UNIVERSITY OF TWENTE.

CREATIVE TECHNOLOGY

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Smart Rainwater Buffer XXL

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Abstract

The water problems in Enschede have not been resolved yet and the development of new innovations to come up with solutions continues. The municipality and waterboard of Enschede collaborate with the University of Twente to find ways to delay rainwater runoff to the sewer system of Enschede. And a rainwater buffer seemed to be a good option. During heavy rainfall it might be able to buffer enough water to prevent floods and during droughts the stored rainwater can be used to complement other water supplies. The SRB XXL is one of those solutions and originates from the DiY SRB. It is an autonomous and smart device that works with weather prediction data to determine its behavior. Where the DiY SRB is meant to get the inhabitants of Enschede themselves to contribute to solving the water problems, the SRB XXL is meant for industrial or urban spaces and would be maintained by the municipality of Enschede. This thesis is about the development of a proof of concept scaled version of an urban SRB XXL that has a purpose at all times. When the buffer is empty it would function as a place for people to sit and when there is rain it can fill up and provide space for rainwater runoff. However as it turns out it is not safe to bring rainwater runoff directly into contact with people. So the SRB XXL aspect in the city is good, but the water quality needs to be improved.

Acknowledgments

Many thanks are owed to all the people that supported me during my graduation project. I would like to start with thanking Richard Bults, my graduation project supervisor, who not only supported the work I did, but also showed patience and understanding for me personally. Then I would also like to thank Hans Scholten who is always fun to talk and discuss with. The sparring sessions with him and Richard taught me a lot and I enjoyed them very much!

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Lastly I want to thank Jeroen Waterink. During my graduation project I also became his assistant to help further develop the non XXL version of the smart rainwater buffer on which this graduation project is built.

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List of Abbreviations

RQ = Research Question
SRB = Smart Rainwater Buffer
SRB XXL = Large Volume Smart Rainwater Buffer
IoT = Internet of Things
DIY = Do-it-yourself

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1 Introduction

Enschede is a city in the eastern part of the Netherlands with a population of approximately 160,000 people. The population is diverse. Reaching from students to seniors. The city was built on a slight slope and has expanded over the years. It expanded especially rapid during the late 1800s when the Dutch government invested in the textile industry in the eastern part of the Netherlands. This had a major impact on the city and its environment, including the water system. Over time, the industry in Enschede started changing from manufacturing to knowledge and distribution. In addition to the changes of the city itself, the climate change took effect as well and environmental issues began to arise. The old-fashioned water management system could no longer handle the water coming from the increasingly heavier rainfall. With floods as a result.

The municipality of Enschede works to resolve these issues [3, 4], but their task is not complete yet. Enschede is not always able to fully deal with heavy rainfall and the municipality is looking for ways to include the water management aspect in a constantly evolving city. Currently the problem is a combination of the lack of capacity within the water management system to hold the increasingly greater amount of rainwater runoff in short periods of time. The challenge is to implement new ways of water management that complement the existing water management system in Enschede. As mentioned before, the main problem is a combination of the lack of capacity of the current system and the increasingly heavier rainfall as a result of climate change. And since creating a weather controlling machine does not seem realistic, it makes sense to look at ways to increase or make more effective use of the current capacity. And even though the weather can not be controlled, it is still possible to control rainfall. For example, by collecting and buffering it. Or by guiding it through gutters or other infrastructure. Some of which the municipality implements already (i.e. green roofs or wadi's). Therefor this bachelor thesis aims at the development of another iteration of a tool that helps control rainwater runoff by collecting and buffering it. Thus, effectively delaying the rainwater from running into the sewer system in Enschede. The city has determined that the tool should be able to buffer at least 20,000 liters of rainwater. These goals resulted in the following research question (RQ).

RQ: *How to develop a smart rainwater buffer into a large volume smart rainwater buffer to delay rainwater runoff to the sewer system of Enschede?*

The RQ is supported by two subquestions.

1. *How are rainwater buffers used to delay rainwater runoff to the sewer system?*
2. *How can the characteristics of existing rainwater buffers be used in the SRB XXL?*

To provide an answer and a solution that meets the demands of the municipality, waterboard and university this document will first examine and describe existing systems that reduce rainwater runoff to sewer systems. Then this document will list the requirements for an upscaled version of the existing SRB. And finally a description of the development steps of a prototype to be tested in Enschede is presented. The structure of the document is derived from the Creative Technology Design Process which will be explained in the 'Methods and Techniques' chapter.

2 Background Research

The background research consists of two parts. Firstly it has the literature review and secondly it has the state of the art. In the literature review a review of what research exists on large scale rainwater buffering is done. In the state of the art the focus lies on existing implementations and their lessons for developing an SRB XXL. The two subquestions will be used as a foundation to determine the relevance of the sources used in this chapter. These two subquestions were:

1. *How are rainwater buffers used to delay rainwater runoff to the sewer system?*
2. *How can the characteristics of existing rainwater buffers be adapted for usage in the SRB XXL?*

2.1 Literature Review

There are many different types of rainwater buffers. The goals of this literature review are to learn about how rainwater buffering has been implemented and what purpose they have. Learning how rainwater buffering has been implemented provides a basis to answer the question what characteristics a rainwater buffer has. These characteristics are important to determine in order to know how to adapt them for use in the SRB XXL. In addition the second goal, namely the purpose of the rainwater buffers, has to be kept in mind in order to form a basis for decision making in terms of implementation. For example it would make sense that a rainwater buffer that has the main purpose of collecting rainwater runoff for consumption has a higher priority towards water filtering in comparison to a rainwater buffer that solely has the purpose to delay rainwater runoff to the sewer system. To form these two bases the literature review will start with describing some general components that the rainwater buffers have. Then the main goals of the different rainwater buffers are listed. The literature used for this literature review is either about one very specific component of a rainwater buffer or they are about large scale rainwater buffers with a capacity of 20,000 liters or more. This is because at a capacity of 20,000 liters we consider an SRB to be XXL.

Rainwater Buffer
Literature shows that there are four components that form a rainwater buffer. These four components are: The *collection surface*, the *gutter*, the *storage* and *the output*. This is one component extra in comparison to what Thomas [5] describes. Thomas does not describe the output component, but from the four variables that Villareal [6] and Heggen [7] describe as key to determine the size of the storage component it is possible to derive the fourth and final component. The variable they describe is the output. According to Villareal [6] and Heggen [7] anything that reduces the amount of water stores in the buffer can

be considered output. The output is relevant for the SRB XXL, because the purpose is to delay rainwater runoff and not to stop it.

All four of these components together form the characteristics of a rainwater buffer and, but they can have different implementations. When looking at each component separately it shows that there is a strong relation between location and implementation of the components. The location can be split into two main categories. First there are the *urban* areas and secondly there are *rural* areas. These locations on their turn correspond with the purpose of the rainwater buffer.

As an example we can look at Singapore and their water management. In the case of Singapore there is a growing population in a densely populated city. Not only Luan [8], but also Etezadzadeh [9] indicate that this urbanization puts pressure on available resources and necessitates measures to sustain the possibility of a good quality of life in these urban areas. Etezadzadeh [9] recommends a circular economy. And Luan [8] uses Singapore as an example. She explains that in Singapore the demand for drinking water is partially solved by using rainwater buffers. The relation between location and purpose in this case is that urbanization creates a demand for drinking water, but at the same time also puts extra pressure on the available space and that future development has to be done with those two variables in mind.

Collection Surface Characteristic

Cities have a lot of roofs, these roofs form a large impervious area that can be used as collection surfaces. But what do we consider a collection surface? *A collection surface is an area that collects precipitation*. This means that all these roofs could potentially be used as a component for a rainwater buffer. Both Thomas [5] and Villareal [6] who were mentioned before give roofs as an example of collection surfaces. Villareal [6] mentions the Izumo Dome in Izumo City which uses its roof as a collection surface of $13,200m^2$. Another research that mentions roofs as impervious areas and thus roofs is Frazer [10].

Roofs are common in cities and can be used as a collection surface for rainwater buffers. Villareal [6] not only inspired the fourth component that helps determine the characteristics of a rainwater buffer, but also provides the example of how the Izumo Dome in Izumo City uses its roof as a collection surface of $13,200m^2$. But in urban areas not only roofs are potential collection surfaces. Frazer [10] points out that there is a lot of paved area in the United States. He mentions that there is a paved area of 43,000 square miles in the United States alone and that this causes floods, because water can't go anywhere when there is heavy rainfall. However these paved areas are also potential collection surfaces for a rainwater buffer, but Frazer [10] also warns for disrupting the hydrological cycle and the ecological effects that has. This means that in urban areas we can look at any surface that is impervious to water as a potential collection surface for a rainwater buffer, but that we have to keep in mind that this can have an effect on the hydrological cycle.

In rural areas there are less surfaces that are impervious to water, but there is still a demand for water. Pandey [11] shows that people have tried to find ways to have access to enough water for a long time and that some of that water supply comes from precipitation. There is evidence that as early as ca. 4500 BC people have tried to find ways to not only collect rainwater, but also to store it. Methods include the creation of storage tanks, but also irrigation. What we can see is that collection surfaces in rural areas often involve the land itself. This was not only the case back in the day, but also now. For example Sazakli [12] describes how on the Greek Island Kefalonia there is a collection surface that guides collected the rainwater runoff from the hills into ferroconcrete storage tanks and Vogel [13] describes a similar usage of gravity in Yemen. In Yemen rainwater runoff was used to irrigate terraced agriculture. So what we can see in rural areas is that in addition to collection surfaces there are areas that do not collect the precipitation, but instead steer the water towards a collection surface.

Gutter Characteristic

This brings us to the second component out of the four characteristics that are present in a rainwater buffer. The second component, as mentioned earlier, is the gutter. *A gutter is a component that facilitates the movement of precipitation from one component to another*. For example the terracing in Yemen described by Vogel [13], it uses underground water conduits as a gutter. Whereas Ghisi [14] describes a system that uses pumps and pipes to move the water. And another example that was mentioned before by Sazakli [12] makes use of the hills and gravity to guide water towards a collection surface and trucks to move the water from the storage tanks to where it is wanted. Luan [8] gives insight in how Singapore built a system similar to a sewer system to transport water throughout the city. All together there are many ways that water can be moved.

Storage Characteristic

The third component of a rainwater buffer is the storage component. *The storage is a component that can hold up to a certain amount of liters of water.* Of course these could be storage tanks that Sazlaki, Villareal and Thomas [5,6,12] already mentioned. But it is also possible to look at reservoirs or basins as mentioned by Querner [15] or even lakes and ponds.

Water buffers in urban areas can however impact the surrounding areas. Frazer [10] already mentioned that the pavement had an impact on the hydrological cycle and so does Querner [15]. However Querner states that the increase of rainwater runoff that ends up in the sewer system due to the large presence of impervious surfaces in urban areas also creates more effluent water to be discharged from the sewage treatment plant. Which prevents droughts elsewhere. So a balance between keeping and discharging water is important.

When storing water there are several aspects to take into consideration. Both Villareal [6] and Heggen [7] mention a couple.

1. Precipitation

2. Accumulated rainwater runoff
3. Volume in storage
4. Consumption or output

Precipitation is about how much precipitation there is at a location over a certain amount of time. The accumulated rainwater runoff is the amount of water that actually reaches the storage and does not get lost on the way. The volume in storage is about how much water is already stored in the buffer. If there is a lot of precipitation the buffer needs to be able to hold more rain in order to retain the function to delay water runoff towards the sewer system. Then there is the consumption or output, which reduces the amount of water in the buffer.

Output Characteristic

The balance of water inside the storage component can be controlled through output, which is the fourth and final component and characteristic that we describe for a rainwater buffer. *An output is a tool to control discharge from the storage component.* Logical examples are faucets and valves that are linked to a storage component. Also pumps might play a role to discharge water from storage [16]. It depends on the use of the water, some use it to water their crops [13] and others to wash their cars or do laundry [6]. The keyword with the output is control. In addition control over a rainwater buffer can turn it into a smart rainwater buffer. So as an extra component to turn the rainwater buffer into an SRB we added autonomy and control.

Smart Characteristic

The smart component has to do with control and autonomy, but there are different interpretations of what *smart* is. Robles [16] has developed an Internet of Things (IoT) based reference architecture for smart water management. This system is designed to give high level commands that are then automatically translated to many small level operations that control the water system and determine what needs to happen. So smart in this context is the ability of the system to convert those high level commands into the desired behavior of the system. Sazonov [17] stresses that a smart system has to have low maintenance cost and has no need for human decision making. To do so a good smart system uses little energy, makes use of ambient energy and operates mostly locally. In this case the smart aspect focuses on autonomy and sustainability. Etezadzadeh's [9] explanation of smart is closest related to the explanation of Sazonov. But Etezadzadeh [9] focuses on the macro level by looking at sustainability at a city level and Sazonov [17] on the micro level by looking at the way a system operates and how resources are used. Etezadzadeh calls for a cradle-to-cradle cycle in cities which means that all resources used should be optimally used and reused without any waste. Some aspect all three agree on is that there is data interpretation in a meaningful way and a method of collecting data in smart systems. So this is what the SRB XXL needs in order to be considered a *smart* system. It needs to be able to handle data in a meaningful way. It has to be autonomous. And next to that it has to be sustainable.

Safety and Security
Sustainability also involves safety and security. To make the system reliable and secure. Ntuli [18] proposes a system architecture for water management systems that makes use of publish-secure design pattern and stateless authentication. Protecting the system in this way is good to make it harder for hackers to abuse the system, however there are more safety and security issues.

Public Health
When working with water and especially in urban context there are public health hazards that need to be considered. The water quality has to be good in order to prevent diseases or other ailments that come from using the SRB XXL. Beenen [19] and Schets [20] both indicate that the collected rainwater most likely contains pollutants. But Beenen [19] says there are insignificant amounts where Schets [20] says they are present in significant numbers. He points out that the lack of safety comes from the presence of fecal matter and human pathogens [20]. Some of which are caused by animals that can access the water.

Legionella
Another known hazard is that of legionella and legionnaires' disease. Fields [21] points towards the ASHRAE guidelines to minimize the threat. In order to do so there are several considerations to keep in mind. For example stagnant areas are difficult to clean and should be avoided. The use of filters should be considered or water should be refreshed regularly. It is also possible to use a biocide to fight the biohazards present in the water. Furthermore the temperature of the water should avoid being between 25°C and 55°C in which the legionella bacteria grows best. Water droplet size is also a factor that determines the threat level, smaller sized droplets are more easily picked up and inhaled. Use of condensers, evaporators, mist generators and other ways of generating small water particles should be used with caution. The risk with rainwater is also greater, because there are likely more nutrients available for bacteria to feed on. So there are plenty of things to consider when dealing with water when it might come into contact with people.

Conclusion
To summarize the aspects of a smart rainwater buffer we found out that there are two layers to keep in mind. The first one being the context. All the research showed that the implementation was built on existing systems with the exception of Singapore that created a new layer of infrastructure on top of existing ones. All other examples integrated the rainwater buffer into the new design or made minor alterations to existing structures or landscape in order to implement it. The four characteristics of a rainwater buffer, namely:

1. Collection surface
2. Gutter
3. Storage
4. Output

They are complemented by the *smart* characteristic in order to form the basis of the SRB XXL. It has to be autonomous, sustainable and manage data in a meaningful way while not producing any waste. And all of these components need to consider safety and security aspects. Where abuse and legionella are considered the main threats. But there are already ways to reduce the risk. Both in the form of a guideline and system design ideas. However the literature is not specifically aimed at the purpose of the SRB XXL. But that might be caused by the fact that the SRB XXL is more or less a combination of existing technology to fulfill a new purpose. In future studies it would probably pay off to include more than one goal for the SRB XXL. Examples could be that the water stored in the buffer could be used for watering plants or cooling down an urban area.

Discussion
The characteristics of the rainwater buffer show that adaptation to the current situation plays a key role. The implementation of rainwater buffers is often on top of existing systems. However it is not clear how difficult it is to adapt to the current situation or make slight alterations to it in comparison to major alterations. None of the used research addresses this issue. It is likely that it is mostly about the costs. Minor alterations to existing structures might be less costly than major changes. In the case of Singapore there is a government who has the power to make major changes and this might not be the case in other places. To heighten the chances of success for the SRB XXL it is worth to research a location within Enschede with existing structures that are easy to adapt or adapt to at low costs. Another thing to note is that water buffers have different purposes for the water stored. Some use it to water their crops and others to do laundry or wash cars. Where the goal of the SRB XXL is to delay rainwater runoff to the sewer system. This suggests that it releases the water into the sewer system after some time while there may be more beneficial uses for the water. Research should be done to find the most effective use for the water stored in the SRB XXL in Enschede.

2.2 State of the Art

In the state of the art section we focus on the existing technologies in a more holistic way. This means that we also look at what purpose they serve besides the technology involved. First of all we look at Enschede and what they have and then the focus shifts towards more global technologies.

2.2.1 Water Management of Enschede

Enschede is a city that actively tries to adapt to the changing climate. When looking at the water management of Enschede there are quite some innovative projects. In appendix A, B and C a summary of the situation can be found. But in short it can be said that Enschede is built on a slope and the water often runs downhill on the streets when there is heavy rainfall, because water infiltrates into to the ground too slowly and the sewer system is also not equipped to deal with it. This is why Enschede has implemented the following technologies.

The Roombeek
The *Roombeek* is an area in Enschede where there was a creek back in the old days and after a disaster that destroyed a lot in that area the creek got remade. The Roombeek has an effect on the water management system in the sense that it decouples 15ha of rainwater. Which means that it leads excess rainwater runoff out of the city through the creek instead of the sewer system. [4] So here the focus lies on stopping rainwater runoff from immediately entering the sewer system and provide an alternative way out of the city.

Wadi
Another technology in Enschede are the wadis. A wadi is an area that collects excess rainwater and lets it infiltrate it into the ground. The name wadi approximately means "dry riverbed" in Arabic, but it also stands for *water, afvoer(disposal), drainage and infiltration*. Figure 1 shows a side view of a wadi and its components. The wadi is focused on providing room from water on the street to go off the street and into the storage of the wadi where it can slowly infiltrate and discharge into the sewer system.

Oldenzaalse Straat
A place where they implement wadis is the *Oldenzaalse Straat*. The Oldenzaalse Straat is a street in Enschede that is being redeveloped. It will house a special type of sewer to deal with 7 million liters of water [22]. This dwarfs the 20,000 liter capacity that SRB XXL aims for, but does not make it redundant.

Green Roofs
Next to the technologies that are implemented on the ground there is also a technology that deals with rainwater before it hits the ground (more or less). On top of a shopping center in Enschede called: *De Miro*. There is a green roof. Greens roofs are also able to hold water and can delay rainwater runoff in that way. [4] The purpose of these green roofs are not limited to their water holding characteristic, but it can also help cool down an area during hot weather.

Smart Rainwater Buffer
Of course there is also the smart rainwater buffer project. Jeroen Waterink developed a DIY smart rainwater barrel that can measure the water level, water

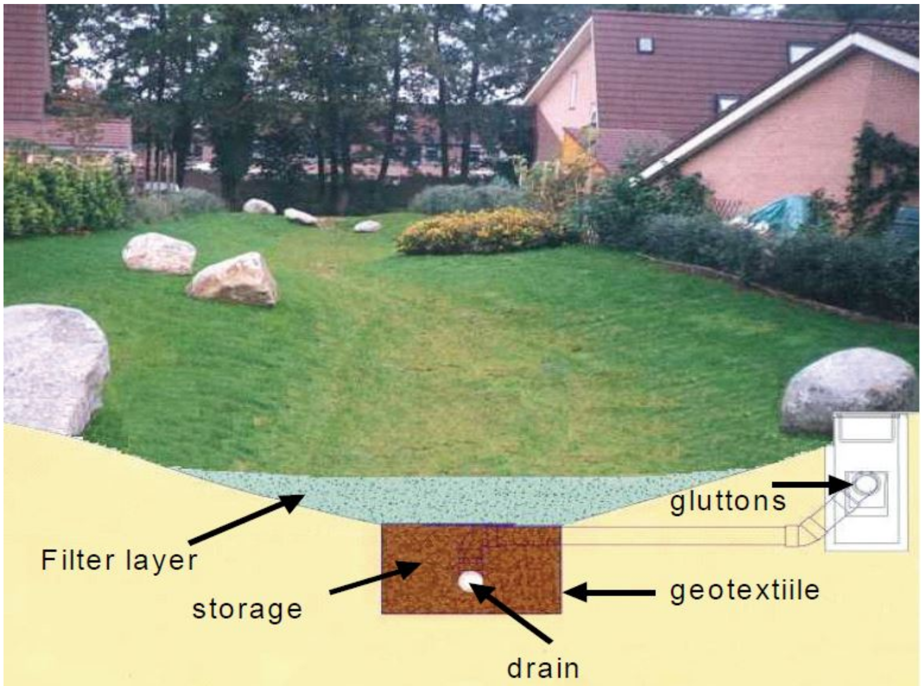

Figure 1: Wadi Enschede

temperature and collect and process precipitation prediction data. On top of that there is a database that saves the data from the barrels and displays it to the user through a dashboard. [23] Jeroen describes more projects that are similar to his such as the *Slimme Regenton, RainGrid, Opti, Loxone Rain Water Harvesting Project, Smart Rainwater Management System by OTA-Analytics* [23]. The purpose is to include a smart element that allow the barrel to run autonomously. So that when rain is coming the barrel creates room. The precipitation prediction plays a major role to allow this behavior.

2.2.2 Water Management in the World

Water management is not new and does not only exist in Enschede. All around the world there are systems that deal with rainwater. Some of them even include a smart element.

Smart Communication

The smart element as found out in the literature review is a combination of sustainability, control, autonomy and it has to be able to collect and handle data in a meaningful way while not producing any waste. Robles [16] as mentioned before developed a system to manage water. This system is able to combine multiple operations and provide them as packages so that with a higher level command a more complex sequence of operations can be executed. This can be used to handle data in a meaningful way. For example when you tell a rainwater buffer to empty 20,000 liters of water it could be that a smart system like this could empty 200 liters from 100 separate buffers units. This means it has to control multiple buffer units as if they are one.

Large Rainwater Buffers
Large rainwater buffers also exist around the world. Up next are some examples of rainwater buffers from different countries.

Japan
The system at the Izumo Dome in Izumo City as described by [6] has a catchment area of 13,200m_2 with two storage tanks that together have 270m_3 of space to store water. Another place in Japan is the Kokugikan Sumo Wrestling Stadium in Tokyo. There they collect rainwater and use it for flushing the toilet and cooling the building. The collected rainwater is stored in 1,000m_3 reservoir in the basement and has 8,400m_2 roof. In an urban area like these two Japanese cities the water buffers need to be compact and fit within the limited space.

Greece
The rainwater buffers on the Greek Island of Kefalonia have a system composing of three parts. It has a rainwater catchment area (that is a combination of a collection surface and a gutter), three main tanks where the water is stored and special trucks that haul the water. The capacity of the main tanks vary between 300 to 1000m_3 and their catchment areas range from 600 to 3000m_2. Figure 2 shows what it looks like. [12] This island is not fully buildup and still has areas where there is room for water buffers like this. In an urban area the same technology would look very different.

Conclusion
Overall the details of each system depend on the context they are implemented in. There are many more small *smart* rainwater buffer systems than there are large ones. But there are large rainwater buffers out there that can be used as an inspiration for the SRB XXL. Larger rainwater buffers put an emphasis on the collection surface size and its relation to tank size. The smaller rainwater buffers try to involve people more than the larger buffers as well. For example the dashboard that is available for the smaller buffers does not appear on the larger buffers.

Discussion
This selection of existing water management and buffering technology only scratches the amount solutions that are out there. The technologies described are created in very different contexts and might not be suitable everywhere.

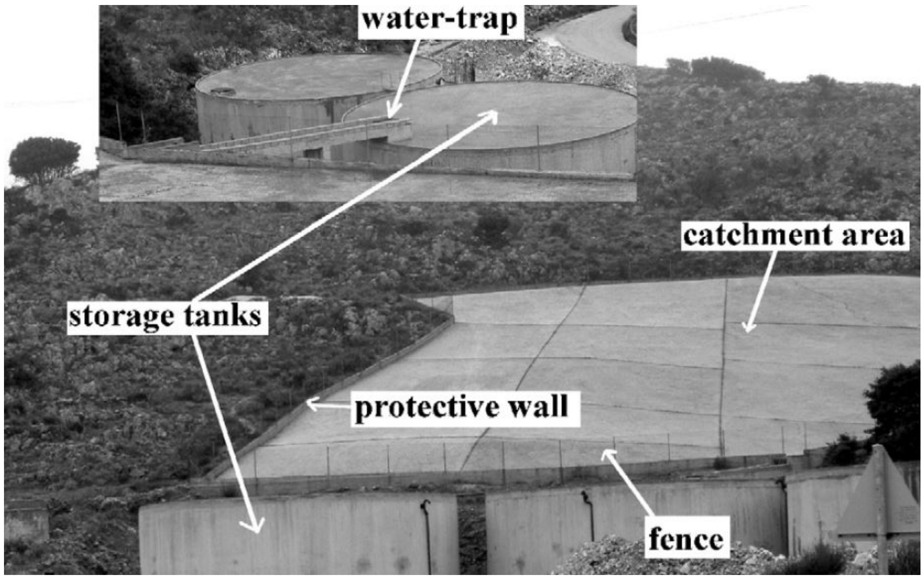

Figure 2: Rainwater Buffer in Kefalonia, Greece

No clear decision making process was described and for the larger buffers it was interpreted based on location. This state of the art review only looks at active rainwater buffers. The normal hydrological cycle and underground systems are not taken into account. This is because the focus lies on the rainwater runoff before it comes into contact with those types of systems. Future research could include these extra systems for a more holistic view. Also the rest of this research should aim for a location specific solution. On top of that it might be interesting to see whether an interaction such as a dashboard would have added value for larger public rainwater buffers.

SRB XXL Research
When we look back at the research question and its two subquestions.

RQ: *How to develop a smart rainwater buffer into a large volume smart rainwater buffer to delay rainwater runoff to the sewer system of Enschede?*

The RQ is supported by two subquestions.

1. *How are rainwater buffers used to delay rainwater runoff to the sewer system?*
2. *How can the characteristics of existing rainwater buffers be used in the SRB XXL?*

Then we can already draw a conclusion based on the literature review and state of the art. The most important finding is that a rainwater buffer should be adapted to its environment. Often there are already systems in place that only require small alterations to redirect the rainwater runoff towards a rainwater buffer instead of the sewer system. The usage of rainwater seems to focus on uses that avoid direct contact with people. For example doing laundry or watering plants. We also noticed that a rainwater buffer has four components and that making it smart can be done by adding some extra sensors and actuators. But also that the smart aspect is about sustainability, monitoring, control and autonomy. On top of that it is also important to include community in order to have a holistic view on the development of a smart rainwater buffer XXL.

3 Methods and Techniques

This chapter describes what methods and techniques were used to do the research.

3.1 Creative Technology Design Process

Based on the research question and the background research a design process is put to work. For this research the Creative Technology Design Process [24] is used. The Creative Technology Design Process consists of several design phases (Figure: 3).

1. *Ideation*
2. *Specification*
3. *Realization*
4. *Evaluation*

3.1.1 Ideation

Ideation is about idea generation. It can be done by tinkering, observing, conducting an interview and many other ways. The stakeholders and their requirements are determined [24]. Luan [8] and Verworn [25] emphasize the importance of a holistic approach that includes all stakeholders. The ideation phase in this research is done by first doing a stakeholder identification and analysis. Then a list of preliminary requirements is presented. Followed by a brainstorm session where 10 concepts are explained. And ultimately the final concept is chosen.

Stakeholder Identification and Analysis
In order to do a good stakeholder identification and analysis Bryson [26] described fifteen different techniques to do them. Where we focus on the techniques that are about proposal development. Since the SRB XXL resulting from this research is ultimately a suggestion to the municipality of Enschede.

PACT Analysis
Both Rindt [27] and Waterink [23] made use of a PACT analysis to better understand the requirements. Rindt describes it as a method to understand user perspectives whereas Waterink used it as a tool to develop user centered scenarios. So both aim at understandign user requirements. Pact stands for *People*, *Activities*, *Context* and *Technologies*. People is about the stakeholders. Activity stands for the type of interactions. Context is about the social, physical and organizational environment of the system. And the last one - technology - is

about in- and output, content and communication. [27] The PACT analysis will be included in this research to support the preliminary requirement method described below.

Preliminary Requirements
The preliminary requirements were found by using the previous research done by Waterink [23] and by conducting semi-structured interviews with the representatives from the municipality of Enschede, waterboard Vechtstromen and University of Twente. The results of this interview are ordered in the so-called MoSCoW way that [28] describes. MoSCoW stands for *Must* have, *Should* have, *Could* have and *Would* have. This ordered lists creates a priority list where the 'must have' is the most important and the 'would have' is the least important.

Brainstorm, concepts and final concept
The brainstorm process was done solo. The concepts were generated using previous experience and by reducing and increasing constraints. This resulted in a broad variety of concepts. Then for each concept a short explanation is given with some of the ideas behind it. After that the final decision is clarified. In this case the decision was made with the supervisor and critical observer from the University of Twente. Do note that the brainstorm does not necessarily take all the preliminary requirements into account. They merely form a guideline.

3.1.2 Specification

An adaptation that this research makes to the Creative Technology Design Process specification phase as described by Mader [24] is that the specification phase does not consist of making many prototypes, but instead it focuses on explaining the system architecture. The reason behind this is that this research is about creating a proof of concept. On top of that, developing more than one prototype does not fit within the time scope of this research. So the specification in this research is about setting goals and expectations for one iteration of an SRB, namely the SRB XXL. System architecture diagrams are used to display the functionality that is aimed to fulfill the requirements that the SRB XXL has. This means that the specification chapter aims at creating a backbone for the development of an SRB XXL without any predefined physical design as long as all the requirements are met it would still be an SRB XXL. It does so by linking requirements to system architecture and visualizing them, step by step through diagrams. Then afterwards a complete list of requirements is made by expanding on the preliminary requirements from the ideation phase. The focus lies on creating an abstract blueprint for a system engineer to use if they want to make their own version of an SRB XXL.

3.1.3 Realization

The realization phase describes how the functional and experience specifications were implemented and what decisions were made along the way. It shows a decomposition of the components and how they are working together in order to fulfill the requirements. [24] It starts by providing an overview of the result and then the steps taken at different stages of the realization.

3.1.4 Evaluation

Evaluation includes user test and comparing the expectations and goals to the results [24]. It will include an unstructured interview and a summary of requirements and whether they are met or not.

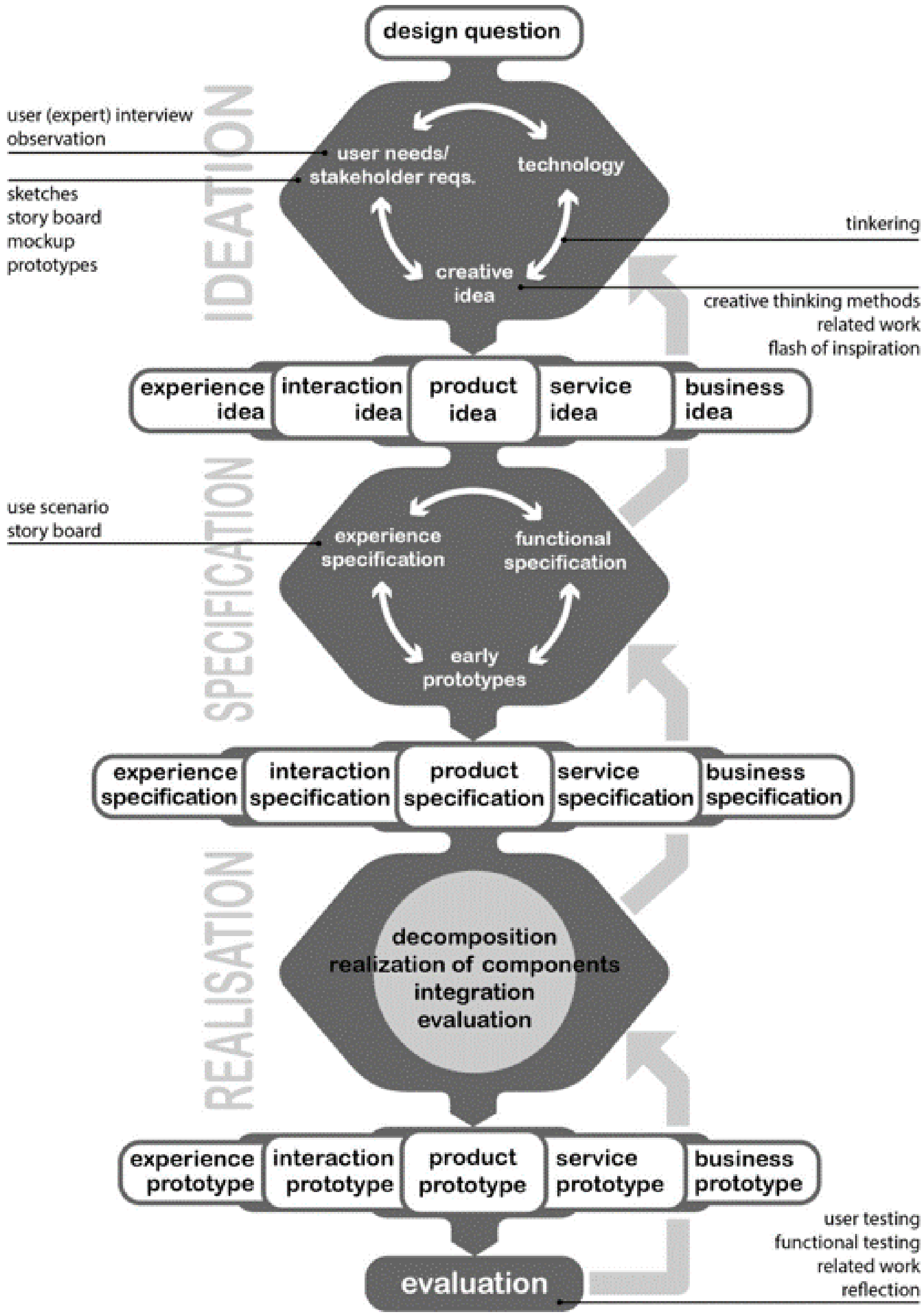

Figure 3: Creative Technology Design Process

4 Ideation

In this section the stakeholder identification and analysis is executed together with a PACT analysis and a set of preliminary requirements that are generated. After that the brainstorm and selection process is summarized.

4.1 Stakeholder Identification and Analysis

The stakeholders in this graduation project are limited to parties that are involved with the development, implementation and utilization of the project. For this thesis the prototype has multiple users. Even though the focus lies on the municipality's water management team.

Main Stakeholders
The first stakeholder is the end user, the end user can be split into two main groups. Namely the *inhabitant of Enschede* that would end up living near the SRB XXL and *visitors of Enschede* who come across and might interact with the SRB XXL.

The second stakeholder is the municipality of Enschede, their role includes: user, policy maker and advisor. Their reason of involvement is determined by their desire to meet climate goals and dealing with droughts and floods in Enschede. The municipality provides advice.

The third stakeholder is the Waterboard Vechtstromen, they are mainly concerned with mater management and operation of the SRB XXL. The Waterboard Vechtstromen is strongly connected with the municipality of Enschede and also provides advice.

The fourth and final stakeholder for the SRB XXL is the University of Twente who want to further develop students and at the same time provide potential solutions to parties that see merit in a cooperation with students. The University of Twente provides two supervisors to assist the student and next to that they provide the materials and space for the SRB XXL to be developed.

Stakeholder Influence
Every stakeholder has a different type and amount of influence on the development of the SRB XXL. The amount of influence is based on a combination of power and interest. The SRB developed by Waterink [23] has many of the same parties as stakeholders, but the influence is distributed differently. The result can be seen in figure: 4.

During the development of the SRB XXL the municipality has a lot of power through initial advice and outspoken requirements, but in the end the SRB XXL is a prototype in order to display an idea for a solution rather than a prototype of the actual solution. This was done because a prototype of an SRB that can hold 20,000 liters can have a much greater impact on the environment than an SRB based on common rain barrels that are already on the market. Safety concerns and the expected larger impact on the environment therefor require more research which are considered out of scope for this research. So this research focuses on presenting an idea with a proof of concept. The role of the municipality is that of a primary user. The municipality needs to be managed closely.

The University of Twente has a lot of power and continues to influence the project throughout its development, but the interest is less than the municipality's. The role of the University is that of an advisor and investor. The University needs to be managed closely.

The waterboard Vechtstromen has medium power and medium interest. They provide information and some advice. The aim is to keep them informed. If the goal of the thesis was to generate a real large SRB XXL instead of a proof of concept, then the waterboard Vechtstromen would play a larger role.

Then last, but not least there are the citizens of Enschede. Where both the inhabitants and visitors have medium interest, but low power. Even though community plays a large role, it is out of the scope of this thesis to involve them in the development in a proof of concept. There are theses underway that are about this community aspect specifically. It is important to monitor the progress of that stakeholder group when moving forward after the proof of concept is delivered.

Stakeholder	Role	Interest	Power	Aim
Municipality of Enschede	Primary user	HIGH	MEDIUM	Manage closely
Citizens of Enschede	Secondary user	MEDIUM	LOW	Monitor
Waterboard Vechtstromen	Tertiary user	MEDIUM	MEDIUM	Keep informed
University of Twente	Advice/investor	MEDIUM	HIGH	Manage closely

Figure 4: Stakeholder Influence

4.2 PACT Analysis

The PACT analysis will further describe the people involved with the SRB XXL by means of a scenario. Two scenarios will be made, one for an industrial context and one for an urban context.

Industrial

People: 55 year old investor that owns a large distribution center near the harbor district in Enschede.

Activities: Using the SRB XXL to collect rainwater to use in the toilets and to clean the trucks.

Context: A large distribution center with a lot of roof at an industrial area in Enschede.

Technology: Smart Rainwater Buffer XXL, industrial style.

Scenario: Mark de Groot is the owner of a large distribution center. On a windy afternoon he received an e-mail from the municipality about participating in a project about climate change. Mark never cared much for climate change and focuses on profit more than anything else. Then right as Mark is about to click away the e-mail he reads one word: 'savings'. This sparked his interest and Mark wants to know more. He takes another moment to read and finds out that the development of an SRB XXL is well underway. He reads past the water trouble that Enschede deals with, because he does not care and the buildings he owns are close to the Twentekanaal and he never experienced trouble with the large amount of water in a short time. In fact he thinks it helps him. All that water cleans the company grounds quite nicely. He wishes it would happen more often.

Then he reads about how the SRB XXL can store water that can be used to clean cars and he realizes that it must mean that it can be used to clean trucks as well! Reading further he also finds out it has potential to be used in toilets as well. But that is too much of a hassle for Mark, besides the smells are already bad enough at the employee toilets. Rainwater is probably not going to help that either.

This doesn't stop Mark from wanting to know more and he replies to the municipality of Enschede that he is interested and wants to be kept up to date on the developments of the SRB XXL.

Not much later there is another e-mail from the municipality asking Mark if he is still interested and if so that there is a student from the University of Twente looking for a spot to test their SRB XXL. The student needs a place with a large roof and a spot where they can store a tank with a capacity of 30,000 liters.

Mark invites the municipality and student to come and visit the distribution center. Surely enough, a few days later a small delegation of people from the university, municipality and waterboard come over and discuss the possibilities. A small prototype is shown and Mark is convinced fairly quickly. The costs are low, the benefits are still marginal as well, but the publicity is priceless.

Then after a while other students got involved with the project as well. Mark has even said yes to using rainwater in the employee toilets. Not only to flush them, but also to clean them. At this point 10 percent of his water usage has been replaced by the SRB XXL and it only cost him some time and got him great publicity.

Mark is very glad he kept reading the invitation e-mail from the municipality and brags about the SRB XXL on birthday parties.

Urban

People: 34 year old shopkeeper with a shop in Enschede

Activities: Using the SRB XXL to entertain kids.

Context: A long street within the city center with many shops where the SRB XXL has been placed.

Technology: Smart Rainwater Buffer XXL, urban style.

Scenario: Two years ago Sarah wrote an e-mail to her landowner that she was thinking about taking her business elsewhere, because people were shopping online more and more and she would had no chance competing.

She had always wanted to sell toys and against all odds her shop lasted. There were still barely enough customers to keep the shop up and running, but she was still in Enschede on the Langestraat. People pass by all the time, but not many people stop to look into her shop despite all the efforts she made.

At this point she is a little sad and began considering moving elsewhere again. Then to make things worse the municipality starts digging up the road in front of her shop! Now the access to her shop is even worse and things are definitely going to go wrong from here.

In her panic she writes a letter to the municipality. In that letter she basically told the municipality that they were going to have to pay for her damages and that she is very angry that she was not informed beforehand, because she would have made her decision to move much earlier.

The municipality did however try to contact her, but she missed the e-mail, the letter and the article in the newspaper. The reply response by the municipality told her to look at those things again and she did.

After that she learned that the new development was going to make the area more attractive to visitors. The new development is a smart rainwater buffer with an element of interaction for people to play with. In the summer it helps cool the area and it always helps to prevent floods.

The municipality made sure that the access to her store was as little obstructed as possible and to Sarah's joy there were even more visitors coming due to the construction of the new SRB XXL. Kids want to watch the trucks and construction machines and are interested to buy the toy version of those trucks and machines. Sarah was clever enough to put them at the front window of her store and she got a little boost in sales.

4.3 Preliminary Requirements

During early phases of the research there were meetings with the municipality of Enschede and Waterboard Vechtstromen. In some of those meetings the supervisor for this research was also present. These meetings resulted in the preliminary requirements that can be seen in table: 1. They are further clarified and expanded on in the specification phase.

PRELIMINARY REQUIREMENTS
MUST
Delay rainwatere runoff to the sewer system Connect to roofs in Enschede Have a capacity of 20,000 liters Work autonomously/smart Be safe Be designed for public or industrial space in Enschede It has to be able to deal with heavy rainfall
SHOULD
The ability to empty within two hours Be weatherproof Be reliable Have data repository communication Be low maintenance Be affordable Be secure Have a name Safe overflow
COULD
Collect water before it goes on the streets Store water for usage in the city Be modular Interact with local end users Dashboard communication
WOULD
Filter water before storing Energy efficient Self test Log errors

Table 1: Preliminary Requirements

4.4 Concepts

Ten concepts were generated to come up with a first design idea. These concepts were hand drawn drawings and contained comments (mostly in Dutch) that would explain certain parts. These concepts are presented in the following paragraphs with some extra comments to describe the idea behind it. Only the core functional requirements such as a the capacity were taken into account.

Blue Green Construction

Idea The idea behind the Blue Green Construction (Figure: 5) is about using rainwater that is collected on roofs of buildings to be directed to a pond that transitions into a stroke of vegetation. The pond contains fish that provide fertilization for the water plants and green stroke.

The key part that drives this concept is sustainability. By using fish and plants the system would manage itself. Maintenance costs would be low. This idea would work best in less urban areas, because in city centers trash is likely to end up in the water and that might cause harm to the fish. On top of that the safety of the fish might be jeopardized when water levels are controlled at a distance. The system would need to ensure that there is always enough water for the fish to be able to live and keep the cycle of fertilization and fish food in balance.

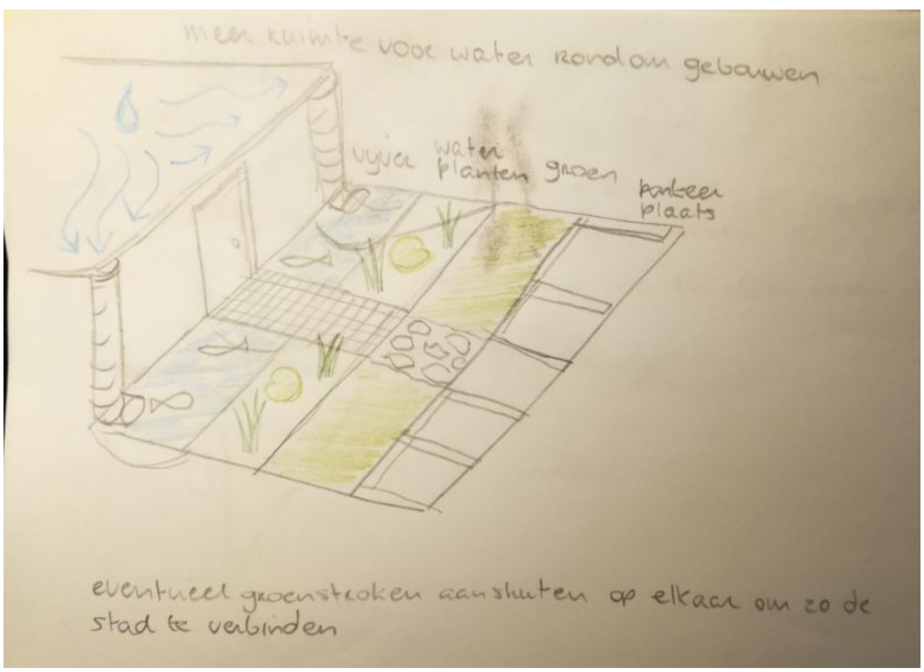

Figure 5: Blue Green Construction

Cycle Roof Buffer

Idea The idea behind the cycle roof buffer (Figure: 6) is to build a roof above cycling paths that are common in the Netherlands. The roof is then overgrown with plants in order to delay the rainwater before it runs into the sewer system. Nearby buildings will redirect the rainwater they collect towards the green roofs above the cycling paths. This way the cyclist stays dry when it rains and rainwater does not run into the sewer system immediately. In addition storage tanks could be added to collect water as well. They would be added on the side as walls or as pipes with a controllable valve. Figure: 6

This idea tries to combine several elements in order to provide benefits for inhabitants of the city. People who dislike cycling in the rain might go by bicycle where they would not have otherwise. Of course it would need to be a substantial amount of roof. Also it would require lighting since it blocks the sun and moonlight. Even though these disadvantages might affect the usefulness, it could still potentially work in some areas where tall buildings are close to each other, but still leave space for a cyclist road. Even stretches of cyclist highway could be upgraded with Cycle Roof Buffers, not only to buffer rainwater, but perhaps also to block wind so that cyclists are less hindered by that.

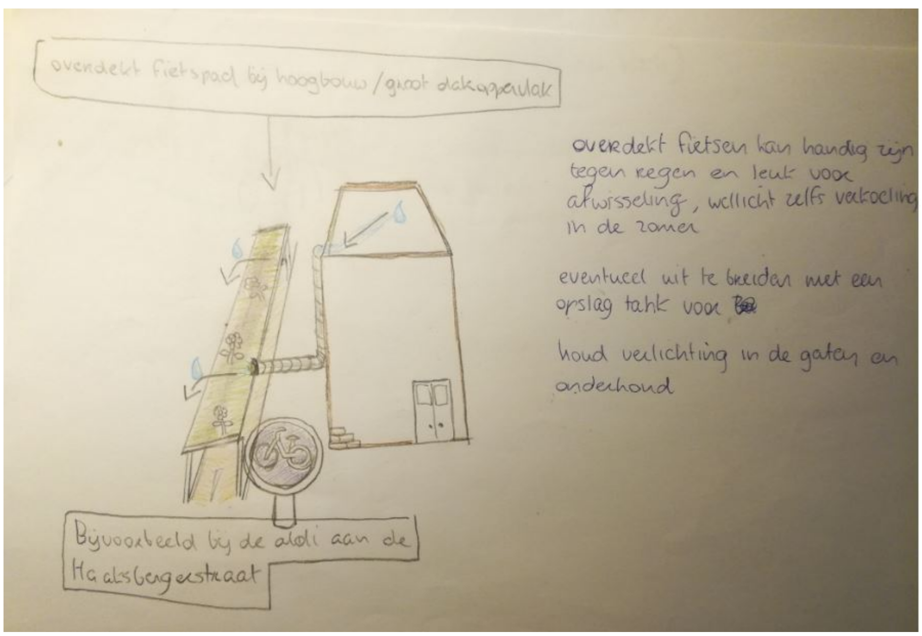

Figure 6: Cycle Roof Buffer

The Gutter Lock

Idea The gutter lock (Figure: 7) is a smart lock connected to a roof. It can be controlled remotely in order to have it participate in a larger system of gutter locks. Flat roofs store water and can be turned into water buffers in that way.

The advantage of this system is that it has the potential to work on any building top that has some type of gutter. However it might be unwise to store water on top of the buildings due to the exposure to sun and bird droppings. When implementing a system like this the water quality has to be monitored closely.

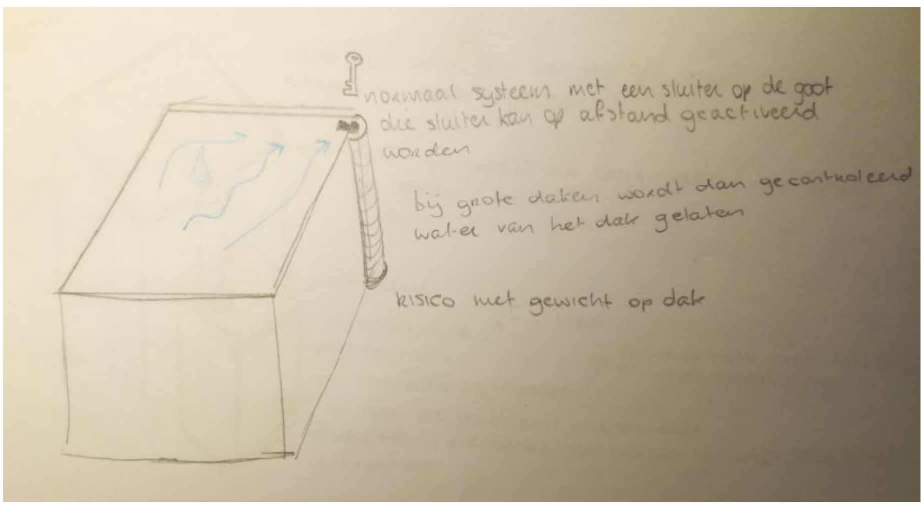

Figure 7: The Gutter Lock

The Flipping Buffer

Idea Figure 8 shows a drawing of the flipping buffer. It is a storage unit that can collect water and release it by tilting the storage component. It is connected to a weather prediction database in order to make sure it empties at the right times. Due to the connection to the weather prediction database it can also be used as an indication of what type of weather to expect for people that can see it when it is located in a public space.

This type of water buffer has some form of communication with the people. The fact that it tilts as a way of bringing across information has potential, but also creates a few challenges. For example when the buffer is full, but there is no prediction it still needs to empty itself. Either by means of an alternative discharge method or by tilting. This concept would be best used in an urban area.

Figure 8: Flipping Buffer

Pond With Tube

Idea Figure 9 shows a drawing of the pond with a tube. The tube is connected to the sewer system. When the pipe is below the water level it will let water run into the sewer system. The pipe's height sets how much water the pond stores.

This concept would be interesting, because it creates a nice visual of how water enters the tube. The idea is simple, but has many mechanical weaknesses and could potentially be dangerous for animals or people who might enter the tube.

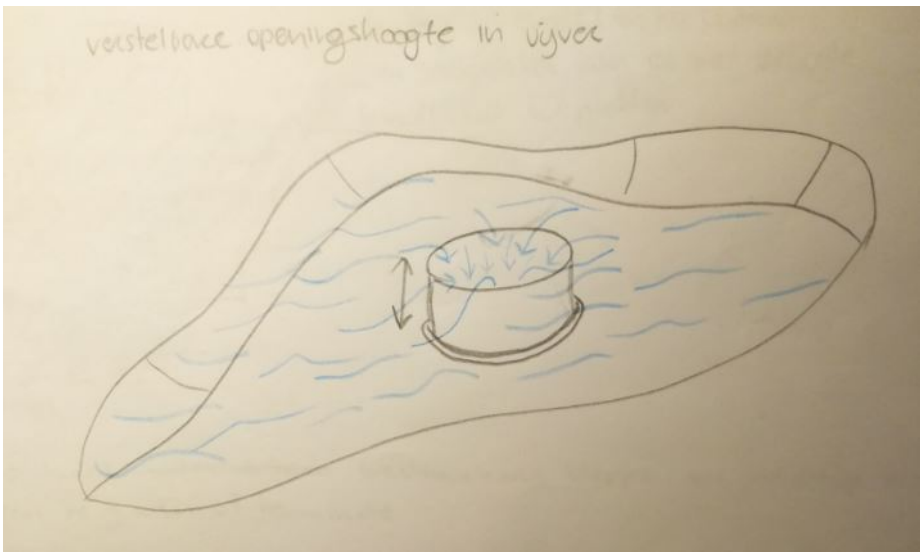

Figure 9: Pond With Tube

Smart Rainwater Buffer

Idea The smart rainwater buffer(Figure: 10) is connected to a roof that guides collected rainwater towards it. The smart rainwater buffer has sensors to measure water quality and is connected to a database and a weather prediction source. The smart rainwater buffer operates autonomously. It has a small pipe to let air out so water can move properly.

This basically sums up what Waterink [23] has created. But at a larger scale this idea might still work. However it would not be a DiY, but an urban implementation. Either in city centers or neighborhoods. Even industrial areas could benefit from a smart rainwater buffer.

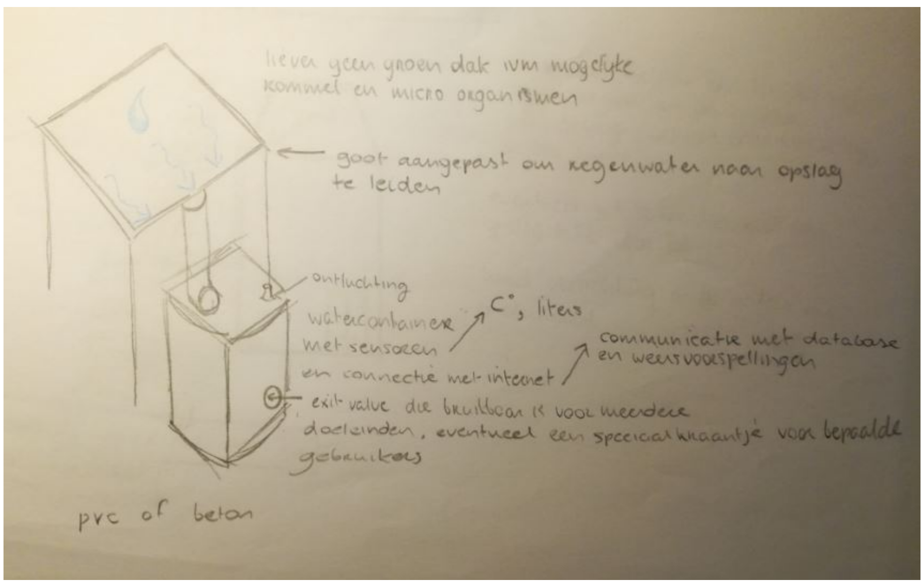

Figure 10: Smart Rainwater Buffer

Staircase City Canal

Idea The staircase city canal(Figure: 11) is a staircase that is simultaneously a moat or canal. It can fill up and thus hold water. This does reduce the amount of steps available on the staircase, but they aren't as needed most likely when it rains a lot. Using controllable valves the water can be kept in the canal or let into the sewer system.

This type of SRB is very suitable for city centers. It has a purpose at all times. During wet times it is able to help delay rainwater runoff to the sewer system and during hot times it can cool down the area by using some of the water it contains. The biggest downside is that it hinders traffic due to its placement. Another potential downside is the maintenance it would require, it is likely that trash will end up in the buffer and that it might affect the water quality. The need to keep it clean will be high when it is used in areas where a lot of people go about their activities.

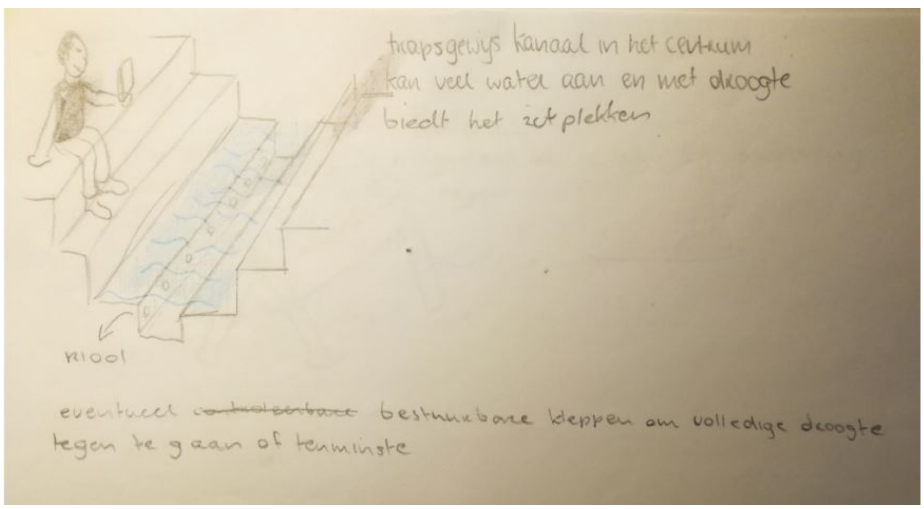

Figure 11: Staircase City Canal

Street Gutter and Buffer

Idea The street gutter and buffer (Figure: 12) is an expansion on existing gutters in the streets. But instead of leading the rainwater runoff into the sewer system it is directed towards a storage unit under the road. These storage units are placed at logical places. Water will run on the street, but there pressure downstream is less.

This idea is just like the Gutter Lock in the sense that it is an adaptation on existing structures. In this case it is infrastructure. Changing infrastructure is however very costly and this would be an addition on alternative to the rework that is being done at the Oldenzaalse Straat in Enschede. More open gutters would be good to keep water of the streets.

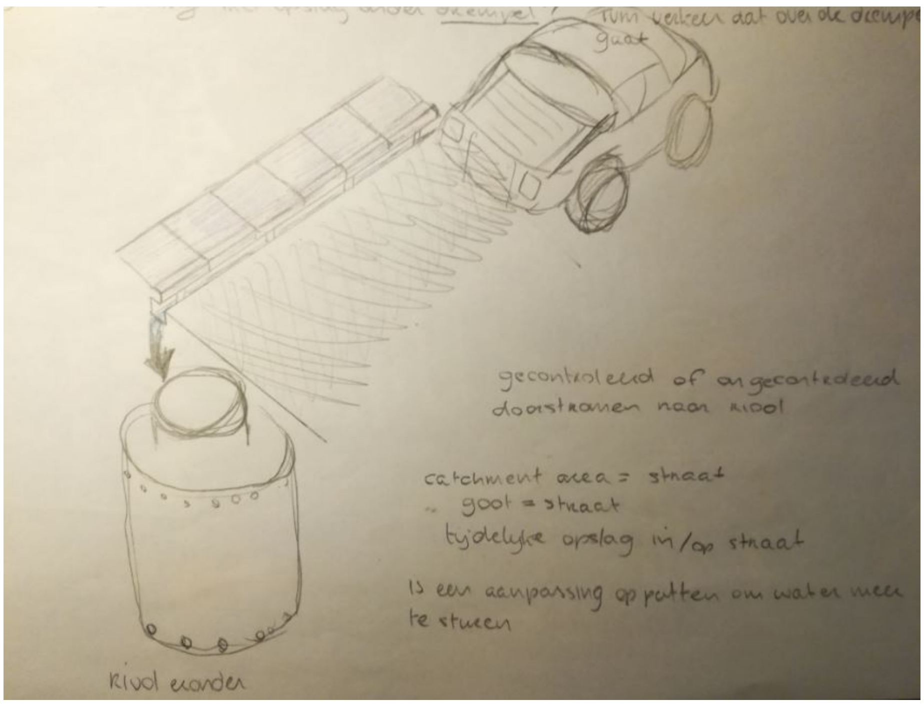

Figure 12: Street Gutter and Buffer

Subterranean Collector

Idea The subterranean collector (Figure: 13) is placed somewhere underground and can collect water from several roofs. The collected water can be used for flushing the toilet and washing clothes after filtering.

The subterranean collector is aimed at collecting rainwater in neighborhoods. A neighborhood could be set up to collect water in a certain tank and that people can get water there to water their plants for example. This would require a neighborhood where people are willing to work with each other. Since it is unlikely that all water would end up being provided or distributed evenly across all neighbors.

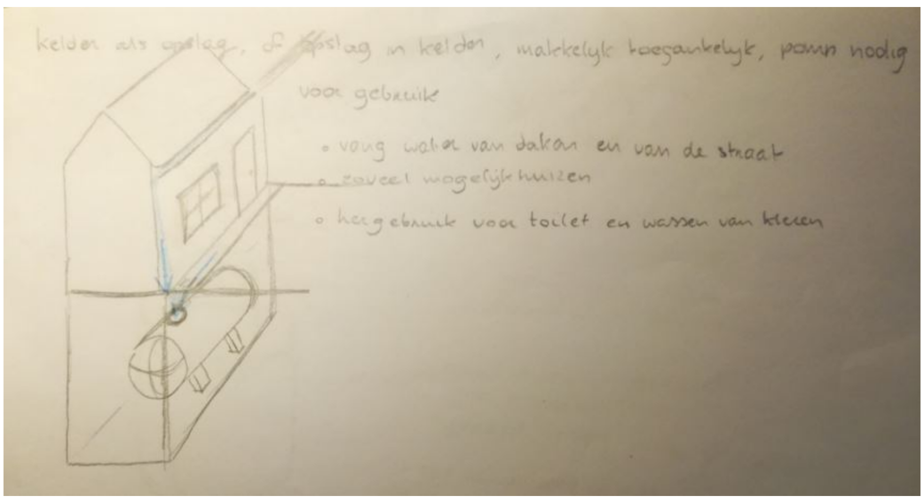

Figure 13: Subterranean Collector

Venschede

Idea Venschede (Figure: 14) is a combination of the name Enschede and the name Venice. Venice is famous for its canals and canals are what Enschede could use as well in order to manage rainwater.

Canals provide a lot of room for water and with some control elements it could easily be turned into an SRB XXL. Just like the Staircasy City Canal it would require good city planning to make sure the disturbance to traffic is not too big. The idea is simple, but requires a huge change in the city.

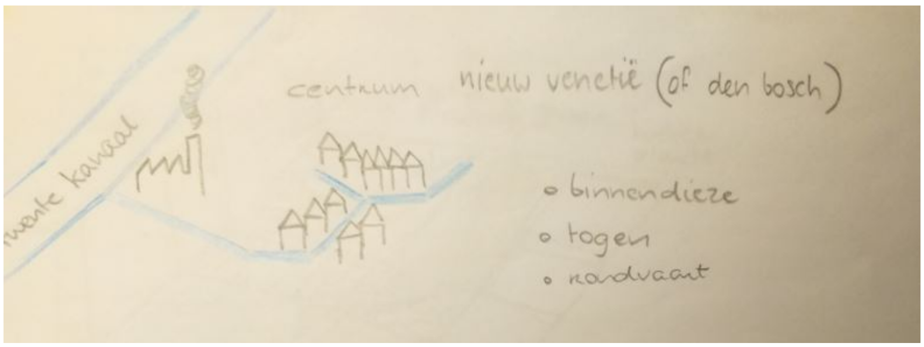

Figure 14: Venschede

4.5 Selection

The selection process was done by presenting the concepts to the University and was based on the current development of the SRB that was still being developed while this thesis was done. So this thesis about the SRB XXL was influenced by the development of the SRB. This makes sense, because both are being developed for the same client and they still have the same desire as before as shown in the stakeholder analysis. The biggest change is the demand for a larger volume and that immediately affects the context as well. The SRB XXL is not suitable for the backyard of most people. So the aim is to change it in such a way so that it suits an industrial zone or urban area.

Choice The staircase city canal ended up becoming the most promising concept. The combination of canals, water buffering and interaction with the public correspond with many characteristics that the municipality and the waterboard desire. The name that it got was "Badi". Due to the overlap in functions with the "Wadi" and in Dutch the word 'baden' means "to bathe". A quick search also revealed that the word means "big" in Hindi. This also fits very well due to the fact that it is called the SRB XXL after all. It is always useful and it can be changed to fit many different urban settings.

Urban This means that the focus of the SRB XXL is going to be urban areas. So the city center of Enschede or perhaps even some neighborhoods. The combination of staircase and the rainwater buffer makes it so that this concept has a use at all times. When it is empty it provides places to sit down and when it is full it serves its purpose as rainwater buffer. A side view of the idea can be seen in figure: 15.

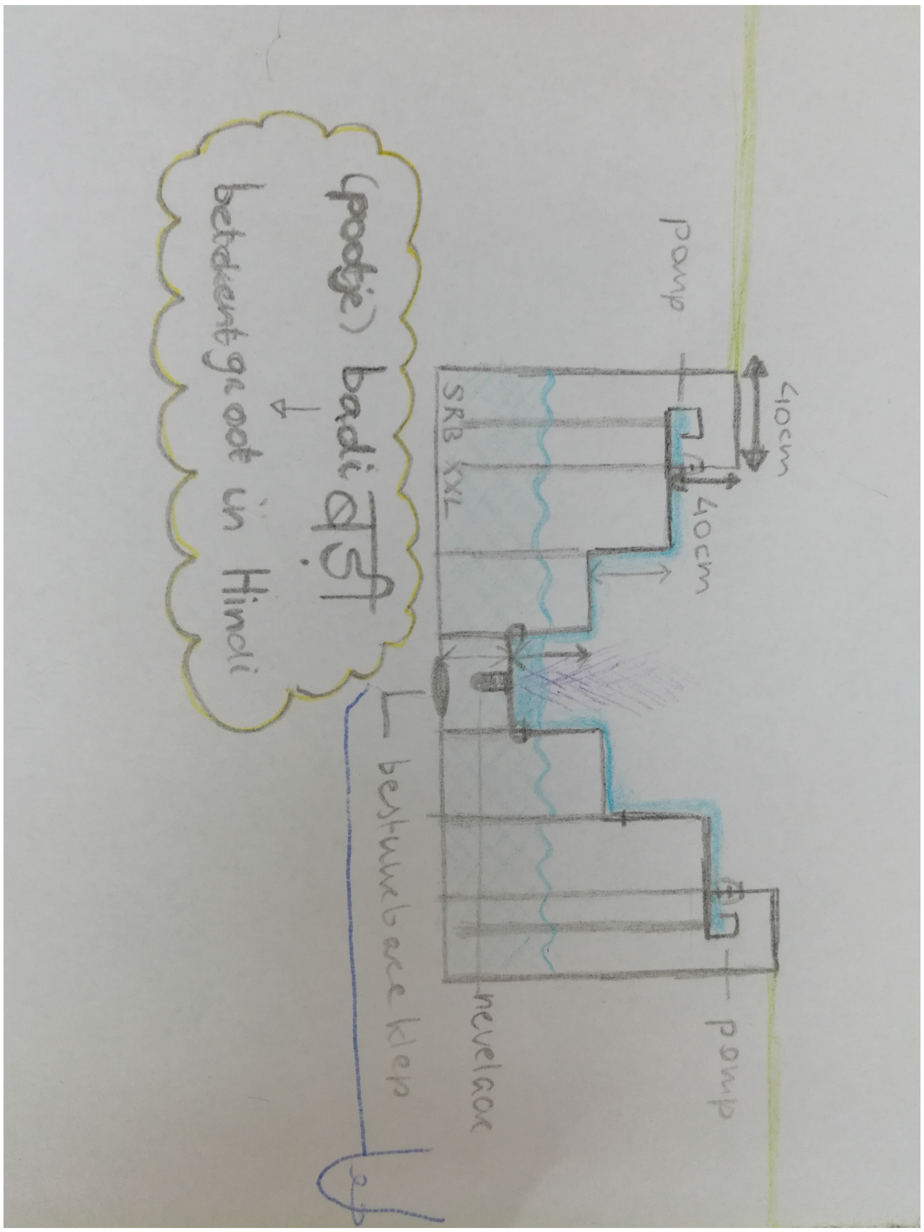

Figure 15: Badi concept side view.

5 Specification

In this chapter we focus on the system architecture of the SRB XXL and what requirements the SRB XXL should fulfill. Based on this chapter it should be possible for a system engineer to create their version of the SRB XXL. The chapter starts by explaining the system architecture and ends with an updated and more specified list of components that are a derived from the preliminary requirements and the system architecture. First the system architecture is explained and then the requirements list is displayed.

5.1 System Architecture Diagrams

This section describes the system down in three levels. It starts with the core system. The core system's purpose is to delay rainwater runoff to the sewer system of Enschede (Figure: 16). After that we want to look at the context from the perspective of the SRB XXL. This thesis will show the three levels as system architecture diagrams, starting at level 0, then level 1 and ending at level 2. Each level zooms in on a different part and the subsystems are explained.

Figure 16: System Simple Overview

5.1.1 System Architecture Diagrams - Level 0

In order to create that perspective from the SRB XXL point of view we create a system architecture diagram where we zoom in on several components of the SRB XXL to show the interactions of the system. We start at the level 0 overview. As seen in figure: 17, there are six external components that the SRB XXL communicates with.

Rainwater Input and Output
The first aspect of the system architecture we describe are the interactions of the rainwater input and output. The primary goal of the system, as mentioned before, is to delay rainwater runoff to the sewer system. Which means that there has to be a source of rainwater runoff. In the case of the SRB XXL it is called the rainwater source. The SRB XXL has the ability to interact with this water source in multiple ways. (Figure: 18 shows the input and output of the system.) Firstly it can accept the incoming water. Next to that it is able to request and receive information about the characteristics of the water source. For example the size of a roof can be considered a characteristic of a water source. Because when a certain amount of rain falls, the roof size is one of the

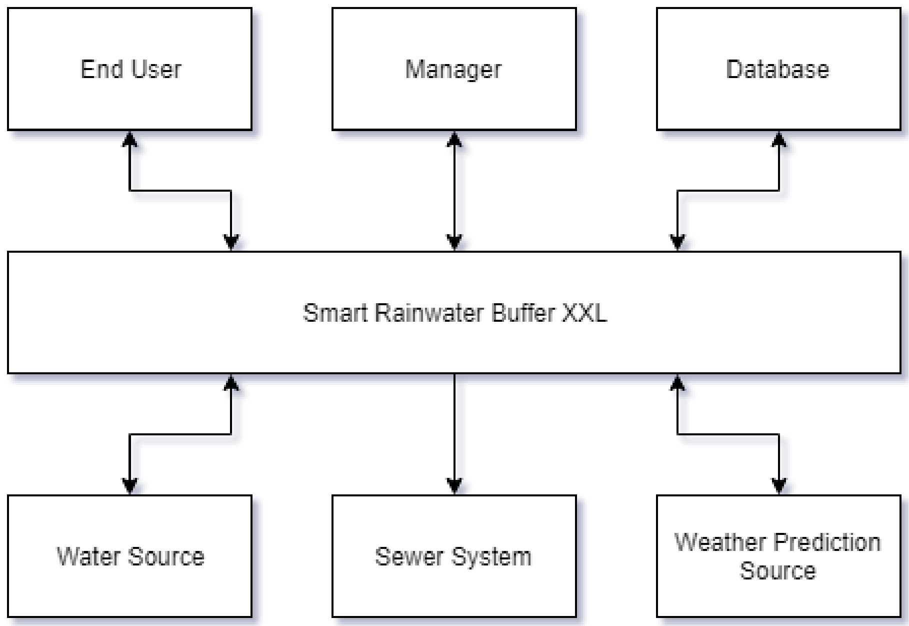

Figure 17: System Architecture Diagram Level 0 Overview

factors that plays a role in determining the amount of expected water. This can also assist in determining the size of the input and storage of the SRB XXL. The output is mostly determined by the input and is only used to discharge water from the storage. The size of the output has to be able to discharge the same amount of water that the SRB XXL can take via the input. This is to make sure that the SRB XXL can also be a neutral object. So that when the SRB XXL stops working it would be the same as if it did not exist. If the output is larger than the input it could mean that there is even more water being led towards the sewer system than without. That would worsen the problem that the municipality of Enschede is trying to solve.

Rainwater Input and Output Requirements
From the preliminary requirements we can find that a couple play a role when considering rainwater input and output:

1. Connect to roofs in Enschede
2. It has to be able to deal with heavy rainfall
3. The ability to empty within two hours
4. Safe overflow
5. Collect water before it goes on the streets

Based on the system architecture and requirements we can determine what factors should play a role in the decision making of the input and output. The input size is determined by the expected input during heavy rainfall and it has to be connected to roofs so that it can receive the water coming from there. The output is determined by the maximum input of the SRB XXL. The maximum expected input is the maximum discharge rate of the roofs towards the SRB XXL. However the SRB XXL should be able to discharge within two hours, so that means that the output has a constraint in the form of a minimum, because the SRB XXL should not discharge more water than is coming in. So it needs a safe overflow. An overflow can technically be seen as another output. This means that the overflow and the controlled output must not be active at the same time or the output capacity could be larger than the input. Or the output rate needs to be controlled.

Input Location Requirements
The preliminary requirement about *collecting water before it goes on the streets* is the odd one out. This requirement is related to placement of the SRB XXL rather than its abilities. Because sometimes water can go on the street and end up in rainwater buffers afterwards. Wadi's often have this issue. Even though they provide rainwater with a place to go, a wadi does not stop rainwater from getting on the streets first. To solve this, more roofs need to be connected to rainwater buffers. Blocking all rain that is directly above the streets is unrealistic. So this means that the SRB XXL should be collecting rainwater from places before it hits the street. This means that water should be redirected into the SRB XXL. Connecting the SRB XXL to the roofs in Enschede is one solution and became a high priority preliminary requirement.

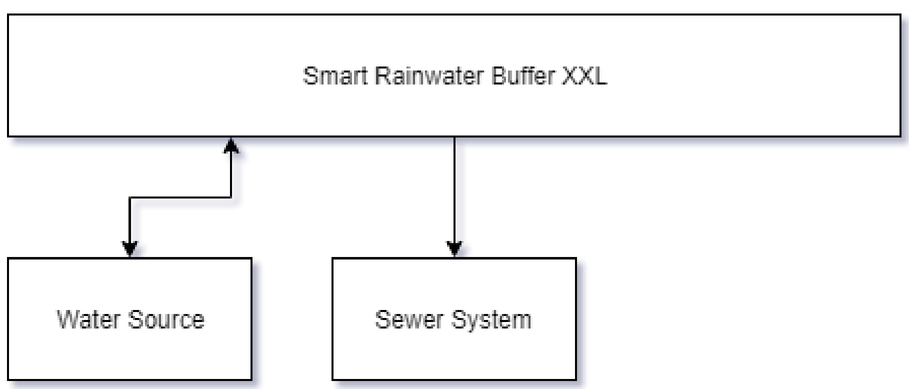

Figure 18: System Architecture Diagram Level 0 Input and Output

Users
Figure: 19 shows the two types of users that the SRB XXL has. The arrows

indicate there is two-way communication and something travels in both directions. But the nature of this interaction is different per user type. We will look at the requirements again to see which requirement fits with what user type. But before we do that it is important to determine what these user types mean.

End User The end user is linked to the citizens of Enschede stakeholder. They are physically near the object when they interact with it.

Manager The manager is linked to the municipality of Enschede, the waterboard Vechtstromen and the University of Twente. They are the user that can change the behavior of the SRB XXL where that is not possible for the End User. For example they can toggle the output of the SRB XXL at any time.

Users Requirements

For the end user there are less requirements than for the manager. This is because the end user has less options when it comes to interacting with the SRB XXL. So first come the end user requirements.

1. Be safe
2. Be affordable
3. Interact with local end users

Then the manager requirements.

1. Work autonomously/smart
2. Be safe
3. Be reliable
4. Have data repository communication
5. Be low maintenance
6. Dashboard communication
7. Self test
8. Log errors

This shows that the requirements for the smart charateristic of the SRB XXL mostly come from the manager. They want to control and monitor the SRB XXL. In order to provide this ability there needs to be a controller that can deal with all sorts of output, information input and user input.

Data Management

The information however does not come falling from of the sky like the rain does, instead there is data exchange. Figure: 20 shows the final two external systems that the SRB XXL interacts with.

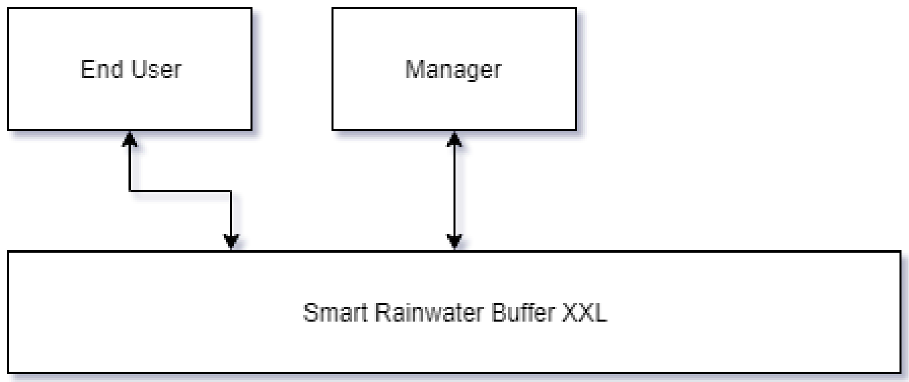

Figure 19: System Architecture Diagram Level 0 Users

Database
For data exchange you need a place to store the data. As mentioned before there is a controller that can deal with output, information input and user input. But the controller is part of the SRB XXL. There is also an external database that the SRB XXL can interact with. The SRB XXL can send a request to the database for information and it can also receive information from the database. Multiple SRB XXL units can connect to the same database and even different types of SRBs could connect to it.

Database Requirements
Just like the other interactions are linked to some of the requirements, so is the database. Some of them are the same as the ones that can be found for the manager requirements as well.

1. Work autonomously/smart
2. Have data repository communication
3. Be modular
4. Dashboard communication

Modularity is established when you connect multiple modules. The SRB XXL could be a module in a larger system that has multiple SRBs. If the system is required to *be modular* by adding more SRBs, then the information exchange has to be standardized. So that you do not need to create multiple information exchange protocols.

Weather Prediction Source
One of the core features of the SRB XXL is that it can convert weather prediction data into behavior that allows it to work autonomously. But the SRB XXL can

not predict the weather itself. It uses an external weather prediction source that the SRB XXL communicates with. It does so by sending a request to the weather prediction source and in return it receives the requested data.

Weather Prediction Source Requirements
There is only one requirement that is linked to the weather prediction source and it is the 'work autonomously/smart'. Weather information is key for determining the behavior of the SRB XXL. For example if there is a prediction that says that the SRB XXL will receive 200 liters, then the SRB can create enough space by emptying before the 200 liters are on their way.

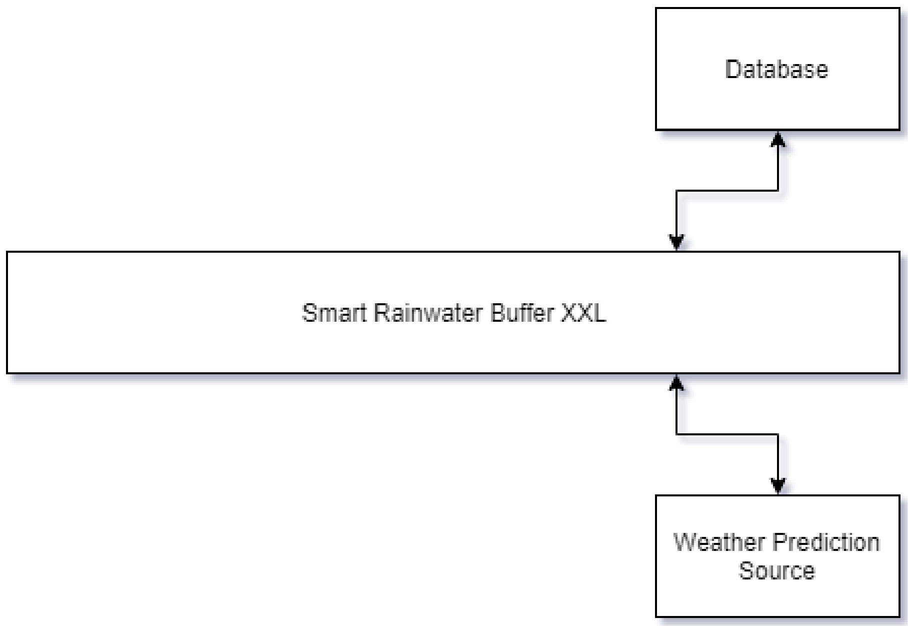

Figure 20: System Architecture Diagram Level 0 Data

5.1.2 System Decomposition - Level 1

After the level 0 overview we look at the level 1 system architecture diagram (Figure: 21). The level 1 diagram zooms in on the SRB XXL and reveals the internal subsystems:

1. Water storage
2. Discharge
3. End User Interaction
4. Water Level Measurement

5. Water Quality Measurement
6. Water Circulation
7. Controller

Each subsystem has a role to play in order for the SRB XXL to do what it needs to do. Below we describe every subsystem.

Water Storage
What we know about the water storage is that it has to be able to hold at least 20,000 liters of water in order to fulfill the SRB XXL requirement. But figure: 21 shows that the water storage receives the water from the water source. Internally the water storage shares its water with several other subsystems. This means that those subsystems use the water as well in one way or another. It does not mean it has to consume the water.

Controller
The only subsystem within the SRB XXL that does not come into contact with the water directly at a level 1 decomposition is the controller. The controller is a system that translates information into actions and will be further explained at the level 2 decomposition where we zoom in on the controller.

Discharge The discharge system is able to discharge water from the water storage. It waits for a request from the controller. For example the controller will request a discharge of 25 liters. Then the discharge system will operate in such a way that it discharges 25 liters.

End User Interaction
The end user interaction subsystem can make use of the water inside the water storage. The end user can place a request through an interaction which is then passed on to the controller that decides whether it is okay to return the requested interaction. Because in some situations it is unwise to bring water in contact with people. Think about legionella for example or simply when the water storage is empty.

Water Level Measurement
The water level measurement subsystem is able to measure the amount of water in the water storage and can relay that information to the controller.

Water Quality Measurement
The water quality measurement subsystem is able to measure whether the water inside the water storage is safe or unsafe to use and can send that information to the controller.

Water Circulation
The water circulation subsystem is able to circulate the water in the water storage and can be toggled by the controller.

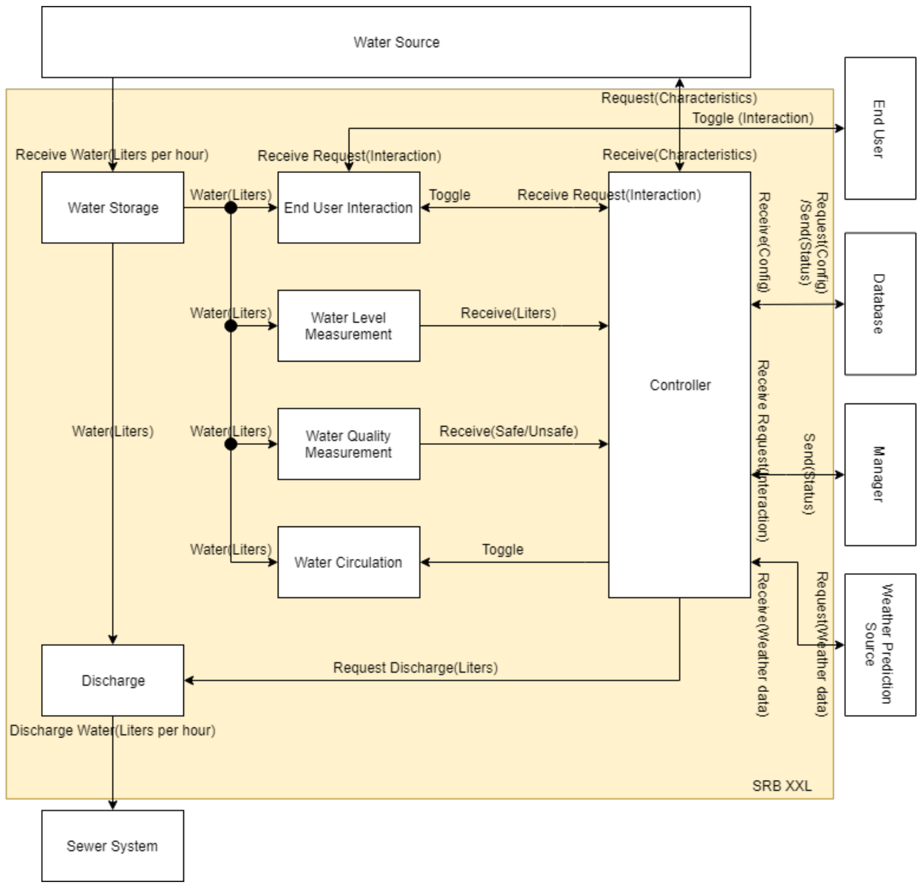

Figure 21: System Decomposition Level 1

5.1.3 System Decomposition - Level 2

As mentioned before the level 2 decomposition zooms in on the controller (figure: 22. It displays the handlers that are used to do the translation of data. Furthermore there is a logic system that converts events into actions. In this case the logic can be in certain states, the state is directly related to the SRB status. Sometimes information about the status is necessary for the handlers to be able to inform external systems like the manager about the status of the SRB XXL. Handlers should be seen as translators between the logic and other systems. The handlers that the SRB XXL has are:

1. Water Source Handler
2. End User Interaction Handler
3. Water Level Handler
4. Water Quality Handler
5. Water Circulation Handler
6. Discharge Handler
7. Management Handler
8. Weather Prediction Handler
9. Database Handler

Interesting to see is that the discharge, water circulator and end user interaction do not use a handler before toggling. They are directly controlled by the logic. This is because there are more events that can trigger these actuators. For example when the water quality handler indicates that the water is unsafe it might be that there is also a discharge action.

Water Source Handler
The water source handler is able to send a request to the water source in order to determine what the characteristics of the water source are. These characteristics are important in combination with the weather prediction source to determine what to expect during certain types of rainfall. The event that it generates is about updating the status of the SRB XXL and the action it receives is a request to update the characteristics.

End User Interaction Handler
The end user interaction handler translates an interaction request into an event. This event goes to the logic that does some checks and does what it is set to do in its current state. For example when there is an end user that presses a button on the SRB XXL, then the end user interaction handler translates that button press into the 'end user wants interaction event'. Then that event goes to the logic and when the water quality is good and there is enough water, then the interaction is toggled.

Water Level Handler
The water level handler translates water level data into an event that tells the logic to update the SRB status with the new water level.

Water Quality Handler
The water quality handler converts water quality data to an event that either says the water quality is safe or unsafe.

Water Circulation Handler
The water circulation handler uses SRB status data to determine whether the water circulation action should be toggled.

Discharge Handler
The discharge handler translates SRB status data into a discharge event. If the status indicates that 25 liters need to be discharged, then the discharge handler knows how long the output should be toggled and sends the corresponding discharge event.

Management Handler
The logic can send the SRB status data to the management handler which translates that data into something that the manager can understand. But the management handler can also translate manager requests into events. These events could be a request to the SRB XXL to empty itself. The logic should then use the discharge handler to create a discharge action.

Weather Prediction Handler
The weather prediction data handles everything that has to do with the weather prediction. The logic can decide that new weather data is required and send an action to the weather prediction handler. The weather prediction handler then transforms the action into a request towards the the weather prediction source. If the weather prediction sends a response the weather prediction handler is able to translate that data into a status update event for the SRB XXL.

Database Handler
The database handler translates requests from the logic to update the SRB status data in the database into a request to the database in the right format. The same goes for the configuration file request. The SRB XXL sometimes wants to update the configuration file. Simply said the database handler works as a translator between the logic and the external system.

5.2 Final Requirements

The requirements shine through the system architecture and where the level 0 overview was linked to most of the requirements. There are new and more specific requirements that can be derived from the level 1 and level 2 decompositions. Where the requirements in the ideation phase come from the stakeholders, here the requirements come from the SRB XXL itself and the way it wants to interact with other systems. But in order to avoid gaps between the stakeholder and system requirements they are split into functional and non-functional requirements (Figure: 23). And the same MoSCoW method is applied to show priorities. The result is a set of requirements that the SRB XXL attempts to fulfill that form the basis for an SRB XXL.

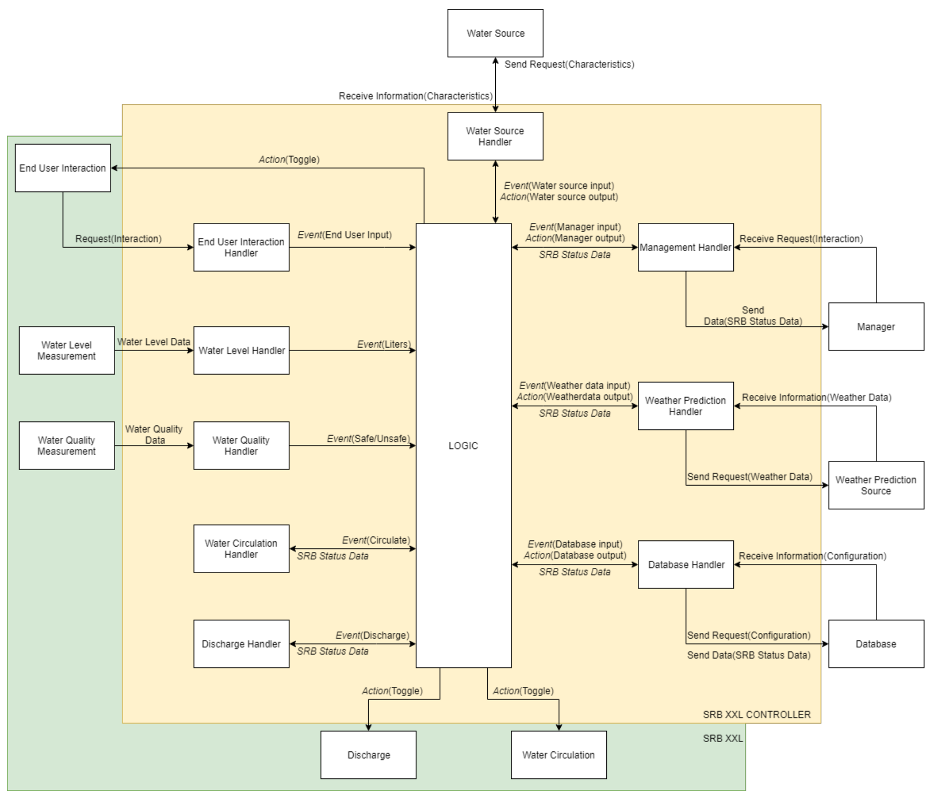

Figure 22: System Decomposition Level 2

Functional Requirements	Non-Functional Requirements
MUST	
The system must delay rainwater runoff to the sewer system	The system must be safe
The system must work autonomously/smart	The system must be designed for public space
The system must never output more water than is coming in	The system must be connected to roofs
The system must be connected to a central database	The system must be modular
The system must be connected to a weather prediction source	
The system must be able to measure the water level inside the water storage	
The system must be able to determine whether the water inside the water storage is safe or unsafe	
The system must be able to use the data from a weather prediction source	
The system must be able to send data to a database	
The system must be able to hold 20,000 liters of water	
SHOULD	
The system input should be determined by the expected input	The system should be weatherproof
The system should be able to empty itself in two hours	The system should be affordable
The system output should not be larger than the system input	The system should have a name
The system should interact with an end user	The system should be secure
The system should be able to be controlled by a manager user	The system should be low maintenance
The system should be able to circulate the water inside the storage	The system should be reliable
The system should be able to translate high level commands into low level actions	The system should have safe overflow
COULD	
The system could communicate through an online dashboard	The system could collect rainwater runoff before it goes on the street
The system could use configuration files to determine its behavior	The system would be able to discharge water for other purposes such as watering plants
WOULD	
The system would filter the water before storage	The system would have another filter variation
The system would be able to notify the manager about status changes	

Figure 23: Functional and non-functional requirements.

6 Realization

This chapter describes the how the requirements from the specification phase are implemented. We start by showing an overview and then break it down into separate parts while providing the reasoning behind some of the implementations. For the SRB XXL this means that we start with showing the end result with all the components and then decompose it into three main parts. First there is the controller. Then the water storage and finally the Badi.

6.1 Overview

The result of the realization phase is a scaled proof of concept in order to demonstrate an idea for the implementation of an SRB XXL in an urban area to the stakeholders. The overview (Figure: 24) shows three components:

1. Controller
2. Water Storage
3. Badi

Together they make up the SRB XXL. The controller is a watertight housing with space for all electronic components. It is in essence the same as the controller unit that Waterink [23] uses. The water storage is combined with the controller to allow the smart aspects to function. On top of that there is the addition of the Badi which is able to expand upon the water storage while leaving the SRB functionality intact. The design of the Badi is that of a mirrored staircase inside a box that allow people to sit comfortably when there is little to no water stored inside. But if there is a lot of water storage required due to heavy rainfall or any other reasons it is possible to store that inside the Badi. This way it has purpose at all times.

6.1.1 Controller

The controller unit is a watertight cylinder shaped box that contains all electronic circuitry (Figure: 25). It is designed by Waterink [23]. It has two temperature sensors. One temperature sensor is to measure the water temperature and the other temperature sensor is to assist the ultrasonic distance sensor, because that sensor depends on the air temperature to do accurate readings. Next to that there are four actuators of which the pumps are added to the design that Waterink made. There are two pumps. One pump is in place to circulate the water and the other is there for the interaction with the end user. Then there is the valve which is the controlled output of the SRB XXL and finally an LED that indicates the status of the SRB XXL. Using the SRB controller that Waterink designed creates the opportunity to expand both systems at once. All tweaks made to controller will affect both SRB types. So that both the SRB (DiY) and the XXL development benefit each other.

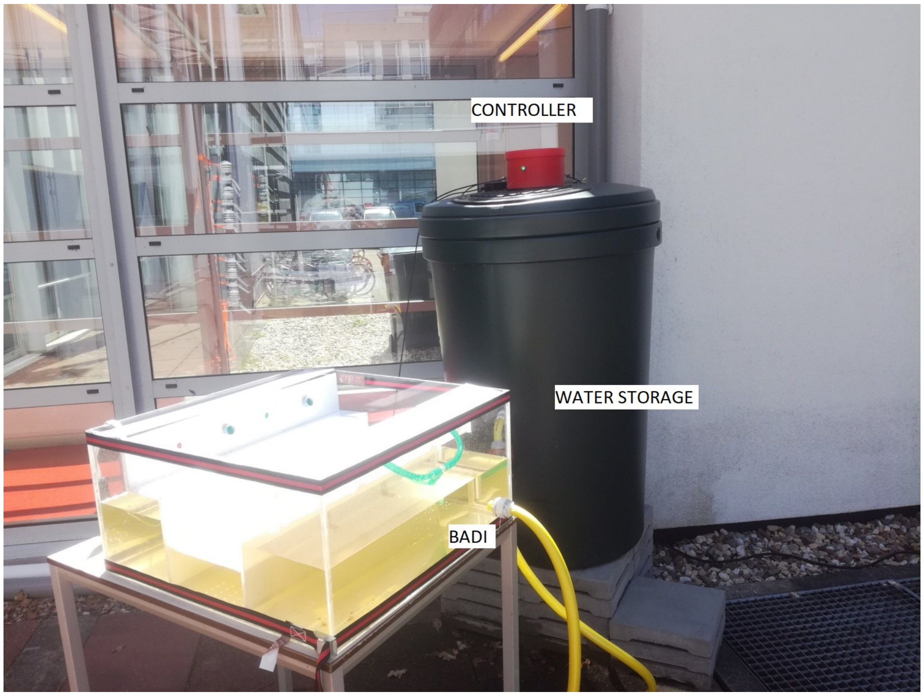

Figure 24: Overview final result.

Controller Montage
Components:

1. SRB Controller (By Waterink [23])
2. HL-525 V1.0.2 relay module
3. (2x) Comet 1300.01.59 Low voltage submersible pump 600 l/h 5.5m
4. Mean Well GST60A12-P1J 12 V/DC 5 A 60 W Power Source
5. Software

The controller that is used was developed by Waterink [23] and only required one extra relay module to be connected in order to connect the pumps. The SRB Controller makes use of a raspberry pi zero and there were GPIO ports available for the extra actuators (pumps).

Wiring
The way it was connected can be seen in figure: 26 and 27. In the second image you see three loose male wires and three loose female wires. The red male wire goes into the yellow female wire to provide the 12 volts DC to the relay and the other two wires connect to the pumps and output of the relay. As indicated

Figure 25: Controller view Badi.

by the names PUMP 1 and PUMP 2 in Figure: 26. Furthermore the ground of the 12 volt DC adapter is connected to the ground of both pumps. In order to provide power to the pumps, the power source needs to be connected to the 230 volt power network. Which in this case is a power outlet close to the SRB XXL's location.

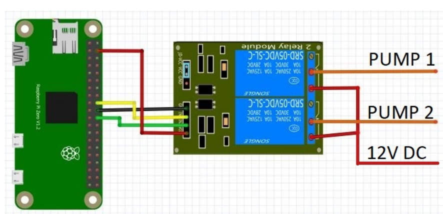

Figure 26: Pump Relay Connection.

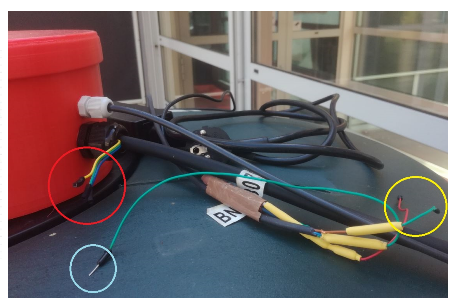

Figure 27: Pump Wiring Connection.

Software

The SRB controller can modify the behavior of the SRB through software. For the SRB XXL there is a side branch that has all the functionalities that Waterink created, but some extra features to enable the pumps. The side branch that exists for the SRB XXL is further explained in appendix: D. What it boils down to is that the system runs in cycles where it first assesses what it should do and what results it expects, then what it can do, then what it shall do and when. In addition it checks every cycle what action needs to be done and does it. After that it evaluates whether the action has the expected result and continues. This differs from the current SRB software. Currently the SRB software repeats a certain set of actions every X minutes. In between the X minutes the system sleeps. This is more efficient than continuously looping, but the system might be asleep when something goes wrong. With a continuous program the system is more flexible and can detect errors more quickly.

6.1.2 Water Storage

The water storage is a barrel that can contain up to 350 liters of water with a small faucet attached to it that can be manually opened and closed. But not at a distance. The rainwater runoff input comes from the roof of the University of Twente building where the SRB XXL is located. The water is led through a downspout into the barrel. This is also where the filter is located. However due to parallel development of the SRB and the SRB XXL and their similarities, the two projects were intertwined. This meant that the water storage would become a regular SRB and that the focus shifted towards the addition of the Badi. So instead of reinventing the wheel, or in this case the SRB, it was more important to figure out how to add the Badi while retaining the functionality of the SRB. This way the water storage would be scalable without requiring many changes to the other parts.

Water Storage Montage
Components:

1. 350L Magnum Rain Barrel Water Butt
2. Hose Connector 19mm (3/4")
3. Hose Repairer 19mm (3/4")
4. (2x) Accessory Adapter American Thread
5. Manual Ball Valve (3/4" and female-female thread)

Water Storage Linking
The water storage needs a way to link to the Badi without interrupting the functionality of the SRB. This means that it has to be able to share the water storage so that they both fill up and also that they both empty when the SRB is instructed to discharge. This is done by creating a connector above the output of the SRB. This connector can be seen in figure: 29. It was made by drilling a hole in the barrel and plugging that with a hose connector to which a 19mm (3/4") hose is connected. That hose then connects to another hose connector that can connect with a manual ball valve (Figure: 28) through another hose connector piece. The manual ball valve is not necessary, but was added in order to be able to interrupt the water flow between the water storage and the Badi.

Figure 28: Manual ball valve for 3/4 inch garden hose.

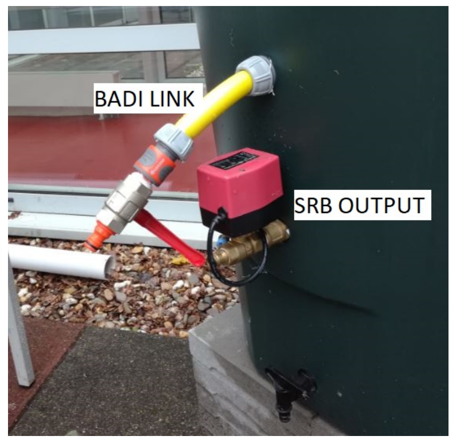

Figure 29: The water storage outputs.

Figure 30: Hose connectors.

6.1.3 Badi

The Badi can be seen as a box with a staircase on both sides on the inside (Figure: 31) and five water spouts that are connected to two pumps (Figure: 32). One pump pushes water through tubes that are connected to the four exits on the vertical part of the staircase and the other pump works as a fountain and pushes water through the tube that is connected to the horizontal board in the middle. It is connected to the water storage by a hose which is used for both input and output of water. The Badi has become the core of this thesis and it is a scale model of what could potentially work in Enschede.

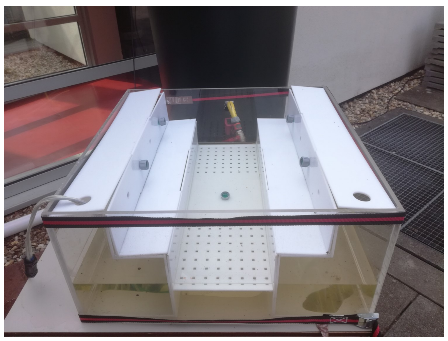

Figure 31: Side view Badi.

Figure 32: Top view Badi (5 spouts marked).

Badi Montage
Components:

1. Plexiglass 600mm x 600mm x 15mm
2. (4x) Plexiglass 608mm x 300mm x 8mm
3. (2x) Acryl 1000mm x 600mm x 4mm
4. Hose Connector 19mm (3/4")
5. Hose Repairer 19mm (3/4")
6. 4 meter tube (inner diameter 10mm, outer diameter 14mm)
7. (3x) T-connector piece for 10mm tube

The Box
The box consists of the plexiglass boards where the bottom board is 15mm thick. It has 4 sides made from the other plexiglass boards that are 8mm thick. They are kept together by glue and two straps. One of those boards has a 38mm diameter hole where a hose connector can be attached (Figure: 30). The hole

is in the bottom, because that is where the water has to leave as well. So the height of the hole also influences the minimum level of water that will be kept in the Badi if water would only be leave through that hole without the use of pumps.

Box Dimensions
The box dimensions are as follows:

Outer Dimensions
It has a length and width of 616mm and a height of 300mm.

Inner Dimensions
On the inside it has a length and width of 600mm and a height of 285mm.

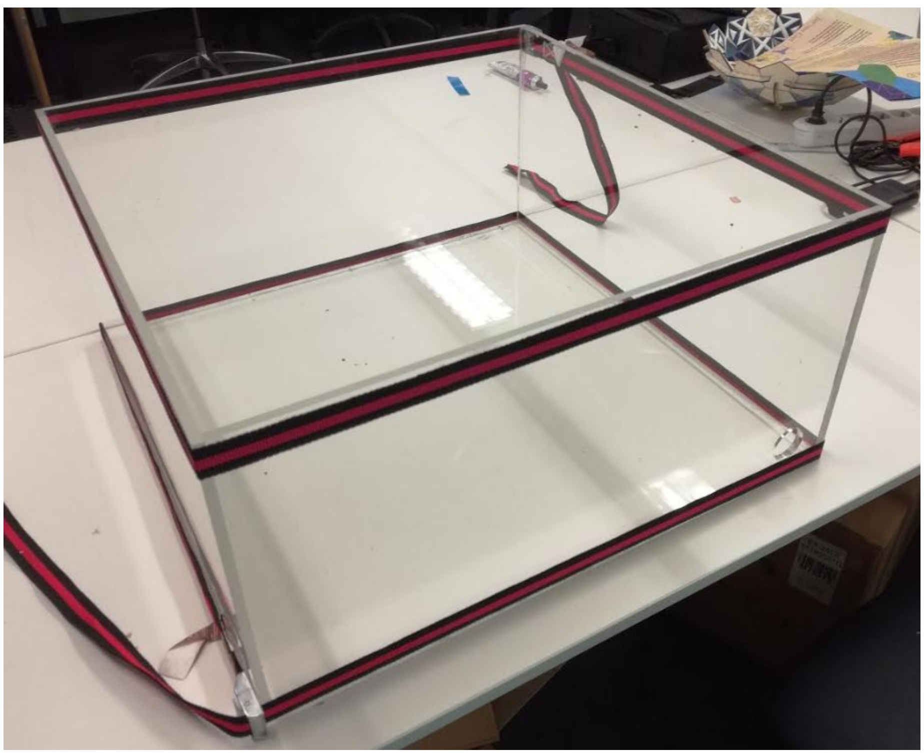

Figure 33: Badi without any attachments.

The Connector
As mentioned before the Badi is connected to the water storage. In order to complete the connection that was described in the water storage section there is another set of hose connectors used to connect a piece of hose to the manual

ball valve on the water storage. The way this is done can be seen in figure: 35 and 34. First one piece of hose connector is added to the box with 1 small piece of hose on the inside as well to prevent water leaking out from around the hose. Then at the end of the hose a connector is added that can be connected to the manual ball valve.

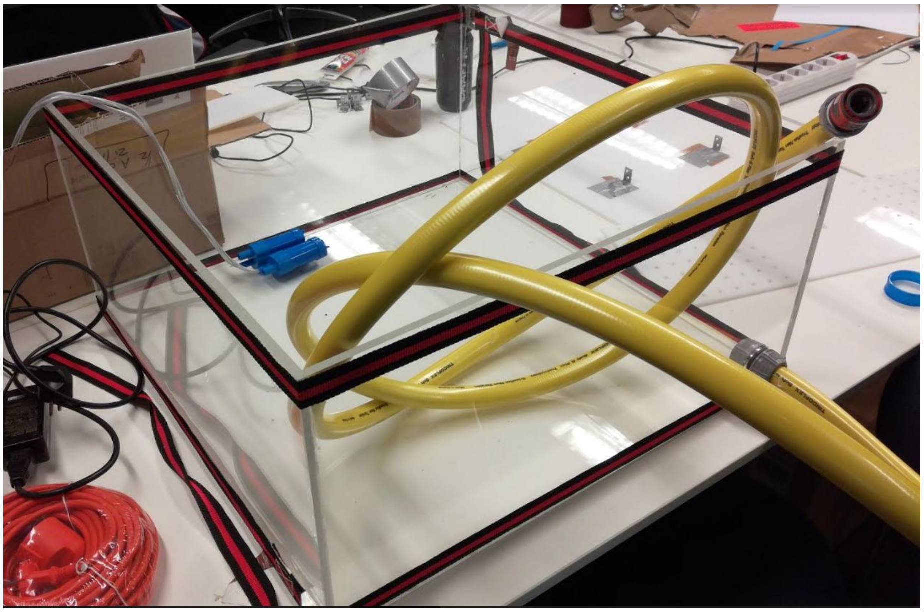

Figure 34: Badi hose with connectors.

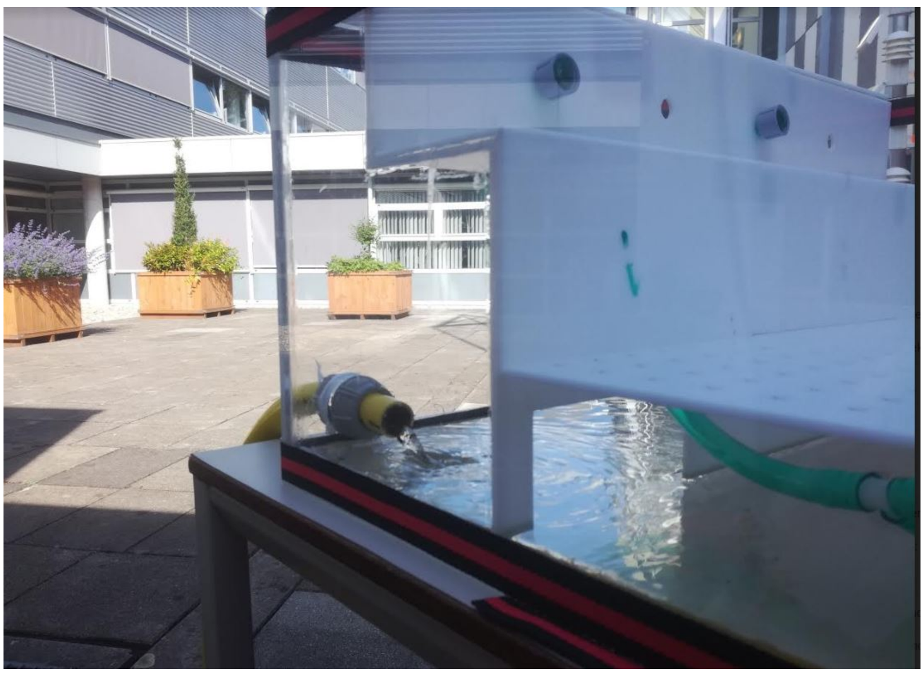

Figure 35: Badi box connection.

The Staircase
On the inside of the box there is a staircase. This staircase (Figure: 31) was cut out from two acryl boards that are 4mm thick. But in order to hold the staircase in place there are several support beams glued to the side of the Badi (Figure: 36). The staircase system is not permanently attached to the box and can be removed. This was done to make it easier to retain access to the pumps that are placed inside the Badi under the staircase.

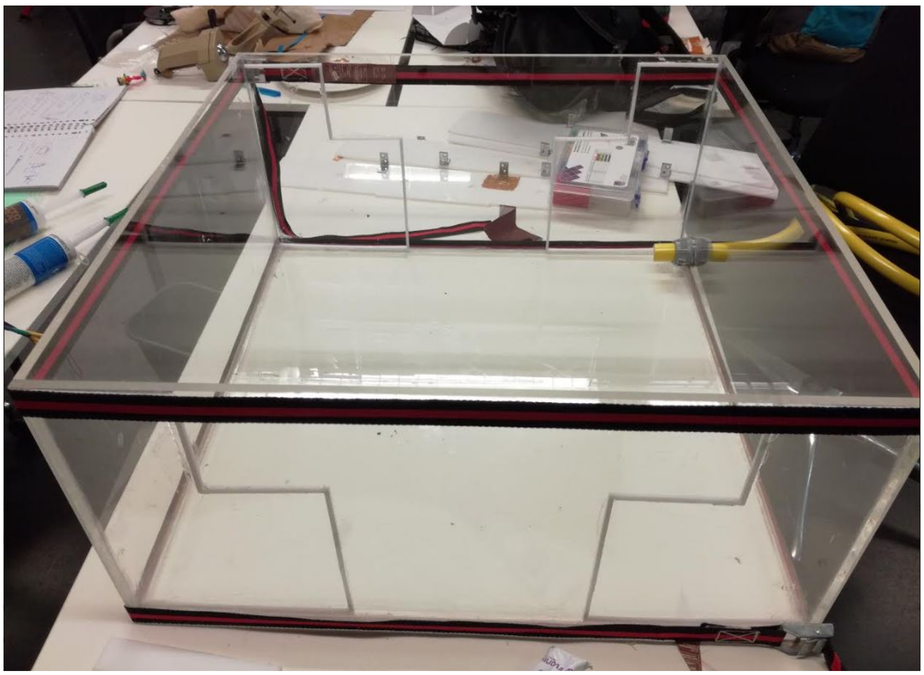

Figure 36: Badi with support beams.

The Steps
The staircase consists of different types of steps. There are five different types of steps. Four are double and the center piece is singular. The different steps are marked in figure: 37.

Step A
Step A is a board with a hole that allows the cables to power the pump to go in. In the full scale version it would be one of the potential sitting places for people.

Step B
Step B is a board with four holes that allow a tube to go through. This is where

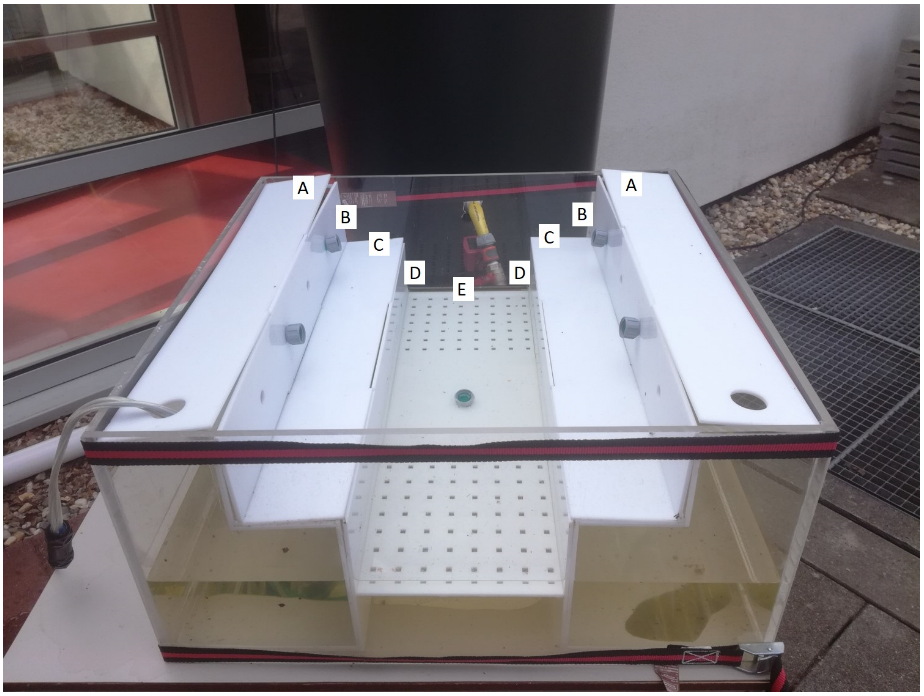

Figure 37: Staircase steps with markers.

the water circulation takes place. The pump connected to these tubes can not be toggled by end users.

Step C
Step C is a board without any holes and solely serves as a step. In the full scale version it would be one of the potential sitting places for people.

Step D
Step D is a vertical board that reaches to the bottom of the box and has a hole in the center to support step E.

Step E
Step E is a horizontal board that has many small holes to leave the water through and one hole to allow a tube to go through. This is where the end user water interaction takes place. The pump connected to this hole can be activated by end users.

Tubing
To complete the SRB XXL only one part is left. This is the tubing. In order for the pumps to move the water through the correct holes there needs to be

some tubing. The spout hole in step E is simply connected by a tube that goes from the pump to the center hole (Figure: 37). But for the spout holes in step B (Figure: 37) one important considerations was made. Namely that in order to spread the water evenly across all four spout holes it is important that the tubing is equal. Tubes need to allow the same amount of water through at the same pressure. So to achieve this, all the tube sizes are the same type and the same length. This is where the tubing and the T-connectors are used.

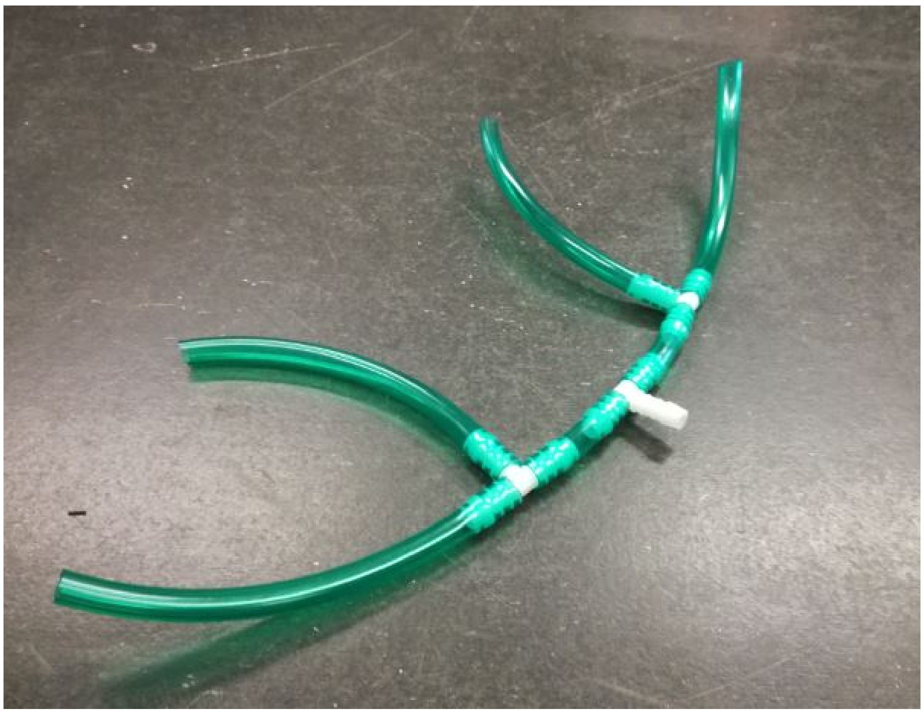

Figure 38: Tubing used inside the Badi.

6.2 Conclusion

The scaled version of the SRB XXL consists of three parts. Two of those parts form the SRB and the final part is the Badi. All components together allow for a large amount of water to be stored. Splitting it up this way makes the SRB XXL easy to expand upon and more water storage could be added easily as long as the core SRB functionality remains the same. By expanding the water storage capacity separate from the SRB functionality it is possible to keep the SRB software and hardware so similar that only very minor changes are necessary to create an SRB of any size.

The Badi aspect of the SRB XXL consists of a stairway that can be used by people to sit on when there is little water in the buffer and it can fill up to expand the storage capacity. This is way it is always of use and is never a waste of space. There are five water spouts that are connected to two pumps. One pump handles four spouts in order to circulate water. The other pump is available for end user interaction and can be toggled to create a small fountain effect.

7 Evaluation

The evaluation consists of two parts. The first part is a session with the external supervisor who will judge the idea and discuss the feasibility. The second part focuses on the technology and whether it functions as it should.

7.1 Evaluation by External Supervisor

Preparation of the evaluation by the external supervisor from the municipality of Enschede was done in the form of a small presentation that explains the idea behind the Badi. Part of the presentation consisted of a definitive redesign of a street in a village named Nijverdal. Another part of the presentation was about the location in Enschede and there was a small bit about water filtering ideas. But before the presentation was shown, the external supervisor was allowed to look at the SRB XXL without any information. Finally after the presentation the unstructured interview took place and the desirability and feasibility were discussed. Which ended up in three main items that needed more investigation. The first one is the safety of the Badi in an urban context where people come into contact with the rainwater runoff. The second one is about the location in combination with groundwater levels and the final one is about end user interaction.

7.1.1 The Introduction

The introduction is about the part where the external supervisor saw the SRB XXL scale model and could look around without being provided with extra information. The result of this part is that without extra information it is not clear what the Badi is for. The fact that it is a scale model in a completely different context makes it hard to determine what the Badi is for and what it does. We can say that in order to present the concept of the Badi better it is important to create more context surrounding the Badi scale model so that people can infer what it is more easily.

7.1.2 The Presentation

As mentioned before the presentation consisted of three parts. One part was about explaining what a full sized SRB XXL would look like and the second part was about where it would be located. Then the final part is about water filtering.

Nijverdal Example
Nijverdal redesigned a street at the same time this thesis graduation project was done and some similarities were found in the ideas. Nijverdal also implemented a staircase near water to generate sitting spots [29]. So it was useful to show the idea in order to demonstrate to the municipality of Enschede what

the Badi would look like in full size. Figure: 39 shows how the idea of creating sitting places was implemented in Nijverdal. However what you see in Nijverdal is a Wadi. Which means it is a place that lets water infiltrate instead of buffering it. The side view of the Wadi in Nijverdal in figure: 40 shows a slightly modified image of what it looks like. The modification were done to make it look more like the Badi idea from this thesis.

Figure 39: Staircase on the street level in Nijverdal.

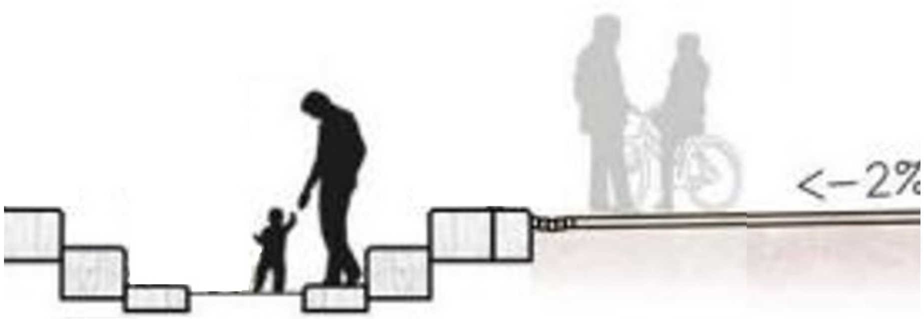

Figure 40: Staircase sideview on the street level in Nijverdal.

Location
After showing what a full sized SRB XXL could be like it was time to give an idea where it could work in Enschede. Since the SRB XXL was meant for urban areas it made sense to find a street in the center of Enschede where there was space for a Badi. The street that deemed most fitting due to location and size was the Langestraat (Figure: **??**). The street is more than 10 meters wide leaving plenty of space for traffic to move around. Even if there is a Badi in place. And since it is in the city center it is likely that people will interact with the Badi and enjoy its presence.

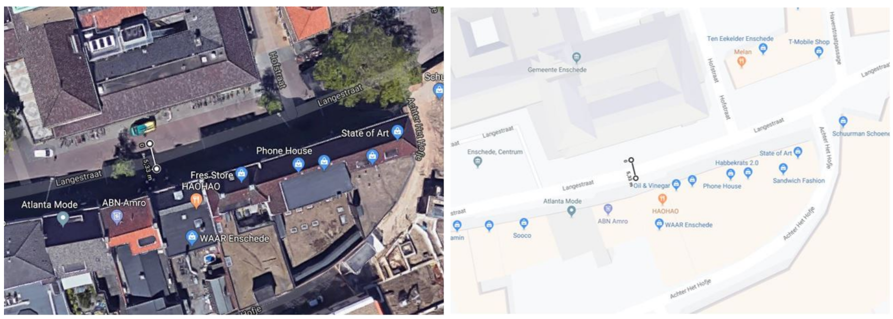

Figure 41: Langestraat satellite and map view.

Filter
During the development of the SRB XXL the filtering aspect moved further to the background. But it was not forgotten, hence this is part of the presentation for the evaluation. The Badi is just one version of the SRB XXL and other iterations could focus more on filtering than water storage. One possible variation of a filter could be the Badi itself. Figure: 37 from the realization phase shows all the steps and step E would be able to hold filtering materials such as sand, charcoal, pebbles, rocks or anything else (Figure: 42).

7.1.3 Unstructured Interview

After the presentation the Badi concept was more clear and a discussion followed. This discussion led to three things that required more investigation. However the idea of the Badi seemed to be good. The way it created an interaction between people and rainwater buffering was good and could definitely have a place in Enschede. It would be a mix between a canal and Wadi with an element of interaction for people to play with. This end user interaction however was one of the three points that required more investigation. And the other two points are the connection between groundwater and the Badi and the safety of the Badi in terms of water quality.

Figure 42: Filter materials that could potentially be used in the Badi.

End User Interaction
The SRB XXL for urban areas was desired to have a form of end user interaction. In the scale model of the SRB XXL there is no way for an end user to do so without having manager types of access. This was left out for a multitude of reasons. The first reason being safety, it was still unclear how safe the water inside the SRB XXL was and giving people the ability to turn the water into vapor or small drops could potentially mean that legionella would be spread. Furthermore the added value of a physical button in comparison to a key press on a computer did not seem worth the extra time and effort for a scaled proof of concept. And the final reason was that it would be a vulnerability since it has the potential of breaking down which could hinder the other aspects of the SRB XXL.

Location and Groundwater
During the discussion the external supervisor from the municipality of Enschede came up with another idea. He wanted to know how steps were re-

quired in order to connect the Badi to the groundwater level in de Langestraat in Enschede. Connecting the Badi to the groundwater level could be nice to display the groundwater levels to the public and raise awareness that way. On top of that it would be a way to keep a constant minimum level of water inside the Badi.

Ground water levels and Badi steps

The full scaled Badi makes use of steps that are 0.4 meters wide and 0.4 meters high. These are good measurements for sitting according to Drury [30]. In order to keep groundwater inside the Badi the depth must reach the ground water from ground level. Figure: 43 and 44 show the ground water levels and ground level at two spots in the city center of Enschede. These two spots are the closest to the Langestraat where the Badi could be placed. What we see there is that the ground water level is roughly between 2 and 5 meters under ground level. The Badi is designed with a staircase on two sides which means that the width of the Badi is doubled. On top of that there are 2 more horizontal steps to form the bottom in the center of the Badi. In order to reach a depth of 2 meters there would need to be: $(2/0.4) * 2 + 2 = 12$ horizontal steps resulting in a width of 4.8 meters. And in order to reach a depth of 5 meters there would need to be: $(5/0.4) * 2 + 2 = 27)$ horizontal steps. Which would be a width of 10.8 meters. Do note that depth of the Badi extends one step further underneath the steps so there can be water inside the Badi while it is not visible to the end user. If you would include the 0.4 meters and allow ground water to be present in the Badi without the end user being able to see it. Then it the Badi could be 0.8 less wide. So to reach a depth of 2 meters you would only need a width of 4 meters and to reach a depth of 5 meters you would need a width of 10 meters. It is unclear how much the rainwater runoff from the SRB XXL would increase the water level inside the Badi. But a width of 10 meters would require major changes in the center of Enschede and does not appear feasible at first glance.

Water Quality inside the Badi

Another question raised by the external supervisor from the municipality is about water quality. During the evaluation it was unclear whether the rainwater runoff would be clean enough to be allowed to come in contact with people. As said before, further investigation was required and the external supervisor recommended to consult an expert. Contact details of Heleen de Man were shared together with a link to a summary document about the thesis by Heleen de Man about water quality in public spaces [31]. In order to get a recommendation from Heleen de Man a document was set up with a few questions. The full version can be found in appendix: E. The short version will be explained next and the answer is translated from Dutch to English. The recommendations were returned in the form of answers on three questions:

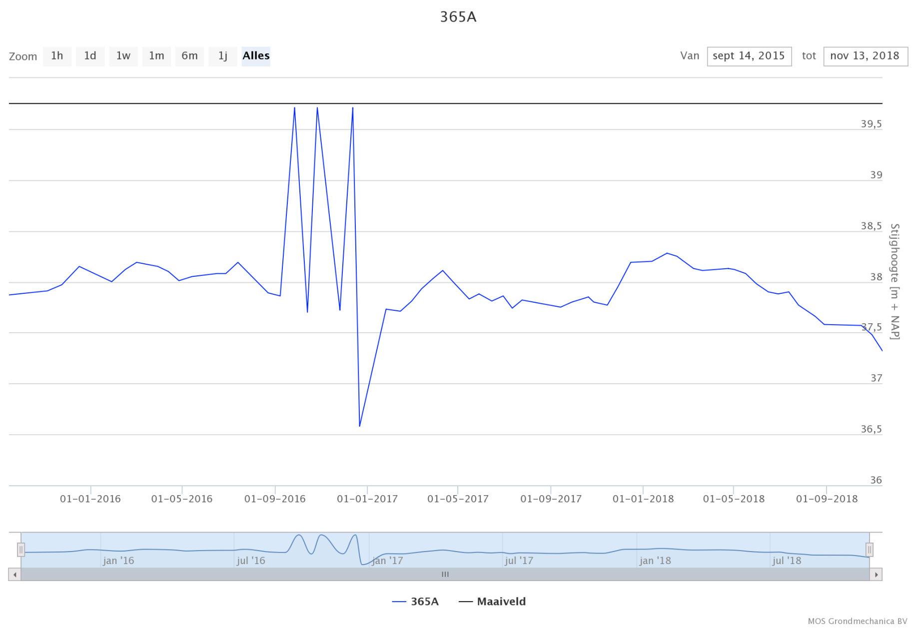

Figure 43: Grondwaterpeil Enschede part 1. [1]

Is it feasible to use rainwater runoff from the roofs in a city center and use it in a city fountain without creating too much risk when case of adults and children come into direct contact with the water? *Answer:* It does not have my preference. In rainwater we find legionella and without disinfection it is unwise to spray water.

Is there a type of rainwater that next to drinking water also keeps the risk of infection low with children and adults? *Answer:* Yes, most of the time ground water suffices, but you would have to keep pumping up fresh ground water. Otherwise it gets contaminated by dog poop and bird droppings and the children themselves.

Is there a type of water that can be relatively easily be filtered and made safe for contact with children and adults? *Answer:* No, a relatively simple filter does not work and does not disinfect. But if ground water and surface water is used of which the quality is good and a constant fresh supply of these types of water is supplied. Then most of the time it is okay to bring it into contact with people.

This means that rainwater runoff is not safe to bring into contact with people directly and that it is only possible with more advanced filtering and disinfecting or a constant new supply of fresh water.

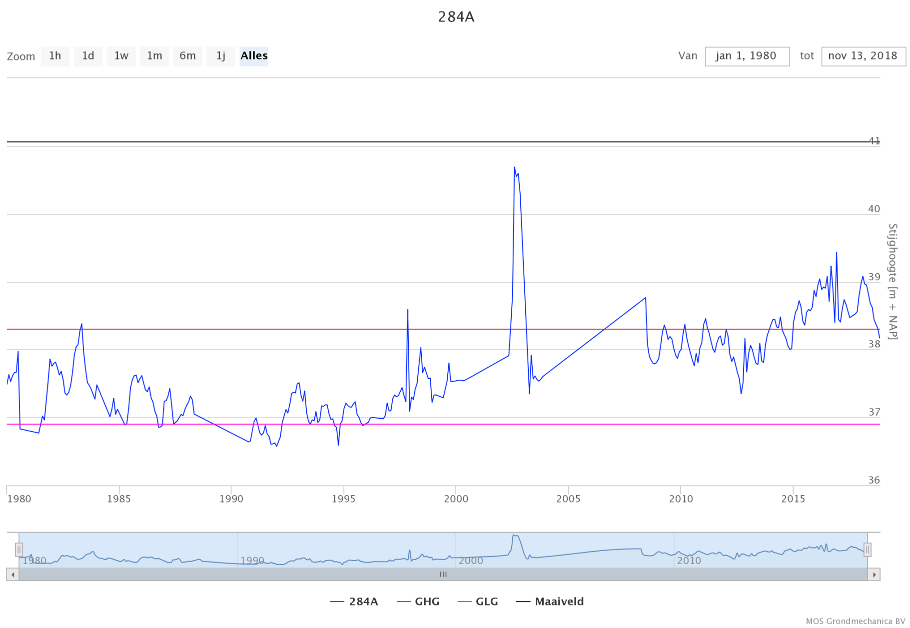

Figure 44: Grondwaterpeil Enschede part 2. [1]

7.2 Requirements Evaluation

In this section we go by the requirements and argue whether they are met sufficiently or insufficiently. The full list of requirements can be found in figure: 23, but we will go over them one by one following the MoSCoW system.

7.2.1 MUST - Functional

The system must delay rainwater runoff to the sewer system.
The system does fulfill this requirement, it interrupts rainwater coming from the roof and is able to store it inside the water storage and the Badi.

The system must work autonomously/smart
The system does fulfill this requirement. Using the SRB controller by Waterink with the addition of two pumps, an adapter and some software it was possible to leave it operating on its own and monitor the changes in water levels.

The system must never output more water than is coming in
The system does fulfill this requirement. Even though the Badi is able to let more water out and in because of its open top. It would still depend on the output on the water storage to make it so that more water leaves the SRB XXL than is coming in.

The system must be connected to a central database/weather prediction source

The system does fulfill this requirement.

The system must be able to measure the water level inside the water storage

The system does fulfill this requirement.

The system must be able to determine whether the water inside the water storage is safe or unsafe
The system does **not** fulfill this requirement. Not only is the water temperature sensor unable to measure the water temperature inside the Badi. It is also insufficient to determine the water safety by temperature alone.

The system must be able to use the data from a weather prediction source
The system does fulfill this requirement.

The system must be able to send data to a database
The system does fulfill this requirement.

The system must be able to hold at least 20,000 liters of water
The system does not fulfill this requirement, but at full scale at a length of 4 meters, width of 3.20 meters and a height of 1.60 meters this is definitely possible.

7.2.2 MUST - Non-Functional

The system must be safe
The system does not fulfill this requirement. It is unsafe to bring people into contact with rainwater runoff from the SRB XXL.

The system must be designed for public space
The system does fulfill this requirement. It has a purpose at all times and is designed to interact with people. However due to the water quality this is unsafe at the time, but with drinking water it would be good.

The system must be connected to roofs
The system does fulfill this requirement.

The system must be modular
The system does fulfill this requirement. The modularity of the SRB XXL is one of the strong points, it is not only a proof of concept for an SRB XXL in public spaces, but also a proof of concept for the ability of the SRB to have different purposes. For example there could be an SRB XXL Filter Badi that can be connected.

7.2.3 SHOULD - Functional

The system input should be determined by the expected input
The system does not fulfill this requirement. At this point the SRB XXL is simply connected to the nearest downspout.

The system should be able to empty itself in two hours
The system does fulfill this requirement. However it is not certain for the full scale. This is because the full size has not been determined yet.

The system output should not be larger than the system input
The system does fulfill this requirement. Even though the Badi is able to let more water out and in because of its open top. The open top is also an input, which equalizes the input and output.

The system output should interact with an end user
The system does not fulfill this requirement. The end user can not interact with the SRB XXL without manager privileges.

The system output should be able to be controlled by a manager user
The system does fulfill this requirement. A manager can control all parts of the SRB XXL through the controller.

The system output should be able to circulate water inside the water storage

The system does fulfill this requirement. But it is only able to circulate water inside the Badi and not the Badi and the water storage of the SRB XXL combined.

The system output should be able to translate high level commands into low level actions
The system does fulfill this requirement. For example opening the valve requires more actions than just one, but can be issued by a single command.

7.2.4 SHOULD - Non-Functional

The system should be weatherproof
The system does not fulfill this requirement. The Badi pumps have an adapter that it is not within the watertight controller housing. Which means that it can not remain outside.

The system should be affordable
The system does not fulfill this requirement. It is unclear what the costs of the SRB XXL on a full scale would be.

The system should have a name
The system does fulfill this requirement.

The system should be secure
The system does not fulfill this requirement. It is secure for development, but not for use in the public.

The system should be low maintenance
The system does fulfill this requirement. It is a modular design and keeping the controller at one location makes it simple.

The system should be reliable
The system does fulfill this requirement. It does work as expected, but needs further evaluation to be certain.

The system should have safe overflow
The system does fulfill this requirement. Water leaving the SRB XXL does not cause any damage.

7.2.5 COULD - Functional

The system could communicate through an online dashboard
The system does fulfill this requirement. Information about the SRB XXL status can be found on a dashboard.

The system could use configuration files to determine its behavior
The system does fulfill this requirement. The SRB XXL branch of the software uses a configuration file to determine its behavior.

7.2.6 COULD - Non-Functional

The system could collect rainwater runoff before it goes on the street
The system does not fulfill this requirement. Besides the roof connection, no other rainwater source connections were made.

The system could be able to discharge water for other purposes such as watering plants
The system does fulfill this requirement. During the development the water that was used for testing or entered the buffer naturally was partially used to water the plants.

7.2.7 WOULD - Functional

The system would filter the water before storage
The system does not fulfill this requirement. No filtering besides the existing filter at the input through the downspout.

The system would be able to notify the manager about status changes
The system does not fulfill this requirement. No special notifications were added.

7.2.8 WOULD - Non-Functional

The system would have another filter variation
The system does not fulfill this requirement. No special filter variations were added.

8 Conclusion and Recommendations

The final chapter of the thesis summarizes the findings and end with a set of recommendations for further development.

8.1 Conclusion

The development of the SRB XXL was done in order to address the water problems in Enschede. Urbanization and climate change created a situation where heavy rainfall can create floods in Enschede, but during the summer more and more dry periods are causing problems as well. Buffering rainwater can assist in resolving both these issues.

The SRB XXL development is a continuation on the development of the DiY SRB which also continued to develop while this thesis was written. The XXL aspect however was new for the SRB and a literature study was done in order to see what characteristics existing large volume rainwater buffers have. It turned out there are four important characteristics. First there is the collection surface, then the gutter, then the storage and finally the output. Also important was the fact that most buffers were integrated in one of two ways. Either the water buffer was included in the land use plans or it was adapted to fit within the existing situation. The smart aspect turned out to be about sustainability, monitoring, control and autonomy.

After this a state of the art research was done in order to get an idea of similar devices that already exist. As it turns out there are quite some large water buffers in use, but none with the purpose to delay rainwater runoff to the sewer system. Most of them focus on using the water for domestic purposes.

Now it was time to find out what the SRB XXL should do and how. So a list of requirements had to be made. Through a stakeholder analysis, the establishment of preliminary requirements and solo brainstorms sessions a bunch of concepts were generated in order to form a basis for the design of the SRB XXL.

The design that came out on top was that of a staircase canal, so basically a water storage tank with a staircase inside with step sizes that would allow people to use it as a bench if it was empty. This design was meant for urban locations such as the city center in Enschede.

After the initial concept had been crafted it had to be further specified how it should operate. By displaying a set of system architecture diagrams it is possible to see all interactions of the system with other external systems and internally with subsystems. The end of the specification chapter consists of a list of requirements that function as a guideline to what the SRB XXL should be able to do.

The realization phase that comes after the specification describes how a proof of concept scaled version of the SRB XXL was created. The SRB XXL was made in three parts, first there is the SRB controller which is the same as the controller for the DiY SRB besides that it has two extra actuators in the form of two pumps of which one is meant for user interaction and the other to circulate the water to prevent things like legionella. The second part is the water storage that is used for all the measurements and the discharge. And finally the Badi, which is a box with a staircase inside that can store water as well and shares the capacity with the water storage. Inside the Badi there are the two pumps that were mentioned before.

After the realization phase, the system had to be evaluated, this was done in the form of an unstructured interview. The evaluation phase resulted into the exposure of three points of attention. The first one is the interaction with the end user that is incomplete and needs to be improved. The second point of attention comes from a suggestion about connecting the SRB XXL to the ground water in order to show the ground water level to the public. And the third point is about safety in terms of water quality. At this point it is unsafe to bring rainwater runoff into contact with people in the way the SRB XXL without proper disinfection. This means that before a large scale version is created a proper solution to this problem should be found. The two other points of attention are possible, but to connect to ground water level in certain places it would mean that the Badi would require a width of approximately 10 meters. However in other places it can be done with a width of 4 meters.

8.2 Recommendations

This chapter attempts to provide some suggestions for further development of the SRB XXL. Due to the relation between the SRB and the SRB XXL it is possible that many recommendations are easily translated to recommendations for the development of any SRB.

The SRB XXL in the form of the Badi should not be used if it is likely to bring people in contact with rainwater runoff, rainwater runoff is not safe. This is of course not good. The combination of a sitting place and water buffer is still good and there are options to maybe make the water of high enough quality. There exist green filters that make use of plants and rocks to filter water from swimming pools. These could also be used in another version the Badi. The box in which the staircase is built is suitable for such a filter. That way the quality of the water could become high enough so that it is safe for use in public spaces.

It would also be worth to investigate the difference between contaminations in ground water and rainwater. Different types of water might be unsafe because of different reasons and different types of filters might be more effective for each type of water.

In terms of interaction there are many options and there could be room for a specific type of interaction that raises awareness or can teach the end user something.

The first recommendation about SRBs in general is that they can definitely be a powerful tool for climate adaptation and ever increasing urbanization. Development should definitely continue and new development in cities should include this type of water management in their new developments. Not only is a water buffer useful to delay rainwater runoff to the sewer system, it is also useful to provide water at times when water is more scarce. While rainwater might not be safe to be brought into contact with people directly it can still have other purposes such as watering plants or washing cars.

Another benefit of SRBs that should be expanded is their ability to communicate about rainwater runoff. Knowing how much rain comes down at certain locations can help provide a holistic view of the water cycle. Which can be used to fine tune the water management systems. For example it could be possible to grow certain crops at certain times based on the amount of water available in certain areas.

On top of this it is good to hold control over the water cycle in an area. Water use changes have an impact on the environment which can be adjusted when you keep control. Passive systems will do what they do when they do it, but a system that can be controlled grants the ability to carefully manage changes. So for example when it turns out that a new Wadi causes groundwater levels to be too high at certain places because it infiltrates too much at the wrong location, an SRB would be able to specifically choose when to discharge and how much.

This flexibility can also be found in the software of the SRB. The SRB should be developed in such a way that any SRB type is able to communicate using the same protocols. That way it is easy to connect multiple SRBs in one system. This thesis showed that it is possible to use the DiY SRB controller for the SRB XXL without many changes to the software.

However next to all the good things there are some things that were suboptimal. The software of the SRB is very chaotic currently and not very flexible. Most of the SRB software is not written in object oriented programming. But object oriented programming would be beneficial in order to make it easier to update or expand functionality. Of course this would need to be done according to a proper software architecture. My recommendation would be to create an SRB class that contains only SRB specific data such as barrel type, ID, components (actuators/sensors), status and location. And an SRB handler class (possibly using the Factory Design Pattern) that uses a configuration file to determine how to behave based on the status of the SRB. The most important part about redesigning the software should be about splitting everything up into independent chunks that can be changed. So another example could be that of a component. When you know that the SRB uses a certain component it is possible to write a class specifically for that component, but can be read or used like any other component. There might be more types of temperature sensors, but they are all used to get a temperature reading. Generalizing behavior of the software while keeping it separate makes it easier to change or expand systems. It can also help keeping code clean and easier to read.

Digitalizing components also forms a step towards creating a digital SRB. A digital SRB could be developed to simulate the behavior of the SRB in certain situations that would otherwise take time or require extra tinkering. Any changes to software could be tested in a simulated environment first before being pushed to real physical SRBs. It would for example be possible to add an extra output to a digital system and if the specifics of that output are correct the effects would be immediately visible.

Finally I would recommend the University of Twente, the municipality of Enschede and waterboard Vechtstromen to continue the collaboration to innovate on water management and to involve experts on water quality. Water quality is essential when it comes to expanding the usefulness of the SRB.

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Appendices

A — Water Management History of Enschede —

Enschede is city in the Netherlands with a population of approximately 160.000 people [32]. In the past Enschede had a much smaller population and the buildup area in the city was much smaller. Water could easily infiltrate in the ground since there was a lot less impervious area. That is why the water in Enschede could relatively easy flow to the two rivers in the vicinity called *De Regge* and *De Dinkel*. When the textile industry expanded in Enschede the city grew alongside it. This industrial growth also impacted the water balance. Groundwater levels dropped due to increased water usage and areas that used to allow water to infiltrate were made impervious by constructing new roads and buildings. [4] Later, when the industry water usage declined, groundwater levels were rising. However the amount of impervious area did not get reduced. This left little room for water to go, but on the streets of Enschede and sometimes even inside the buildings.

B — Geological Situation of Enschede —

Enschede is built up against a slope and when the city expanded during the period of industrial growth, it also expanded downhill [4]. Because water flows downhill these areas are vulnerable to excess water when it cannot infiltrate into the ground.

C — Sewer System of Enschede —

The sewer system of Enschede is not equipped for heavy rainfall, which is one of the core motivations of the municipality to support this graduation project. Figure 45 and 46 respectively show where the choke points lie within the sewer system and the groundwater levels in Enschede.
Figure 47 shows where water can infiltrate. The yellow areas indicate where water can infiltrate more easily and the red areas are more impervious to water.

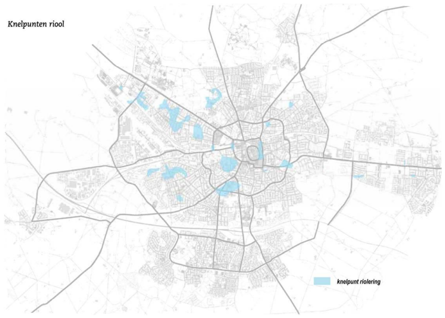


Figure 45: Choke Points Sewer System Enschede

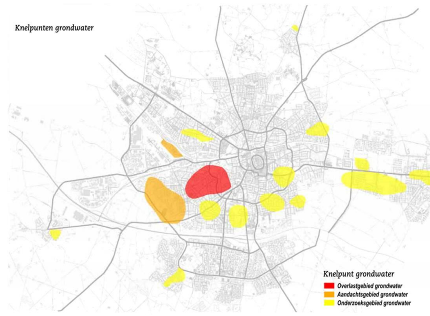


Figure 46: Choke Points Groundwater Enschede

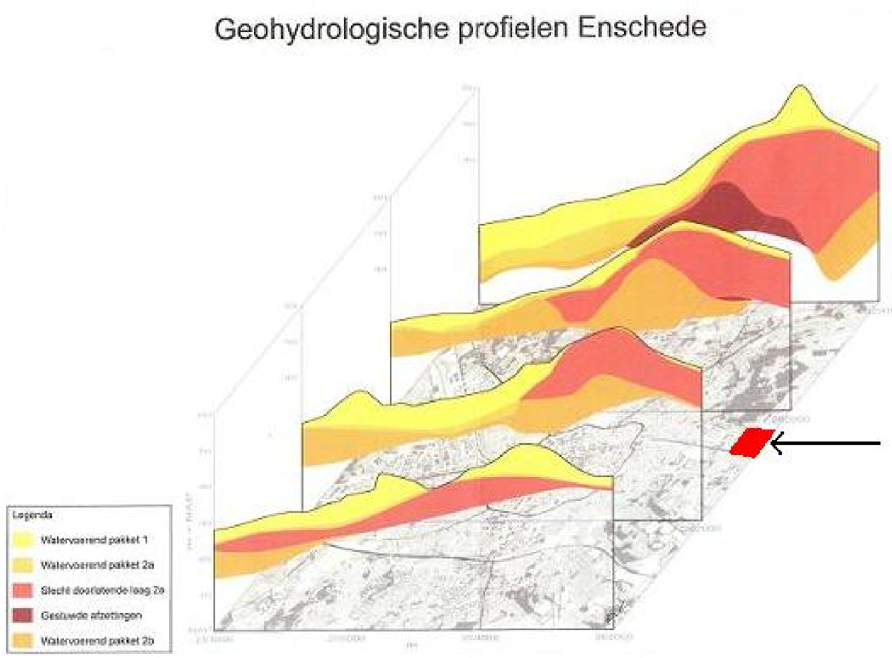


Figure 47: Geohydrologisch Profiel Enschede

D — State Machine Diagram Brainstorm/Concept —

Off and On The first State Machine Diagram (Figure: 48) simply shows the two basic states that the SRB XXL can have. It is powered up or it is not. Even though it is simple, it is still important to know how the system behaves in both situations. This is because components might be in a different state than expected. For example there might be a valve that was opened during the on state. But in what state is that valve when the SRB XXL no longer has power. The SRB XXL can be in only one state at a time. This means that the state of the components are additive to the state of the SRB XXL. Using the same valve example it is possible to have the states: OffAndValveOpen, OffAndValveClosed, OnAndValveOpen or OnAndValveClosed. If more states are added then the system becomes overly complicated.

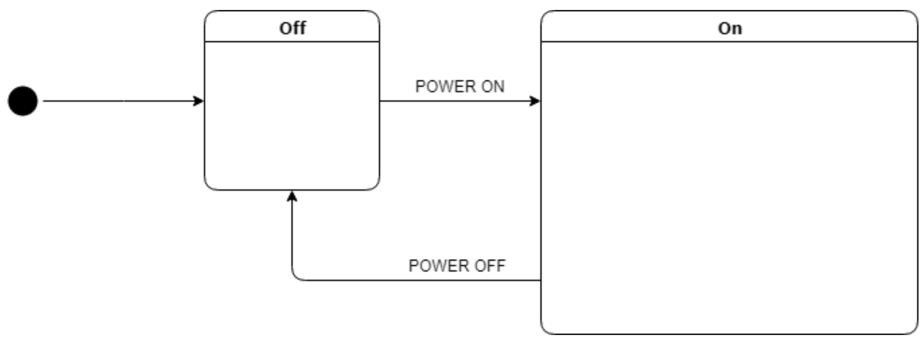


Figure 48: State Machine Diagram Off or On

Deterministic and Nondeterministic Rabin [33] shows deterministic finite and nondeterministic finite automaton. Where the difference is that for the deterministic a certain input at a certain state will always lead to the same resulting state. For the nondeterministic automaton this is not the case. If figure: 48 represents the SRB XXL with valve it would mean that it is non deterministic since turning it on could result in having an open or closed valve. This is unclear.

Predictability Whether it is important if the valve is open or closed when the SRB XXL is not powered has not been evaluated. However, predictability and tracking the states is important. This is because the SRB XXL is a prototype and the final behavior should be adjustable. To accomodate this it is best to have the highest amount of control over the SRB XXL that is possible while also maintaining a clear understanding of what the SRB XXL is doing at any given point.

Modularity In order to gain that control it works to make the system modular. This means that the components such as a valve can be seen separate from the SRB XXL. This corresponds with the heterogeneity of the functions of the SRB XXL that were described earlier. Schilling [34] explains that modularity enables a system to have these types of heterogeneous functions. So for the SRB XXL it means that it doesn't have functions like discharging itself, but only the function to command a discharge. So instead of the SRB XXL itself discharging water from the water storage there is an SRB XXL that commands a discharge component to discharge water from a water storage component.

Disambiguation However looking at the modularity of the SRB XXL in this way means that it is possible to have everything as a modular part of the SRB XXL as long as it communicates with something considered to be the SRB XXL. It would turn the SRB XXL into an ambiguous system that has no clear beginning or end.

Communication However the modular approach does effectively turn the implementation of the SRB XXL into a communication device that for example can not discharge itself, but can send a message to another component to discharge. This means that it can't be in a state where a valve is open. Because it does not have a valve. It can only communicate with a valve or any other type of component.

Off and On [Initiating, Diagnosing and Operating] The SRB XXL implementation can now safely be split into the states on and off again, but no longer has to represent the state of a valve for example. Instead the focus lies on the logic of the SRB XXL. The on state has a set of substates in which it is either initiating, diagnosing or operating (Figure: 49).

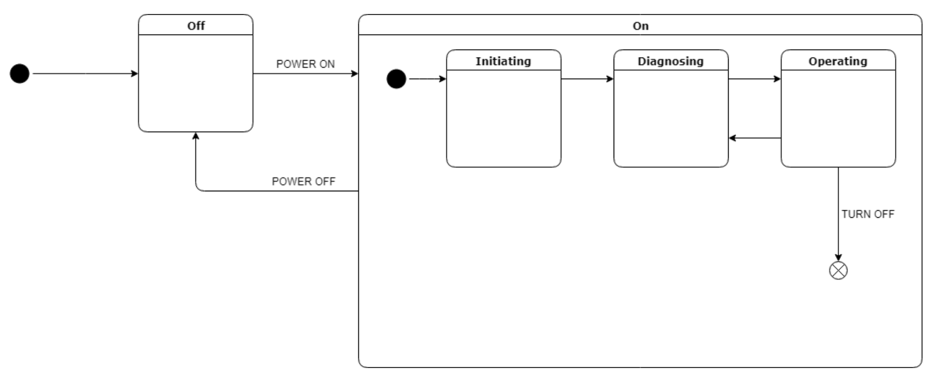


Figure 49: State Machine Diagram Off or On[Initiating, Diagnosing, Operating]

Initiating When the SRB XXL is powered up the initiating state is entered. The SRB XXL connects to the internet, loads all settings from a configuration file and continues to the next state.

Diagnosing The next state is the diagnosing state, in this state the SRB XXL evaluates what is working and what is not. It does not try to solve any issues it discovers. The diagnosis depends on a configuration file that knows what components the SRB XXL contains. For every component there should be a method of testing whether it is functioning properly.

Operating The operating state handles all incoming events and is able to go back to the diagnosing state. Once again, the configuration file is a key element in this state. It contains all the decision making. For example it can couple a discharge function to a water level measurement component and a water quality component. But it also describes what thresholds exist before it can command a certain action. For example if the diagnosis revealed that the water level measurement component is unreliable it is described in the configuration file what to do.

Configuration File It has become apparent that the configuration file is a key element for the SRB XXL to function properly. It is the input space for a decision making element. This means that the configuration file describes what behavior is desired at what moment. For the configuration file a special parser has to be created.

Generalization For this to be possible the SRB XXL needs to be able to describe what it can do. All SRB XXL components are modular and can vary per SRB XXL. This means that the capabilities of the components need to be measurable. When they can be measured they can also be diagnosed. And because it is undesirable to have to write a unique configuration file for every SRB XXL so the capabilities will be generalized to the functions previously described in the functions chapter.

SRB XXL System Process and the Nursing Process The word diagnosis is often used in health care and Treas [2] describes it as one of the phases in the nursing process (Figure: 50). And there are similarities between what the SRB XXL system does and what a nurse has to do according to this process described by Treas [2]. In this case the SRB XXL can be seen as a nurse and patient at the same time. This is because the system performs the process on itself.

Assessment Phase The assessment phase is the first phase. During this phase information is obtained from many different sources. Data is gathered to draw conclusions about the status of the SRB XXL in this case. [2]

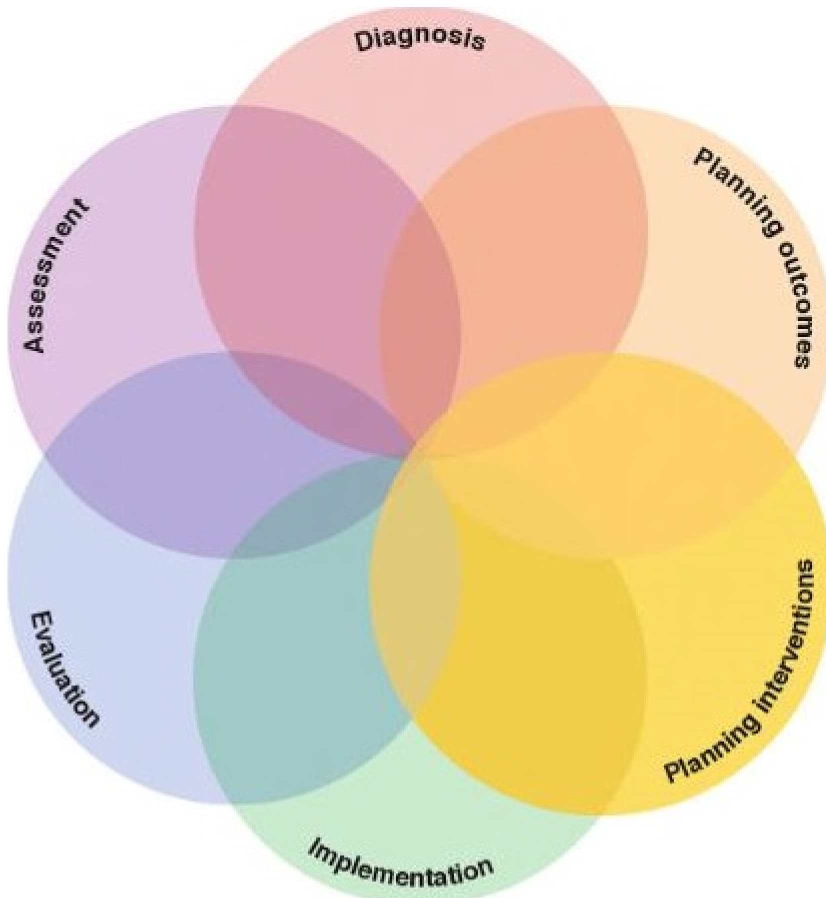


Figure 50: The phases of the nursing process [2].

Diagnosis The second phase is the diagnosis. In this phase the needs are identified in the form of a problem. All data needs to be analyzed and an hypothesis about the status is generated. [2] The result is an overview of what the system is able or unable to do. As a nursing example it would be similar to when a patient comes in with a broken arm, the diagnosis would include the things that the patient is now incapable of certain actions. For the SRB XXL an example would be that the water level measuring function is not working and then the diagnosis would be that the SRB XXL is unable to measure water levels.

Planning The next phases are about planning. The result of this phase is a holistic plan of what the SRB XXL operations are going to be (operations plan). In the nursing context it would be a care plan [2].

Outcomes The outcomes are about the goals of the system. [2] An example can be: *The system will request new weather data in 1 minutes and 23 seconds as evidenced by the time since last check for new weather data was 13 minutes and 37 seconds ago and is set to be done every 15 minutes.*

Interventions This phase generates a list of possible interventions that the system has available to deal with situations. Then the best intervention is selected to achieve the goals that were set. [2]

Implementation During the implementation phase the planned interventions are executed[2]. This could be a system shutdown if the diagnosis revealed that none of the components are working and all options have been explored.

Evaluation The final phase is evaluation and is about determining what results have been achieved. If a result is reached it is compared to the goals and then the operations plan is adjusted accordingly. After the evaluation the assessment process starts again. So the process is cyclical.

The SRB XXL Process As seen in figure: 51 the result of mimicking the nursing process is that the initiating state is gone. This is because the system now runs fully cyclical and an initiating state is only entered once everytime the system goes on. All desired behavior that originally belonged in the initiating state comes in one of the cycles. For example when the SRB XXL is turned on and the diagnosis reveals that the SRB XXL cannot make use of any functions that required an internet connection the planning phase will plan a connect for the operating phase.

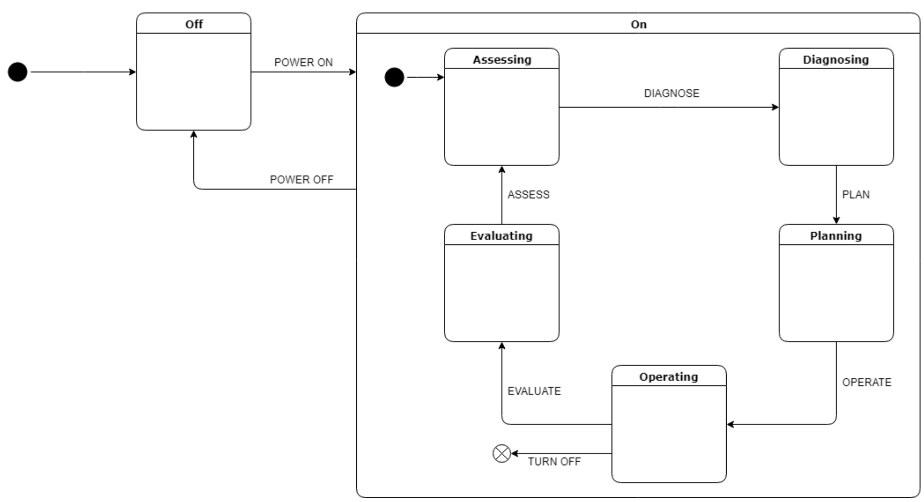


Figure 51: State Machine Diagram: The SRB XXL Process

Walkthrough An example of how the system operates goes as follows. The SRB XXL is positioned in the center of town and has a few downspouts connected to it. It has not been operating for a few days, because it was turned off for maintenance purposes. Then the system is turned on and the assessment begins. The assessment identifies that all systems function except there is no internet connection. This list of system functions and their status is then passed on to the diagnosing phase. During the diagnosing phase the system analyses what it is capable or incapable of doing. This information then moves on towards the planning phase where it checks what the SRB XXL's goals are. It then schedules what the SRB XXL needs to do in order to accomplish the goals and for that it uses the information from the diagnosis. In this example it includes the fact that the SRB XXL has no internet connection, because of this the SRB XXL also plans an action to attempt to restore the internet connection. After this the assessment phase begins again and the process continues until the system is turned off.

E — Question About Water Quality to Heleen de Man —

Verzoek advies met betrekking tot veiligheid gebruik regenwater in Enschede

Specifiek gericht aan Heleen de Man – Ingediend door Jelle Galgenbeld

Aanleiding

De reden dat ik dit verzoek indien komt vanuit de evaluatie van het schaalmodel van een concept dat ik bedacht heb en het gesprek dat ik had met Hendrik Jan Teekens. Tijdens die evaluatie kwam veiligheid aan bod en toen verwees hij mij door naar een rapport geschreven door jou en Imke Leenen. Het gaat hier om het rapport: "Water in de openbare ruimte heeft risico's voor de gezondheid." Ik was al op de hoogte van mogelijke verontreiniging, maar dat rapport heeft zeker nog meer vragen opgeleverd. En dan met name over het gebruik van regenwater dat van de daken komt. Dit regenwater wordt natuurlijk blootgesteld aan vogelpoep en dergelijke. Het concept dat ik heb bedacht zal ik zometeen verder uitleggen, maar in het kort komt het erop neer dat ik dat regenwater wil opvangen om dan ook in contact te brengen met mensen door middel van kleine pompjes die het water in beweging houden.

Het Concept

Het concept is ontstaan uit de ontwikkeling van de slimme regenwater buffer (SRB). Ik geloof dat Hendrik Jan het project al met je had gedeeld via de mail, maar ik zal de link hier nogmaals plaatsen (https://ruimtelijkeadaptatie.nl/voorbeelden/@206863/regentoren/). Uiteindelijk komt het erop neer dat er water meer gedecentraliseerd wordt om onder andere het rioleringssysteem te ontlasten bij zware regenbuien.

Ik had de taak om een versie te bedenken die minimaal 20,000 liter water kan behouden en gecontroleerd door kan laten stromen. De zogeheten slimme regenwater buffer XXL (SRB XXL). Het uiteindelijke concept is bedoeld om eventueel in het centrum van Enschede te gebruiken. Eventueel volledig op regenwater, maar het kan ook zijn dat het op grondwaterniveau komt te staan. Dus dat het grondwaterniveau zichtbaar wordt in de SRB XXL.

De vormgeving is gebaseerd een systeem van treden *(zie figuur 1, 2 & 3)* die men kan gebruiken als bankje wanneer het waterniveau laag is en het dient als wateropslag wanneer het waterniveau stijgt. Daarnaast zitten er twee pompjes in het systeem. De eerste pomp zorgt ervoor dat het water rond stroomt en in beweging blijft. Dit water zal over een deel van de treden lopen en dat kan eventueel de omgeving verkoelen. De tweede pomp is een kleine fontein die het water iets omhoog spuit. Omdat ik op de hoogte was van legionella gevaar heb ik geprobeerd te voorkomen dat er veel spetterend water is en dikke druppels. Maar na het lezen van jouw rapport lijkt het mij onvoldoende.

Figure 52: Verzoek page 1.

Verzoek

Wat ik begrijp uit het rapport is dat de bron van het water het belangrijkste aspect is als het aankomt op de kwaliteit van het water en dat filteren marginaal helpt. Het advies wat ik dan uit het rapport opmaak is dan ook om drinkwater te gebruiken. Alleen is in het geval van de SRB XXL de essentie dat het gebruik maakt van regenwater. Dit leidt tot de hamvraag die ik ook als eerste wil stellen.

Is het haalbaar om regenwater dat van de daken in een stadscentrum komt te gebruiken in een stadsfontein zonder dat het infectiegevaar van kinderen en volwassenen die ermee in aanraking komen te hoog wordt?

Uit het rapport begreep ik ook dat water van de straat weinig risico met zich meebracht, maar er wordt ook genoemd dat lastig te meten was door slib. Nu weet ik alleen niet of dit alsnog betekent dat water op straat op zichzelf weinig risico met zich meebrengt. Vanzelfsprekend is er geen contact met riolering in deze situatie. Daarom mijn tweede vraag.

Is er een type water naast drinkwater dat ook het risico op infectie bij kinderen en volwassenen laag houdt?

Met de vervolgvraag.

Is er een type water naast drinkwater dat met een relatief eenvoudig filter geschikt kan worden gemaakt voor contact met kinderen en volwassenen?

Al deze vragen zijn natuurlijk al flinke onderzoeken op zichzelf, daarom hoop ik ook op advies dat is gebaseerd op de ervaringen die je al hebt. In ieder geval wordt alle inbreng zeer gewaardeerd.

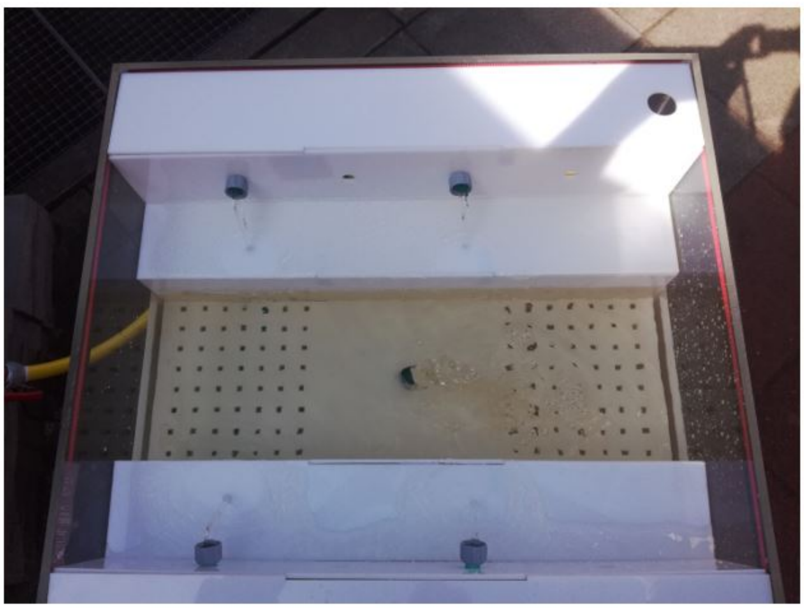
Slot

Allereerst wil ik je bedanken voor de aandacht en overweging tot het geven van advies. Los van mijn afstuderen heb ik als doel in mijn carrière om in Nederland de overstap van drinkwater gebruik in toiletten uit te bannen en een duurzamere variant te introduceren.

Figure 53: Verzoek page 2.

Figuur 1: Overzicht schaalmodel SRB XXL

Figure 54: Verzoek page 3.



Figuur 2: Bovenaanzicht schaalmodel SRB XXL

Figure 55: Verzoek page 4.

Figuur 3: Zijaanzicht schaalmodel SRB XXL

Figure 56: Verzoek page 5.