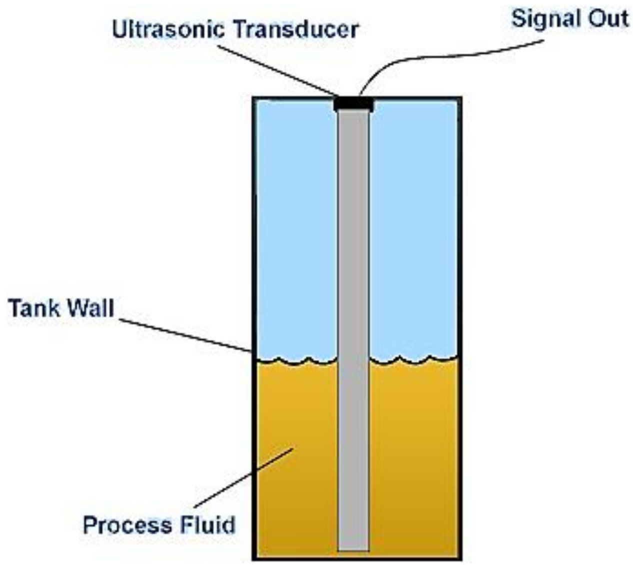


Figure 82: Fluid level measuring concept 2, full length pipe wave guide. Original image source: Chipkin Automation Systems Inc.

Figure 83: Concept 2 prototype

Concept 3

Concept 3 is a next iteration on concept 2. This concept is focused on using the US-100 and HC-SR04P sensor because these sensor already have a small measring angle and also because these sensor can measure distances closer to the sensor than the other two sensors. Concept 3 introduces a temperature sensor inside the pipe and a housing that is waterproof which is also easy to assemble (see figure 84). This module holds all the sensors the SRB needs. The module is 3d printed and can be screwed on the barrel. The module is designed to be used with or without pipe wave guide. The design of the module also follows the guidelines on design for DIY found in the literature reseach in chapter 2. The sensor module itself is modular and is also designed for easy fabrication. Once all the parts are printed they can easely be screwed on eachother and the module is assembeld.

Because the sensor module was designed to be waterproof it is also airtight. This causes problems when using the sensor module in combination with the pipe. When the pipe is inserted into the water there is no way for the air to get out of the pipe resulting in that the pipe gets presurised. This is a problem for the measuring of the water level, because the level in the pipe is not the same anymore as in the level in the barrel. As posible solution for this was already found in the research in chapter 6.1.7.2 on improving fluid level measuring sensors. As stated by [92], there must be two air vent holes located just beneath the coupling with the sensor located in the sensors deadband. This was done (see figure 85) but this introduced a lot of false echoes which are not wanted.

It was decided not the use the air vent holes in the pipe but to place the air vent holes in the sensor module itself. This was tested by removing the temperature sensor from the module and replacing it with a tube between the inner and outer cable gland that is normally used for a waterproof connection with the cable (see figure 86). The result from these tests were excellent, the sensor measured without any major errors. The air can get in and out of the pipe while still keeping the sensor module waterproof. In a next iteration the sensor module should be altered by adding 2 extra cable glands for the air vent tube.

This sensor module now meets almost all requirments for a good sensor module. It is reliable, easy to install, robust, and weather proof. But the sensor that is used in this module is not waterproof. It will not come in direct contact with water but it might get damaged because of water vapor for this reason there will an other iteration of the sensor module, which uses a waterproof sensor.

Figure 84: Concept 3 prototype

Figure 85: pipe wave guide with air vent holes

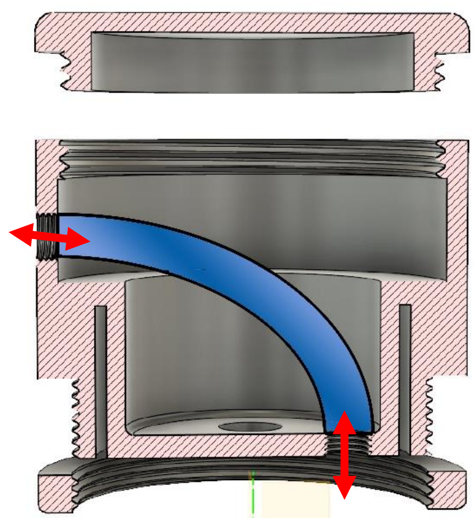


Figure 86: intersection of sensor module showing air vent concept

Concept 4

This concept is developed for the waterproof tranceiver based sensor JSN-SR04T-2.0 (see figure 87). Out of previous tests it was concluded that this sensor does not work inside a pipe because of the wide measurement angle. The sensor also has a measurement range starting a 20 cm from the sensor, this should not a problem for the barrel that is used for the SRB, because the sensor is mounted on top of the lid which has distance of approximatly 20 cm from the water surface at the maximal water level. This concept also contains a rubber ring that seals the top of the sensor module. The connection between sensor and the sensor module is sealed with silicone sealant in order to make sure the module is waterproof.

During testing of this sensor module (see appendix H) it was found that the JSN-SR04T-2.0 has the most steady measurements with the lowest error rate compared to the results of the other sensors.

In order to make this sensor module also compatible with the pipe wave guide a second cone shaped wave guide is needed to narrow down the measurement angle of the sensor (see figure 88). Unforunatly it was not possible to realise this within this graduation project due to time constraints.

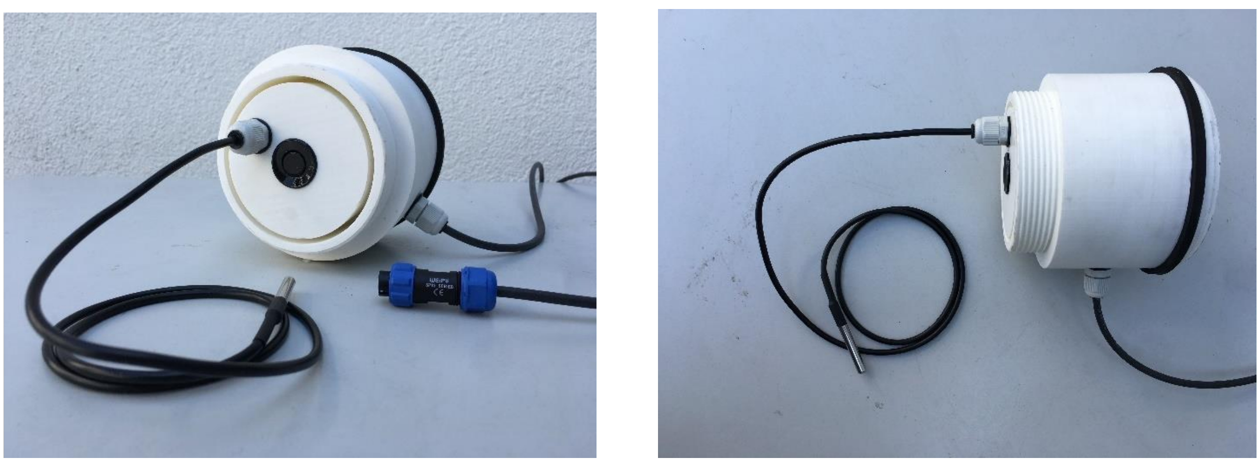


Figure 87: concept 4 prototype

Figure 88: concept of sensor module showing wave guide concept

6.2.3 Temperature measuring

As described in the components section on temperature sensors it was decided to use the DS18B20 waterproof temperature sensor. The sensor is connected to the Raspberry Pi and initialized by the guidelines provided by [102]. See figure 89 and table 11 for the wiring scheme. The resistor between the data cable (yellow) and VCC (red) must be 4.7 KΩ

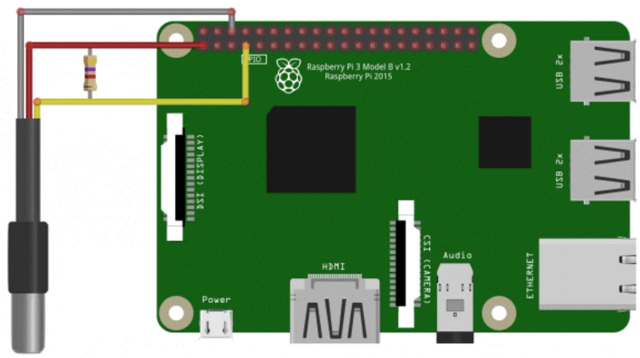


Figure 89: DS18B20 wiring scheme

Table 11: DS1820 wiring table

DS18B20	RPI	RPI pin
Red	VCC 3.3V	1
Black	GND	6
Yellow	GPIO 4	7

6.2.4 Networking and Logic

As described in the components section on network connection it was decided to develop two prototypes in parallel, one prototype that uses NB-IoT and the other uses Wi-Fi.

NB-IoT

The research in appendix C on available IoT networks in Enschede showed that during the time period of this graduation project there was only one publicly availably NB-IoT network. This was the NB-IoT network of T-Mobile. Because NB-IoT operates in the 4G band it is only available on the frequencies that T-Mobile can use for 4G. In the Netherland these are the 900 MHz, 1800 MHz, and 2600 MHz frequencies [103].

Since it was decide to use the Raspberry Pi as controller research was done on NB-IoT connectivity for the Raspberry Pi. It was found the most easy and accessible option is to use an NB-IoT shield designed for the Raspberry Pi. The only option available during the time period of this graduation project was the Sixfab Raspberry Pi NB-IoT Shield. The problem with this shield is that the networking chip (LTE BC95 B20 800MHz) only supports the 800 MHz frequency. T-Mobile does not operate on this frequency, meaning that this shield could not be used. There were other shields with compatible network chips available for pre-order, but these would not be delivered in time. For this reason, it was chosen to stop the development of an NB-IoT connected SRB and fully focus on a Wi-Fi connected SRB. Research showed that there is a lot of development in NB-IoT shields, but this will not be relevant for this Graduation project anymore.

Wi-Fi

The second option for a data communication technique is Wi-Fi. The advantage of the Raspberry Pi is that it has a build in Wi-Fi module. The biggest challenge is connecting the Raspberry Pi with the private Wi-Fi network of the SRB user. The most common and supported method of connecting to a Wi-Fi network is by specifying a SSID (network name) and a password. These credentials must be specified by the user. State of the Art research was done on how to make this process user friendly and easy. It was found that almost all Wi-Fi enabled smart home products without a screen (e.g. Chromecast, Alexa) use a technique that lets the product itself broadcast an open Wi-Fi network. The user can connect to this Wi-Fi network with his or her phone and will then be redirected to a locally hosted setup page that asks the user to specify to which Wi-Fi network the product should connect to. Once this is done the product connects to the specified network and now has an internet connection.

It was found that there is an opensource application for the Raspberry Pi on GitHub[4] that provides a service just like described above. For this project the application was altered a bit in order to meet the requirements of being user-friendly and easy to install. With the changes made to the application it now features a user friendly and simple user interface. The application is universal and works both on hidden and not hidden networks. Once the user fills in the network credentials the system will always try to connect to the given network with the given credentials. By doing this the system can handle network loss and will reconnect to the network once the network is available again. The application can be put back into configuration mode by pressing a button. If the user makes a mistake it is possible to reset the system to configure the system again.

6.2.5 Filtering

As discussed in the components section on filtering, the stakeholder wants to filter the water as much as possible in a way that it requires no or less maintenance by the user. It was decided that a filter sock of Nylon filter mesh will be used for this (see figure 90). An adapter was developed in order to connect the filter to the input of the buffer. The adapter is made of a 70 mm PVC sleeve, a 70 mm 90° PVC angle, and an 60-80 mm RVS hose clamp (see figure 91). This adapter fits tight inside the rain pipe connector. The length of the 40 sock is 40 centimeters, with this length

[4] https://github.com/jasbur/RaspiWiFi

the filter sock can not float in the range of the sensor. The filter sock was also tested during a heavy rain shower. This showed that the filter is not able to filter out very small dust particles, but it perfectly filters out any other type of bigger debris (see figure 92). It was also found that most of the dust particles that are not captured by the filter will easily drain together with the rainwater when the buffer is being drained.

Figure 90: Prototype nylon filter socks in different sizes

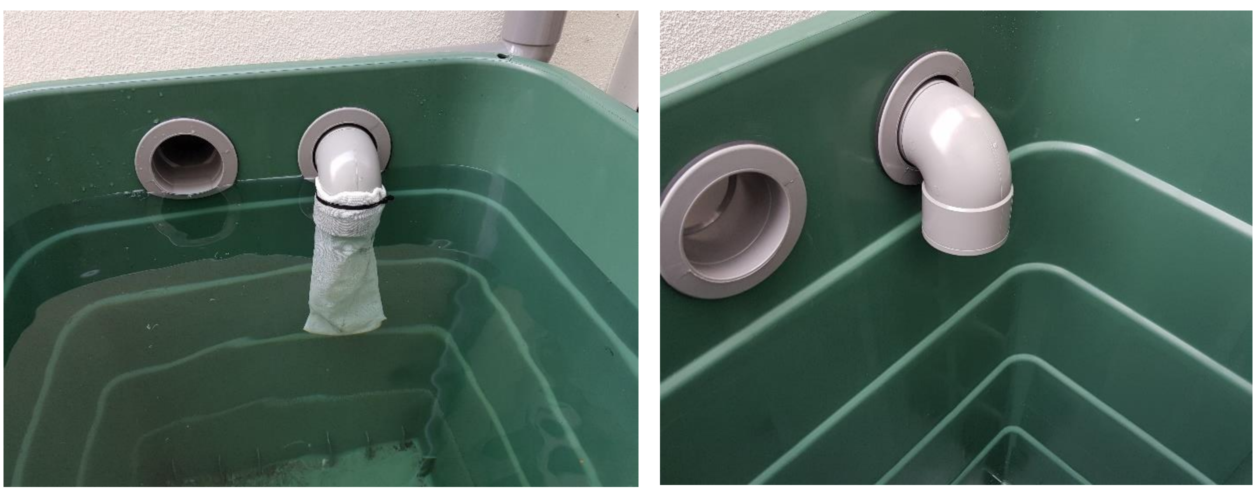


Figure 91: Filter adapter prototype

Figure 92: Filter sock after rain shower

6.2.6 Weather prediction data and logic

As described in the components section on data sources Buienradar and Dark Sky will be used as weather prediction sources. The following prototype for the SRB logic was realized: The Buienradar 5-minute predictions for 2 hours will be used a main guideline for draining water. Simply because this is the most accurate and detailed source that is available at the moment. Every 5 minutes the newest prediction for 2 hours in advance will be requested. This value will be transformed in millimeters per 5 minutes and this value will be used to calculate how much water in liters will be collected by a roof with a certain area in 5 minutes time. The buffer will check if there is enough capacity left to buffer these liters, if not the buffer will drain the amount that is needed to provide enough capacity. For this the buffer also takes into account the previous 5-minute predictions for the last 2 hours.

Buienradar is only used to make decision on draining but it cannot be used to plan discharges. Since it is a requirement to plan discharges for the user interface the Dark Sky API will be used for this. Once every hour the system will request the hourly precipitation predictions for the next two days. The predictions will be filtered on there probably, if the precipitation probability is higher than 0.75 percent than the system will save this locally and also send it to the central data repository. In case Buienradar cannot be reached three times in a row than the hourly planned prediction in the database will be used to decide if the buffer needs to free up capacity. If the buffer does this than the buffer will start trying to request Buienradar predictions again after the hour of the planned discharge making sure that the buffer doesn’t drain twice for the same rain shower.

Dark sky will also be used as weather prediction source for the freeze guard functionality that protects the system from freezing. Once a day at 12 PM the system will request the minimal temperature for the next day. If the user enabled the freeze guard and the minimal temperature for the next day is below zero than the buffer will drain all the water, leave the valve open, and block the system from draining. The next day the system will check again if the temperature is above zero degrees than the system will close the valve again and enable the system to drain again. See the list below for a complete overview of the requests.

- **Every 5 minutes** request precipitation data from Buienradar and decide whether to drain or not.
- **Every hour** request precipitation data from Buienradar and register planned discharges.
- **Every day at 12 PM** request minimal temperature for the next day and decide whether to activate the freeze guard protocol or not.

6.3 Prototypes

During this graduation project two prototypes were developed the first prototype was focused on exploring different kinds of hardware solutions, testing the developed subsystems, and testing the concept of an SRB. The second prototype is focused on designing for DIY and creating a consumer ready and robust system.

6.3.1 Version 1.0: Test version

As described before this prototype is focused on testing the concept of the SRB, evaluating the hardware choices and testing the developed subsystems. The prototype is made of a repurposed industrial 200-liter barrel (see figure 93). The barrel was painted green in order for it to better fit in the neighborhood.

Situation

The buffer was located on the highest floor an apartment complex in the middle of the city center. The barrel was connected to one of the four rain pipes connected to a section of the flat roof of the apartment complex. The barrel was connected to outlet B, displayed in figure 94. The total area of the roof section is roughly 400 square meters. Assuming that 25% of the water that is collected on the roof ends up in outlet B, then the water collection area of this buffer is approximately 100 square meters.

Figure 93: Prototype version 1.0 installed

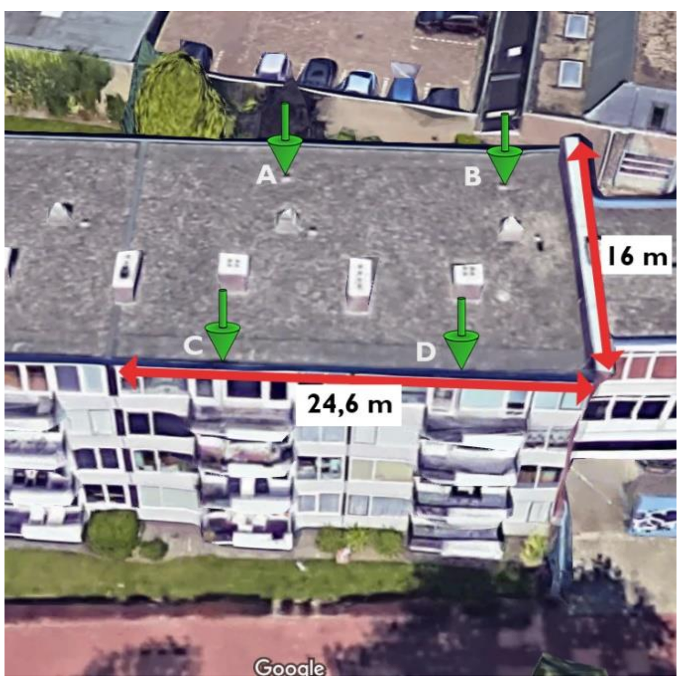


Figure 94: Prototype 1 situation. Source: Google Maps

Design

The first prototype was equipped with an input, overflow, electric valve, temperature sensor, ultrasonic sensor, and Raspberry Pi. The prototype did not include all the functional and nonfunctional requirements, but it did include the basic functionality of an SRB. It could automatically drain a specific amount of water based on the Buienradar predictions and it was able to log the temperature of the water.

During the development of the prototype it was confirmed that using an ultrasonic sensor in a round barrel resulted in false echoes that corrupted the measurements. The second concept iteration of the sensor module was used to place the sensor inside a full-length pipe wave guide. The used pipe was an ordinary rain pipe with a diameter of 80 millimeter and a length of 1 meter. The pipe wave guide solved the problems with false echoes making the sensor reliable enough for the calculations done on the Raspberry Pi. The Raspberry Pi measured the distance between the water and the sensor and used the basic mathematical formula to calculate the volume of a cylinder to calculate the amount of water in the buffer. Every 5 minutes the Raspberry Pi requests the latest 5 minute prediction for the next 2 hours. Based on this prediction the Raspberry Pi calculated the needed capacity and drained a certain amount of water if there was not enough capacity.

Test prototype evaluation

This first prototype gave insight in the concept of the SRB and it also showed that it is very important that the water level measurements are correct. Wrong measurements result in wrong calculations and unnecessary loss of water. This prototype also showed that the CWX valve works very reliably. The valve functioned 5 weeks long without any error. The most interesting insight that was found in using this prototype was that the roof is also an unpredictable factor. After a long period of dry weather, it took some time before water came pouring down the drainpipes while it was raining heavily. This is because the roof that the prototype was connected to has a layer of gravel on the roof and the drainpipes are located a bit higher than the gravel otherwise the gravel could end up in the drainpipe. This resulted in that it took 30 minutes during a have rain shower before the drainpipes started pouring water into the buffer. The roof also buffers some water, this water is never drained to the sewage system, but it will evaporate overtime. After the water level on the roof is high enough the drainpipe will start to poor. Because of this the calculations for the expected buffered water did not correspond with the actual amount buffered. In the case of this specific roof the calculation need to be altered in a way that they also take into account the buffer capacity of the roof and the amount of water left on the roof before a rain shower.

6.3.2 Version 2.0: DIY Consumer version

This second prototype is fully focused on designing for DIY and creating a consumer ready, robust, and easy to install system which follows the specified requirements.

Design

A big part of the design process is designing for DIY. This version is designed following the guidelines given in the literature research on design for DIY in chapter 2. The system is designed to be modular, all subsystems are divided over modules that can be connected to each other. This in not only convenient for the DIY aspect of the product but also for the flexibility of the system and the ability to perform maintenance on the system. As mentioned in the beginning of this chapter all parts have are of good quality and almost all the components are standardized components that are available in every hardware store. It was also tried to keep the number of components at a minimum by combining components into multifactional components. Finally, the packaging was also kept at a minimum because all the components that are needed can be shipped inside the barrel (see figure 95).

Figure 95: packaging of final design

Figure 96 and 97 shows the final design of the DIY and consumer ready SRB. As can be seen, the design is kept simple and robust. The sensor module is placed on top of the barrel and the computing unit and valve are placed underneath the barrel inside the base. The design features a manual tap on the front that allows the user to use water locally. Most of the "smart" components are hidden underneath the barrel, this way the most critical parts of the system are protected well and do not require a custom housing. Another advantage of the valve being located inside the base is a better protection from freezing.

All the electric parts can be connected with waterproof plugs to the control unit (see figure 97 A and C). The control unit contains the Raspberry Pi, power adapter, relays for the valve control, and the waterproof connector sockets. All the components are soldered onto a Raspberry Pi development board that can easily be connected to the Raspberry Pi (See figure 97 B). In this prototype the control unit is powered by a power plug, but the system is designed to not use more than 5 volts making it possible to run the system on solar power in the future.

For this type of barrel, the pipe wave guide is not really necessary, but if later modifications or tests show that it is necessary it can easily be connected to the sensor module without any screws because the pipe connector on the sensor module is conical (see figure 96 E).

The filter module is place inside the input rain pipe connector (see figure 96 D). The filter sock can be replaced by untightening the hose clamp and taking of the filter sock. The filter sock can be cleaned and can be used again.

The hose clamps on the hose that is connected to the automatic valve are hose clamps that do not need a screw driver (see figure 97 F). This make the DIY process easier. The rain pipe connectors are universal and can be connected to both 70 mm and 80 mm drainpipes (see figure 96 B) . The user is free to decided were to put these rain pipe connects the same counts for the manual tap and the hole for the cable (see figure 97 D and E). The output hose that is connected to the automatic valve features metal GEKA connectors. These connectors are durable and robust and are widely available.

The installation process of the buffers only requires a drill and a hole saw in multiple diameters. The holes are easily drilled into the buffer because it is made of a relative soft plastic (PP). The remained of the installation process is simply connecting parts together. In order to make the installation process more user-friendly DIY instructions and an instruction video were made in collaboration with co-developer Tunç, more details on this can be found in the Thesis of Tunç.

Figure 96: Final design. A) front view of the buffer, B) input and overflow connectors, C) Custom designed sensor module, D) Inside of the barrel, E) Waveguide connected to sensor module

Figure 97: Final design. A) Valve and computing unit, B) computing unit, C) Waterproof connectors, D) cable hole, E) Back of the buffer, F) output hose with DIY friendly hose clamp and GEKA connector

Figure 98 shows an exploded view of the system, showing all the parts and their location. When designing the system, it was tried to keep the number of parts as low as possible, in order to keep the DIY process simple. Appendix E gives a complete list of all the parts, suppliers, and prices. The total cost of the system is 235 euros which is 15 euros below the goal of 250 euros set by the municipality.

Figure 98: exploded view final design

Connectivity

As mentioned before in section 6.2.4 the SRB will be connect the internet via the private Wi-Fi network of the SRB owner. But in order to do this the user needs to setup the connection on the buffer. To make this as user friendly and universal as possible it was decided to let the Raspberry Pi inside the computing unit broadcast a local network that the user can connect to and use to setup the SRB without having to perform any hard-technical task.

When the SRB is powered on for the first time it will automatically boot in to configuration mode. The Raspberry Pi will than broadcast a Wi-Fi network with an SSID starting with "SRB-". The user can connect to this network with his or her phone and will automatically be redirected to setup page (see figure 99 and 100) were the user is asked to select an SSID and fill in the corresponding password. Once the user submits the form the Raspberry Pi will reboot and try to connect to the selected Wi-Fi network. Once the Raspberry Pi has a Wi-Fi connection it will send a status update to the central data repository. This is used to tell the user via the user interface that the SRB was able to successfully connect to the specified network. If the Raspberry Pi could not connect to the Wi-Fi network, it will continuously try to connect to the network and the user interface will give the suggestion to the user to check if his or her Wi-Fi network is working or to reset the SRB back to the configuration mode.

Figure 99: Connecting to local SRB Wi-Fi network

Figure 100: Wi-Fi setup interface

The SRB can be reset by pushing the button on the computing unit for more than 10 seconds. The Raspberry Pi will than reboot into the configuration mode and the user is able to setup the SRB again. It was chosen to go for this approach because this seemed like the most user-friendly solution. It would not be user friendly if the Raspberry Pi resets every time when it cannot connect to the Wi-Fi network. This would mean that the user would have to configure the SRB every time the Wi-Fi router is power off or doesn't function for any other particular reason. Now the SRB only resets when the button on the computing unit is pressed.

Logic

As mentioned in chapter 6.1.5 and 6.1.9 the system is controlled by a Raspberry Pi running a Python program. The Raspberry Pi interfaces with the sensors and actuators via the GPIO pins and uses a Wi-Fi connection to send and request data to external systems: weather predictions sources and the central data repository from the Climate Adaptive City Enschede project. The system is designed to be reliable and robust. The system will be able to operate independently for 2 days if network connection is lost or if the data sources are offline. The system is also designed to store measurement data locally in case the connection with the central data repository is lost. SQLite is used database engine for the local database on the Raspberry Pi, making it easy to query the database.

The structure of the program running on the raspberry pi is based on the functional system architecture given in chapter 5 of this report. The logic of the system can be seen as the main program that run on the Raspberry Pi. This program contains multiple functions which are called by a job scheduler function. This is implemented by using the Cron tab functionality of Linux. The list below gives an overview of the scheduled functions.

- **Every minute:** Request a status update of the system, temperature and water level are saved in a local database. Also check if there was water drained manually and check if the water temperature is above the legionella risk threshold.
- **Every 5 minutes:** Request precipitation data from Buienradar and decide whether to drain or not. In case of a drain then send this to the central data repository.
- **Every 15 minutes:** Send the status updates that are saved in the local database to the central data repository. If the central data repository confirms that a status update is received than delete the status update from the local database.
- **Every hour:** Request precipitation data from Dark sky and register planned discharges in the local database and send them to the central data repository.
- **Every day at 12 PM:** Request the minimal temperature for the next day and decide whether to activate the freeze guard protocol.

Communication handler

As explained in section 6.2.6 the SRB will be able to connect to three different services: The central data repository, Buienradar, and Dark Sky. This is implemented by giving each service its own library that is imported by the main program. Each library contains the necessary functions for the specific service. The SRB also runs a local database this database is used to save planned discharges and status updates. The status updates remain stored in the local database until the central data repository has confirmed receiving them. The SRB also uses the central data repository to request configuration data, once this data is received it will be permanently stored on the SRB but can be update by the user via the user-interface connected to the central data repository. See figure 101 for an impression of the connection between the different services.

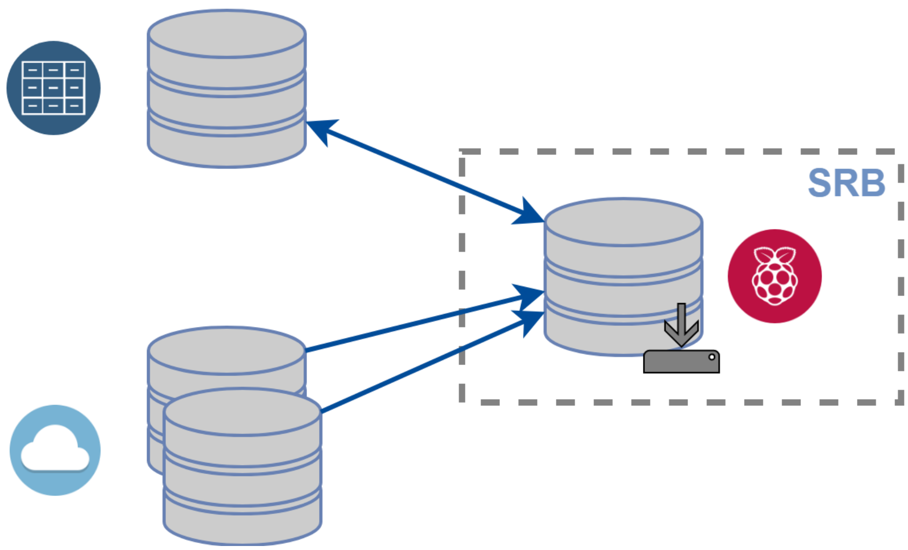


Figure 101: SRB by and connected services

Water level measurements

The water level the inside the barrel is measure by the ultrasonic sensor in the sensor module. As Groeneveld [14] pointed out in his research, ultrasonic sensors have a small deviation in measuring distances because the amplitude of the received echo can deviate. A signal could be received a fraction later if the amplitude is not above the threshold value of the sensor. It was found that a measurement is more accurate if it takes the average of a burst of measurements. Finally, it is important that this measurement is checked on being realistic, taking into account the barrel size and the previous measurement.

This is implemented in the SRB in three functions. 1) The single measurement function, which simply returns the distance between the water and the sensor. 2) The burst measurement function which uses the single measurement function 10 times in a row and returns the average distance. 3) The smart measurement function, which uses the burst measurement function and checks if the output of this function is realistic. This is based several levels of validating the measurement. 1) Validating if the measurement is in a possible range, based on the dimensions of the buffer. 2) Validating if the measurement is within a certain range from the previous measurement. 3) If the measurement was not validated by level 2 it is saved as possible distance and the validation process starts again and now uses the possible distance for validation in level 2. 4) if the measurement was not validated 5 times in a row than the function will output a measurement error.

Temperature measurements

The temperature measurements are less susceptible for errors for this reason the temperature is only measured once per request. This is implemented by two functions. 1) the get raw temperature measurement function returns the raw measurement value from the sensor. 2) The get temperature function uses the output of the get raw temperature function and calculated the temperature in degrees Celsius.

Discharges

The system has several discharge functions: drain amount, drain till, and drain all. These functions are called by the scheduled functions in the main program. The drain functions use the smart measurement function as input for opening and closing the valve. Every minute the buffer compares the current water level to the previous water level. If there is less water in the buffer and there was no automatic discharge of the system than the buffer will register this as a manual discharge. Every 5 minutes the system checks the Buienradar predictions. In case a rain shower is predicted the SRB will drain the amount water that is needed to free up enough space to buffer the expected water.

Water quality guard

If the user has enabled the water quality guard function than the SRB will check the water quality every minute. The SRB checks if the temperature is not above the threshold of 20 degrees for 10 days in a row, in order to prevent risks for legionella. The system keeps track of this using a counter and once the counter reaches 10 than the SRB will call the drain all function. The counter will be reset when the buffer is fully emptied.

Freeze guard

If the user has enabled the Freeze guard function than the buffer will once a day request the minimal temperature for the next day. If the minimal temperature is below zero than the buffer will open the valve and keeps the valve open until it receives a minimal temperature above zero.

Wiring scheme
The sensors and actuator are connected to the Raspberry Pi using a prototype shield. See figure 102 for the wiring scheme of the final prototype.

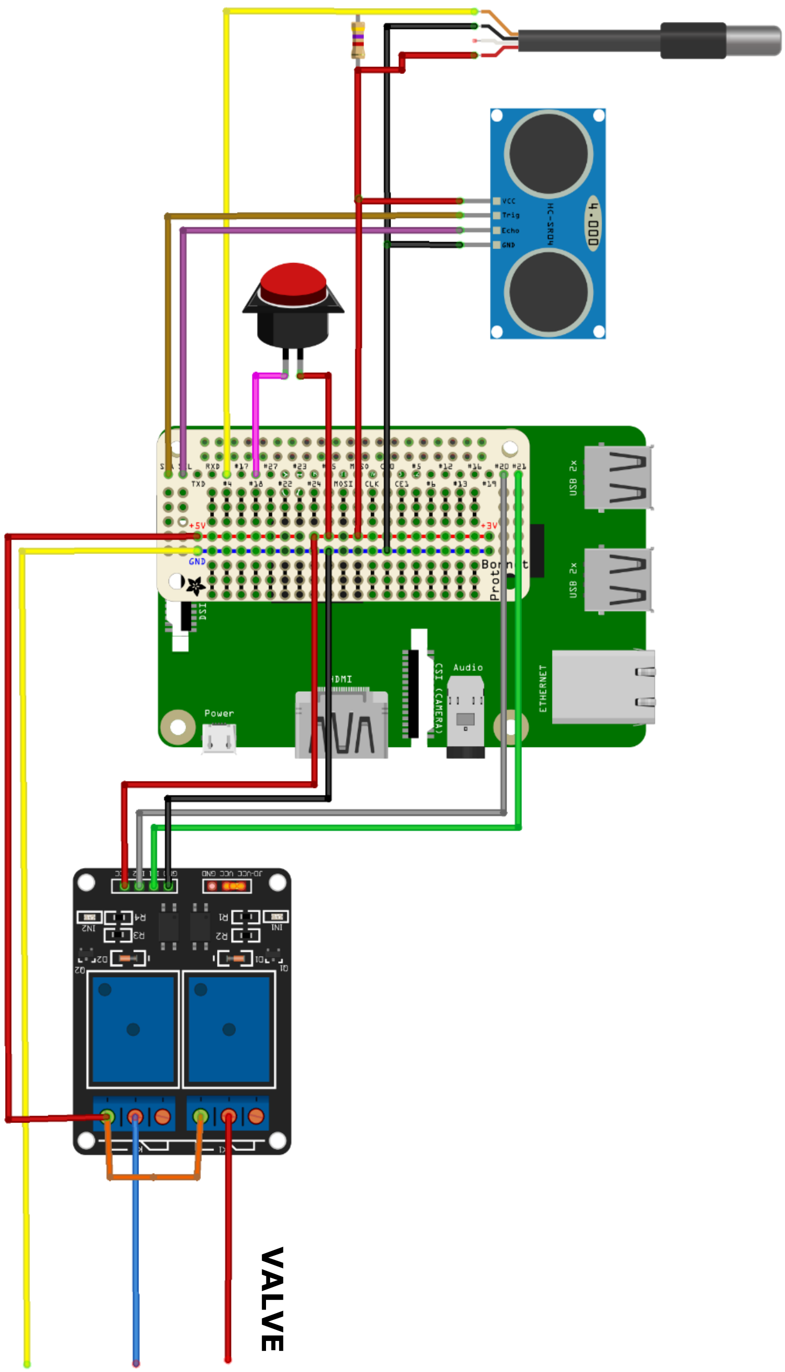


Figure 102: Wiring final prototype

7 EVALUATION

This chapter contains the evaluation of the final prototype of the DIY and consumer ready smart rain water buffer. This chapter starts with the evaluation of the requirements that were specified in chapter 5. Secondly a price evaluation of the system will be given. This price evaluation gives insight in the total costs of the system and what modules are the most expensive. After that an evaluation based on the Design for DIY research found in chapter 2 is presented. Finally, the feedback of the stakeholders is discussed.

7.1 Requirements evaluation

In this section the requirements that were specified in chapter 5 are evaluated. This is done by assessing the final prototype and validating if the prototype fulfills the requirements. As specified in in the methods chapter, the requirements are sorted using the MoSCoW method. In the evaluation it is the most important that all "must have" requirements are met and next to that also most of the "should have" requirements should be met. A new requirements table was constructed, were the requirements that were met are highlighted green and the requirements that were met under certain conditions are highlighted yellow. Some requirement have shared responsibilities with other solutions that are developed by co-developers and therefore some of the implementation responsibilities of the requirements lay outside the scope of this graduation project.

It was found that all "must have" functional and Non-functional requirements are met. The system contains all the necessary functions. The implementation of some functions is a shared responsibility. For example, the nonfunctional requirement that the system must be secure is a shared responsibility between the SRB and the central data repository. It can be confirmed that the SRB is secure, but this is not the case for the central data repository. The central data repository was not secure at the moment of evaluating which makes the SRB also less secure. If the central data repository would be secure than the SRB would also be secure. This dependency of security on the central data repository could be eliminated on the SRB side but this would mean that other requirements that were set for the SRB will be compromised, for example setting up the system via the user dashboard.

Next to the "must have" requirements also all the functional and nonfunctional "should have" requirements have been met. But some of these requirements are shared responsibilities between the SRB and the user dashboard. Notifying people about errors must be implemented on both sides. The SRB is able to create an error event in the central data repository, but the user dashboard is responsible to show this to the user. This dependency could for instance be eliminated by using a status LED on the buffer but then the buffer would also need a screen to tell the user what type of error occurred. Only this would make the system less simple and possibly less durable and robust. Next to that there are also shared dependencies for the requirement that the system should promote being environmentally friendly. This has been implemented in the design of the buffer by providing a manual tab, registering manual discharges, and providing a universal outlet and overflow. But next to these design choices it is also important that the users are informed well and triggered into being environmentally friendly this is a responsibility that lays at the DIY instructions and the user dashboard which both are out of the scope of this graduation project.

Most of the “could have” requirements are met or partially met. Only some of requirements are met under certain conditions. The requirement that the system could be independent from the user’s private communication infrastructure is only met if the user connects it to a public, no privately-owned Wi-Fi network. Next to that the system also meets the requirement of being scalable in the sense that software on the buffer supports changing the maximum capacity of the buffer. Next to that the software is already prepared to support connecting extra modules but the hardware must be altered to support this.

7.2 Price evaluation

The stakeholders set the requirement that the complete system should cost not more than 250 euro. The price evaluation below shows the total price of the system and what parts of the system are the most expensive. For a complete list of the parts see appendix E

Appendix E shows that the total price of the final prototype is 235 euros, which is lower than the maximal price of 250 euros including taxes. Figure 103 shows a price analysis of the system. As can be observed in figure 103, the computing unit is the most expensive part of the system. But this is also the part that could become cheaper by replacing the computing unit. The computing unit which is used now is a Raspberry Pi 3b but it could be replaced with the cheaper Raspberry Pi zero. Next to that if all parts would be bought in bulk than the price of the overall system could potentially be lowered than 200 euros.

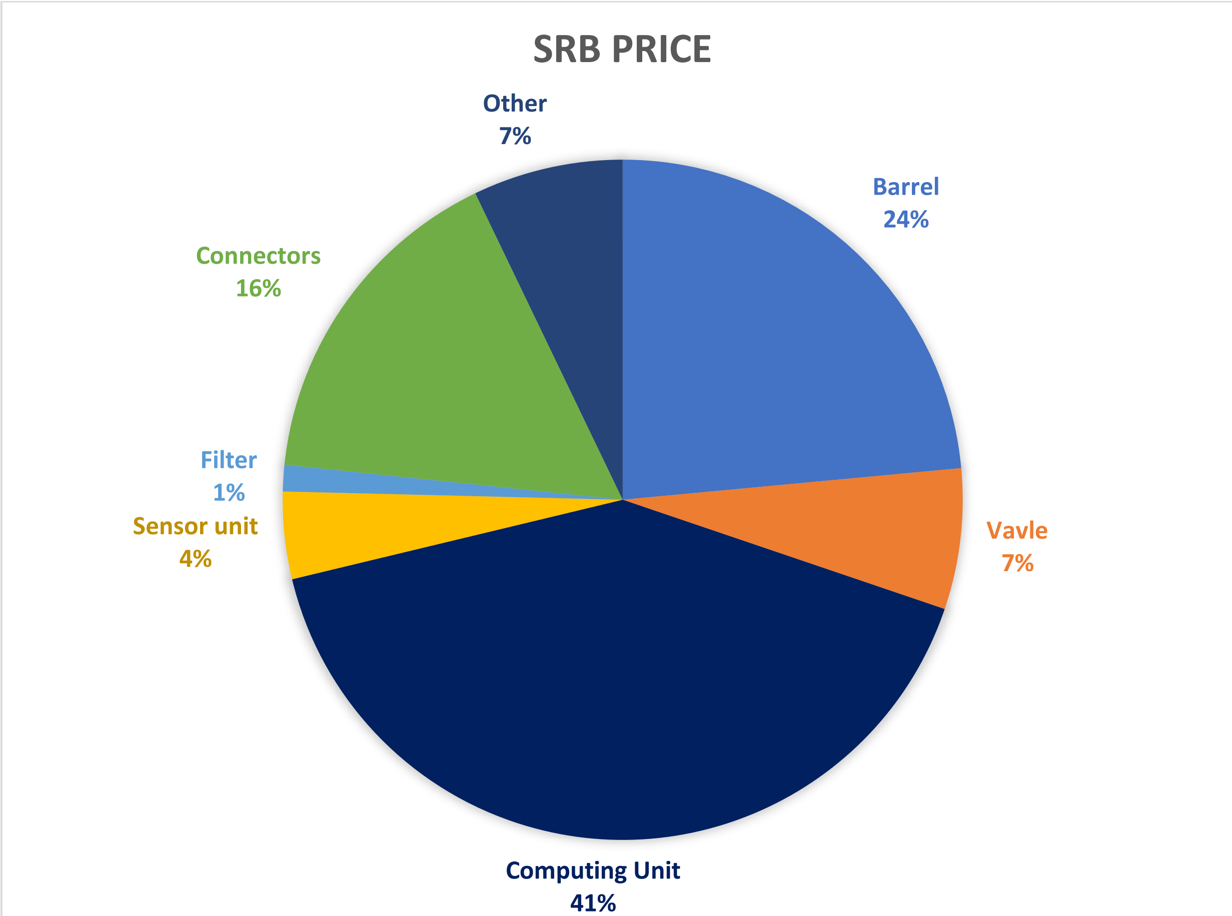


Figure 103: SRB price analysis

7.3 Design for DIY evaluation

The literature research in chapter 2 on Design for DIY presented two guidelines, design for assembly and evaluating assembly complexity. These two guidelines were used to evaluate the design choices that were made for DIY in the final prototype.

7.3.1 Design for assembly

Reduce the total number of parts: During the design process of the barrel is was tried to keep the number of parts as low as possible. This is done by creating modules, like for example the sensor module, filter module and computing module. These modules already come pre-assemble lowering the amount of parts that need to be assembled by the end user. Next to this it was also chosen to use universal parts, for example the input and overflow of the barrel are suitable for drainpipes from 70 and 80 millimeters. Instead of proving multiple parts in multiple sizes it has been limited to one part with a universal size.

Design a modular system: The SRB is designed to be modular to simplify manufacturing. The modular design allows for easier assembly, testing, inspection, redesigning and maintenance.

Use standard components: The SRB consist of almost all standard components. These components are cheaper than custom components and are also widely available.

Design parts to be multi-functional: Where possible it was tried to design parts to be multifunctional. For example, the sensor module of the SRB has a wave guide mount that can both position and fasten the wave guide.

Design parts for multi-use: The SRB was designed to use parts that are the same but can be used for different purposes. For example, the input and overflow parts are the same and the GEKA connectors used for connecting the valve to the hose are the same connector that the user can use to connect a garden supply to the output hose of the SRB.

Design for ease of fabrication: The parts that were custom designed for the SRB are designed to require the least amount of extra work in order to construct them in to DIY ready modules. This is for example done in the 3D models that are 3D printed. The screwing thread in these 3D models have been designed so they do not need polishing before they can be screwed together.

Avoid separate fasteners: Fasteners like screws have been avoided in the design of the SRB. For example, the sensor module uses a conical connector to connect to the wave guide, no separate fasteners are needed.

Minimize assembly directions: The SRB does not follow this design rule very well. Since the SRB mostly uses standard components it was not possible to design the system in a way that all parts can be assembled from only one direction.

Maximize compliance: The design uses qualitatively good and robust parts. These parts will not easily break during or after the DIY assembly.

Minimize handling – The SRB doesn’t follow this design rule very well. Because the SRB mainly uses standard components it was not possible to alter these components to give them arrows or directions for self-assembly. This could of course be done using stickers but this would require extra work in preparing the parts to go into the SRB assembly kit. Instead of putting assembly clues on the parts it was chosen to give these clues in the assembly manual.

7.3.2 Evaluating assembly complexity

Symmetrical planes: Because of the use of standard components it was not possible to follow this design rule. As explained before the assembly manual will contain clues for assembly and the orientation of parts.

Novel assemblies: The number of unique assembly steps was kept low in the design of the SRB in order to lower the difficulty of the assembly. This is done by following the same rules in multiple assembly steps. For example, all parts that are directly connected to the buffer follow the rule that the rubber must be on the inside of the barrel.

Selections: This design rule is not implemented in the Design of the SRB but in the design of the instruction manual.

Fastening points: Since the SRB uses a standard rain barrel it was not possible to provide any pre-drilled holes. These holes have to be drilled by the user, making the difficulty level of the assembly higher.

Fastenings: Only two types of fastenings are used. Parts can either be screwed on or screwed thigh.

Parts: As pointed out before in the evaluation in the rules on design for assembly, the amount of parts is minimized by the use of modules and multifunctional parts.

7.3.3 Conclusion

Based on the rules on design for assembly and assembly complexity it can be concluded that most aspects of the design are DIY friendly. But there are some aspects that could be improved. The biggest improvement in the design could be made by using a custom designed barrel. A barrel that has predefined holes that allows parts to be connected from only one direction would have a big impact on lowering the assembly complexity.

7.4 Software tests

The software of the system was also tested this was done by testing each function individually and by testing the complete system in different scenarios. The first scenario that the systems was tested in was by installing the system and letting it run for 2 weeks. Unfortunately, there was no rain in the two weeks that the barrel was tested but there were still some important results found. The first thing that was found is that water quality guard works properly. After 10 days the risk for legionella became too high and the system automatically drained the buffer. It was also found that the threshold 0.25 liter that was used to determine if water was drained by the manual tap is too low. The measured values deviated too much, resulting in false manual discharges. After the threshold was changes to 1 liter the problem was solved.

The second situation that the system was test in was by shutting down the central data repository for 3 days. Normally when the central data repository is online the SRB will every 15 minutes send its status updates, which are generated every minute. When the central data repository is offline the SRB will store its status data locally. After 3 days the SRB was still working as intended. Once the central data repository came back online the SRB send all the collected measurement to the central data repository at once. Both the SRB and central data repository could handle this perfectly fine. But for the future it is important the think about what would happen if for example 10 000 SRBs would send all of their measurements for the past few days to the central data repository at once. The SRBs will be able to handle this but the capacity of the central data repository might not be big enough. Maybe it might be needed that the uploads by the SRBs must be coordinated if this would happen.

7.5 Stakeholder feedback

Finally, the stakeholders were also asked for feedback on the final prototype. The municipality was very pleased with the design of the final prototype. They were satisfied with the end result. They pointed out the system is very robust and practical. They could also imagine this design being placed in a garden. The final remark that they made is that they would prefer the system to be solar powered. This would give the installation a more environmentally friendly image and it would make the placement of the buffer more flexible.

The stakeholders from the university were also satisfied with the end product but they pointed out the it might be a problem if people want to get to the computing unit which is located in the base of the barrel if the barrel is filled with water. The computing unit can only be reached if the barrel is empty. In most cases this will not be a problem but if people for example want the change the Wi-Fi connection of the barrel than the barrel must be emptied in order to be able to press on the Wi-Fi reset button. This could for instance be solved by moving the button or by allowing the user to change the Wi-Fi settings via the user interface.

Next to the municipality and the university also the possible end users were asked to give feedback on the design of the buffer. In total 15 possible end users were asked on their opinion on the buffer. The first thing that became clear is that user still see it as a basic rainwater buffer, but with extra functionalities. All users agreed that the design is durable, and 92 percent of the potential users would consider placing the buffer in their garden. 2 persons indicated that they like the concept, but they would like to pick their own rain barrel instead of the barrel that is provided. Finally, all users showed interest in a solar powered SRB instead of an SRB with a power plug.

Conclusion

Overall the end product was received very well by the end users, but some small remarks were made on some of the design choices. All stakeholders agreed that a solar powered SRB would be interesting, but the reliability of the system must not be influenced by this. Next to that it was also found that there is some interest in an SRB concept that allows users to user their own rain barrel.

8 CONCLUSION AND RECOMMENDATIONS

This chapter presents the overall conclusion of this graduation project. The research question that is stated in chapter 1.2 is answered. Finally, recommendations for future research and development of the smart rainwater buffer are given.

8.1 Conclusion

This graduation project presents the development of a smart rainwater buffer that can be placed in the gardens of the inhabitants of Enschede. The SRB provides a solution for the problem of flooding in the city of Enschede caused by climate change and urbanization. The goal of the SRB is to reduce the strain on the sewage system. It does this by buffering the water during rainfall and releasing it on a less critical time in the sewage system or in the garden. There was some previous research done on the potential of the concept of the SRB which concluded that there is indeed a demand for a smart rainwater buffer not only by the municipality of Enschede but also by its inhabitants. This research also showed that in this stage of the product there is demand for a Do It Yourself smart rainwater buffer. That is why the goal of this graduation project was to redesign the SRB to be consumer ready. The research question that was formulate at the start of the project was: "How to develop a DIY and consumer ready Smart Rainwater Buffer for deployment in the city of Enschede?".

The first steps that were taken in answering this research question were to conduct a literature study and state of the art research. The literature research resulted in guidelines on "Design for DIY". These guidelines have been used throughout the project to ensure that the system is DIY friendly. The state of the art research showed that the research was still novel because there are no other solutions on the market or publicly in development that had the same goal as the to be developed SRB. Namely, solving flooding issues in the city by developing a DIY and consumer ready smart rainwater buffer.

Next the stakeholders were involved in the design process to collect requirements on the to be developed solution. These requirements were used to ideate serval concepts. The final concept that was chosen by the stakeholders was an SRB in the form of a DIY rain barrel that can be placed in the garden of an inhabitant of the city of Enschede. The design must be simple and robust and must by universal to fit in every type of garden. Next to that the system must work fully autonomous and should require low maintenance. The buffer uses precipitation prediction sources to control the system and it also takes into account the protection of the user and the system.

Once the concept and the requirements were finalized the SRB was realized. The SRB was designed following the Design for DIY methods specified in chapter 2. The design uses as much standard components as possible, next to that it was verified that all components are of good quality and will be durable enough for self-assembly by the user. It was also found that a good sensor module design is crucial for the reliability of the system. Literature research on sensing methods was conducted and gave insight in what sensor to use. It was decided to use ultrasonic sensors for the fluid level measuring in the barrel. Ultrasonic sensors are reliable but also very cost effective. But ultrasonic sensors are also very prone to errors because of noise originating from the measurement surroundings. Literature research was done on improving ultrasonic sensors and it was found that wave guide are the best solution. Several wave guide designs were proposed but the full-length pipe wave guide was the most suitable solution for the SRB. This wave guide made the sensor module universal to use in any type of buffer, making this sensor module not only usable for this version of the SRB but also compatible with future versions using different kind of barrels.

Furthermore, there was also a literature research conducted on the data communication technologies suitable for smart city IoT, especially focused on the SRB. It was found the public long-range networks are the most promising technologies to use because these networks are very reliable and do not need a manual setup by the end user. The most promising long-range network that was found is NB-IoT. Unfortunately, the necessary hardware to connect to the NB-IoT network available in the Netherlands was not available at time of conducting this research and it was decided to use an alternative. The sort range data communication technology Wi-Fi was selected as alternative because most inhabitants in the Netherlands already have their own private Wi-Fi network. The downside of using Wi-Fi is that the SRB becomes reliable on the private network infrastructure of the user for which the quality cannot be guaranteed.

The buffer was programmed to be as autonomous and reliable as possible. This was done by providing the system with advanced measurement functions and implementing a backup system for precipitation predictions. The backup system allows the system to stay operational for 2 days if the connection to the precipitation prediction sources is lost. The buffer also takes into account the indirect effects of the weather, in order to protect the user and the system itself. The system guard to user for a too high legionella risk and also protects the system from getting damaged if it is freezing.

The evaluation of the system showed that the concept is indeed DIY friendly and that the system operates as intended. By concluding all results discussed above an answer to the research question can be given. A DIY and consumer ready Smart Rainwater Buffer for the deployment in the city of Enschede can be developed by following the guidelines on Design for DIY, using a reliable sensor module and network connection, and using a controller that is able to run the system autonomous and reliable. Nevertheless, the best way to prove if the Design is DIY friendly, consumer ready, and reliable is by testing it in a pilot project with real users in a real use case scenario. More on this is discussed in the next section on recommendations.

8.2 Recommendations

Several recommendations can be giving on the research and development of the DIY and consumer ready Smart Rainwater Buffer. In order to prove that the Design is DIY friendly, consumer ready, and reliable it is recommended to start a pilot project with real users building and using the SRB. By testing the system in a real scenario with a real user it can really become clear if the product is ready to be used by the inhabitant of Enschede.

Next to that it is also recommended to continue the research in using NB-IoT. NB-IoT is being developed very fast and more and more hardware is becoming available. The use of NB-IoT could make the system even more user friendly. With the use of NB-IoT a manual network setup by the user is no longer required. Potentially NB-IoT could also be used for getting the location of the buffer, which could bring the SRB one step closer to not needing any type a manual setup by the user itself, making the system less dependent on the user.

It was also found that the stakeholders prefer the system to be power by solar power. This would make the system more flexible and less reliant on the location of a power plug. Next to that it would also give the SRB a more environmentally friendly image. But when powering the system with solar power it is important the this will not influence the reliability of the system. The power source should be able to provide the system with enough power to let the system continuously run in every type of weather.

Finally, it is recommended to research what modifications the system needs in order to get certified to be sold to inhabitants in Enschede.

References

[1] V. R. Golroudbary, "Trends in rainfall extremes over the Netherlands: changes due to climate and urbanization," 2013 - 2017. [Online]. Available: https://www.itc.nl/Pub/WCC/WCC-projects/PhD-project-Trends-in-rainfall-extremes-over-the-Netherlands-changes-due-to-climate-and-urbanization.html.

[2] S. Anand and M. Anand, "Smart Cities: Environmental Challenges and Green Computing," *International Journal of Advanced Research in Computer Science,* pp. 221-226, 2017.

[3] Twenty-Twente, "ENSCHEDE WORDT EEN SMART CITY," 16 03 2017. [Online]. Available: https://www.twente.com/twenty-twente/enschede-wordt-een-smart-city/. [Accessed 05 04 2018].

[4] CBS , „Bevolkingsontwikkeling; regio per maand; Enschede," 28 Feb 2018. [Online]. Available: https://opendata.cbs.nl/statline/#/CBS/nl/dataset/37230ned/table?ts=1520774007776.

[5] Gemeente Enschede, "Water in Enschede: feiten, cijfers en trends," Gemeente Enschede, 2012.

[6] Waterschap Vechtstromen, "KlimaatActieve Stad (KAS)," 2016. [Online]. Available: https://www.vechtstromen.nl/over/klimaat/klimaatactieve/. [Accessed 05 04 2018].

[7] M. Zuithof, "Waterbeheer centraal in klimaat adaptieve stad," *Vitale groene stad,* vol. 05, no. 02, 2017.

[8] H. J. Teekens, Composer, *Slimme regenton van UT voert water af voor regenbui.* [Sound Recording]. Tubantia. 2017.

[9] Gemeente Enschede, "Slimme regenton," 2017. [Online]. Available: https://www.enschede.nl/duurzame-daad/slimme-regenton.

[10] G. Steeghs, "Developing a smart rainwater buffering system for the municipality of Enschede," University of Twente, Enschede, 2017.

[11] F. Rindt, "DEVELOPING A SMART RAINWATER BUFFERING SYSTEM FOR THE CITIZENS OF ENSCHEDE," University of Twente, Enschede, 2017.

[12] B. Vetter, "Designing a Smart Rainwater Buffer," University of Twente, Enschede, 2017.

[13] D. Defize, "Climate Active City Enschede," University of Twente, Enschede, 2018.

[14] J. Groeneveld, "Inhoud Smart Rain Water Buffer," University of Twente, Enschede, 2018.

[15] Buienradar, "Gratis Weerdata," Buienradar, 2018. [Online]. Available: https://www.buienradar.nl/overbuienradar/gratis-weerdata. [Accessed 05 04 2018].

[16] M. Richardson, "Errors, accidents and self-assembly products," *Contemporary Ergonomics,* vol. 10, no. 305, 2007.

[17] M. Richardson, "Assembly Complexity and the design of self-assembly products," in *Human Factors and Ergonomics in Consumer Product Design: Methods and Techniques*, CRC Press, 2011, pp. 187-200.

[18] T. C. Chang, R. A. Wysk and H. P. Wang, Computer-Aided Manufacturing, 2e ed., Pearson Education Limited, 1997, pp. 596-598.

[19] M. Richardson, G. Jones, M. Torrance and T. Baguley, "Identifying the task variables that predict object assembly difficulty," *Human Factors,* 2006.

[20] M. Madan, T. Bramorski and R. P. Sundarraj, "The effects of grouping parts for ready-to-assemble products on assembly time: An experimental study," *International Journal of Operations and Production Management,* pp. 39-49, 1995.

[21] B. Sala, "Studio Bas Sala," 2017. [Online]. Available: http://www.slimmeregenton.nl. [Accessed 05 05 2018].

[22] RiverSides, "RiverSides," [Online]. Available: http://www.riversides.org/. [Accessed 05 05 2018].

[23] RainGrid, "RainGrid," [Online]. Available: https://www.raingrid.com/. [Accessed 05 05 2018].

[24] RainGrid, " RainGrid Cistern Manual," 06 2016. [Online]. Available: https://www.raingrid.com/wp-content/uploads/2016/08/RainGrid-Cistern-InstallationAndOperationGuide-June2016.pdf. [Accessed 05 05 2018].

[25] Opti, "Opti," [Online]. Available: https://optirtc.com/. [Accessed 05 05 2018].

[26] M. Quigley, "Opti," OptiRTC, 22 03 2018. [Online]. Available: https://optirtc-cso.com/. [Accessed 22 03 2018].

[27] P. Schuster, "Rainwater Harvesting – The Smart Way!," 12 02 2014. [Online]. Available: https://www.loxone.com/enen/rainwater-harvesting/. [Accessed 05 05 2018].

[28] P. Schuster, "Rainwater Harvesting – The Smart Way!," 12 02 2014. [Online]. Available: https://www.loxone.com/enen/rainwater-harvesting/.

[29] Catapult Future Cities, "Smart Rainwater Management System – Over The Air Analytics (OTA)," [Online]. Available: http://futurecities.catapult.org.uk/smart-rainwater-management-system-ota/. [Accessed 05 05 2018].

[30] Catapult, "Smart Rainwater Management System – Over The Air Analytics (OTA)," 21 07 2017. [Online]. Available: http://futurecities.catapult.org.uk/smart-rainwater-management-system-ota/.

[31] Graf, "Rainwater harvesting systems," [Online]. Available: http://www.graf-water.com/rainwater-harvesting.html. [Accessed 05 05 2018].

[32] S.A.R.G water solutions, "Underground Water Storage Tanks - Modular," [Online]. Available: http://sargwatersolutions.com/modular-underground-water-tanks.html. [Accessed 05 05 2018].

[33] Atlantis, "Atlantis Rainwater Harvesting Tank System," [Online]. Available: https://www.atlantis-america.com/?page_id=12061. [Accessed 05 05 2018].

[34] D. t. Good, Director, *Top 7 Mistakes to Avoid when Harvesting Rain Water.* [Film]. United States.2016.

[35] G. Hiebert, Director, *Building a Rain Barrel - Easy as 1, 2, 3.* [Film]. Canada: Okanagan WaterWise, 2012.

[36] A. H. Mader and W. Eggink, "A Design Process for Creative Technology," *Proceedings of the 16th International conference on Engineering and Product Design,* pp. 568-573, 2014.

[37] C. J. Jones, Design methods, London: Wiley-Interscience, 1970.

[38] J. M. Bryson, "What to do when stakeholders matter," *Public Management Review,* vol. 1, no. 6, pp. 21-53, 2004.

[39] H. Sharp, A. Finkelstein and G. Galal, "Stakeholder Identification in the Requirements Engineering Process," *DEXA '99 Proceedings of the 10th*

International Workshop on Database & Expert Systems Applications, vol. 10, no. 99, pp. 387-392, 1999.

[40] R. Thompson, "Stakeholder Analysis," 2018. [Online]. Available: https://www.mindtools.com/pages/article/newPPM_07.htm. [Accessed 26 4 2018].

[41] A. L. Mendelow, "Environmental Scanning--The Impact of the Stakeholder Concept," *International Conference on Information Systems,* pp. 407-417, 1981.

[42] D. Haughey, "MoSCoW Method," 2014. [Online]. Available: https://www.projectsmart.co.uk/moscow-method.php. [Accessed 27 4 2018].

[43] P. L. Eide, Quantification and Traceability of Requirements, Trondheim: Norwegian University of Science and Technology, 2005.

[44] J. Van Helver and C. Fowler, "Scenario-based User Needs Analysis," *Chimera Working Paper,* vol. 2003, no. 02, 2003.

[45] I. Widya, R. G. Bults, M. Huis in 't Veld and M. M. R. Vollenbroek-Hutten, "Scenario-based Requirements Elicitation in a Pain-teletreatment Application," *Proceedings of the ICSOFT 4th. International Conference on Software and Data Technologies,* vol. 4, no. 2, pp. 406-413, 2009.

[46] D. Benyon and C. Macaulay, "Scenarios and the HCI-SE design problem," *Interacting with Computers,* no. 14, pp. 397-405, 2002.

[47] R. M. Huis in ’t Veld, I. A. Widya, R. G. Bults, L. Sandsjo, H. J. Hermens and M. M. Vollenbroek-Hutten, "A scenario guideline for designing new teletreatments: a multidisciplinary approach," *Journal of Telemedicine and Telecare,* no. 16, p. 302–307, 2010.

[48] V. Trulock, "PACT Analysis," 12 08 2005. [Online]. Available: http://hci.ilikecake.ie/requirements/pact.htm. [Accessed 29 04 2018].

[49] H. Faste, N. Rachmel, R. Essary and E. Sheehan, "Brainstorm, chainstorm, cheatstorm, tweetstorm: New ideation strategies for distributed HCI design," *Conference on Human Factors in Computing Systems - Proceedings,* vol. 31, pp. 1343-1352, 2013.

[50] A. Bryman, Social research methods, 4e ed., New York: Oxford University Press, 2012.

[51] uml-diagrams.org, "Activity Diagrams," uml-diagrams, [Online]. Available: https://www.uml-diagrams.org/activity-diagrams.html. [Accessed 15 05 2018].

[52] Enschede, "Duurzaamheid," 2018. [Online]. Available: https://www.ruimtelijkeplannen.enschede.nl/NL.IMRO.0153.SV00001-0003/b_NL.IMRO.0153.SV00001-0003_6.6.1.html. [Accessed 27 4 2018].

[53] E. M. Rogers, Diffusion of innovation, Simon and Schuste, 2010.

[54] Rainwinner, "The Rainwinner," [Online]. Available: http://www.rainwinner.nl/. [Accessed 16 05 2018].

[55] deduurzametuin, "Rainwinner," [Online]. Available: https://www.deduurzametuin.nl/winkel/tuinmaterialen/rainwinner-set-van-3/. [Accessed 16 05 2018].

[56] Enexis, "Richtlijnen meterkast en bouwkast," 2016. [Online]. Available: https://www.enexis.nl/over-ons/documenten-en-publicaties/richtlijnen-meterkast-en-bouwkast. [Accessed 19 05 2018].

[57] Y. Li, X. Cheng, Y. Cao, D. Wang and L. Yang, "Smart Choice for the Smart Grid: Narrowband Internet of Things (NB-IoT)," *IEEE INTERNET OF THINGS JOURNAL,* 2017.

[58] Ericsson, "Cellular networks for massive IoT," White paper, 2016.

[59] U. Raza, P. Kulkarni and M. Sooriyabandara, "Low Power Wide Area Networks: An Overview," *IEEE COMMUNICATIONS SURVEYS & TUTORIALS,* pp. 855-873, 2017.

[60] W. Zhai, "Design of narrowband-IoT oriented wireless sensor network in urban smart parking," *International Journal of Online Engineering,* Vols. Volume 13, Issue 12, pp. 116-126, 2017.

[61] J. M. Marais, R. Malekian and A. M. Abu-Mahfouz, "LoRa and LoRaWAN testbeds: A review," *2017 IEEE AFRICON: Science, Technology and Innovation for Africa,* pp. 1496-1501, 2017.

[62] Y. Song, J. Lin, M. Tang and S. Dong, "An Internet of Energy Things Based on Wireless LPWAN," *Engineering 3,* pp. 460-466, 2017.

[63] S. E. Bibri, "The IoT for smart sustainable cities of the future: An analytical framework for sensor-based big data applications for environmental sustainability," *Sustainable Cities and Society 38,* pp. 230-253, 2018.

[64] R. S. Iborra, S. J. Gomez, J. B. Viñas, M. D. Cano and A. . F. Skarmeta, "Performance Evaluation of LoRa Considering Scenario Conditions," *Sensors,* 2018.

[65] B. Vejlgaard, M. Lauridsen, H. Nguyen, I. Z. Kovács, P. Mogensen and M. Sørensen, "Coverage and Capacity Analysis of Sigfox, LoRa, GPRS, and NB-IoT," in *IEEE Vehicular Technology Conference* , Australia, 2017.

[66] F. Adelantado, X. Vilajosana, P. Tuset-Peiro, B. Martinez, J. Melià-Seguí and T. Watteyne, "Understanding the Limits of LoRaWAN," *IEEE Communications Magazine,* Vols. Volume 55, Issue 9, pp. 34-40, 2017.

[67] 3GPP, "Progress on 3GPP IoT," The 3rd generation partnership project, 29 02 2016. [Online]. Available: http://www.3gpp.org.

[68] W. Yang, M. Wang, J. Zhang, J. Zou, M. Hua, T. Xia and X. You, "Narrowband Wireless Access for Low-Power Massive Internet of Things: A Bandwidth Perspective," *IEEE Wireless Communications,* no. Volume 24, Issue 3, pp. 138-145, 25 may 2017.

[69] M. D. Cano and R. S. Iborra, "State of the Art in LP-WAN Solutions for Industrial," *Sensors,* 2016.

[70] A. Augustin, J. Yi, T. Clausen and W. M. Townsley, "A Study of LoRa: Long Range & Low Power Networks for the Internet of Things," *Sensors,* 2016.

[71] F. Bonavolontà, A. Tedesco, R. S. L. Moriello and A. Tufano, "Enabling wireless technologies for Industry 4.0: State of the Art," *2017 IEEE International Workshop on Measurement and Networking,* 2017.

[72] Aerea, "Aerea Sigfox IOT network," [Online]. Available: http://www.aerea.nl/. [Accessed 10 05 2018].

[73] S. Al-Sarawi, M. Anbar, K. Alieyan and M. Alzubaidi, "Internet of Things (IoT) Communication Protocols : Review," *International Conference on Information Technology (ICIT),* 2017.

[74] A. B. A. Rahman, "Comparison of Internet of Things (IoT) Data Link Protocols," *Washington University in St. Louis,* pp. 1-21, 2015.

[75] M. W. Ahmad, M. Mourshed, D. Mundow, M. Sisinni and Y. Rezgui, "Building energy metering and environmental monitoring – A state-of-the-art review and directions for future research," *Energy and Buildings,* vol. 2016, no. 120, pp. 85-102, 2016.

[76] Y. Chen and D. Han, "Water quality monitoring in smart city: A pilot project," *Automation in Construction,* no. 89, pp. 307-316, 2018.

[77] H. Hopper, "A Dozen Ways to Measure Fluid Level and How They Work," 1 12 2004. [Online]. Available: https://www.sensorsmag.com/components/a-dozen-ways-to-measure-fluid-level-and-how-they-work.

[78] S. B. Reddy, "Operationg Priciple of Displacer Level Sensors," 03 2013. [Online]. Available: http://www.instrumentationtoolbox.com/2013/03/operating-principle-of-displacer-level.html#axzz5AUoG4uFj.

[79] Automation Wiki, "Bubbler Level Measurement," 25 03 2010. [Online]. Available: http://automationwiki.com/index.php?title=Bubbler_Level_Measurement.

[80] Automation Wiki, "Differential Pressure Level Measurement," 10 06 2017. [Online]. Available: http://automationwiki.com/index.php/Differential_Pressure_Level_Measurement.

[81] Automation Wiki, "Load Cell," 24 02 2010. [Online]. Available: http://automationwiki.com/index.php/Load_Cell.

[82] Pepperl+Fuchs, "The pulse of automation: Technology Guide," 2018.

[83] Siemens, "Ultrasoinc sensor systems," [Online]. Available: https://w3.siemens.com/mcms/sensor-systems/en/process-instrumentation/level-measurement-with-level-measuring-instruments/continuous/ultrasonic/pages/ultrasonic.aspx. [Accessed 29 05 2018].

[84] Siemens, "Siemens Ultrasonic Level Measurement," 2017.

[85] Siemens, "What is Auto False-Echo Suppression," 2017.

[86] Pulsar Process Measurement, "Echo Detection with DATEM echo processing software," [Online]. Available: https://www.pulsar-pm.com/instrumentation/technologies/echo-processing.aspx. [Accessed 30 05 2018].

[87] FlowLine, "Ultrasonic Level Sensor Beam Width Explained," Liquid Level Solutions, 2011.

[88] Flood Network, "Oxford Flood Network Sensor build," [Online]. Available: https://flood.network/. [Accessed 30 05 2018].

[89] NPX, "Enabled Ultrasonic Distance Measurement," 03 2014. [Online]. Available: https://www.nxp.com/docs/en/application-note/AN4841.pdf. [Accessed 30 05 2018].

[90] Murata, "Ultrasonic Sensor Open Structure Type," 10 2016. [Online]. Available: https://www.murata.com/~/media/webrenewal/products/sensor/ultrasonic/open/applinote_maopn.ashx?la=en. [Accessed 30 05 2018].

[91] Lesman Tech Tips, "Does ultrasonic level measurement work with a standpipe?," 29 04 2014. [Online]. Available: https://blog.lesman.com/2014/04/29/does-ultrasonic-level-measurement-work-with-a-standpipe/. [Accessed 30 05 2018].

[92] Omega, "Applying Ultrasonic Level Sensors in Life Science Pre-Treatment," [Online]. Available: https://www.omega.com/technical-learning/ultrasonic-level-transmitters-in-life-science-pre-treatment.html. [Accessed 30 05 2018].

[93] APG, "How To Make A Standpipe And Wave Guide For Your Ultrasonic Sensor," 16 10 2013. [Online]. Available: https://www.apgsensors.com/about-us/blog/how-to-make-a-standpipe-and-wave-guide-for-your-ultrasonic-sensor. [Accessed 30 05 2018].

[94] Global Water, "Ultrasonic level sensors," [Online]. Available: http://www.globalw.com/support/ultrasonic.html. [Accessed 30 05 2018].

[95] Jon's Blog, "Arduino Nano Ultrasonic Level Sensor Tutorial," 12 10 2017. [Online]. Available: https://chemejon.wordpress.com/2017/10/12/arduino-nano-ultrasonic-level-sensor-tutorial-hc-srf05/. [Accessed 30 05 2018].

[96] S. Wielenberg, "Using an Ultrasonic Sensor Inside of a Pipe," 11 07 2016. [Online]. Available: https://www.maxbotix.com/Tutorials/124.htm. [Accessed 30 05 2018].

[97] S. Hicks, "Ultrasonic water depth sensor," 07 08 2014. [Online]. Available: https://www.envirodiy.org/ultrasonic-water-depth-sensor/. [Accessed 30 05 2018].

[98] D. Green, "Legionella: The Invisible Killer," *IOSH London Metropolitan Branch Meeting,* pp. 1 - 5, 2013.

[99] Freerain Ltd, "Is Legionella problem for rainwater harvesting systems?," 05 12 2008. [Online]. Available: http://rainwater-harvesting-systems.blogspot.com/2008/12/is-legionella-problem-for-rainwater.html. [Accessed 30 05 2018].

[100] P. Díaz, F. Royo, T. Olivares, F. R. Mireles and L. O. Barbosa, "A Case Study on the Power-Aware Protocol Framework for wireless sensor networks," *International Journal of Distributed Sensor Networks,* vol. 12, no. 9, 2013.

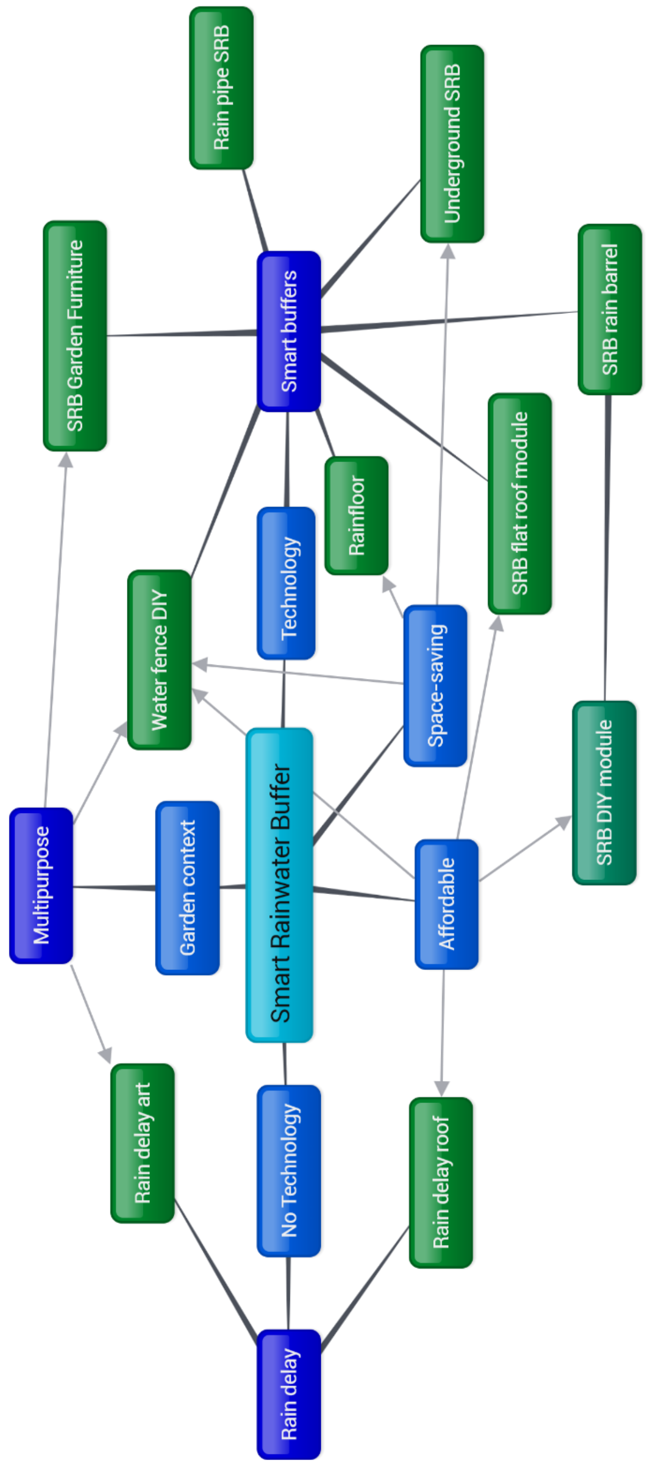
[101] R. Shi and Y. Li, "An intelligent solar energy-harvesting system for wireless sensor networks," *Journal on Wireless Communications and Networking,* vol. 2015, no. 179, 2015.

[102] R. IJzermans, "DS18B20 waterdichte temperatuur sensor aansluiten op Raspberry Pi," 01 08 2017. [Online]. Available: https://raspberrytips.nl/ds18b20-raspberry-pi/. [Accessed 20 06 2018].

[103] 4G-dekking, "4G-dekking T-Mobile," 2018. [Online]. Available: https://www.4gdekking.nl/alles-over-4g. [Accessed 30 06 2018].

APPENDIX

A. Result Brainstorm



B. Barrel comparison

Barrel	Specs	Pros and cons	Supplier	Price
	- 300 liters - Rectangular - Tap - Base - Lid - 122 x 80 x 66 cm	**+ Large capacity** **+ Made of 100% plastic** **+ Relatively low price** **+ Made in Germany** **+ 100% recyclable** **+ Easy to install** **+ Also available in bigger and smaller size** - No predrilled holes besides hole for the tap	Hornbach	€ 58,-
	- 320 liters - Rectangular - Tap - Lid - 135 x 60 x 40 cm - Level indicator	**+ Large capacity** **+ Space saving** - Leaks - Tap placement not ideal - No base - Not flat inside - Predrilled holes are to small	Warentuin.nl	€ 135,-
	- 300 liters - Round - Tap - Planter on top	**+ Large capacity** **+ Multi-functional** **+ Design fits in context of garden** **-** Relatively high price - No base - No flat sides - No predrilled holes besides hole for the tap	Formido	€ 205,-

	- 280 liters - Rectangular - Tap - Lid - Base - 152 x 52 x 52 cm	**+ Space saving** **+ Base** - Low quality - No flat sides - Less attractive design	kunststofregenton.nl	€ 100,-
	- 350 Liters - Round - Tap - 2 predrilled holes - 120 x 78 cm	**+ Large capacity** **+ Good quality** **+ 2 predrilled holes** - Not space saving - No base - No flat sides	Voertonnen.nl	€ 150,-
	- 380 liters - Foldable - Lightweight - 100 x 70 cm	**+ Easy shipping** **+ Large capacity** - Lower quality - No option to drill extra holes - No lid - No base - Not durable	kunststofregenton.nl	€ 150,-
	- 227 liters - Lid - Tap - 96 x 60	**+ Base** - No flat sides	kunststofregenton.nl	€ 90,-

	- 275 liters - Tap - 105 x 80 x 40 cm	**+ Space saving** **+ Fits in context of garden** **-** Relatively high price - No base - No predrilled holes besides hole for the tap	kunststofregenton.nl	€ 260,-
	- 200 Liters - Planter on top - Tap - Extra hole - 105 x 60 cm	**+ Large capacity** **+ Multi-functional** **+ Nice design** **+ Good quality** - No base - No flat sides	Elho.com	€ 130,-
	- 800 liters - Foldable - 110 x 110 cm - Wood - frost resistant	**+ Frost resistant** **+ Easy shipping** **+ Fits in context of garden** **+ Large capacity** **+ Good quality** - No option to drill extra holes - No lid - No base	Magazijnblijdorp.nl	€ 250,-
	- 300 liters - 117 x 60 x 68 - 2 predrilled holes - Lid	**+ Large capacity** **+ Good quality** **+ 2 predrilled holes** **+ Flat back** **+ Flat sides** **+ Space saving** - No base	Tuinadvies.nl	€ 120,-

C. Relevant IoT networking projects

This section contains an overview of the available IoT networks in Enschede.

NB-IoT by T-Mobile

T-Mobile is the first provider in the Netherlands that has country wide NB-IoT coverage. For approximately 1 euro a month per connection the network can be used. The use of the network is sim based so every device should be equipped with a sim card. T-Mobile allows 120 messages per day. For the SRB that would mean 5 messages per hour. For more information see the T-Mobile NB-IoT webpage[5].

LoRa by KPN

LoRa by KPN has full coverage across the Netherlands. The company has not published the prices for the use of the network. SIMPoint a reseller of KNP LoRa does have prices published. SIMPoint provides Postpaid subscriptions and prepaid products. A postpaid subscription with 9000 uplinks and 900 downlinks costs between 1,20 and 1 euro per month per device. A prepaid bundle of 109500 uplinks and 9000 downlinks cost 16,30 euro per year per device. For more information see the SIMPoint website[6] and the KPN LoRa website[7].

LoRa by The Things Network

The Things Network is a community based LoRa network. The platform is completely open, everyone is allowed to use it. The downside of the network is that they want to keep the downlink at a minimum. The things network has a Fair Access Policy that limits the uplink airtime to 30 seconds per day (24 hours) per node and the downlink messages to 10 messages per day (24 hours) per node. This is a problem because the SRB needs to download prediction data more than 10 times a day. For more information see the The Things Network website[8].

SigFox by SigFox

The SigFox network provided by SigFox is a low power wide area network that has country wide coverage in the Netherlands. The pricing of SigFox depends on the volume of devices. Ranging from 1 euro per device per month to 1 euro per device per year. SigFox allows 140 messages per day this is because of European regulations. For more information see the SigFox website[9].

[5] https://iot.t-mobile.nl/waarom-iot
[6] https://www.simpoint.com/lora/
[7] https://www.kpn.com/zakelijk/grootzakelijk/internet-of-things/lora-netwerk.htm
[8] https://www.thethingsnetwork.org/
[9] https://www.sigfox.com/en

LTE-M by KPN
Next to LoRa KPN also offers LTE-M which has the advantage of higher data rates but the disadvantage of being less energy efficient than LoRa. The network has country wide coverage in the Netherlands. The network has just been rolled out so there are no prices available yet. For more information see the KPN LTE-M website[10].

Particle (spark)
Particle offers 3G development boards and sim cards for 69 dollars. They offer a subscription plan for 3 MB for 3 dollars per device per month. 1 MB extra will cost 0,40-dollar cents per MB. They have full coverage in the Netherlands because they use the T-Mobile network. See the Particle website for more information[11].

CheerIoT
CheerIoT provides sim card subscriptions in the form of a physical or soft sim. They provide subscriptions of ranging from 1 MB for 0,40 euro per month to 60 MB for 2 euro per month. See the CheerIoT website for more information[12].

[10] https://www.kpn.com/zakelijk/grootzakelijk/internet-of-things/lte-m-connectiviteit.htm
[11] https://www.particle.io/
[12] https://www.cheeriot.com/sim/

D. Data sources

Previous research did not elaborate why a certain weather prediction data source was used. That is why in this section the open data sources are presented. There a lots of weather institutes all around the world but only a few of them make their detailed precipitation predictions publicly available in a raw format.

Buienradar

Buienradar provides a data source with 5-minute predictions for the next 2 hours. It uses coordinates (latitude and longitude) as input. The response of the http call returns a text file. This file contains the precipitation for the next 2 hours for the given latitude and longitude. A value of 0 means it is dry and a value of 255 means heavy rainfall. Formula 1 can be used to convert this value to millimeter per hour. Buienradar gets its information from multiple sources: KNMI, MetOffice, EUMetsat, DWD, KMI, SMHI, MF.

$$Precipitation\ intensity = 10^{((value-109)/32)}$$

Formula 1: Precipitation intensity

Address:	https://gadgets.buienradar.nl/data/raintext?lat=52.09&lon=5.11
Format:	Plain text
Interval:	5 minutes for next 2 hours
Accuracy:	Coordinate based, see grid on map in figure D.1 for the maximum accuracy based on the allowed input of maximum precision of coordinates. As can be seen in figure D.1, Enschede can be divided into 6 x 4 sections.

Figure D.1: Enschede coordinate grid accuracy Buienradar. Source: Google Maps

Norwegian Meteorological Institute

The Norwegian weather institute provides an open API that allows getting forecast data based on cities. It can give forecast information for Enschede for different intervals, the smallest is 1 hour and the largest is 6 hours. The original data is provided by the Norwegian Meteorological Institute, European Centre for Medium-Range Weather Forecasts (ECMWF) and European Organization for the Exploitation of Meteorological Satellites (EUMETSAT). For more information see the API documentation of yr.no[13].

Feed 1:

Address: http://www.yr.no/place/Netherlands/Overijssel/Enschede/forecast.xml

Format: XML

Interval: 6 hour prediction for next 10 days

Accuracy: City based

Data: precipitation, wind direction, wind speed, temperature, pressure

Feed 2:

Address: http://www.yr.no/place/Netherlands/Overijssel/Enschede/forecast_hour_by_hour.xml

Format: XML

Interval: 1 hour prediction for next 2 days

Accuracy: City based

Data: precipitation, wind direction, wind speed, temperature, pressure

[13] http://om.yr.no/info/verdata/xml/

DarkSky

Darksky is an American company that uses data sources from all around the world and applies data fusion to the data to get the best weather prediction. The data sources used for predictions in Enschede are: isd, dwdpa, cmc, gfs and madis. The API request returns the forecast weather conditions hour-by-hour for the next 48 hours, and a day-by-day forecast for the next week. The location of the prediction is based on precise coordinates. For more information see the API documentation of DarkSky[14].

Address:	https://api.darksky.net/forecast/[key]/[latitude],[longitude]
Format:	JSON
Limitation:	Per day 1000 free API request, if more than $0.0001 per request.
Interval:	1 hour prediction for next 2 days and day prediction for next 7 days
Accuracy:	Coordinate based, location precise prediction(example 52.xxxx, 6.xxxx)
Data:	precipitation intensity, precipitation probability, precipitation Type, temperature, apparent temperature, dewpoint, humidity, pressure, wind gust, wind speed, wind bearing, cloud cover, UV index, visibility, ozone

Conclusion

The data with the smallest interval can be provided by Buienradar. This data is accurate enough to divide Enschede into 20 sections. The data is only providing insight in the predictions for the next 2 hours. The data also doesn't contain the precipitation probability. For the next project phases, it is worth researching if the data from Buienradar can be made more accurate by applying data fusion with the data of the other sources or data from the sensors that are placed in Enschede. The daily precipitation predictions and precipitation probability combined with the 2-hour predictions of Buienradar could possibly result in a more accurate prediction, this will be further researched in the next phases of the project.

[14] https://darksky.net/dev/docs#forecast-request

E. Part list – Final prototype

Part	Name	Supplier	Price
	Barrel + Tap 300 Liters	Hornbach	€ 35,-
	Barrel Base	Hornbach	€ 23,-
	Electronic Ball Valve 5v, DN32, CR02	CWX	€ 16,50
	Pp reservoir connector DN32	Wildkamp	€ 9,-
	Geka koppeling binnendraad 1 ¼ DN32	PVC24	€ 3,-
	Raspberry pi 3B	Farnell	€ 35,-
	Micro sd card, 8 GB, class 10	Farnell	€ 8,-

	Adafruit Perma Proto Bonnet Mini Kit	Kiwi electronics	€ 5,-
	JSN-SR04T	Your Cee	€ 7,-
	DS18b20 1 meter	HwaYeh	€ 1,-
	Waterproof button	Kiwi electronics	€ 1,-
	2 Way Relay Module With Optocoupler Protection	Kiwi electronics	€ 1,-
	Kabeltronik Stuurkabel LiYY 6 x	Conrad	€ 1,50
	2x S-lon® pvc gootuitloop met wartel 70 - 80 mm	Wildkamp	€ 10,- (1) € 20,- (2)
	VDL® vlakke epdm afdichtingsring, voor doorvoer, 3" 80 mm	Wildkamp	€ 3,- (1) € 12,- (4)
	PVC HWA bocht 70 mm	PVC voordeelshop	€ 1,40
	PVC HWA mof 60 to 70 mm	PVC voordeelshop	€ 0,90

	Productkenmerken NYLON FILTERKOUS voor bronfilter 75 mm 1 meter	PVC voordeelshop	€ 0,80
	MIKALOR RVS SLANGKLEM 60 - 80	PVC voordeelshop	€ 2,-
	Wartel M12 Polyamide Lichtgrijs (RAL 7035) TRU COMPONENTS TC-AGR12LGY4203 1 stuks	Conrad	€ 0,36 (1) € 0,72 (2)
	Super Tricoflex® pvc waterslang, 19 x 25,5 mm, l = 100 m 1 meter	Wildkamp	€ 4,60
	RIV messing koppeling met bajonetaansluiting, type 3302, 1x slangtule, 20 mm	Wildkamp	€ 4,- (1) € 8,- (2)
	Mikalor® verzinkte wormschroef slangklem, 16 - 27 mm	Wildkamp	€ 0,50 (1) € 1 ,- (2)
	Hammond Electronics RP1085C Universele behuizing 105 x 75 x 40 ABS Lichtgrijs	Conrad	€ 11,50
	5v	Farnell	€ 7,70
	Stroom Kabel HAWA 1008278 Zwart 5.00 m	Conrad	€ 5,-

	Kabelschoen (rond) Bus, recht Serie (ronde connectors): SP13 Totaal aantal polen: 3 SP1310 / S 3 I Weipu 1 stuks	Conrad	€ 4,50
	Kabelschoen (rond) Stekker, inbouw Serie (ronde connectors): SP13 Totaal aantal polen: 3 SP1312 / P 3 Weipu 1 stuks	Conrad	€ 4,50
	Kabelschoen (rond) Bus, recht Serie (ronde connectors): SP13 Totaal aantal polen: 4 SP1310 / S 4 I Weipu 1 stuks	Conrad	€ 4,50
	IP68-connector serie SP13 Apparaatstekker voor frontmontage Weipu SP1312 / P 4 IP68 Aantal polen: 4	Conrad	€ 4,50
	Kabelschoen (rond) Bus, recht Serie (ronde connectors): SP13 Totaal aantal polen: 6 SP1310 / S 6 I Weipu 1 stuks	Conrad	€ 4,50
	IP68-connector serie SP13 Apparaatstekker voor frontmontage Weipu SP1312 / P 6 IP68 Aantal polen: 6	Conrad	€ 4,50
	Total:		€ 235,62

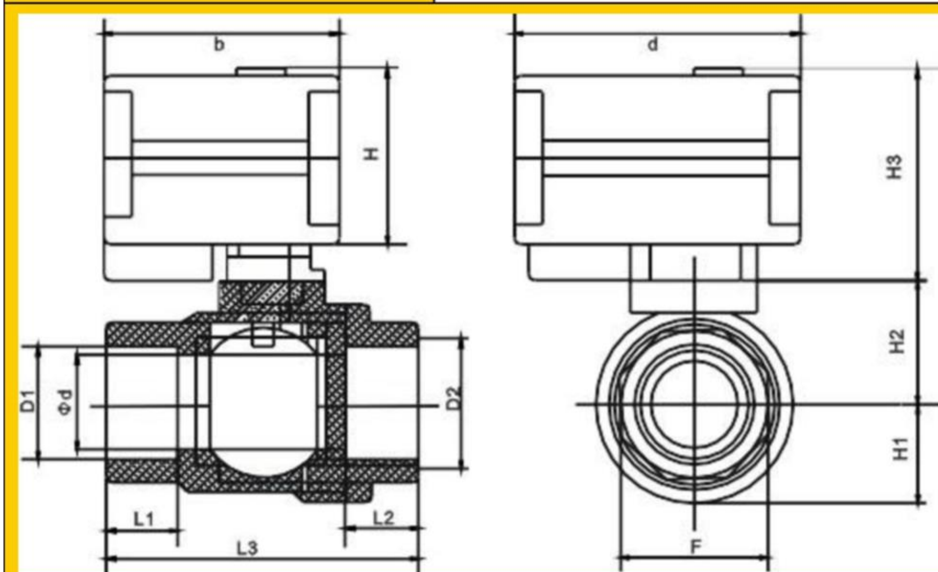
F. Valve specifications

CWX-15 SERIES 2-WAY MOTORIZED VALVE (BRASS)

TECHNICAL PARAMETERS

Series	Max torque	Operating time	Working voltage	Max power	Enclosure	Max pressure	Medium temperature	Ambient temperature
CWX-15	2N.m	3-5S	DC5V AC/DC9-24V AC85-265V	<2W	IP65	1 Mpa	0-100℃	-20℃<t<45℃

FEATURES	APPLICATION
Mini dimension suit for small equipment	HVAC
Patented technology-floating seal structure	Water treatment
Long service life: 80000-100000 circles	Chemical process
Low working current, suitable for battery driving	Small equipment for automatic Control
Quickly open and position indicator	Replacing solenoid valve, particularly when solenoid can't work reliably
Metal gearbox and POM gear	
High flow capability	



PARTS	MATERIAL
Actuator housing	ABS
Valve body	Brass
Valve ball	Brass
Stem	Brass
Ball seat	PTFE
Seal	EPDM

Valve size(mm)	Size	D1/D2	Φd	L1	L2	L3	F	H1	H2	H3	b	d	W(kg)
NPT, BSP Both Female screw Full Port	DN15	G1/2"	15	11	11	54	27	16	22	50	52	62	0.342
	DN20	G3/4"	20	10	10	61	30	22	22	50	52	62	0.330
	DN25	G1"	25	16	18	72	38	26	26	50	52	62	0.499

Control model & Wiring diagram

CR01(2 wires)	CR02(3wires)	CR03(3wires)	CR04(2wiers)	CR05(5wires)
Standard control	Two point control	One point control	Auto-return	Signal feedback

G. Valve test

In order to proof that the foreign bought valve is of good quality several tests were conducted to research the quality of the valve. The tested valve is the CWX-15, DN15, CR03, 3-6 volt version (see figure G.1) . The valve was tested in low temperatures, underwater, in dirty water and by intentionally blocking the valve from closing.

Figure G.1: CWX 15 valve

Freeze test

The valve was tested by putting it in the freezer for 24 hours. The specifications of the valve (see appendix F) say that the valve should be able to handle temperatures between -20 and 45 degrees Celsius. Because it the valve will be used outside it is possible that the temperature will be below zero. This was simulated in this test, the valve was put in to the freezer with a temperature of -18 degrees Celsius. The valve worked perfectly fine after this test, so it can be concluded that the valve indeed can handle temperature below zero. Of course, this test does not say anything about a longer exposure to low temperatures, but this test can be used as an indication that it probably also can handle low temperatures for a longer period of time. Next to that the valve was also not tested with water inside the valve. This was not done because the it is already known that water that freezes will expand and that this could possibly damage the valve.

Waterproof test

The valve specifications tell that the valve has an IP65 rating. This means that the valve is dust tight and that the valve has protection against water jets. In order to test this the valve was put under water for 24 hours, while the valve was opened and closed every 15 minutes. After the 24 hours the valve worked perfectly fine, there were also no signs of water damage. If the valve can be place underwater for 24 hours than one could also safely assume that the valve will be rain proof. See figure G.2 for an impression of the test setup.

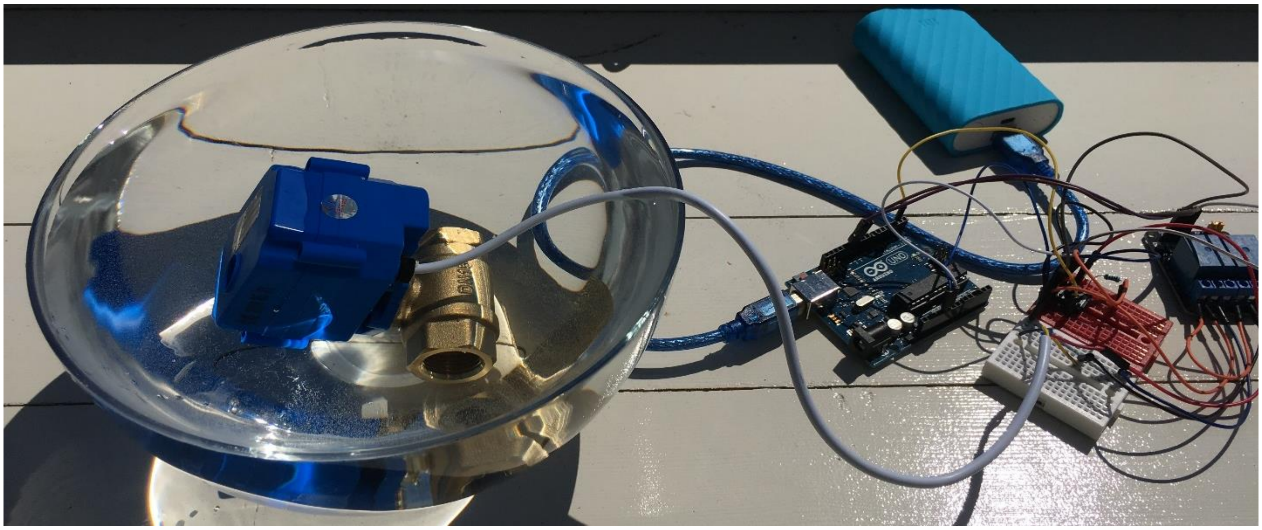


Figure G.2: CWX 15 waterproof test setup

Debris test

The valve was also tested in dirty water with leaves and sand. The valve remained functioning properly even in the dirty water. The valve was strong enough to close even when it was blocked by small soft debris.

Blocking test

Finally, the valve was tested on what would happen if the valve gets blocked and cannot close completely. Because the valve will operate in an environmental that cannot guarantee a perfect water quality it is important to know what would happen if the valve would get blocked. This was tested by blocking the valve with a wooden skewer. The tests showed that the valve indeed could not close with the skewer blocking the valve. It was found the valve has a build in safety mechanism that prevents the valve from getting damaged when it is blocked. Once the valve is blocked it simply switches of the motor.

Conclusion

From the performed tests it can be concluded that the valve is of good quality and that the valve is reliable enough to use in a consumer product. The valve is weather proof and is also protected from getting damaged if it is blocked.

H. Ultrasonic sensor measurement tests

This section contains the test results of the US-100, hc-sr04p, JSN-SR04T-2.0, and generic 40 KHz ultrasonic transceiver unit ultrasonic sensors. All sensors have been tested in measuring the water level in a buffer. The sensors were polled every second while draining and filling the barrel. The results are visualized in graphs. These tests were performed in order to study the behavior of the different sensors while filling and draining the buffer.

Test setup
Barrel type: 300 liter, Garantia rectangular rain buffer
Barrel height: 84 cm
Barrel width top: 72 cm
Barrel depth top: 57 cm
Barrel width bottom: 56 cm
Barrel depth bottom: 42.5 cm
Outdoor temperature: 15 °C
Controller: Arduino Uno
Measurement frequency: 1 s
Test date: 12-06-2018

US-100 & hc-sr04p

Since the US-100 & hc-sr04p are both made of the same components it was decided to only test the hc-sr04p because early tests showed that the measurement results of the two sensors are almost identical. The hc-sr04p will be tested with and without wave guide. See figure H.2 to H.5 for the results.

Test 1: **No wave guide**
Sensor positioned on the center of the barrel lid, placed 86 cm above the bottom of the barrel (see figure H.1).

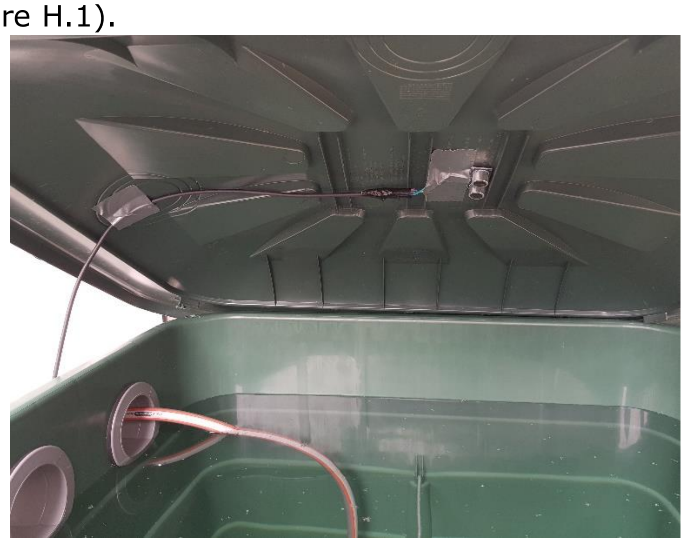


Figure H.1: Sensor placement hc-sr04p, test 1

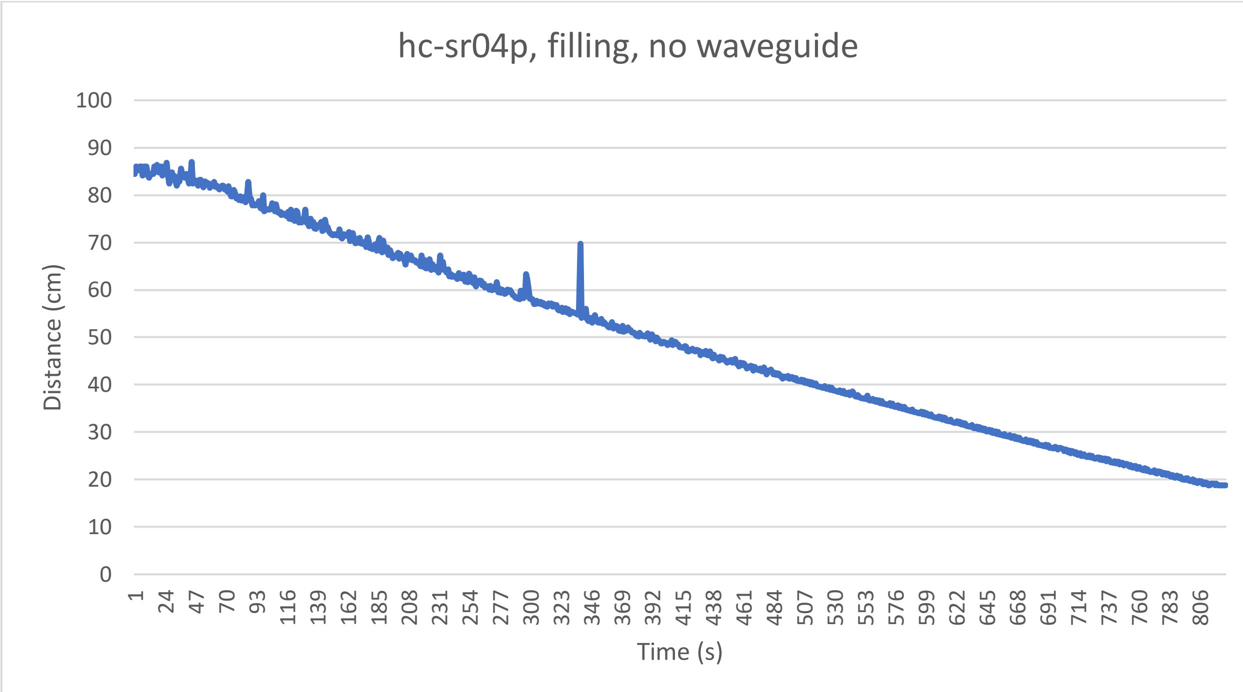


Figure H.2: hc-sr04p, filling, test 1

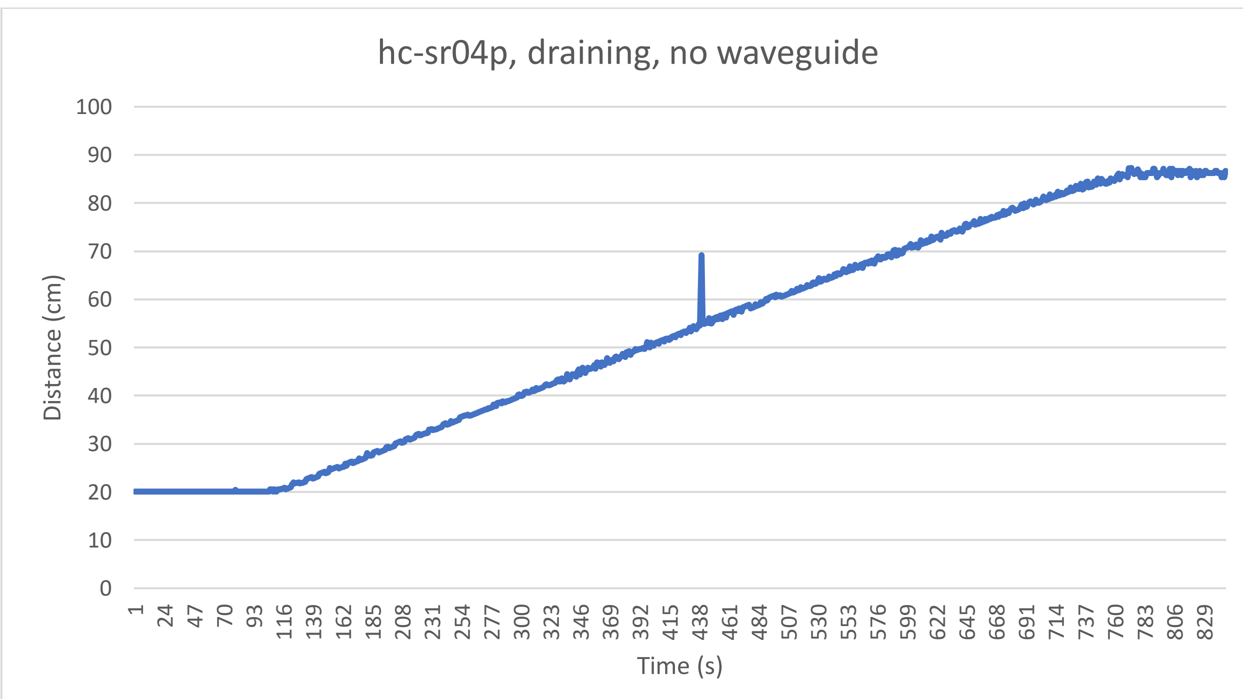


Figure H.3: hc-sr04p, draining, test 1

Test 2: **Full length pipe wave guide**
Sensor positioned 10 cm from the center of the barrel lid, placed 86 cm above the bottom of the barrel.

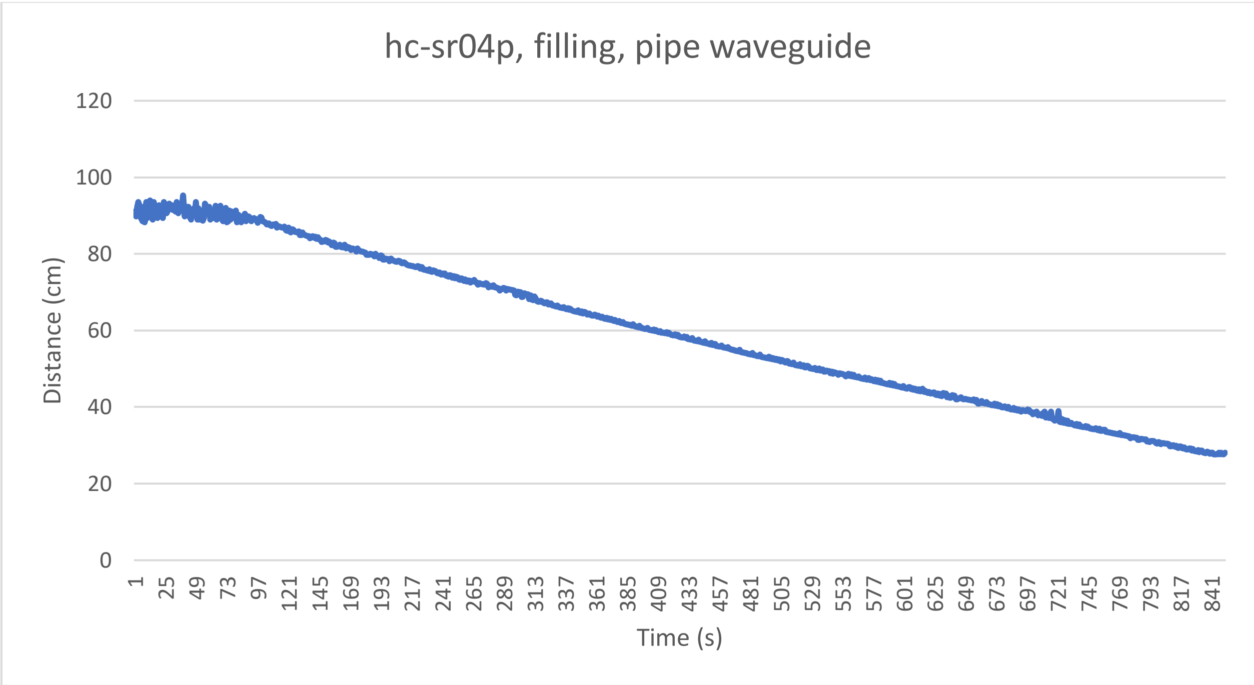


Figure H.4: hc-sr04p, filling, test 2

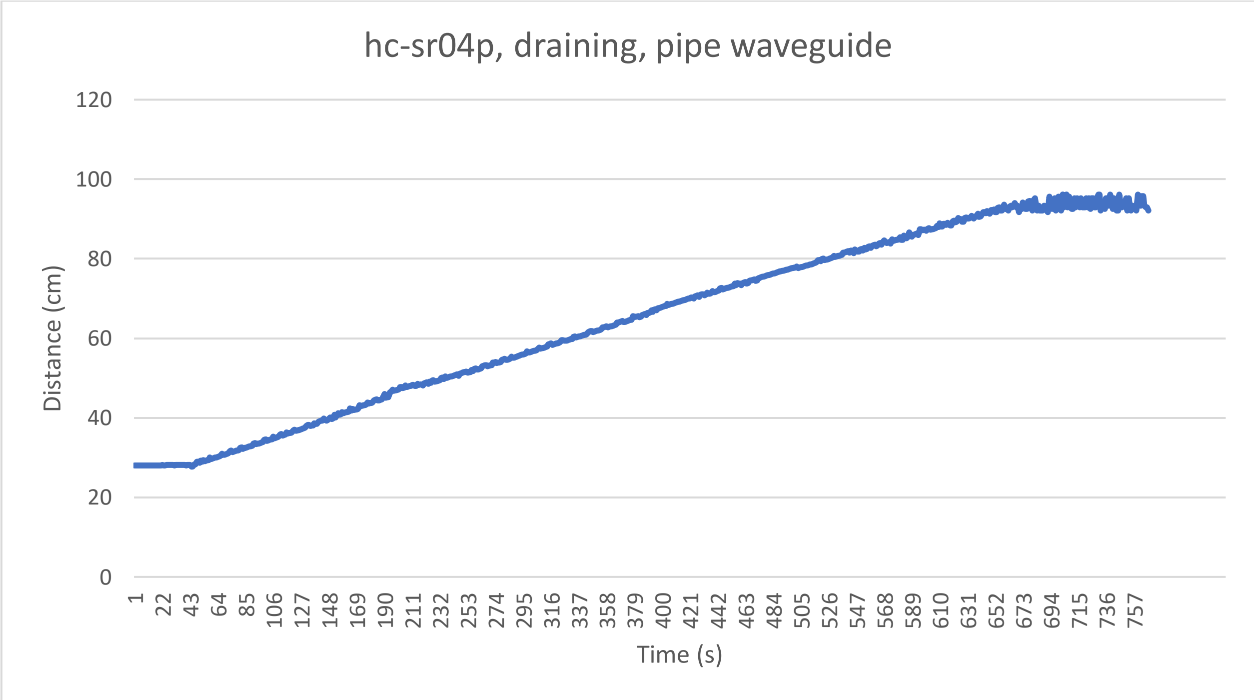


Figure H.5: hc-sr04p, draining, test 2

JSN-SR04T-2.0

Since the JSN-SR04T-2.0 has a measurement angle of 75 degrees this sensor will not work in a full-length pipe wave guide. For this reason, the JSN-SR04T-2.0 will only be tested without pipe wave guide. The Sensor was positioned on the center of the barrel lid, placed 86 cm above the bottom of the barrel. See figure H.6 and H.7 for the results.

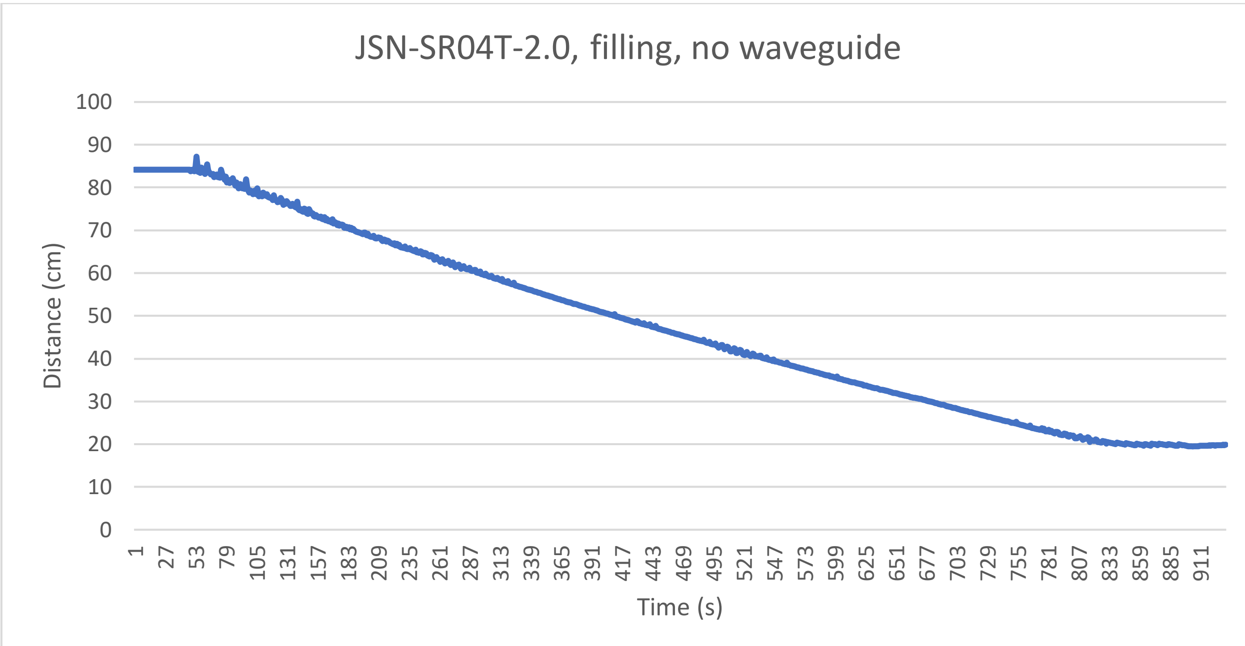


Figure H.6: JSN-SR04T-2.0*, filling*

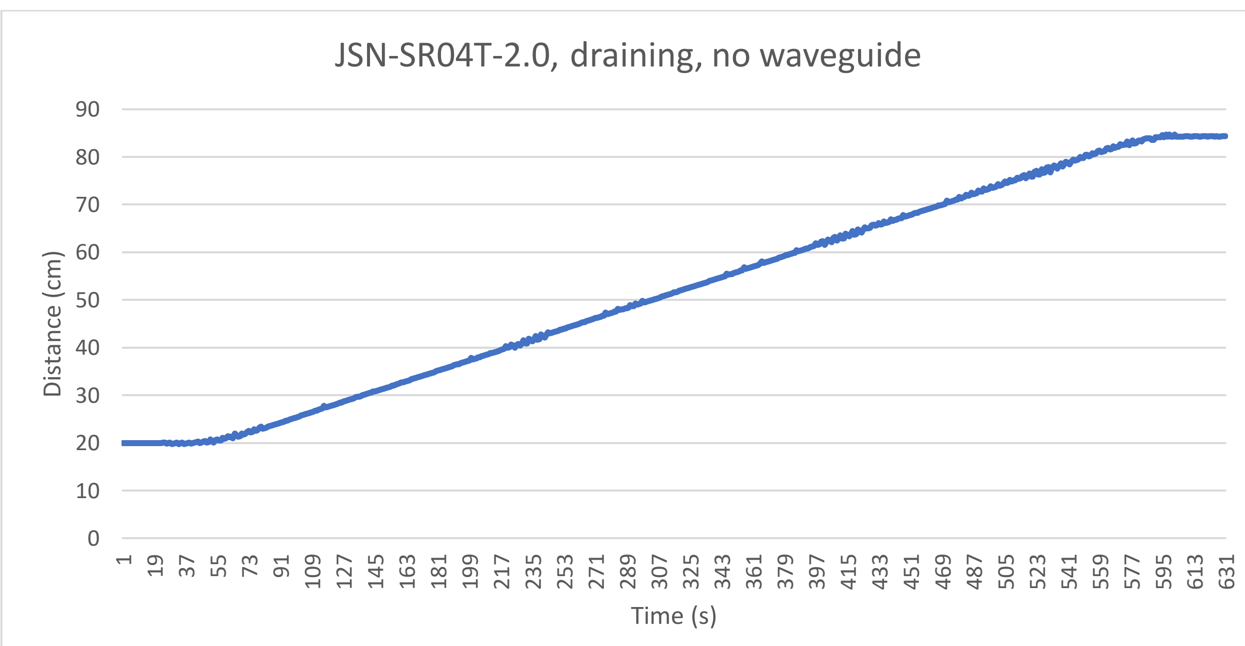


Figure H.7: JSN-SR04T-2.0*, draining*

Generic 40 KHz ultrasonic transceiver unit

Since the transceiver unit also has a measurement angle of 75 degrees this sensor will not work in a full-length pipe wave guide. For this reason, the transceiver unit will only be tested without pipe wave guide. The Sensor was positioned on the center of the barrel lid, placed 86 cm above the bottom of the barrel. Placed inside a 3d printed mount. It was found that the mount was too tight for the sensor resulting in errors. For this reason, the sensor was only tested with draining the barrel to get a general impression of the sensors performance. See figure H.8 for the result.

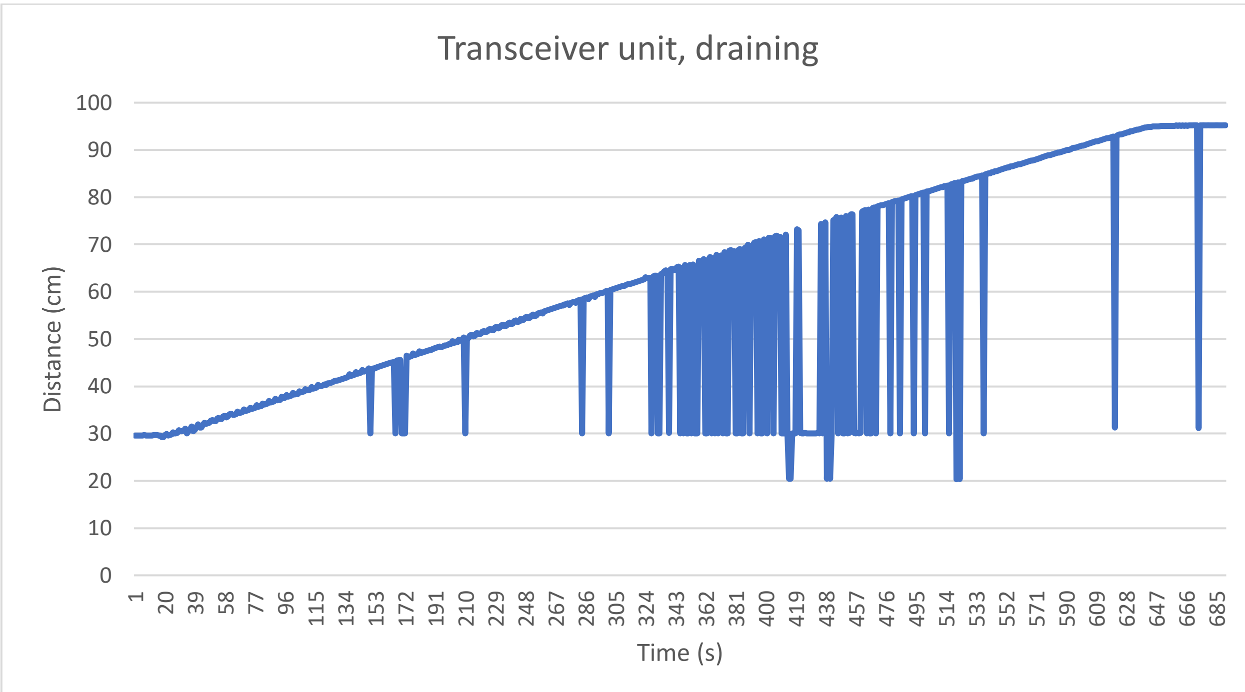


Figure H.8: Transceiver unit*, draining*

Discussion

The tests with the hc-sr04p show that this sensor has less interference when a pipe wave guide is used. Based on these tests the hc-sr04p and US-100 could be used for the SRB. Both have overall good results but the measurements with the wave guide are significantly better than without. The test on the JSN-SR04T-2.0 showed that this sensor is a reliable without any modifications. This sensor would be the best fit for the barrel that is used for the prototype, also because it is waterproof. For a universal sensor module that works on every type of barrel this sensor would not be the best option because this sensor does not work without modifications in a pipe wave guide. The Generic 40 KHz ultrasonic transceiver unit showed some very promising results but is by far not as reliable as the other two sensors. If this sensor would be used it is important that has the correct mount that does not corrupt the measurements.

I. Evaluated Requirements

Table I.1 gives an overview of the evaluated requirements. This overview was constructed by assessing the final prototype and validating if the prototype fulfills the requirements. The requirements that were met are highlighted green and the requirements that were met under certain conditions are highlighted yellow.

Table I.1: Evaluated requirements

Functional requirements	Non-Functional requirements
Must	
The system must be able to buffer water	The system must be durable
The system must work autonomously	The system must be robust
The system must be able to measure the water level in the buffer	The system must be weather proof
The system must be able to drain water to the sewage system	The system must be reliable
The system must be manually drainable	The system must be secure
The system must provide the option to connect the overflow to the garden or sewage system	The system must be easy to assemble
The system must send the system status to a central data repository	The system's capacity must be at least 200 liters
The system must use weather prediction data to regulate the buffer capacity	The system must be safe to use
The system must be able to measure the water temperature in the buffer	The system must fit in a garden
The system must be able to store measurement data until it is send to the central data repository	The system must be modular
The system must drain 2 hours prior rainfall.	The system must be designed for DIY
The system must support an online personal monitoring dashboard	The system must require low maintenance
The system must send the status information to the central data repository	The system must be installable by the user self
The system must filter the water before it enters the barrel	
The system must have a rainwater overflow	
Should	
The system should remind the user to clean the filter	The system should use a wireless networking technology
The system should indicate if an error occurred	The system should promote being environmentally friendly

The system should measure the system status every minute	The system should be energy efficient
The system should send the system status every 15 minutes to the central data repository	The complete system should cost not more than 250 euro
The system should automatically drain the water in case of risk for legionella	The user should be able to opt out for the option to drain water in case of risks for legionella
The system should automatically drain in case of risk for freezing.	The user should be able to opt out for the option to drain water in case of risks for freezing
The system should be able to notify the user in case of an error.	A bucket should fit underneath the manual tab
The system should be able to warn the user about risk for legionella.	The system should communicate with the central data repository via an API
The system should be able to automatically drain water to the garden	
The system should send planned discharges to the central data repository.	
Could	
The system could only overflow into the garden between a predefined period of time.	The system could be independent from the user's private communication infrastructure.
The system could be configurable via the central data repository.	The system could be scalable
The system could still function for a few days if the network connection fails.	The system could be setup via a web interface in the to be developed user dashboard.
	The system should be upgradable with extra control or sensor modules
Would	
The system would support over-the-air (OTA) software updates.	There would be two versions of the system, the basic and extended version.
The system would have a self-sufficient power source (e.g. solar/battery combination)	The system would have predefined holes for the installation of parts in the DIY assembly process.
	The system would not require a software setup process by the user.