BACHELOR THESIS FOR CREATIVE TECHNOLOGY

Smart Rainwater Buffer XXL - Concept for UT Campus

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July 3 - 2020

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Abstract

A recurring situation many people all over the globe are facing these days, is climate change. Two problems climate change is responsible for that affect the Netherlands (among other countries), is the increase of extreme precipitation and arid summers. Due to the heavy rainfall in such a short time period, the sewer and runoff systems are overloaded and may cause overflowing water to fill the streets. The other extreme weather condition, being droughts, lead to increased evaporation of water in lakes, water ditches, and the earth.

To tackle these unfortunate events, a solution is presented which covers the following main requirements; firstly, it must offer a large water storage capacity in the events of an extreme rainfall approaching the Netherlands to control water overflow for safe distribution, and secondly, the solution has to make it possible to harvest and store rainfall so as to have a backup water-supply in case of a dry spell. The solution comes in the form of a large volume Smart Rainwater Buffer (a.k.a. SRB XXL); a large silo tank, with a volume of 30 cubic meters, which collects rainwater from nearby rooftops and is able to self-regulate the stored water content in order to be most efficient depending on the current or near-future weather conditions and located on the campus-terrain of the University of Twente at the “Sport-Centre” building.

In this bachelor thesis, research, stakeholder interview-sessions and the Creative Technology Design Process are performed to create a concept for the SRB-XXL which satisfies the condition of being both a rainwater buffer as well as a harvester. The concept involves two water discharge ports; one for supplying the client with stored water to be used for campus facility maintenance, and the other for increasing rainwater storage capacity and removing settled sludge from the tank. Furthermore, a user interface dashboard design is created with the purpose of providing the user of the SRB-XXL with information regarding the water level, status conditions and future precipitation events, as well as allow the user to perform system-control commands. Also, the rainwater router is realized to direct the overflow water in case the tank reaches full water capacity and to minimize altering the storage tank’s base composition.

Both the user interface as well as the rainwater router prototypes are evaluated for their fulfillment of the requirements made by the stakeholders in a functional and user evaluation. The prototypes satisfied almost all of the requirements and the client was pleased with the user interface design. The SRB-XXL concept should be realized in future projects, taking also the user interface and the rainwater router into account.

Acknowledgements

During the creation of this thesis and graduation project, a number of people have been of great help to me and therefore deserve mentioning in this Acknowledgement section.
First of all, I would like to sincerely thank my supervisor Richard Bults and critical observer Hans Scholten for helping me overcome the obstacles met during this project and for the invaluable feedback sessions where a lot of brainstorming was done.
I would also like to thank the project-client Andre de Brouwer for sharing his insights into creating the SRB-XXL concept and his cooperation during interviews.
Furthermore, Hendrik Jan Teekens and Eddo Pruim have been a great source of inspiration and wonderful traveling companions during the DeLaval company visit in Groningen.
Lastly and most importantly, I am immensely grateful for the support my parents Ageeth and Bas and my sister Noa have given me during the tough moments, and my cat Gizmo for constantly hogging the keyboard when I was working on my thesis during the COVID-19 quarantine.

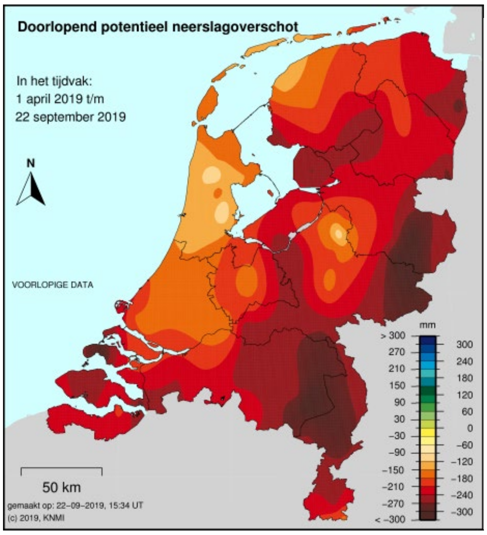
Contents

Chapter 1: Introduction

In this chapter the reader will be informed of the various problems caused by climate change on multiple scales: global, in the Netherlands, and in Enschede. Then it is mentioned what the challenges are for the municipality of Enschede and how they have designed solutions for these challenges. This is followed up with the description of the research question and related sub-questions and the chapter ends with an outline of the thesis.

1.1 Climate Change Adaptation

A recurring situation many people all over the globe are facing these days, is climate change. A number of well-known effects are the shrinking of glaciers, water levels are rising at an accelerating rate and ecosystems are in disarray **[1]**. However in terms of weather-issues, climate change is responsible for more extreme events such as droughts and heavy rainfalls, which are causes for forest fires and floods respectively.
The Netherlands are a target of changes in weather as well. What were once many divided rainfalls with a small amount of precipitation, became more extreme showers with a high level of precipitation. The reason for the more intense rainfalls is that, as the climate warms the earth more, there is a higher level of moisture in the air available for rainstorms **[2&3]**. This brings the Dutch climate at a more imbalanced state with fewer rains and long-lasting droughts with increasing temperatures. According to the Royal Netherlands Meteorological Institute (KNMI), the spring and summer of the year 2017 was an especially dry year for the South-Eastern regions of the Netherlands due to the high air pressure, which makes it unable to form clouds in the sky and ultimately transform into rain **[4]**.



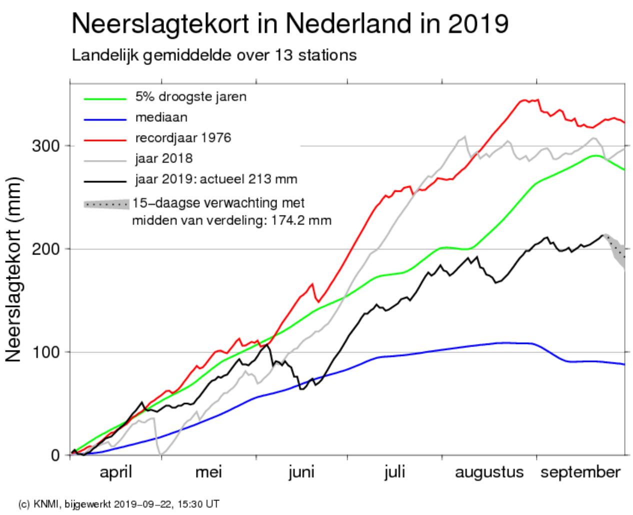


Figure 1: Average precipitation deficit of the Netherlands in the course of several time periods

Figure 2: Precipitation surplus in the summer period of 1 april - 22 september 2019

Furthermore, the weather was hot and sunny which led to increased evaporation of water in the ground, which has devastating consequences towards the plants and landscapes that rely on high groundwater levels. These patterns of dryness unfortunately do not seem to be stopping anytime soon, as the summer of 2018 came close to the driest year in recorded history of the Netherlands **(Figure 1)** and the current summer of 2019 has a rainfall deficit of around 200 mm and even lower in areas such as Enschede and Eindhoven **(Figure 2)**.

In the city of Enschede dry spells are causing heat stress to build up in the city, which has consequences to both the citizens, whom are more susceptible to heat strokes, and their environment. Next to the droughts, the municipality of Enschede is also the victim of water damage. Because the city lies on a slight slope, the lower parts of the region are stricken by floods at times of heavy rain showers. The damage to the streets and households are further increased since the water has nowhere to sink in, due to constructions and pavings **[5]**.

1.2 Rainwater management in Enschede

To tackle these unfortunate events, Enschede is presenting and searching for solutions that adapt to the following main challenges:

1. The solution has to make it possible to harvest and store rainfall so as to have a backup water-supply in case of a dry spell.
2. It must offer a large water storage capacity in the events of an extreme rainfall approaching the Netherlands to control water overflow for safe distribution

The municipality of Enschede has already executed some effective measures. These come in the form of Wadi's, low-lying capture areas towards which water flows to, and a project on the street "Oldenzaalsestraat" where a water-storage sewer is being built. The city of Enschede is continuously fighting against both the water damage and the heat stress and aims to include and rely (non-commercial) businesses to come up with new solutions, and citizens for support, e.g. by incorporating more green in their homes (green roofs and fewer tiles).

1.3 Research Questions

The University of Twente has also come up with a measure which aims to deal with the two challenges. This solution comes in the form of a Smart Rainwater Buffer (a.k.a. SRB) XXL; a large silo tank, with a volume of 30 cubic metres, which should able to self-regulate the stored water content in order to be most efficient depending on the current or near-future weather conditions. This revolves around the extreme weather conditions of drought and heavy rainfalls, as mentioned earlier in the Problem Description. If the SRB detects incoming rainfalls, the tank must have enough storage space available for the rainwater and thus may need to drain the already contained water to make room. It must be kept in mind though, that the outflowing water has to be expelled at a rate that it won't cause water pools or floods, otherwise the "buffer-element" of the system will become obsolete. However, a deficit of water storage is also undesirable, as the harvested water may be needed in case of droughts. The client of this project requires the silo tank to be stationed on the campus-terrain of the University of Twente and will therefore be placed at the "Sport-Centre" building. The related research question to this project is thus:

"How to develop a large volume smart rainwater harvesting & buffer system for the UT campus?"

Next to the main challenges of the SRB-XXL having to act as both a rainfall buffer and water harvester, there exist a number of side challenges/requirements. One of these challenges concerns the rate at which the water that comes in and goes out of the tank, which is also known as in- and outflow. If the SRB-XXL detects incoming rainfall, the system must have enough storage capacity available for the rainwater and thus may need to drain the already contained water to create this capacity. The outflowing water has to be expelled at a rate that it won't cause water pools or floods, which ultimately defeats the purpose of the tank being a buffer. Furthermore, the quality of the water that goes in and out of the SRB is also a main concern. The water that is collected from the rooftops may contain contaminants in the forms of debris or bacteria and can cause the water quality to deteriorate even further inside the storage tank. In terms of monitoring and controlling the SRB, the tank must also have a user interface with which the user is able to evaluate the current status of the SRB. These concerns ultimately boil down to these three sub questions:

1. "What actions must be taken to control the rate of water in- and outflow of the SRB-XXL?
2. "How is the water quality of in- and outflowing water of the storage tank best purified/maintained?"
3. "What user interface systems can be applied to RWH systems?"

1.4 Thesis Outline

Following the introduction, chapter 2 of this report will focus on reviewing literature of installations and state-of-the-art projects similar to the SRB-XXL. The applications and solutions presented in these articles will provide insight into both the challenges that may arise during the project, and opportunities within the analysed subjects. The third chapter revolves around the ideation of the SRB, which consists of envisioning ideas or versions of the rainwater tank that work within the provided design space laid out by the relevant stakeholders. Chapter 4, which is the specification phase, builds on the previous chapter by narrating to the stakeholders how the user may interact with the tank with e.g. storyboards or user scenarios. With the gained feedback this phase polishes the user requirements and the stakeholders version of the product. After the envisioning of the SRB has been established, the realisation of the system's implementation will be described in chapter 5. The sixth chapter is where the final product is evaluated and compared to the requirements laid out in the specification phase.

Chapter 2: State of the Art

In order to come with solutions for the SRB's research question(s), proper research must be conducted by gathering information related to this project. The state of the art chapter displays this information in three sections: the background information of the SRB-XXL project, the scientific literature research related to the three sub-questions, and state of the art solutions similar to the SRB and faced with the same challenges.

2.1 Background Information

The background information is used as an introduction to the reader as to what the SRB-XXL entails as a technological system. This subchapter is divided into an explanation of rainwater harvesting systems basic components, the technological functions and known information of the SRB-XXL and concludes with an alternative application of an RWH system, namely the dual-purpose system.

2.1.1 Conventional RWH Systems

Before going into detail of the different applications of an SRB, it must first be stated what makes the basics of a conventional rainwater harvesting system. A conventional Rainwater Harvesting (RWH) system has as core component the rainwater tank, which allows storage and treatment of harvested water. During rain events water is collected on catchment surfaces (in this project's case a roof) which is directed via a collection system to the tank for storage. Separate appliances are connected to the tank for rainwater uses (e.g. toilet flushing, gardening, etc.) and receive water using pumps that give the appropriate amount of pressure **[6]**. The system is usually included with quality control devices such as first flush diverters and debris screens/filters which (respectively) reroute polluted runoff and intercept contaminants **[7]**.These systems can be modified in order for it to fulfill the requirements of various circumstances and specific environments. In Figure 3, the image shows how a RWH system is used as a water-source for toilet-flushing and washing machines.

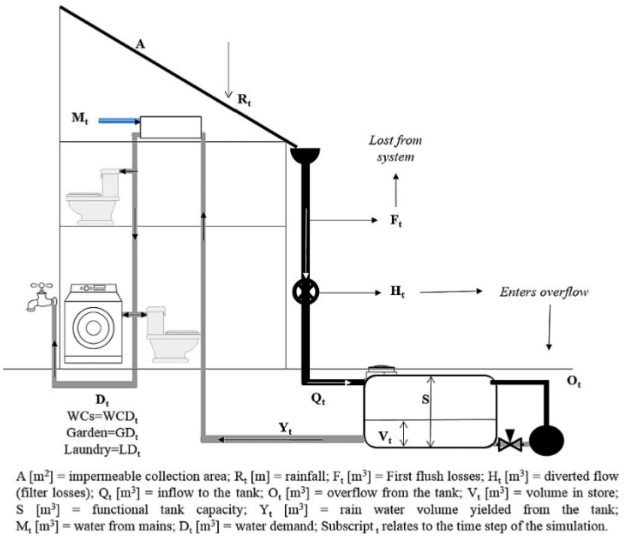


Figure 3: Components of a typical RWH system in a domestic environment.

2.1.2 Specifications of the SRB-XXL

The Smart Rainwater Buffer-XXL is at its basics a larger version of its predecessor, the SRB, with the additional challenge of working as a harvesting system against dry periods. These two versions therefore share many similar functions, including the implementation of smart elements so the system can make sound decisions on water storage capacity in case of rainfall events. One of these elements is the connection to an online weather-prediction website to strongly support the SRB by measuring the intensity and duration of the rainfall and calculating the amount of storage needed. It also has sensors placed in the tank to measure its current water-level and flow-rate. Furthermore it is capable of autonomously discharging water to make room for the predicted capacity to be stored.
The user is allowed access to information and data regarding the SRB's status and/or future weather through a user interface. The interface can also be used to manually control the system for system management purposes (e.g. turning it on or off, maintenance), or to drain water for specific water use purposes.
The XXL portion of the project is, as stated previously, due to its increased size in comparison of its predecessor. The provided storage tank is a cylindrical silo from the company DeLaval with a total storage volume of 30.000 liters.
As stated in the previous chapter, the client of this project requires the silo tank to be stationed on the University of Twente campus-terrain, specifically on the lower west side of the "Sport-Centre" (building 49 on Figure 5).

Figure 4: DeLaval silo-tank

Figure 5: Map of the University of Twente campus marked with location of the SRB-XXL

2.1.3 Dual-purpose systems

Rainwater harvesting systems that act as both stormwater management and water-conservation practices often have the problem that the systems remain full a large portion of the time. This is troublesome in case of a rainstorm, as the tank must have enough volume to store a runoff event.

Recent projects have therefore incorporated dual-purpose facilities into RWH installations **[9a]**. A dual-purpose system is created by dividing the storage tank into two segments: a "detention" storage volume and a "retention" storage volume. The retention storage volume makes up the lower part of the tank and is used for water extraction to meet user demands. The detention storage volume, the upper part of the system, acts as the temporary holding space for runoff but has a different water release mechanism depending on the approach.
The passive- and active release technologies are two approaches which improve the tank's ability to act as a dual-purpose system **[9]**. The passive approach works with a so called "passive release orifice" which slowly drains water between storm events which allows storage room for the next event while also containing a portion of water supply in the retention storage volume. The active release approach incorporates a real-time control (RTC) device that exclusively releases harvested water based on forecasted precipitation and current water level within the RWH system.
The dual-purpose system is a viable solution to the main challenge of the SRB-XXL and should therefore be considered as an optional incorporation.

2.2 Literature Research

Apart from the challenge of the SRB-XXL being both a harvesting and buffering system, problems such as water flow control, contaminants and data visualization must also be addressed as subjects of interest (as per mentioned in Chapter 1). It is therefore of great importance that they are analysed using relevant scientific literature to come to terms with the causes of these problems and their appropriate solutions. These sources are compared with one another to result in either shared or differing opinions and can thus build upon or refute each others findings. Using this method, conclusions can be made on the subjects concerning water in- and outflow control, contaminants and appropriate filtering mechanisms, and data visualization on the user interface.

2.2.1 Water inflow and outflow control

Controlling the water in- and outflow is one of the most crucial functions an RWH system must possess. As stated by Palla et al., domestic rainwater harvesting systems operate as source control solutions, thus limiting overflow discharges and drainage system failures. He further states that satisfactory system performance is achieved if the tank sizing criteria is based on water demand and runoff volume as key parameters **[10]**. This section will therefore discuss methods to determine the volume or rate of runoff and how to properly control it. According to Kim et al. **[11]** and Kim, Han and Lee **[12]**, rainwater harvesting systems have three main stages in which rainwater travels: the catchment area, the storage unit and the discharge (a.k.a. runoff or overflow). Palla et al. highlights that the specific features of the catchment area strongly affect the performance of volume reduction rate **[10]**. Based on field research study **[11]**, an equation is created which determines the runoff quantity from a catchment surface over a period of time:
Qc,t=t=0t [I(t)AC]
In this equation, $Q_{c,t}$ is the cumulative runoff quantity from the roof over time t, A the catchment area and I(t) the rainfall intensity at time t. Kim, Han and Lee **[12]**, however, have a slight alternative approach towards calculating the catchment runoff where factors such as evaporation and retention on the catchment hold an effect **(Figure 6)**. This equation states that there is no catchment outflow until the rainfall is higher than a certain degree of evaporation and retention.

$$Q_{out,c} = \begin{cases} 0 & r \leq \frac{EA + S_c}{A} \\ rA - EA - S_c r > \frac{EA + S_c}{A} \end{cases}$$

Where

$Q_{out,c}$	the volume of outflow from the catchment [L^3]
r	rainfall to the catchment [L]
E	evaporation from the catchment [L]
A	area of catchment [L^2]
S_c	retention on the catchment [L^3]

Figure 6: Mass balance equation for calculating catchment runoff

$$Q_{out,t} = \begin{cases} 0 & V_t \geq Q_{in,t} + S_{tb} - Q_s \\ Q_{in,t} + S_{tb} - Q_s - V_t & V_t < Q_{in,t} + S_{tb} - Q_s \end{cases}$$

Where

$Q_{out,t}$	outflow from the tank [L3]
V_t	volume of tank [L3]
$Q_{in,t}$	inflow to the tank [L3]
S_{tb}	stored rainwater in tank before rainfall event [L3]
Q_s	required rainwater quantity for demand [L3]

Figure 7: Mass balance equation for storage tank outflow

In a similar fashion, Kim, Han and Lee have devised a calculation for the storage tank in and outflow **(Figure 7)** for a system that first supplies the incoming water to appliance demands Qs (e.g. toilet flushing, gardening), then into the storage tank and lastly, when the storage capacity is maxed out, as tank outflow $Q_{out,t}$.

In rooftop rainwater harvesting systems, the process of how the water can flow in and out of the tank can have various effects on the system in terms of water quality and system maintenance. Martinson and Thomas **[13,14]** point out that the inlet of the storage tank should be arranged such that it travels all the way to the bottom of the tank. This is because particulates, that may have slipped through the filters, settle on the bottom of the tank and through the inlet won't constantly mix with the upper layers. Using a break ring surrounding the inlet breaks downward flow and protects the settled material from any disturbance. For the outlet, it is best to take water from the top as the dirtiest water lies on the bottom. The outlet must thus be connected to a flexible hose with a float on the top.

When a rainwater storage system is full but still receives incoming water, the system experiences the phenomenon overflow, which is when excess water is dispelled out of the tank and into the street runoff, storm sewer networks, etc. Martinson and Thomas **[13,14]** found that overflow inside the tank can be managed through four different arrangements: a) the standard arrangement: bottom-in top-out. b) inflow exclusion: overflow water is blocked from reaching the storage area. c) Desludging bottom exit: a method which dispels the dirtiest water taken from the bottom of the tank. d) Top cleaning siphonic action (best if entered debris floats): overflow with floating matter is sucked into a pipe, cleaning the top of the tank **(Figure 8)**. It is believed that traditional RWH systems use a mechanism where the water flows out of an outlet positioned on a higher level of the tank, thus discharging the water into its surroundings without disturbing the tank mechanism **[8,13,14]**. Dillon **[15]** however, objects to this and states that excess overflow water can, instead of being discharged into the street runoff or sewer networks, be infiltrated into the ground for groundwater recharge. Hamel et al. **[16]** support Dillon as this method increases moisture content and evapotranspiration which can help in modifying the urban microclimate.

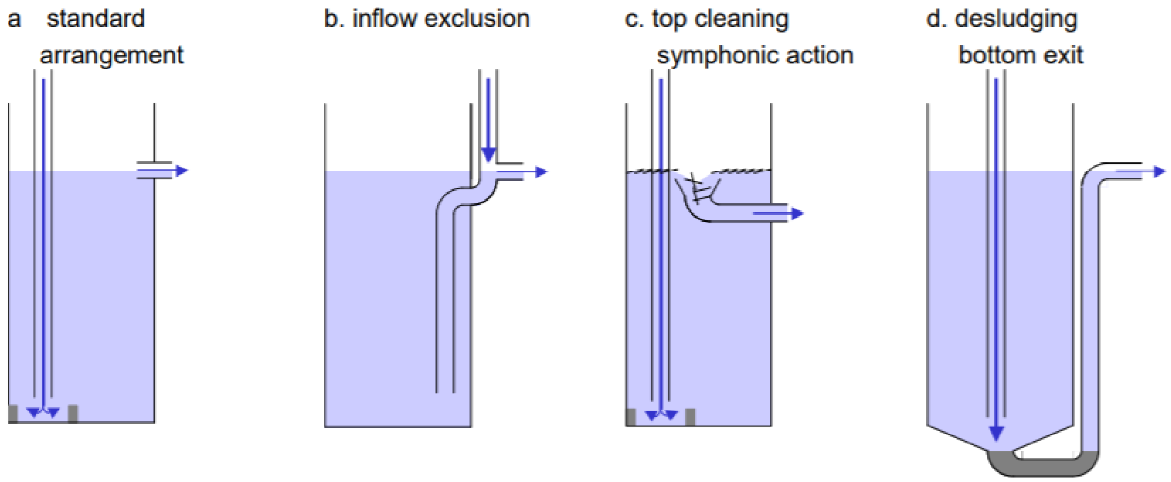


Figure 8: Overflow arrangements

To sum up, multiple equations and methods can be used to determine the volume or rate of runoff of RWH systems and how to properly control it. Furthermore, certain arrangements of the in- and outlet of the storage unit prove to be beneficial towards water quality preservation. The same is said for overflow arrangements, but there is debate towards the discharge location.

2.2.2 Filtering and maintenance

Storage units for rainwater require specific filtration and sanitation for the preserved water to maintain pure quality so it still holds the potential to be used in households, irrigation and other recreational practices. This section is divided in the discussion of which contaminants have the possibility of affecting the water quality, and what filtering mechanisms are agreed upon by relevant sources to be successful.

Abbasi and Abbasi **[7]** concur with Meera and Ahammed **[17]** that a rooftop harvester (RTH) can have contaminants that are either chemical, microbiological or physical. Abbasi and Abbasi list the following sources where these contaminants can originate from: wet deposition, air the raindrops fall through before landing on the roof, atmospheric deposition, contaminants derived from heavy traffic, industry, etc., the rooftops and drainage pipes, and lastly inside the storage tank. The wet deposition can receive chemical and physical contaminants from sources such as industrial air pollutants or aerially sprayed pesticides. Meera and Ahammed **[17]** assess that the roof can be a possible source of contamination through heavy-metals, depending on the construction materials of the roof (lead-based paints), but Abbasi and Abbasi **[7]** include materials deposited on the roof (s.a. dry deposition) and the roof maintenance as polluting sources. Abbasi and Abbasi add that microbiological pollutants originate from soil and leaf litter accumulated on the roof and drainage pipes, fecal material deposited by birds, lizards, mice, rats, and insects, deceased animals and insects either on the rooftop or in the storage tank, airborne microorganisms blown in by wind.

As countermeasure against these pollutants, filtering mechanisms are installed which provide a certain amount of insurance for water quality preservation. It is similarly thought by multiple sources that the "first-flush" method has great effect in the pre-storage rainwater purification **[7, 18-21]**. As the name describes, the first-flush is the first part of the rainfall runoff which contains large forms of pollutants and high concentrations of contaminants which, instead of falling into the storage unit, will be bypassed to street drainage systems and other surrounding water catchments. Many low population areas in Australia make use of this method for their rainwater tanks because it significantly improves the water quality of the rainwater collected in the tank, but also reduces the treatment and energy requirements for filtration **[18]**. Helmreich and Horn **[20]** add that other benefits of the system are that it operates automatically, reduces tank maintenance and can be made in different shapes and sizes to fit the requirements. According to Abbasi and Abbasi **[7]**, the amount of water to divert in the first flush depends on the dry days preceding the rainfall, the amount and type of debris, the season and the quality of the roof surface. The method they propose to execute an automatic first-flush is to add a flush chamber, a downpipe with a small drain hole, which can hold the required amount of runoff while letting the water slowly drain off. When the flush chamber is full, the water flows over the chamber and into the storage tank. This method can be further modified with a float.

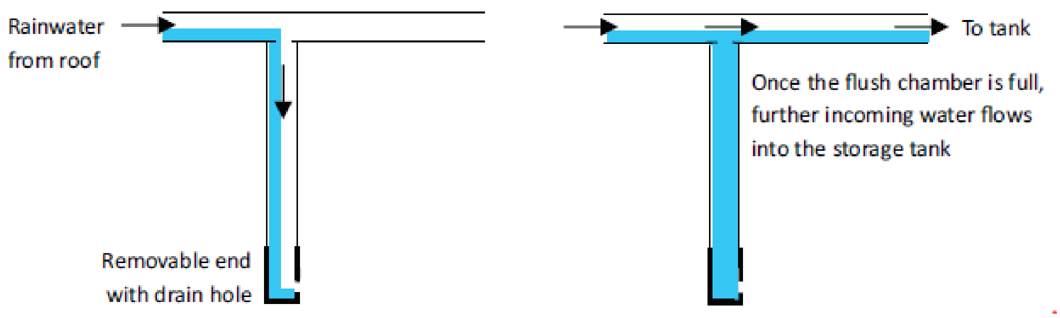


Figure 9: Automatic first flush diverter schematic

De Kwaadsteniet et al. **[21]** are of opinion that slow sand filtration is also an efficient filter to be added to rainwater tanks. A slow sand filter is constructed using graded sand layers from the top layer being the coarsest to the bottom layer being the finest. Although ineffective in removing viruses, they have a high percentage removal of bacteria and protozoa. However, Fewster et al. and Palmateer et al. **[22,23]** argue that they are effective in the sense that they remain in service for many weeks/months, but the limits are that they can only reduce microorganisms and essentially need a constant flow of water to work properly.
Aside from the first-flush system and slow sand filter, methods that increase water quality at the inflow station, Helmreich and Horn **[20]** and De Kwaadsteniet et al. **[21]** see eye to eye that treatment of microbially contaminated water can be performed with the use of solar pasteurization a.k.a solar disinfection (SODIS), eliminating bacteria such as Escherichia coli in tested on water-batches. The duration of this method is dependant on the water-body of the batch. SODIS is best performed in ideal conditions, however there exists disagreement between the two sources on what that entails.
In conclusion, RWH systems can be polluted by contaminants of the chemical, microbiological or physical variety, originating from sources outside the system (e.g. the atmosphere) or in the system itself, such as rooftop materials. Agreed upon by multiple sources, first-flush filtration, the slow sand filter and solar pasteurization appear to be effective filtration/sanitation methods against these contaminants, although there are differing opinions on the benefits and downsides of these mechanisms.

2.2.3 User interface data visualization

Next to a rainwater harvesting system being able to work properly, it is also vital for the user to have insight of the current status of the system. This entails that the SRB's user interface is able to visualize certain data for the user to effectively make out what the conditions are of the system (e.g. water level and precipitation predictions). Chen, Samuelson and Tong **[24]** found in their project paper that rainwater management systems should incorporate local precipitation data, runoff prediction and site conditions into the visualization development. Young et al. **[25]** agreed in terms of precipitation data and runoff prediction in their own case study, but add that the system should also be comprised of a user-friendly interface which allows the user to input, output and analyze data, set options and run the model. Moeseneder et al. **[26]** share with Young

et al. the incorporation of an interactive-simulation element in their findings as it could play a key role in linking information and decision making.
With regards to the manner in which the data should be visualized, Friendly **[27]** and Kelleher & Wagener **[28]** see eye to eye that the viewer has a better overview of information if it is presented in graphs or patterns instead of large amounts of texts and numbers. Meloncon and Warner **[29]** discovered in their research that pictographs, icon arrays and bar charts are superior in terms of user comprehension, that simplicity was relevant in data visualization by focusing on one key factor, but also state that interactivity features can decrease understanding for users. Valdez et al. **[30]** disagree with the statement of interactivity being a confusing element, as they believe that interaction methods are crucial for exploring data. Mechanisms such as search, rotation of data or tool-tips can reduce complexity in multidimensional data.
User interfaces of RWH systems incorporate multiple data systems and visualization methods to inform the user of current status and future decision making. Precipitation data and runoff prediction are agreed upon visualization subjects, but interactive simulation seems to be a useful integration as well. In terms of visualization method, graphs or patterns present a clear overview of information and that pictographs, icon arrays and bar charts help with user comprehension. It is debated whether interactivity is a desirable feature, as one side believes that it obstructs user understanding while the opposition affirms that interactivity allows the user to explore and reduce complexity in multidimensional data.

2.2.4 Conclusion

The goal of this literature research was to gain more knowledge and insight concerning subjects that prove to be of significant importance in the realization of designing a successful rainwater harvesting system. With that in mind, scientific literature sources were analyzed and resulted in the following conclusions relating to in- and outflow control, water quality purification and maintenance, and data visualization. Equations and methods can be used to ascertain and gain control of the volume or rate of runoff in catchment areas and tank in- and outflow of RWH systems. Arrangements of the in- and outlet of the storage unit, such as a break ring, prove to be beneficial towards water quality preservation. Overflow can be controlled as well, using various methods with each their own benefits. There exists disagreement whether system overflow should be discharged into street runoff and sewer systems, or infiltrated into the ground for purposes such as groundwater recharge. RWH systems can come in contact with pollutants of the chemical, microbiological or physical variety, originating from sources outside the system (e.g. the atmosphere) or from materials within the system itself. Agreed upon by multiple sources, first-flush filtration, the slow sand filter and solar pasteurization appear to be effective filtration/sanitation methods against these contaminants, although there are differing opinions on the (dis)advantages of these mechanisms, such as whether a slow sand filter is effective if it requires a constant water flow. User interfaces of RWH systems incorporate multiple data systems and visualization methods to inform the user of current status and future decision making. Precipitation data and runoff prediction are agreed upon visualization subjects, but interactive simulation seems to be a useful integration as well. In terms of visualization method, graphs or patterns present a clear overview of information and that pictographs, icon arrays and bar charts help with user comprehension. It is debated whether interactivity is a desirable feature, as one side believes that it obstructs user understanding while the opposition affirms that interactivity allows the user to explore and reduce complexity in multidimensional data. Using the findings from this research, proper installation propositions can be made towards the ideation and realization of the SRB-XXL.

2.3 State of the Art

In this section, multiple state of the art rainwater management(/harvesting) solutions will be reviewed based on their functions and/or impact on its surroundings. The solutions are divided by their location-based use or origin starting with projects in Enschede, then in the Netherlands and lastly across the world. Each solution is concluded with a a statement on how it can benefit the SRB-XXL project and inspire to take similar approaches towards its development.

2.3.1 RWH systems in Enschede

Wadi's

The Wadi's (a Dutch acronym for "Water Afvoer Drainage Infiltratie") are low-lying capture areas which aim to collect rainwater in order for the water to safely seep into the ground and prevent high groundwater levels **[5]**. This system is beneficial in preventing the ground to dry up and, moreover, forms a buffer against heavy rainfalls. The upper layer of Wadi's are usually covered in grass and small flowers which contribute to removing pollutants from the water, give support for the bees, but are also aesthetically pleasing. Although invented and executed in Enschede (the municipality possessing over 180 of them), there are Wadi's implemented in the "Leidsche Rijn" and in Belgium's Mechelen train station, among others **[31]**. The Wadi's function to use nature as a purification system for incoming precipitation are fascinating and could be implemented in the SRB's filtration system.

Green Roofs

In support of making Enschede a greener city and better resistant to water overflow, roofs that lie on top of houses or sheds are installed with small gardens or sedum moss, ultimately making them "green roofs". The roots of the plants hold on to the water during precipitation and slowly dispose of it afterwards, making it less likely for sewers to become overloaded. Although this system is not suitable as a replacement for roof-insulation, they make the roofs more sun- and soundproof **[5,32]**. The buffer factor of the green roofs, specifically the moss, are quite appealing in the sense that it acts as an additional water storage unit aside from the main storage tank.

The Groene Linie

The Groene Linie is city-center project on the street "Oldenzaalsestraat" where a giant water-storage sewer and a green area, filled with Wadi's, are being constructed to better transport and store water. The project is being worked on for years and is expected to be finished in April 2020. Next to the Groene Linie being a water harvesting system that can hold seven million liters of water, it is better qualified against the changing climate by capturing incoming heat due to the greener design **[5]**. Being both a buffer and harvesting system, the Groene Linie acts as a solution to both main challenges of the SRB-XXL. It is also an inspirational project for the municipality as it is highly promoted and visually pleasing due to the green aspect.

The Regentoren Project

Originating from the University of Twente student competition "Creathon", where it was the goal to produce a solution for a community problem, the Ensketon was created as a concept to augment rainwater tanks to become intelligent and store/release water depending on future

rainfall **[5]**. It is the founding father of the Regentoren: a project pursued by the UT, Waterschap Vechtstromen and the municipality of Enschede to create a network of smart rainwater buffers throughout the city**[33]**.
After the Ensketon, the Regentoren project has been taken up by various students of the University of Twente as graduation projects, each with their own version or prototype of an SRB, to research it's reaction to weather prediction and create a user monitoring system. "Tonnie" is a prototype of the SRB created by Gelieke Steeghs, Felicia Rindt, Jeroen Klein Brinke and Dennis van der Zwet, which was intended to be placed on private property for domestic use. This rainwater barrel was equipped with water level and flow sensors, an internet connection to retrieve weather forecast, which resulted in opening/closing the valves to the sewage system and garden if rain was predicted, and a website dashboard for the user which showed data of Tonnie to the user. **[34]**

Figure 10: Rainwater Buffer of the pre-pilot

The pilot of the Regentoren project is to implement and test a number of SRBs of 250 liter on participant's property. If this is successful, the next step is to do perform a similar pilot but with the differences being that the SRBs are an XXL version of its predecessors and be suitable for business parks. As successor of the current project it is of vital importance to take the previous designers' successful functions and advice on future recommendations into account for the design of the SRB-XXL.

2.3.2 RWH systems in the Netherlands

Groasis Waterboxx

Invented by the Dutch former flower exporter Pieter Hoff, the Groasis Waterboxx is a device designed to help trees survive in dry areas by creating a supportive micro-climate with captured rainwater. The Groasis is a bucket with a lid that acts as an insulator for seeds or saplings. The lid has a tubular opening in the middle which allows one or two small trees to grow. The design of the Groasis shelters the plant from the heat of the sun while collecting water during rain or condensation periods. A wick inside of the box drips 50 ml of water every day into the ground-area of the sheltered plant(s) **[35]**. Although the tank-design for the SRB doesn't allow for the same plant-protection functions as the Groasis Waterboxx does, it may be useful to consider the insulating factor of the stored water in the tank to be used for specific temperature control against droughts.

Figure 11: The Groasis Waterboxx: a technology that supports the growth of plants using water conservation

Stormbrixx

On the industrial area of Limburg, ACO Water Management has introduced the infiltration system "Stormbrixx" **[36]**. The system is spread out over 2300 cubic metres which aim for the catchment and infiltration of rainwater into the ground in order to reduce the load on the sewer system. Stormbrixx is the construction of stackable/fusible elements made from recycled polypropylene. Because the system is made up of multiple small elements, it's easy to transport, inspect and install. In the 2012 British Construction Industry Awards, Stormbrixx won the "Product Design Innovation Award" **[37]**. The Stormbrixx system could possibly be used to better control the runoff/overflow of the SRB in order for it to safely infiltrate into the ground.

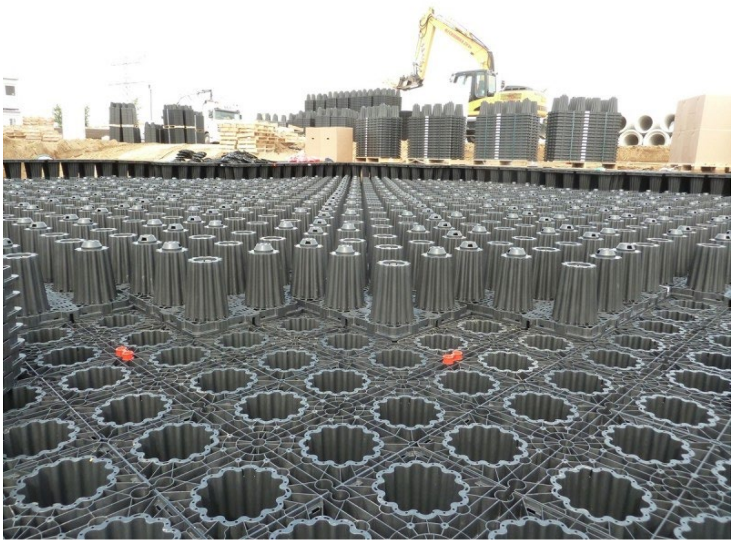


Figure 12: The construction of the Stormbrixx infiltration system in Limburg

The Slimme Regenton "Diamant"

The Slimme Regenton "Diamant" (e.g. dutch for "smart rain tank 'diamond'") is designed by Studio Bas Sala, located in Rotterdam, as a rainwater catchment solution for areas that are mostly surrounded by pavement, which prevent the water from seeping into the ground and thus cause flooding of the streets. The Slimme Regenton is a tank connected to the internet for two purposes: 1) It can be controlled remotely by the user. 2) It is coupled with the local weather forecast can make room for the calculated amount of precipitation by releasing the stored water through a tap. The diamond-like design is chosen to emphasise how valuable rainwater is and to appeal to the public so it can be implemented in areas like company gardens and parks **[38]**. The smart elements of the Diamant are similar to the goals that the SRB's user interface should achieve, thus can be used as a working example to achieve the same results.

Figure 13: The Slimme Regenton "Diamant" in Marineterrein Amsterdam Living Lab

2.3.3 RWH systems in the rest of the world

Bangalore RWH Theme Park

In Bangalore, India lies the "Sir M. Visvesvaraya Rainwater Harvesting Theme Park" which displays 26 different rainwater harvesting models to the public in order for them to learn how to best conserve water and raise awareness about water usage. These models come in the form of a house entirely equipped with rainwater, swales and garden paths which allow water to flow easily to the ground, water wise landscaping and more **[39]**. The Bangalore RWH theme park is inspiring for the SRB-XXl not so much for a specific technical function, but as its impact to the public.

Figure 14: Sir M. Visvesvaraya Rainwater Harvesting Theme Park

Atlantis Flo-Tank® Modular Tank System

The Australian corporation "Atlantis" has provided over 50 countries products that capture rainfall and allow the stored water to be reused. One of these products is the Flo-Tank®, a structural black box used to construct underground water storage for various applications. Due to the cubic nature of the system, it can accomodate any volume conditions depending on the site in where it is constructed. The system can be applicated into various projects, each with their own specific goals. One of these is the "Atlantis Rainwater Harvesting Tank", where the water from surface and roof areas go through a filtration unit and is captured by the underground modular system, stored to later be used when necessary **[40]**. It's captivating how the Atlantis Rainwater Harvesting Tank is able to rely on the successful performance of the filtration unit and water quality preserving functions of the Flo-Tank modules to, not only provide clean water, but also to refrain from having to clean out the underground storage system.

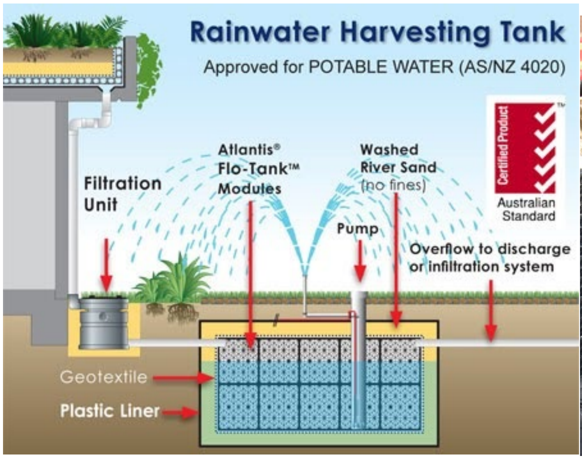


Figure 15: The construction of an infiltration tank system using Flo-Tanks®

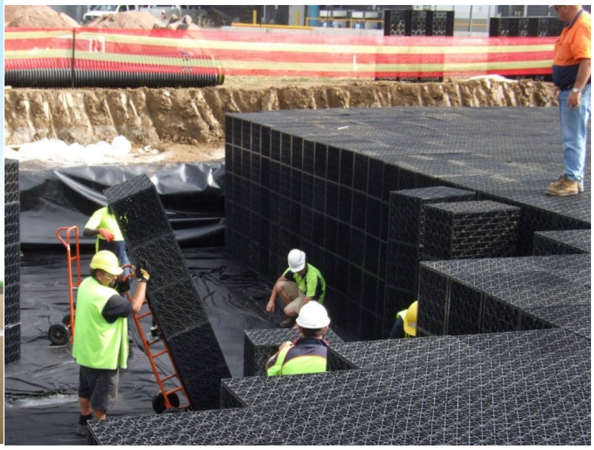


Figure 16: Atlantis Rainwater Harvesting Tank.

The “One Million Cisterns” Programme

In 2003, the social movement called the Cisterns Programme was organised by the Articulação Semiarido Brazileiro (ASA) in the Semi-arid region of Brazil (a.k.a. SAB). The goal of this concept was to install one million collection cisterns to the homes of residents of the SAB area to provide potable water during the dry seasons. The cisterns were later expanded with the goal of collecting water for agriculture and municipal schools. As of 2014, the goal of installing one million cisterns was realised and has since been complemented with an additional quarter million. Furthermore, the policy was awarded with the Future Policy Silver Award 2017 by the World Future Council and UNCCD **[41]**. Similar to the Bangalore theme park, the “One Million Cisterns” programme is inspirational for its high scale impact and endeavour to highlight the importance of water preservation.

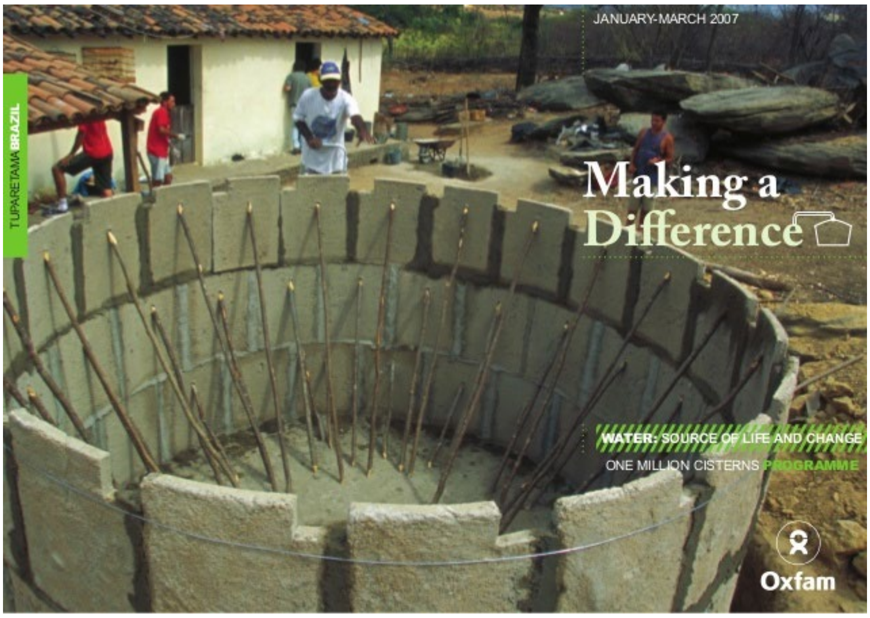


Figure 17: The construction of a cistern as part of the One Million Cisterns programme

2.3.4 Conclusion

State of the art solutions to rainwater harvesting and buffering were analysed with the goal to discover which functions or approaches of the solutions could be used in the SRB-XXL installation.
The solutions located in Enschede apply natural elements in their system which each have their own benefits; Wadi’s use nature as a purification system for incoming precipitation, the moss on the Green Roofs acts as a buffer factor and an additional water water capture unit, and the Groene Linie is a solution to both main challenges of the SRB-XXL being both a buffer and harvesting system while also being visually pleasing to the municipality due to its green aspect. The Regenton project showed the importance of taking previous designers’ successful functions and advice on future recommendations into account for the design of the SRB-XXL.
The Groasis Waterboxx is inspirational for its insulating factor of the stored water, since the same can be used for the tank’s temperature control. The Stormbrixx system could possibly be used to better control the runoff/overflow of the SRB in order for it to safely infiltrate into the ground. The smart elements of the Diamant are similar to the goals that the SRB’s user interface should achieve, thus can be used as a working example to achieve the same results.

The Bangalore RWH theme park and One Million Cisterns programme are both inspiring for their high scale impact and endeavour to highlight the importance of water preservation. The Atlantis Rainwater Harvesting Tank is able to rely on the successful performance of the filtration unit and water quality preserving functions of the Flo-Tank modules to, not only provide clean water, but also to refrain from having to clean out the underground storage system.

Chapter 3: Methods and Techniques

As a measure to structurize the development of the Smart Rainwater Buffer XXL, various product design methods and techniques will be discussed. These methods and techniques will be used in four divided sections which make up the entire "Creative Technology" design process **[42]** of the SRB-XXL project.

3.1 Creative Technology Design Process

A suggested product design process for the bachelor-project of the Creative Technology study, is the so called "Creative Technology Design Process" (see **Figure 18**). This process involves a set of four sections which each consist of a divergence phase and convergence phase. In the divergence phase the design space is opened up and multiple dimensions are explored to find many possibilities concerning the execution of the design process, while the convergence phase narrows the options down to come up with one (or a few) definite solutions. The entire process is divided into the four sections: ideation, specification, realization and finally, evaluation. The content and execution of these sections will be shortly explained in this sub-chapter and will be further iterated in the rest of the Methods and Techniques chapter.

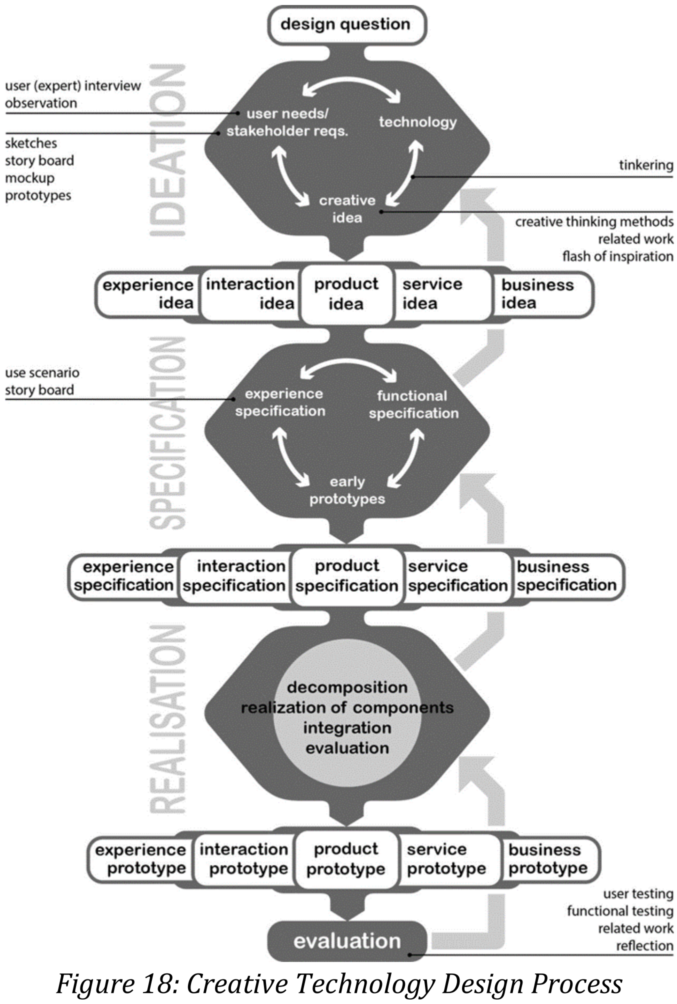


Figure 18: Creative Technology Design Process

3.1.1 Ideation

The first section (or phase) of the design process is Ideation, where the primary objective is to generate multiple concepts for the envisioned product and end up with a single concept-design which fulfills the needs of the stakeholders. Through research on existing rainwater harvesting systems and brainstorm sessions (**see § 3.4**), several concepts are created. After presenting these concepts to the relevant stakeholders, of whom the relevance is determined through stakeholder analyses (**see § 3.2**), the preliminary requirements and user needs are specified which will be acquired through semi-structured interviews (**see § 3.5**). These preliminary requirements will be put into a MOSCOW table (**see § 3.8**) to define their level of importance. The end goal of the project is to at least realize the requirements in the M category, which stands for "Must Have". Finally, a final concept of the product and its sub-systems is created and discussed in a "PACT method" (**see § 3.6**) story scenario through the eyes of the user.

3.1.2 Specification

Building on the preliminary requirements and final concept gained from the ideation phase, the goal of the specification phase is to analyze the functionalities the system must, could and should have and determine how these functions will work. To gain better understanding of the execution of these functionalities, they will be presented in a "functional system architecture" visualized with block- and activity-diagrams. These depict both the user-product interaction as well as the communication between the sub-systems and is used to structure the realization process implementation tasks. The section ends with a second MOSCOW table to reach the finalized set of (non-)functional requirements.

3.1.3 Realization

The realization phase is where a working prototype of the SRB-XXL is built based on the final concept, created in the ideation phase, and the functional system architecture and requirements developed in the specification phase. The product's functional aspects, also obtained from the specification, are realized as the overall architecture is split into sub-systems (e.g. interface, filtration system) of which the intertwined workings and the choices made throughout the product-development are explained. The result is a working prototype which will be tested by the researcher and the stakeholder(s) in the evaluation phase.

3.1.4 Evaluation

The evaluation phase entails a thorough review of the prototype product. Functional testing is used to fulfill the requirements set by the specification phase. The objective of this phase is reached when all the components are properly tested and fitted together into a whole working product. After the functional testing has been completed and it has been confirmed that the functionalities perform correctly, the stakeholder evaluation is executed. This evaluation is performed by the target user(s) of the SRB-XXL who will give feedback using their experience in the subject at hand. The user test ends with a final interview containing the opinion and recommendations of the involved stakeholder(s).

The most important goals of this phase (and by relation the entire Graduation Project) are reached when:

1) The prioritized functional requirements, especially the "must-have requirements" from the specification phase, are reached and realized.
2) Applying the user experience requirements from the PACT/ user scenario's in combination with non-functional requirements, the involved stakeholders have their expectations met at an acceptable level.

The following sections go into further detail of the methods and techniques used in the described phases.

3.2 Stakeholder Identification & Analysis

The stakeholders of a project are all the internal people and teams whom the project will involve or affect in some manner. The purpose of performing a stakeholder identification and analysis is due to these four main benefits **[43]**:

1) By approaching relevant stakeholders at an early stage, their knowledge can help in successfully defining the product. Stakeholders become relevant once they have been identified as people of interest who have influence in the succession of the SRB-XXL.
2) To gain support from important stakeholders who can offer their resources, such as materials or money.
3) To have a clear view on the product's requirements and gain mutual understanding of the user's needs.
4) To preemptively address problems and roadblocks that the stakeholders see within the product and win them over by making the right adjustments.

Thompson **[44]**, who created an adapted guideline of Mendelow's paper **[45]**, evaluates the three steps that make up the Stakeholder Identification & Analysis:

1) Identify your Stakeholders
2) Prioritize your Stakeholders
3) Understand your Key Stakeholders

3.2.1 Stakeholder Identification

The first is to identify the stakeholders to understand who specifically are involved in the succession and existence of the product. This can include the people who are affected by it, have influence over it, or rely on the product's (or the developer's) success. To identify the stakeholders, they are put into a table of three columns consisting of their name, which company or organization they represent, and what role they play in the product. Table 1 acts as an example to how such a table would be displayed in the fictional context of constructing a new KFC in Enschede:

Stakeholder	Contact	Role
Municipality of Enschede	Frans Smith	Supervisor
KFC	Colonel Sanders	Project Owner
The people of Enchede	-	Potential customers

Table 1: Example Stakeholder Table

3.2.2 Stakeholder Analysis

The next step is to prioritize the stakeholders by dividing them into specific categories. These categories are affected by two variables; "power", which is the ability to stop or change the project, and "interest", which accounts for the overlap between the goals of the stakeholder and the project. These two categories are plotted on a two-axis grid (**Figure 19**) where the stakeholders are allocated according to their relevant position.

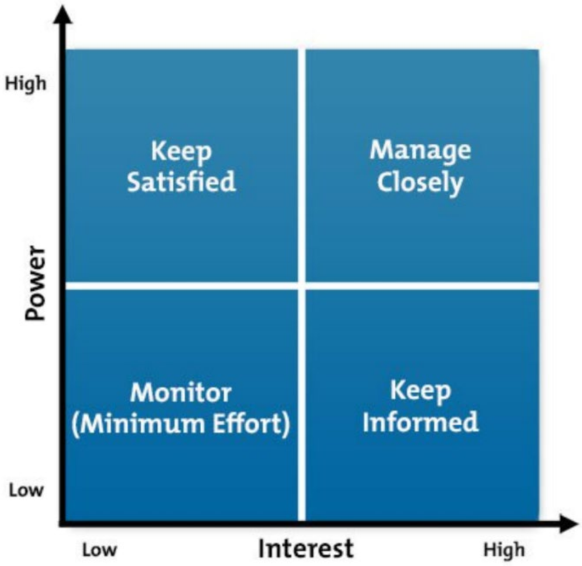


Figure 19: Stakeholder Analysis Matrix

3.2.3 Understand your Key Stakeholders

The final step is to gain understanding of the stakeholders that lie in the "Manage Closely" section of the Stakeholder Analysis Matrix. This entails subjects such as how these stakeholders feel about the project and how to best communicate with them. This type of information can be gathered during interviews with the Stakeholders by asking them questions such as:

- "What financial or emotional interest do they have in the outcome of your work? Is it positive or negative?"
- "What motivates them most of all?"

Depending on the stakeholders placed on the grid, certain actions must be taken to approach them properly. Those who are low in power and interest must at most be monitored and don't require excessive information. Although for stakeholders highly interested in the product, it is important to keep them updated on subjects (e.g. regarding the development process) as their input can be deemed helpful. Powerful stakeholders that don't require much detailed information but must be satisfied with their needs nonetheless, otherwise they may put the project on hold over minor issues. Lastly, those with both high power and interest must be kept in the loop as close as possible and have to be thoroughly managed. The goal of this step is to better understand the Stakeholders' line of thinking and create a better relationship with them. The Stakeholder Identification & Analysis method is applied in the ideation phase of the design process and the results are displayed in sub-chapter 4.1.

3.3 Research

As mentioned in section 3.1, the ideation phase is focused on coming up with multiple concepts of the envisioned product by performing brainstorms and interviews. Proper preparation for these techniques is executed by conducting research into existing products of the sub-systems part of the SRB-XXL.

One area that is researched is the sort of filters used by rainwater harvesting systems and sold by companies that deal in water-purification all over the world. These filters are reviewed for their thoroughness in capturing contaminants, maintenance costs and possibility of implementation into the product's environment.

The next researched subject is what system arrangements or tecniques are used to control the inflow and outflow of the tank-water. This entails safely conducting the water that goes in and outside the system without endangering the outside environment or the system itself.

Lastly, user interface designs are evaluated from reports of previous versions of the Smart Rainwater Buffer. Based on the results of the final realizations, successful features included in these versions will be analyzed to gain inspiration into what could be repeated or improved in the user interface design of the SRB-XXL.

3.4 Brainstorm Session

The concept development starts with brainstorming for new ideas on how to envision the SRB-XXL in new ways. This is done individually by the designer in an attempt to come up with new designs for the main system, using system schematics, user interface design and the outward appearance of the SRB-XXL to make it more accessible for public display. The system schematics explain roughly what sub-systems make up for the entire system and how they are connected to one another. Several techniques to facilitate creative idea generation are **[46]**:

- **Silence**: this process involves the person setting no concrete guidelines and instructions at the beginning of the silence period, except for the explicit goal to generate as many creative ideas as possible.
- **Lines of evolution**: stimulate the thought process on how the current form of the product can be changed into the next evolutionary form (an example of product evolution is inventing chocolate milk from chocolate.
- **Random connections**: create ideas by making unrelated connections between the product and various concepts. These random associations can come from anything or anywhere the thought process leads to, e.g. an object in the room or a video on the internet.
- **SCAMPER**: this method uses seven approaches to think of possible changes to existing versions of the product. These are **S**ubstitute (remove a part of the system with something different), **C**ombine (join two or more concepts together), **A**dapt (change a part of the product so it works in a previously unsuitable environment), **M**odify (change attributes such as size, shape or color), **P**urpose (put the product to some other use), **E**liminate (remove elements of the product to reduce it to its core functionality), **R**everse/**R**earrange (change the direction or hierarchy of operations)

Of the above mentioned techniques, the individual brainstorm session makes use of the "Random connections" and "SCAMPER" methods. This is because it is believed to have the greatest potential to create concepts that makes use of combinations that haven't been thought of before.

3.5 Interview Techniques

Once several concepts have been generated for the sub-systems of the SRB-XXL during the brainstorm, interviews are held with the available stakeholders involved to gain insight on their respective requirements of the system functionalities and what should change about the first concept ideas. The purpose of an interview is to "gather descriptions of the life-world of the interviewee with respect to interpretation of the meaning of the described phenomena" **[47]**. Opdenakker **[48]** describes in his research how four different interview techniques have certain (dis)advantages and how they differ from each other. The techniques reviewed are interviews face-to-face, by telephone, by MSN and by e-mail. Although all techniques are appropriate for the use of gathering information, the most distinctive difference between the face-to-face technique and the others is that this technique has most advantageous position of collecting information involving social cues from the interviewee. This is very important when the subject in question depends on the overall opinion of the respondent.

The interview techniques used for the SRB-XXL stakeholders are face-to-face and by telephone. The face-to-face technique was chosen to reach a better understanding of their opinions and to be able to communicate with one another by drawings and displaying the concepts generated in the brainstorm. The telephone technique was used when the stakeholder was unable to meet in person, which limited the use of visual communication but still made it able to gain relevant information. Both techniques were performed using a "semi-structured interview" where a set of predetermined questions are applied, but may follow up with more questions to go into further detail of the subject and allow new ideas to be brought up. This differs from a "structured interview" where diversion of the subject is strictly avoided **[49].**

3.6 PACT Analysis

As a means to portray the functionalities of the system and its interaction with the user, scenarios are written. Using the PACT framework these scenarios are written in the ideation phase where they are displayed through the eyes of the user.

The PACT analysis is used by designers to help understand the contexts from how a technology should be improved by imagining a scenario where the user experiences communication with the product **[50]**. The acronym PACT stands for:

- **People**: The target market of the product. This part describes the typical person (i.e. the user) who will use the product and what their characteristics and skills are in this context.
- **Activities**: What activities are carried out? What goals must be reached? When must action be taken by the user? What input does the user gives to the system (i.e. data or commands) and what is the output returned as a result?

- **Contexts**: the environment in which the product will be used. This entails the physical environment (such as weather or the materials used), the social environment (e.g. the channels of communication) and other circumstances under which the activities happen.
- **Technologies**: the gadgets, screens and tools used to make the system a working product.

The scenarios are divided by a main user scenario and scenario's with slight changes in context. The main user scenario is developed by creating a step-by-step short story going through the thought process and interactions of the user with the system in question. The other scenario's explain the differences in these user-system interactions.

3.7 Functional System Architecture

At the specification phase, a functional system architecture is created to have an overview of the functionalities of the SRB-XXL and it's sub-functions. The architecture is divided into layered decomposition levels that handle the design complexity of the system. These levels are visualized through block-schematics containing actions that have different functions or identities defined by their description, shape or color.

3.8 MOSCOW method

The ideation phase and the specification phase both end with a set of requirements placed by the stakeholders, established through the information gained during the interviews and PACT analysis, and by the designer after the realization of a PACT scenario and the functional system architecture. These requirements are prioritized using the MoSCoW method **[51, 52]**, which divides the requirements set by the stakeholders or designer into levels of importance. These levels categorized as follows:

- **Must have:** the most critical requirements, which are essential for the success of the product in question. If even one of the Must Have's is not met, the product is considered as a failure
- **Should have:** important, but not necessary for the current goals set by the stakeholders and designer, as they are not as time-critical as the Must Have's.
- **Could have:** requirements that could improve the user experience or satisfaction and are usually fulfilled if time and effort allows so.
- **Won't have:** not planned or appropriate at the time of delivery.

Next to the level of importance, the requirements are also sectioned as "functional" and "non-functional". A functional requirement's definition is something that the system should do, while the non-functional requirement specifies how the system should behave. The former focusses on abilities the system should have and the latter on the quality attributes.

3.9 Evaluation

At the end of the realization phase, where a working prototype of the envisioned system has been built, two types of evaluation are performed: the "functional evaluation" and the "user evaluation". These evaluations have the objectives to test if the system has addressed the requirements set in the ideation and specification phases and if the stakeholders are satisfied with the results.

3.9.1 Functional Evaluation

Using the MOSCOW requirements set in the ideation phase as a guideline, the prototype is tested on its most important functionalities to fulfill the "Must Have" requirements of the stakeholders. The tests are performed by the designer who checks the reactions of the system based on user interactions (e.g. with the user interface) and weather simulations, by manually releasing water onto the system and observing the results. If, however, a functionality is unsatisfactory in its performance, it has to be corrected before the user tests begin.

3.9.2 Stakeholder Evaluation

The final product test involves the main users or stakeholders of the system (determined in the Stakeholder Identification phase) who verify whether their initial demands, collected in the ideation phase, are met. This is also known as a "summative evaluation", as the goal is to determine if the end-design meets the performance requirements, in contrast to a "formative evaluation" which is used to find and eliminate occurring problems in the system during development. According to the "Usability Body of Knowledge" there are several means to execute a user evaluation **[53]**:

- **Summative Usability Testing:** used to check if usability goals are met through defined measurement elements such as efficiency, effectiveness and user satisfaction of the product. The procedure is done in a controlled environment where the subjects are first asked to fill in a pre-test questionnaire for demographic data, then are subjugated to solving realistic tasks using the designed product, and lastly feedback is received whether the expectations of the users are met.
- **Remote Evaluation:** a usability testing method where the evaluator and user participant are not in the same location. This can be performed with the evaluator observing the participant in real time, or unmoderated with the participant working without direct observation or interaction.
- **Wizard of Oz:** a user-based evaluation where the developer (a.k.a. wizard) simulates responses of the system with or without knowledge of the user. This method investigates how the user reacts to design features before they have been fully automated into a more expensive or high-stakes version of the product.

The evaluation of the final prototype will be performed using a combination of "summative usability testing" and the "wizard of oz method". This entails that the stakeholder first fills in the pre-test questionnaire, hereafter the user will be in a controlled environment where they solve tasks set by the evaluator which are guided by the evaluator controlling the system behind the screens. The test ends with a survey and feedback session of the user which will determine whether the product has met their expectations.

Chapter 4: Ideation

The first step in the Creative Technology design process is Ideation, where the purpose is to generate ideas for the envisioned product and end up with multiple concepts. The order of actions that must be taken to reach the desired result is as follows:

1. Identify and analyze the stakeholders involved in the SRB-XXL project and prioritize those with the highest power and interest.
2. Based on the sub-questions in Chapter 2 State of the Art, research is performed on existing versions of the subsystems involved in the SRB-XXL.
3. Using the results of the research, a brainstorm session is conducted to come up with initial concepts.
4. Face-to-face and through-the-phone interviews are performed with prioritized stakeholders with the purpose of acquiring the user requirements.
5. A list of pre-liminary user requirements is made in a MoSCoW framework.
6. A final concept of the SRB-XXL is developed.
7. The final concept is elaborated through a user-based story scenario.

4.1 Stakeholder Identification & Analysis

As stated in the previous chapter, the Stakeholder Analysis needs to be performed to gain multiple benefits concerning the Ideation phase of the SRB-XXL project. The analysis is split into three separate steps that make up the whole of the process; identification, analysis and prioritization.

4.1.1 Identification

First and foremost, the people who the SRB-XXL will affect or are directly involved in the project are identified. The table below displays (from left to right) the identified stakeholders, the contact(s) representing the stakeholder and the role that the contact(s) take on in relation to the SRB-XXL project **(Table 1)**. Each stakeholder is briefly described through their involvement in the project and how they should be managed through the development process.

Stakeholder	Contact	Role
University of Twente - Campus & Facility Management	Andre de Brouwer	Client & User
University of Twente	Richard Bults, Hans Scholten	Supervisor, Critical Observer
Municipality of Enschede	Hendrik Jan Teekens	Project Partner
Waterschap Vechtstromen	Stefan Nijwening	Project Partner
Waterschap Vechtstromen (former)	Jeroen Buitenweg	Consultant
DeLaval	Eddo Pruim	Service Engineer & Consultant
Krinkels	-	User
Passers-by	Students, Campus-residents, visitors	Viewers

Table 2: List of Stakeholders with associated contact(s) and role(s)

UT Campus & Facility Management – Andre de Brouwer

Andre de Brouwer is the client of the Smart Rainwater Buffer XXL. He represents the Facility Management of the UT, which maintains the plants and (sport)fields located on the campus grounds, among other tasks. As the main user, Andre would benefit greatly from the realization of the SRB-XXL since it would act as an additional water supply for the watering of the plants on campus. Andre has much experience in terms of hands-on projects related to rainwater harvesting and rainwater use, such as the "Technohal" which is located on the UT Campus. He is the most important decision-maker and should be "managed closely" during the development process.

University of Twente – Richard Bults & Hans Scholten

Richard Bults and Hans Scholten are the representatives of the University of Twente. Richard acts as the supervisor of the project which entails directing and overseeing the work of my research. His involvement in the SRB-XXL project (and predecessors) stems from the goal to make the SRB project a realization. Having worked close with many similar projects, Richard has much knowledge to offer that can be helpful with the decision making of multiple project-phases. Hans Scholten is the critical observer of the graduation project. He gives relevant feedback on my work and inputs valuable information regarding the technological subjects. Both Richard and Hans will assess the graduation work at the end of the semester and review the end-report accordingly, meaning they are high in power and interest and should be "managed closely".

Municipality of Enschede – Hendrik Jan Teekens

Hendrik Jan Teekens represents the Municipality of Enschede and has interest in the SRB-XXL project due to its future prospect of being implemented in the city to reduce flooding in the water treatment systems and employing it alongside other water storage projects (e.g. Oldenzaalsestraat). Hendrik has been involved in previous SRB projects, making him experienced in the subject. This makes him a major stakeholder with high power and intel which means that he, as well, should be "managed closely".

Waterschap Vechtstromen – Stefan Nijwening & Jeroen Buitenweg

A waterboard (Dutch for "Waterschap") is a layer of government in the Netherlands representing citizens, companies, agriculture and nature. Vechtstromen is the waterboard in charge of Twente, Northeast Overijssel and Southeast Drenthe. They have the duty of cleaning polluted water, focus on water-related issues and create a suitable environment for people and nature. The SRB-XXL can contribute towards the goals of Waterschap Vechtstromen and is represented by project-partner Stefan Nijwening who holds much power over the success of this project, has much experience in water-management and should therefore be "managed closely". Former Waterschap Vechtstromen employee Jeroen Buitenweg acts as a consultant for this project as he can provide information regarding proper water treatment, though he is less dependent on the overall end-result than his former colleague and is "kept informed

DeLaval – Eddo Pruim

DeLaval is the company with which an agreement has been made to provide a silo tank acting as the main storage unit for the SRB-XXL. Eddo Pruim is the contact person in regards to the background information of the silo tank is currently the owner of a rainwater harvesting system, making him a person of interest for gathering information and should also be “kept informed”.

Krinkels

The terrain of the University of Twente (UT) is largely maintained by the company Krinkels. This entails green space, sport terrains and sewage among others, but also water management. Krinkels has a contract with the UT Facility Management department for maintenance of the grounds and landscaping. Through communication and approval of the main client Andre, they are potential users of the SRB-XXL. Krinkels doesn’t have much power in the success of the system but should be “kept informed” either way so they know how to properly work with the system.

Passers-by

If the tank were to be placed on the university campus, it would be seen by many walking past the Sportcentre building. These people don’t have direct power over the project and generally don’t possess valuable information regarding the technological details. However, they are the viewers of the system and it might be worth finding out what their opinion is on matters concerning outward appearance and general facts and stats displayed on a screen or poster. At best these stakeholders should be “monitored” and don’t require much effort to involve them in the project.

4.1.2 Analysis

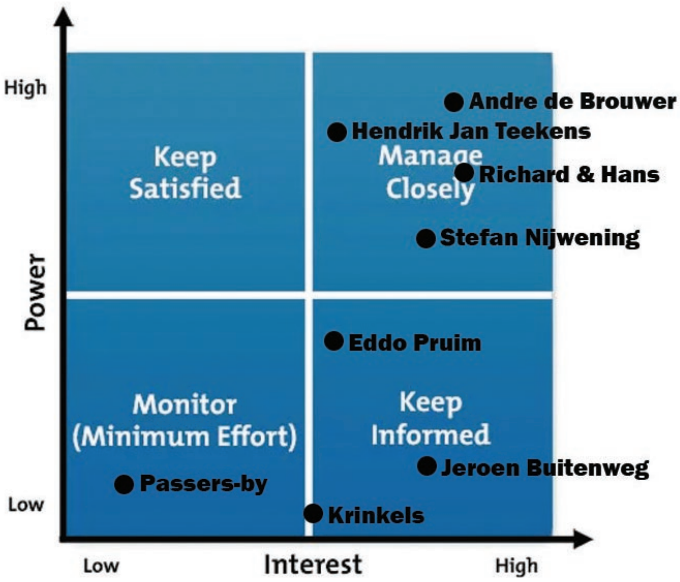


Figure 20: Stakeholder Matrix with prioritized stakeholders

The second step of a stakeholder analysis is to divide the stakeholders into a matrix with a power and interest axis (see **Figure 20**). The stakeholders with power have more influence over the succession/failure of the project and those high on the interest axis must be communicated with often to both give and receive relevant information.
The most important person in the matrix in terms of both power AND interest, is the client **Andre de Brouwer**. He is the one for whom the project is being developed, plus his input on requirements and technical knowledge is invaluable. **Richard and Hans** are the second most valuable stakeholders since they have to assess the graduation report at the end of the project. Because of frequent progress meetings, they are the stakeholders who are most informed on my progress. **Hendrik Jan Teekens** is chosen to be in the "Manage Closely" box as well, since the Municipality of Enschede has had high stakes on this project for the last few years and can provide technical knowledge, such as water preservation techniques. Just like the Municipality of Enschede, Waterschap Vechtstromen representative **Stefan Nijwening** is high on both axis on the matrix. Although it is believed that Enschede has more direct power in the succession of the SRB-XXL, Vechtstromen can provide more information on water quality, flow and control. **Eddo Pruim** and **Jeroen Buitenweg** are in the "Keep Informed" category since they don't hold much power, but are quite knowledgeable in the researched subject. **Krinkels** is also in the "Keep informed" category because of their future involvement in using the system. Lastly, the **Passers-by** are simply to be monitored as they have little to none influence on the project and no knowledge on technological details.

4.1.3 Prioritization

The final step is to gain understanding of the above-mentioned stakeholders placed in the "Manage Closely" area and find out what their motivation is behind the successful realization of this project. This step is important since these stakeholders will be sought out the most for their involvement in this project through interviews and requirement elicitation. As pre-mentioned, Andre de Brouwer would benefit greatly from the realization of the SRB-XXL since it would act as an additional water supply for the watering of the plants. Richard and Hans rely on the success of the SRB-XXL since it is the next step in the SRB project. Through the interviews it has been determined what the motivations are of some of the other stakeholders. Hendrik Jan Teekens describes that the project's success would show how serious the Municipality of Enschede is with gaining results, especially through the transition from smaller smart rainwater buffers to the bigger and more effective water tanks, but also as physical proof of their hard work. Jeroen Buitenweg claims it comes down to that the Municipality of Enschede and Waterschap Vechtstromen have the same goal to move from a centralized water storage system to multiple decentralized systems in addition to current water treatment systems. It is also a means to raise awareness for water-use of the public so they realize how precious potable water is.

Now that the stakeholders have been identified and prioritized by their power-interest, further decisions can be made towards the rest of the ideation phase taking the Stakeholder Analysis into account. This includes who have top priority in information gathering during the interviews and who's requirements should be fulfilled.

4.2 Research

As preparation for initial concept development through brainstorms and for discussed subjects during stakeholder interviews, research into filters, waterflow controls/arrangements and user interface features is performed. The discovered results are taken from both the State of the Art research (Chapter 2) and from products found online (e.g. from rainwater harvesting companies).

4.2.1 Filtration

These are the researched options for filters:

- **First Flush filter**: The first flush mechanism makes use of a by-pass system that transports the first part of rainfall runoff, which contains a substantial amount of pollutants, outside the rainwater storage system. This method reduces treatment and energy requirements for filtration. A proposed method is the automatic first flush method (see Figure 9 in Chapter 2.2.2) installed with a float that seals off flow into the diverter pipe and further incoming water flows into the storage tank.
- **Coarse Leaf Screen filter:** A screen that removes leaves and other coarse debris from the rainwater. It is recommended to be placed in the gutter, as it prevents leaf buildup and reduces mosquito breeding. The downside is that this filter can be expensive to maintain if it covers large catchment areas, which brings more debris into the filter.
- **Hydraulic Jump filter:** inspired by the mechanisms of streams in nature, the PURAIN Hydraulic Jump filter collects rainwater that flows over a rounded surface and drops to the bottom of the filter. This is when the hydraulic jump occurs, as the flow at the bottom of the drop changes and creates turbulence. This results in the transport of impurities and debris away from the filter, making it self-cleaning. This method is particularly useful for large roof area's ranging from 60 to 15.000 square meters and requires low maintenance **[54,55].**

4.2.2 Inflow and Outflow Control

After the water has gone through the filtering system(s), the water flows into the tank for storage and is discharged of the tank when the capacity is at its limit. This must be done in a controlled manner for water quality and tank safety purposes. The following shows various techniques used to control the flow of in and out ported water.

As analyzed in section 2.2.1, there are four tank arrangements that can be used in the flow control of the SRB-XXL:

- **Bottom-in Top-out arrangement:** The incoming water should go through a pipe that travels all the way down to the bottom of the tank so that any debris that came through the filters settle at the bottom of the tank and don't mix with upper layers.
- **Inflow Exclusion**: Overflow is blocked from reaching the storage area and gets immediately discharged.
- **Top cleansing symphonic action**: When there's full capacity inside the tank, the upper layer of water is sucked through a pipe, thus cleaning the top of the tank by pulling in any floating matter into the overflow.

- **Desludging bottom exit**: a method which dispels possible settled matter formed at the bottom of the tank. Although practical for desludging the bottom, floating matter will still have to be skimmed.

The following arrangements can each be further fitted into the SRB-XXL to regulate the flow:
- **Pipe Diameter and Catchment Area**: The diameter of the inflow pipes have to be large enough to receive the incoming flow of the catchment water. To be more specific, the pipe diameter has to be designed in a way that it is able receive the maximum rate of runoff from the roof in order to prevent overflow from occurring.
- **Break Ring**: The break ring is a device connected to the bottom of the inlet pipe within the tank. The purpose of the break ring is to break downward flow so it protects the settled material from any disturbance, preventing it from mixing with the cleaner water.
- **Floating Suction Filter**: This floating device is used to extract the cleanest water from the tank, which is located just below the water surface where floating debris may be located. The hose that directs the desired water to the outlet of the tank, sucks the stored water through a suction filter connected to a ball that floats allowing the suction point to rise and fall with the water level **[56,57]**. Because the water is sucked from a higher water level there is a much lower water pressure on the valves compared to the extraction from the bottom of the tank, making the water flow-rate easier to control.

4.3 Brainstorm

The concept development starts with brainstorming for new ideas on how to envision the SRB-XXL in new ways. This is done individually by the designer in an attempt to come up with new designs for the main system, using system schematics, user interface design and the outward appearance of the SRB-XXL to make it more accessible for public display. The system schematics explain roughly what sub-systems make up for the entire system and how they are connected to one another. These concepts will be reviewed and put forward to the client Andre de Brouwer and supervisors Richard Bults and Hans Scholten to get their opinion on them and thus receive feedback to narrow down on options or even gain new insights.

4.3.1 User Interface

As mentioned in the previous sub-chapter, the user interface gives the user control over the SRB-XXL using a selected control system. These systems can vary from digital interfaces on a computer screen, to the more physical means of man-machine communication. Therefore, this section contains both digital and physical designs for the UI, which are displayed in Appendix A, Figure A1.

Digital UI Design

The first idea that came to mind was a digital user interface on a digital screen, such as a computer or an iPad. Previous SRB project grad-students Gelieke Steeghs **[58]** and Thijs Dortmann **[59]** followed this principle and based on their results the UI concepts were created. These screens are filled with various information boxes, or features, that show data regarding the SRB. The following features were implemented into the initial design (see **Appendix A: Figure A1-1** for the sketch):

- **Warning/Notification Signal**: In the top right corner, an icon displays the SRB's status with a checkmark when everything is functional, but a warning signal if the user has to be notified when something is wrong. This can relate, for example, to filters or pumps not working due to power shortage or low battery life.
- **SRB Status:** This displays information such as the current storage capacity (in liters or percentage) and water-temperature in the tank. An additional idea for this feature was to make it able to zoom in on the status and give detailed information on multiple components of the SRB, such as the filters or water control units. This feature is intended for hands-on users such as the client Andre to understand the SRB-XXL's operational status.
- **Weather Radar:** A display of actual weather data in the Netherlands through connection with an online weather website, such as "Buienradar" or "Weeronline".
- **Water Level**: A graph showing the water level of the tank over a certain period of time.
- **Precipitation Forecast:** A similar graph to the Water Level graph as it shows the precipitation in Enschede over a selected time-period.
- **Top-Left Menu:** Most apps today give the user access to a menu where he/she is able to look deeper into the settings of the site, app, etc. This would allow the user to select the data to be viewed on the big screen, edit the user's profile, click the help button if something is unclear, or to learn more about the background-information of the SRB-XXL
- **Zoom in option:** For every feature (except for menu) it is possible to get a broader view by clicking/tapping on the "+" icon on the top right corner of the feature box. The user can use this to, i.e. have a bigger view on the time line of precipitation or water level of the tank.

Physical UI Designs

To make the options of the User Interface not limited to the virtual realm, a number of hands-on approaches have been designed as well. These are inspirations from control systems derived from our surroundings, the media and fantasy culture, (see **Figure A1-2 & A1-3** for the sketches).

1) **Control Board**: Inspired through control boards of sound systems in e.g. auditoriums, this design gives the user control through switches, buttons and sliders to view information or change the commands which the SRB-XXL must follow. The board is also equipped with LED's to show the status of certain variables, such as the capacity/water level
2) **Miniature Version SRB-XXL**: Although ironic in name, the idea of the "Mini" SRB-XXL is to give off the feeling of actually tinkering with its 6 meter tall counter-part. By opening the wedge in the cylinder, the user has overview of the status with buttons and lights (similar to the Control Board).
3) **Remote Control**: Using the same method as how to control a television-set, the Remote Control is a handheld stick of machinery with buttons and sends infrared signals to communicate with the main system.

4) **Steampunk Control-Wall:** This design is inspired from the fiction genre “Steampunk” where machinery is displayed in a Victorianesque fashion and controlled through steam-pipes, gears and levers. Although the practicality of this design is somewhat overly complicated, the appearance is unique and in contrast with modern technology designs.

4.3.2 Public Appearance

Next to the technical and user interface subjects, how the public views the SRB-XXL is of importance as well. For this reason multiple public appearance concepts have been made each with different purposes ranging from raising awareness of water preservation to simply appeal to the eye. The sketches of the concepts can be viewed in Appendix A, Figure A2.

1) **First Flush Display:** Two separate containers with the first filled with unfiltered “first-flush” water and the second being clean filtered water. The aim is to raise awareness of the debris on roofs and the effectiveness of cleaning devices of the SRB. **(Figure A2-1)**
2) **Nature’s Embrace**: The SRB is coated with devices that sprout artificial plants, such as ivy, depending on the level of stored water; an empty tank shows nothing while a full tank shows many flora. **(Figure A2-1)**
3) **Music & Lights with LED’s:** The outside of the tank is covered in LED’s that light up different patterns, the water level and more. It is also installed with speakers which play songs depending on the weather (e.g. Rihanna’s “Umbrella” during rain and The Tramps “Disco Inferno” during a dry period”). **(Figure A2-1)**
4) **“Buff the Tank”:** the mascot Buff the Tank is a cartoonish character who’s aim is to educate the passers-by on the SRB-XXL’s background information and/or status. It’s outward appearance is dependent on the water level in the tank: a small skinny physique when empty, but a muscular build when full. Buff can be visualized on a screen or as a blow-up doll. **(Figure A2-2)**
5) **Save Enschede Quiz:** The tank is comprised of an outside connected pipe system divided by valves into multiple sections filled with miniature houses. These pipes are gradually filled with water from the tank, which has to be expelled through a series of questions to be answered correctly by a random passers-by. The questions are related to the water treatment in Enschede and, when answered correctly, release the valves so the miniature buildings aren’t flooded anymore. This symbolizes the effective water treatment in Enschede. **(Figure A2-2)**
6) **Lasershow**: Similar to the LED display, the tank projects lights from a laser-emitting device that can take on various shapes or figures related to the tank. **(Figure A2-2)**
7) **Fountain Art Piece / Rain Glass Window**: These displays are more art-related compared to the others, with the main goal to divert the viewer from the cold steel appearance of the tank and have them focus more on what the SRB represents. The Fountain art piece symbolizes through bowls of water, which flows the stream into the lower bowls when full, the water storage systems in Enschede. **(Figure A2-3)**
8) **Hourglass - Drought vs. Flood:** By using hourglasses to represent the drought and wet periods, passers-by can see how long a certain period has lasted. **(Figure A2-3)**

9) **Hydro/Solar Power Generator:** Connecting hydro or solar powered devices to the tank, it becomes self-sufficient in electrical power adding focus to the green power initiative. **(Figure A2-3)**
10) **Water Droplet Shapes:** Inspired by the Gatorade commercial, water droplets are perfectly timed to make figures when falling down. **(Figure A2-4)**

4.3.3 Schematic Overview

This session is comprised of the brainstormed designs of two initial ideation sketches of filters and water flow arrangements that make up the core system of the SRB-XXL, based on the research performed in section 4.2. These will be walked through to reach understanding as to how the rainwater flows through the entirety of the system and what the functions are of the bypassing components. The purpose of brainstorming schematics of the SRB-XXL, is to exercise how such a system fits together in all the necessary components and to discuss and challenge these ideas with relevant stakeholders, such as Andre de Brouwer. The sketches can be found in Appendix A.

In this section two SRB-XXL designs will be walked through to explain their functioning in efficiently storing and releasing rainwater.: “Design #1” (**Figure A3-1**) and “Design #2” (**Figure A3-2**). Although both designs share a number of resemblances, the most notable differences are in the types of filters used and the realisation of water control mechanisms. For both designs the rainwater first falls on the roof of the Sport-Center and flows through a coarse leaf filter to separate large debris from the water. The water then flows through a pipe and reaches the first-flush filter, which by-passes the first amount of rainwater containing smaller pollutants. In Design #1 this follows up with a Slow Sand Filter while in Design #2 the filtering process is continued with micro-filters. Finally the filtered water reaches a junction with one pipe leading towards the storage tank and the other acting as the overflow pipe through which water will travel once the tank is full. Design #2 is equipped with a hydraulic jump (Purain) filter at this junction for further separation from contaminants. The rainwater then enters the tank through the break ring to calmly allow water to flow in without disturbing settled material. In both designs the “desired” water (to be reused by the client Andre) is sucked through a floating suction device leading towards the manually controlled valve once opened. Design #2 uses an electric pump during this action for a higher flow rate. To discharge the tank from old water, Design #1 uses a drain pipe at the bottom of the tank to carry settled debris along with the dispelled water. Design #2, however, makes room in the tank by installing the drainpipe on half the height of the storage tank, slowly emptying the tank until half the capacity.

Both designs were displayed to relevant stakeholders during semi-structured interviews to get their input on what is possible/practical and what they would (not) wish to see in the final concept.

4.4 Requirements Elicitation

To gain insight on the requirements needed for the successful realization of the SRB-XXL, interviews with the most important stakeholders were conducted (see **Chapter 4.1**). These interviews were either performed face-to-face in the same room, or through the phone as a backup option. The subjects that were discussed involved the research questions (waterflow control, water filtering and the means to which the user controls the system) and the premature designs created in the brainstorm section. A list of functional and non-functional requirements are put down below each interview. These will be put into the next sub-chapter's final MOSCOW table to determine all the requirements the SRB-XXL must possess. The full interviews can be seen in Appendix B.

Interview with Andre de Brouwer & Richard Bults

This interview was conducted in the Paviljoen building together with Richard Bults as observer/backup to clear up confusion or to look further into the discussed subjects. The interview started with the discussion on how much area of the Sport Center should be connected to the tank. After the discussion it was concluded that the amount of catchment area must be decided accordingly to the intensity of the rainfall, meaning that we shouldn't use as much area as possible as this could lead to a full tank in relatively short time. When overflow occurs because the tank is to full, it should be made clear to the public. The tank must work according to the weather analyzed predictions and make room for the calculated incoming rainfall.

Andre was also enthusiastic about the idea of installing a Pluvia filtering system **[60]** onto the roof as this was also done on the Technohal. Including the Pluvia, he would like to see similar workings of the Technohal in the SRB-XXL. The system is best kept clean by removing the water and sucking out the sludge on the bottom of the storage unit. When shown the designs of the system schematics Andre stated that there was no need for thorough microfilters and slow-sand filters, since the stored water is allowed to contain bacteria and viruses. The three important things to find out are WHAT is filtered, WHERE will be filtered, and the COST of the filter, including maintenance. For each plant-watering session 5 cubic meters is needed, which means that the tank must have enough capacity for a couple of these sessions. The water supply of the tank must be manually opened and closed and shut off from public use making it only accessible to persons of authority, such as Krinkels, so that people with ill intentions don't mess with the SRB.

Andre claimed a full tank would be more desirable than an empty tank. For the user interface, Andre wants it to show the SRB-XXL's water level and how the system functions (number of times emptied, accurate predictions, and the amount of captured water after a rainfall). It's also important to show where the outflow goes once the tank is full or when room has to be made. The medium used for the user interface is not relevant to me.

Functional Requirements	Non-Functional Requirements
The system must be able to store a large amount of water	The system must be viewable to the public
The system must be able to act as a buffer for its surroundings by capturing and storing incoming rainfall	The public must be able to see where the outflow/overflow of the water goes.
The tank must work according to the weather analyzed predictions and make room at least 2 hours prior to the incoming rainfall	
The user interface must show the SRB-XXL's water level and temperature	

The user interface must show how the SRB functions: - How many times did the tank have to empty? - How much water was in the tank before and after a certain rain period?	
The water supply must be opened by a manually controlled valve and only be accessible by authorized people	
The system should show to the public when the tank is in overflow	
The tank should be able to discharge 5 cubic meters for watering sessions in a short amount of time.	
The tank should be full rather than empty	
The system won't have thorough filtering systems.	

Interview with Hendrik Jan Teekens

This interview was conducted through a phone conversation, thus the focus lies primarily on questions and answers and less so on the envisioned concepts. Hendrik Jan's motivation for the success of the SRB-XXL is that it shows the results of the hard work of all the participants in the Regentoren project and how serious everyone is with gaining results. Much has to be done, but the realization is in sight. Once the SRB-XXL is realized it will be attached with logos that supported the Regentoren, including the Municipality of Enschede, which can be a stepping stone towards other companies in Enschede that would like to have it installed to their rooftops.

The SRB-XXL has to be sturdy like a sewer system. Also, the system must be installed with an automated tap which releases water to make room for incoming rainfall and is functional 100% of the time. Both the goals of buffer and water preserve are equally important. However, in terms of the sewer system's safety, it's crucial to carefully regulate the outflow. This can be done by, e.g. choosing the right pipe or valve diameter.

Hendrik Jan also stated that there is no need for installing bacteria & virus removing filters if the stored water is used for non-potable purpose. It's important to remove as much sludge from the bottom of the tank as you can by having a drain at the bottom. It's also important to monitor the temperature of the tank to warn the user of Legionella risks. The two types of filters that intrigued Hendrik Jan are the ones currently used in Technohal (a.k.a. the Pluvia filter), and a filter which uses a cloth that catches the water which, when it has become filled with debris, is automatically replaced with a clean cloth.

The user interface information he would like to see is what the tank specifically does in certain situations, future prospects and water preservation details. In short he would like to see the exact benefits of the SRB-XXL, but also the actual information on the tank (e.g. water level and temperature). Hendrik Jan thinks putting it online would be a good way to display the information, but he would definitely also like to see it on a digital screen placed on the tank.

Functional Requirements	Non-Functional Requirements
The system must be fitted with an automated outflow tap which is always functional	The SRB-XXL must be sturdy, meaning it has to work properly for a long time
The tank must have a drain at the bottom to remove settled sludge from the tank.	
The water inflow should enter the tank without disturbing the water inside the system	
The outflow rate should be able to be regulated	
The system should monitor the water temperature to warn the user of legionella risk	
The SRB-XXL information could be displayed on a screen attached to the tank	

Interview with Jeroen Buitenweg

This interview was also performed through a phone conversation. The Municipality of Enschede and Waterschap Vechtstromen have the same goals to move from centralized to decentralized water storage systems and to raise public awareness for water-use.

The best way to reach both goals of buffering and harvesting rainwater is to make the tank flexible in storage capacity to be better prepared for faulty weather predictions. It depends on the user whether you lean towards free storage capacity or more water preservation: homeowners want a full tank, while the municipality wants more capacity to store rainwater.

You have to make sure clean water goes in the tank while dirty water is expelled and make the user aware of the risk of holding water for a long period without exchanging it for cleaner water. Sludge that rests on the bottom of the tank must be flushed to keep the stored water as clean as possible.

Jeroen believes that you have to use as much catchment area as possible, since roof-area that isn't connected to the SRB will otherwise direct water to the sewage system. By not doing so you would waste water that could have otherwise been caught in the tank. This requirement is in contradiction with the roof-area request of client Andre, and thus is overruled by Andre due to his power/interest in the SRB-XXL.

From the public's point of view, he would find it interesting to know how much potable water we have saved by using the SRB's water to provide for the plants instead of valuable drinking-quality water. This would reinforce the importance of water-reuse. This comes down to numbers that show, firstly, how much tank water has been used and, secondly, how much water has been harvested and/or released by the tank from incoming rainfall. The last number shows the public how much the tank provides in terms of water storage. Actual information such as current water level and temperature (in relation to Legionella) is also important.

Functional Requirements	Non-Functional Requirements
The tank must be able to flush out dirty water and built up sludge at the bottom of the tank	

The SRB-XXL information could be displayed on a screen attached to the tank	
The information screen could show the benefits of the SRB: what the tank specifically does in certain situations, future prospects and water preservation details	
The information screen could show information regarding water recycling, e.g. how much potable water is saved.	

Interview with Eddo Pruim

Eddo became a stakeholder for the SRB-XXL project through contact with Hendrik Jan and Richard Bults, with whom he discussed his findings with. Eddo has two rainwater tank projects which he has worked with: two plastic rainwater barrels with a total capacity of 400 liters (see **Figure 21**), and a silo tank of 3000 liter capacity made from an isolated metal (see **Figure 22**). To keep the stored water at an acceptable quality, Eddo installed a "Gootdrain" (gutter-filter) on both projects, making sure large contaminants (e.g. leaves & vermin) don't mix with the water. This however still lets smaller contaminants through like birch seeds, which requires a more thorough filter. But even with these filters, small particles such as sand often reaches the storage unit, collecting as a sludge at the bottom layer which he proclaims must be dealt with. The silo tank has an advantage due to its design, which discharges all the water and debris contained within the tank. He advises to install the opening for requested water a meter high from the bottom of the 30.000 liter DeLaval tank.

Figure 21: Rainwater Barrels project

Figure 22: Silo tank (3000 liter) project

The cooling system is not installed into the delivered tank, but that doesn't matter since the tank is made from an isolated material which keeps outward temperatures from reaching the inside. Eddo advises to connect one part of the roof to the tank and direct the rest to whatever infiltration or sewage systems in the area.

To check the water level of the silo tank, Eddo has a transparent tube on the outside of the tank which shows a water level that rises accordingly with the tank. For the SRB-XXL he proposes to use a sensor that floats on the water within the tube, which is surrounded by a magnetic field and gives the sensor different signals depending on the height of the floating sensor.

Eddo suggests not using an electrical pump to discharge water but instead make the exit of the supply pipe at a low point, using gravity as the main driving power. Lastly, he believes that an electrical valve is appropriate to control opening and closing the outflow pipe.

Functional Requirements	Non-Functional Requirements
The supply pipe should be placed on a low height	The outflow pipe should be controlled by an electrical valve
The water level could be measured using a magnetic float sensor	The system could be fitted with a coarse leaf filter

Sport-Centre & Groningen visit

Together with stakeholders Andre Brouwer, Eddo Pruim, Hendrik Jan Teekens and Richard Bults a meeting was held at the Paviljoen building to discuss matters regarding what would be possible to implement on the SRB-XXL and how it would be connected to the rainwater drainage system on the Sport-Centre roof, which is where the discussion would further commence. Later on, a visit was made to the "DeLaval" company in Groningen together with Hendrik Jan and Eddo. This is where the agreed upon silo-tank was being held which would later become an essential part of the SRB-XXL. The purpose of this visit was to meet Albert Wilder, the boss of "Alfa Koeling" which is the dealer-company of DeLaval, and gain more information towards the possibilities and recommendations on the alternations which the tank could/would receive to achieve its goal of becoming a functional smart rainwater buffer/storage system.

During the first discussion at the Paviljoen it was stated by Andre that regarding the surveillance of the SRB-XXL's supply pipe he wanted a lock-key mechanism so that only authorized personnel (e.g. Krinkels) have access. He also rejected the idea of a ladder leading toward the top of the tank, which is needed for the biyearly inspection/tank-cleaning, as this would provoke bypassing wrongdoers. Instead Andre proposed to install a fenced-platform on the tanks top-surface which would be accessible by using a lifting ramp.
The next topic-of-discussion was the filtering of the tank, or more specifically, the before-mentioned "Pluvia-system". Andre explained that at its core Pluvia is an effective and space-saving water transportation device, however it doesn't filter the rainwater from small contaminants such as seeds and dirt. This means that the idea of installing the Pluvia is rejected and another filtering measure must be found.
Thirdly, the overflow of the rainwater tank was discussed. Andre insisted on preventing overflowing storage water from traveling over the tanks surface since this could cause a layer of filth to form over the tank. A solution here for would be to contain the overflow water so it would travel straight into the underground sewers. Richard further commented on this that when installing in- and outgoing pipes to the SRB-XXL, preserving the original state of the SRB-XXL and reducing the construction costs as much as possible was also an important factor to keep in mind.

At the SRB-XXL's intended location at the Sport Centre building (see **Figure 23**), the following points of interest became clear:

- The required Sport-Centre roof area is 9-10 meter above ground.
- The drainage pipes were 125mm in diameter

- The area of the roof was approx. 1500 m^2, which was separated in two equal sections through a bulge in the middle with 9 pipes connected to each side.
- Of the pipes on the roof area (750 m^2) available to be connected to the tank, two pipes would be able to reach the inflow point of the tank. This makes it so that approximately 170 m^2 of roof area is directly available for the SRB-XXL.
- Next to the roof area connected to the two available pipes, the rest of the 750 m^2 roof area could be redirected by placing sandbags to cut off the current flow to the SRB-XXL.
- The roof was fitted with openings alongside the drainage pipes as a safety measure against overflow.
- The foundation on which the silo tank will be placed is made of 30 cm thick reinforced concrete.

Figure 23: Planned SRB-XXL location @Sport Centre building

Hereafter, at the DeLaval building in Groningen together with Eddo Pruim and Hendrik Jan Teekens, a meeting/tour was held by Albert Wilder to learn more about the operations of silo tanks which were built to be used as functional storage containers at milking facilities. He explained that the temperature isolation of the tanks had the effect of the fluid inside the tank taking 12 hours to gain/lower one degree Celsius towards the outside temperature. This was to prevent the milk from freezing or reaching a high temperature at which the milk would spoil. The isolation material was 10 cm thick. For the SRB-XXL, Albert recommended to program an "escape-mechanism" that would release the stored water if the temperature were to reach freezing or legionella levels.
The tour partially took place outside where the storage tank intended for realizing the SRB-XXL was located (see **Figure 26 &** 27). For the cleaning of the tank's insides, a spinner sprinkler is used. This device is located at the top of the tank and receives water from an external water source (e.g. tap) and effectively removes any remaining contaminants after the tank is emptied. The silo-tank is further equipped with a top-lid, a release "butterfly" valve of measure "DN80" (see **Figure** 24), and a ventilation duct, which additionally acts as a support pipe when the tank is relocated.
When the topic of overflow redirection came up, a suggestion was made to build a T-junction high in the tank, comprised of the inflow pipe, the storage pipe, and the outflow/overflow pipe. For future projects, the overflow/outflow pipe could be connected to a second silo-tank and act

as an inflow point. This could be used for multiple-tank linkage to increase the maximum storage capacity. Albert also suggested to use stainless steel for the pipes (with exception to the Sport-Centre's PVC pipes) as this material is, although more costly, sturdy and more sustainable than PVC.
It was agreed upon to install a fenced platform displayed in **Figure25** without ladders, as it would prevent outside interference (just like Andre stated), make it able for the user to safely open the top-lid and to avoid required safety evaluations.

Functional Requirements	Non-Functional Requirements
The tank must be fitted with a fenced-platform on the top-surface exclusively accessible by a lifting ramp	The water supply valve must be protected by a lock
The overflow water must not flow over the tank's outer surface.	The tank's original state must be preserved as much as possible concerning the in- and outgoing piping connections
	The storage tank must be made of stainless steel.

Figure 24: DN80 Butterfly Valve

Figure 25: Fenced Platform

Figure 26 & 27: Storage tank reserved for future SRB-XXL

Technohal visit & Roy Ramakers Interview

After the information received from the Sport-Centre interview, it has been widely agreed upon that the Pluvia system will not be integrated into the grand plan of the SRB-XXL rainwater harvesting system. It is, however, still relevant as to how the newly built UT building the

“Technohal” incorporates the Pluvia water treatment and what elements could possibly be brought over to the SRB’s technical design. Therefore an interview was scheduled with Roy Ramakers, a mechanical engineer and one of the experts responsible for designing and upholding the water treatment in the Technohal building. Accompanied by Richard Bults, the interview was held in the main hall of the building where we would later be led by Roy to look behind the scenes how and where the water is being treated and distributed.

During the interview, Roy displayed the program where a live visualization was presented of the sensors, filters and other measurement systems built in the interior water system. He noted that it’s essential to have an agreed upon programming language which professionals can use to have vision on what’s currently happening on all fronts of the water treatment. Richard commented that this method should be incorporated into the User Interface of the SRB-XXL.
The way to measure the amount of water inside the storage tanks was not by using ultrasonic sensors, as was done by previous SRB-projects, but by using pressure sensors. Roy stated that the pressure sensor is reliable as it accurately measures the real-time water-level/pressure inside the tank.
To prevent contamination from the collected roof water which will be processed into drinking water and other appliances, coarse filters and membrane filters are used during the elaborate water collection/filtration process.
Lastly, Roy comments that the regulation technologies used in the Technohal water treatment (e.g. valves and pumps) have been engineered into various University of Twente facilities such as the swimming pool and sports field sprinkling systems.

At the end of the interview Roy agreed to divulge the technical components such as the sensors, valves and pumps used in the Technohal and other UT-facilities. It would be very beneficial to incorporate these into the SRB-XXL, as their success in the Technohal is a great indicator of their validity in performance.

Functional Requirements	Non-Functional Requirements
	The SRB-XXL should use a hydrostatic pressure sensor to measure the water level.

4.5 MOSCOW table

The analysis of the interviews has resulted in a number of requirements set by the interviewed stakeholders. These preliminary requirements are divided into “Must Have”, “Should Have”, “Could Have” and “Won’t Have” sections. This has the purpose to structure the need for fulfillment of the requirements from most to least important. Lastly, the requirements are split into “Functional” and “Non-functional” depending on if they are related to an ability the SRB-XXL must be able to perform or if it is a quality attribute that the system must have (such as size or material of the storage tank)

Functional Requirements	Non-Functional Requirements
Must	
The system must be able to store a large amount of water	The system must be viewable to the public
The system must be able to act as a buffer for its surroundings by capturing and storing incoming rainfall	The system must be placed on a sturdy platform to hold the silo tank, including the weight of stored water.

The amount of roof area must be decided accordingly to the rainfall intensity	The public must be able to see where the outflow/overflow of the water goes.
The tank must work according to the weather analyzed predictions and make room at least 2 hours prior to the incoming rainfall	There must be a rainwater catchment area in close vicinity of the SRB-XXL
The water supply must be opened by a manually controlled valve and only be accessible by authorized people	The storage tank must be made of stainless steel.
The system must accurately measure the water level inside the tank	The outflow port should be at a low point of the tank
The tank's original state must be preserved as much as possible concerning the in- and outgoing piping connections	The SRB-XXL must be sturdy, meaning it has to work properly for a long time
The system must be fitted with an automated outflow tap which is always functional	The water supply valve must be protected by a lock
The tank must have a drain at the bottom to remove settled sludge from the tank.	The tank must be fitted with a fenced-platform on the top-surface exclusively accessible by a lifting ramp
The discharge flow-rate must be controllable	
The supply pipe should be placed on a low height	
Any overflow water must be able to be distributed without disturbing the water inside the system	
The tank must be able to flush out dirty water and built up sludge at the bottom of the tank	
The overflow water must not flow over the tank's outer surface.	
The user interface must show the water level and temperature of the tank	
The user interface must show how the SRB functions: - How many times did the tank have to empty? - How much water was in the tank before and after a certain rain period?	
Should	
The tank should be able to discharge 5 cubic meters for watering sessions in a short amount of time.	The SRB-XXL should use a hydrostatic pressure sensor to measure the water level.
The system should show to the public when the tank is full and directing overflowing water into the runoff location	The outflow pipe should be controlled by an electrical valve
The tank should be isolated in such a manner that it prevents outside temperatures from changing the temperature of the stored water	
The water inflow should enter the SRB-XXL without disturbing the settled sludge in the tank	
The water level should be observable when standing in front of it.	
The water outflow rate should be able to be regulated	

The system should monitor the water temperature to warn the user of legionella risk	
Could	
The system could filter out smaller substances, such as sand, before entering the tank	The SRB-XXL information could be displayed on a screen attached to the tank
The information screen could show the benefits of the SRB: what the tank specifically does in certain situations, future prospects and water preservation details	The system could be fitted with a coarse leaf filter
The information screen could show information regarding water recycling, e.g. how much potable water is saved.	
The water level could be measured using a magnetic float sensor	
Would not	
The system would not have thorough filters that eliminate bacteria or viruses	

4.6 Final Concept Development Phase

Having finished acquiring the necessary requirements set by the stakeholders, it was time to come up with multiple iterations for the final concept of the SRB-XXL. This paragraph discusses the idea behind three concept designs and what had to change in order to satisfy the stakeholders. First is explained what characteristics stay the same throughout the development. Hereafter are short elaborations of concepts that differ from one another concerning overflow regulation, safety of the system, and user comfortability.
The concepts were then put against each other to determine which parts of the design were desirable for the final concept.

4.6.1 Shared Characteristics

The SRB-XXL consists of a storage tank capable of holding 30 cubic meters of water placed in the vicinity of the Sport-Centre roof which acts as a catchment area for rainwater. During rain events the water falls onto the roof and flows through rain pipes into the storage unit through a pipe with a break ring to not disturb any settled debris at the bottom of the tank. Placed just above the break ring are the temperature and hydrostatic pressure sensors which measure the water temperature and water level (based on the pressure). To prevent a pressurized implosion within the tank, a ventilation duct is placed on top of the tank.
The tank is fitted with a physically controlled "supply pipe", with the purpose of the user manually draining water from the tank for reusable objectives, and an electrical "drain valve" located at the bottom-area of the tank. This valve is automatically opened or closed by the system's "control box" to dispel water and settled sludge. The amount of dispelled water is determined by the rainfall prediction and the minimum required amount of water to be remained inside the tank (which is decided by the client). The control box is the control and data center for the incoming sensor signals and user & system commands. Once the water level reaches a certain point during rainfall (e.g. a full tank), the drain valve is programmed to open so the water can flow out of the tank. As an extra safety measure (in case of a system failure) and to make the SRB-XXL fully autonomous, an overflow measure is installed to divert inflowing rainwater at a full tank. Different approaches of these measures are discussed in the multiple concepts.
The client monitors the tank through the user interface which shows the water level and water temperature, how much water the tank has emptied, the accuracy of the weather predictions and the amount of water in the tank within a time period.
Furthermore, the top of the tank is fitted with a fenced platform upon which authorized users can stand to perform safety and cleaning regulations. This platform can be reached by using a lifting ramp. The tank is further equipped with a manhole just above the supply pipe which makes it possible to climb inside and thoroughly inspect/clean the water-tank.

4.6.2 Concept A

The first concept that was laid in front of the stakeholders was Concept A (see **Figure 28**). What stands out from this concept is the use of an open space beneath the tank which, in this concept, is used to safely hide the control box and the drain valve. To physically access the empty space, a foot-high door with a key-lock is constructed. This solution makes it so the control box is out of sight, making the SRB-XXL more aesthetically pleasing, and secures it from unwanted tampering.

Aside from the safety of the control box, the supply pipe and manhole are equipped with security locks.
The overflow is regulated through the use of a pipe which distributes incoming water at a water level above the tank, to reduce the amount of unnecessary holes to be drilled into the storage tank. The pipe travels downward alongside the tank with piping-clamps fitted to the pipe. This overflow solution makes it possible for the tank to be fully autonomous, carries potential floating debris out of the tank, and prevents tank water from flowing over the tank causing a filth layer to form.
The downsides of this concept are the construction costs for the foot-high door, the inconvenient location of the control box (e.g. the user has to crouch to reach or work on it), and the piping-clamps which would damage the outer hull.

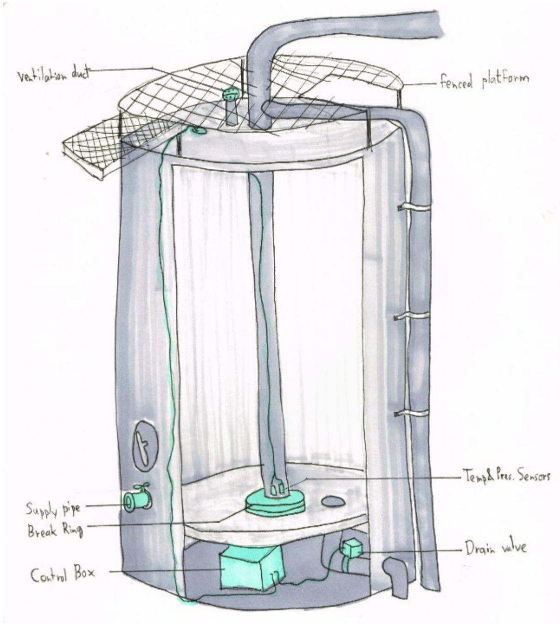


Figure 28: Concept A

4.6.3 Concept B

Concept B differs from Concept A in respect to the safety measures and usage, but also the overflow regulation (see **Figure 29**). This concept uses the overflow approach to be mostly dependent on the drain valve, saving on construction costs and saves space. If a blackout or system failure does occur, leaving the flush gate closed, the water can still escape through the ventilation duct.
The safety of the smart elements are secured using a fenced box with a locked door with measurements of approx. 2 meters high, and 0.5 meters broad and wide. Advantages of this safety measure are that it merely requires one lock instead of the multiple used in Concept A, and the ease of access for the user.
The cons of this concept are that the fenced area takes in extra space, but also that the ventilation duct is not a secure overflow measure and lets the stored water flow over the surface of the storage tank.

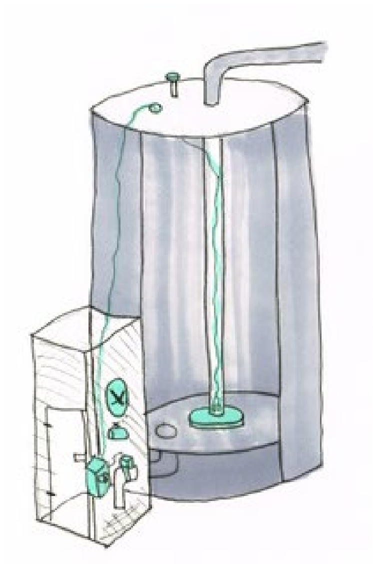


Figure 29: Concept B

4.6.4 Concept C

Concept C uses a more basic and simple approach compared to the previous ones. At a full tank, the overflow flows through holes made in the inflow pipe and is contained by implementing a metal strip along the roof surface of the tank. This strip has two holes from which the water flows out of and along a chosen surface of the tank (preferably out of public sight). The control box is placed on the roof area of the tank, keeping it out of sight and reach for wrongdoers. Just as with Concept A, this concept secures the supply pipe and manhole with security locks. Although this concept acquires many pro's for being simple in design, construction and doesn't take in extra space, it does have some con's. Downsides are that the security of the drain valve is impaired, the surface of the tank is still vulnerable to filth and the control box is only accessible on the fenced platform making it very inconvenient for the user.

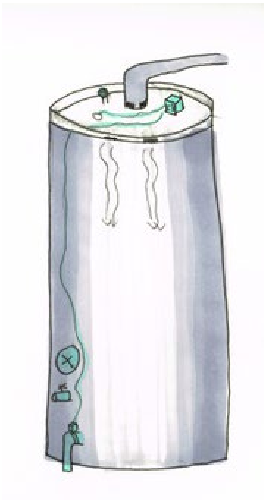


Figure 30: Concept C

4.7 Final Concept

After presenting the three concepts to the stakeholders and discussing which parts of each concept were desired or had to be thrown away, the final concept for the SRB-XXL was developed in the form of Concept D & E (see **Figure 31**). The two concepts are completely identical aside from the placement of the overflow pipe which will be further discussed in this section.

For safety measures, the final concept uses the fenced box mechanism designed in Concept B but with smaller measurements so it acts more like a secured cover for the manhole, supply pipe, control box and drain pipe instead of a spacious area for the user to stand in. This security measure was chosen for the ease of access to the interactive elements, the implementation (which doesn't require tampering with the tank itself) and the reduction of locks needed to secure the supply pipe and manhole.

The overflow method chosen was the pipe with clamps used in Concept A. The reason for this is that it prevents water from traveling over the tank surface and it makes the SRB-XXL fully autonomous. A change from Concept A, however, is the placement of the overflow pipe. Instead of attaching the pipe with the clamps to the rainwater tank, it is attached to the wall of the Sport-Centre building thus avoiding the need to drill screws into the tank and damaging the outer hull. As prementioned, the difference in Concept D & E is the placement of the pipe on the wall. While Concept D uses the method of installing the pipe on a new location, Concept E uses the overflow pipe which is already installed on the Sport-Centre building, therefor saving the cost and construction of adding a new pipe.

As shown in **Figure 31**, the manner in which the rainwater flows into the tank and out through the overflow pipe is done using a slightly bent T-junction in the pipes. Through gravity, the inflowing water travels downwards into the sloped pipe leading to the SRB-XXL, but when the water level rises the water can only escape through the overflow pipe on the other side of the junction leading it towards the water treatment system below the water tank.

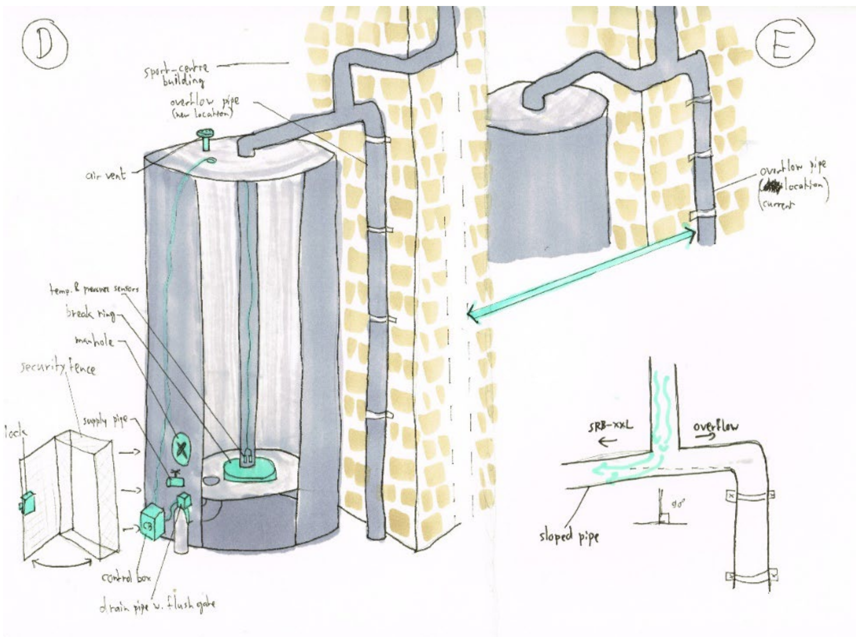


Figure 31: SRB Final Concept

4.8 PACT analysis

This sub-chapter represents the PACT analysis, which was previously introduced in the "Methods & Techniques" chapter. Using the PACT framework an explanation will be given how the system is used through the eyes of the user.

People
Andre de Brouwer: represents the Facility Management of the University of Twente, main client of the SRB-XXL project, contacts Frank in regards of the SRB-XXL.
Frank Groenen (fictional): employee of the company Krinkels, his job is to maintain the grounds and plants of the University.

Activities
A person of authority (Krinkels) is at the location of the system and aims to collect stored water from it. An amount of 5 cubic meters of water is drained from the rainwater tank's supply pipe into a storage unit. This unit is moved around campus to be used for watering the plants on the UT campus. This action is performed when the plants are dried out and are in need of moisturization. Andre's role is to check the SRB-XXL's status on the user interface and inform Krinkels of the situation, but also to instruct Krinkels of the plants that need watering.

Contexts
The scenario takes in the summer when nature is struggling to cope with a drought. The SRB-XXL is standing next to the sport-center from which it receives roof-caught rainwater during rain events. Andre is in his office and can contact the Krinkels employee Frank through the phone.

Technologies
The person on the scene can turn the manually controlled valve on the supply pipe which in turn lets water flow out of the system. The user in control of the user interface has access to the system's controllable units and measured data through wi-fi connection and can decide to release water by opening the drain valve. The SRB-XXL's control unit autonomously receives data from the SRB back-end system informing whether to release water or not.

User Scenario

1. During the morning in the dry and hot month of June, Andre is working at his job at the University of Twente Campus and Facility Management. While looking at his schedule, he notices that one of the daily tasks is to water the plants on campus. He knows that this has to be done regularly since it has been a while that rain has fallen over Enschede and that the plants will dry out if nothing is done.
2. He looks on his laptop on which he goes to the website linked to the Smart Rainwater Buffer XXL, a rainwater tank located on campus which is used by Andre and his coworkers as a water supply for the plants. He sees on the website that the tank is 60% full and that it contains 18.000 liters of water, which is plenty for one watering session of 5 cubic meters. He also observes that the water is at a temperature of 7 degrees Celsius, which means that the water is safe from Legionella contamination.
3. He calls Frank Groenen to inform him of the tank being full, to which Frank moves with a team in a truck to where the Smart Rainwater Buffer XXL is located. Inside the truck is a 5 cubic water container and a hose able to fit around the supply pipe of the tank.
4. Frank opens the locked fenced gate surrounding the interactive elements of the SRB-XXL and connects the rainwater tank's supply pipe to the transported container after which

he turns the valve and opens the flush gate. This lets water flow from the tank into the container until it is full after a couple of minutes.

5. Frank and his team close off the valve from the water container in the truck and relock the fenced gate to prevent unauthorized use of the SRB-XXL. They then move around campus to provide water for the dried-out plants. After they're finished, Frank and co. return to their office to work on the other assignments.

Four scenario's

Below are four possible scenarios that can occur with the tank either through rain events, or interactions with Krinkels and/or Andre.

- **Light rain (10 mm), no usage**

During light rain events, the goal is to preserve the quality of the stored water by removing the settled sludge within the SRB-XXL. Rain water travels from the roof into the tank. Once the pressure sensor measures the tank is full, the Control Box opens the drain valve and empties the bottom layer of the tank. This contains the most debris and thus acts as a cleaning mechanism.

- **No rain, Krinkels water transportation**

Krinkels put the key into the gate-lock protecting the pipes and connect the rainwater tank's supply pipe to the transported container and opens the flush gate. This lets water flow from the SRB-XXL into the container until it is full after a couple of minutes. Hereafter, Krinkels closes the flush gate and locks the fenced gate to prevent unauthorized people from meddling with the SRB-XXL

- **Heavy rain (50 mm)**

During heavy rain the main goal is to prevent the water treatment systems from overloading. The SRB-XXL supports this by emptying the tank in a controlled flow hours before the expected precipitation. This way the tank has enough capacity for the rainfall and the water treatment system has had enough time to safely disperse the stored water.

- **User Intervention**

The user the SRB-XXL, Andre, issues a command to empty the tank. Probable reasons for this is to discharge water that reach temperature levels which make Legionella contamination possible, or to allow maintenance to be done on the tank. The user issues the command by opening the User Interface, going to the user control option and pressing the button to open the Drain valve and empty the tank to a specified water level.

Chapter 5: Specification

The specification chapter focuses on the final concept acquired in the ideation and going into further detail how on multiple levels the system functions. This is explained using block- and activity-diagrams of the functional system architecture. These depict both the user's interaction with the SRB-XXL Dashboard as well as the communication between the sub-systems. Hereafter, a specification is given of the overflow measure called the Rainwater Router. Then a detailed description is given of the User Interface Dashboard with the help of a flowchart. The section ends with a second MOSCOW table to reach the finalized set of (non-)functional requirements.

5.1 Functional system architecture

This sub-chapter regarding the functional system architecture presents a more detailed description of the SRB-XXL's functionalities. These descriptions include a basic overview of the SRB-XXL and its connected systems, and a block- and activity-flowchart describing the rainwater storage and release process.

5.1.1 Level 0: SRB-XXL System Overview

Level 0 (a.k.a. the black box) shows the general SRB-XXL input and output commands which make up the communication between the SRB-XXL and the other data systems. Figure 25 below shows how the systems deliver and receive data from one another. The SRB-XXL receives input from outside sources: the water volume and temperature of the rainwater supply from the connected roof. The user has overview of the SRB's sensor data on the User Interface Dashboard and oversees the past and real-time status of the SRB-XXL. The user can input commands to overrule the SRB-XXL's autonomous control system (e.g. can also request precipitation data). The precipitation source sends data to the Back End Server system, which sends instructions to the SRB-XXL for specific water control behavior, such as to release stored water.

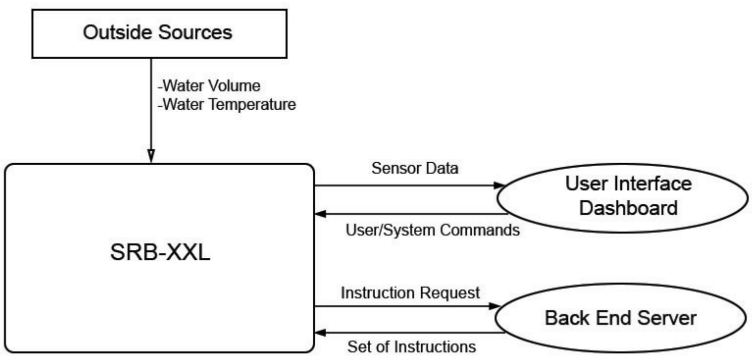


Figure 32: SRB-XXL System Overview

5.1.2 Block- and Activity Flowchart

The block- and activity-flowchart in Figure 26 summarizes the first level of the system's behind-the-scenes decision making process regarding the collection and release of the harvested rainwater. The flowchart blocks are divided into four different categories: SRB-XXL device, discharged water, water of acceptable quality, water/substances of unsuitable quality, and a systematic decision (as can be seen in the legend). The rainwater first lands on the catchment area where it mixes with debris resting on the roof. The stirred water then travels through the inflow pipe into the storage unit where, with the assistance of the "break ring", it gently fills the tank so as to separate the debris from the rainwater. If the tank reaches its capacity-limit or storage space is required for incoming rainfall, the water gets released through the electrically controlled "drain pipe" taking any settled sludge with it. As a failsafe to keep the SRB-XXL fully autonomous, the overflow water can still be directed to the runoff destination through the "rainwater router" (of which the details will be clarified in paragraph 5.2). Finally, those with authorized access (a.k.a. Krinkels) can manually discharge water through the "supply pipe" and reuse the stored water for campus maintenance purposes.

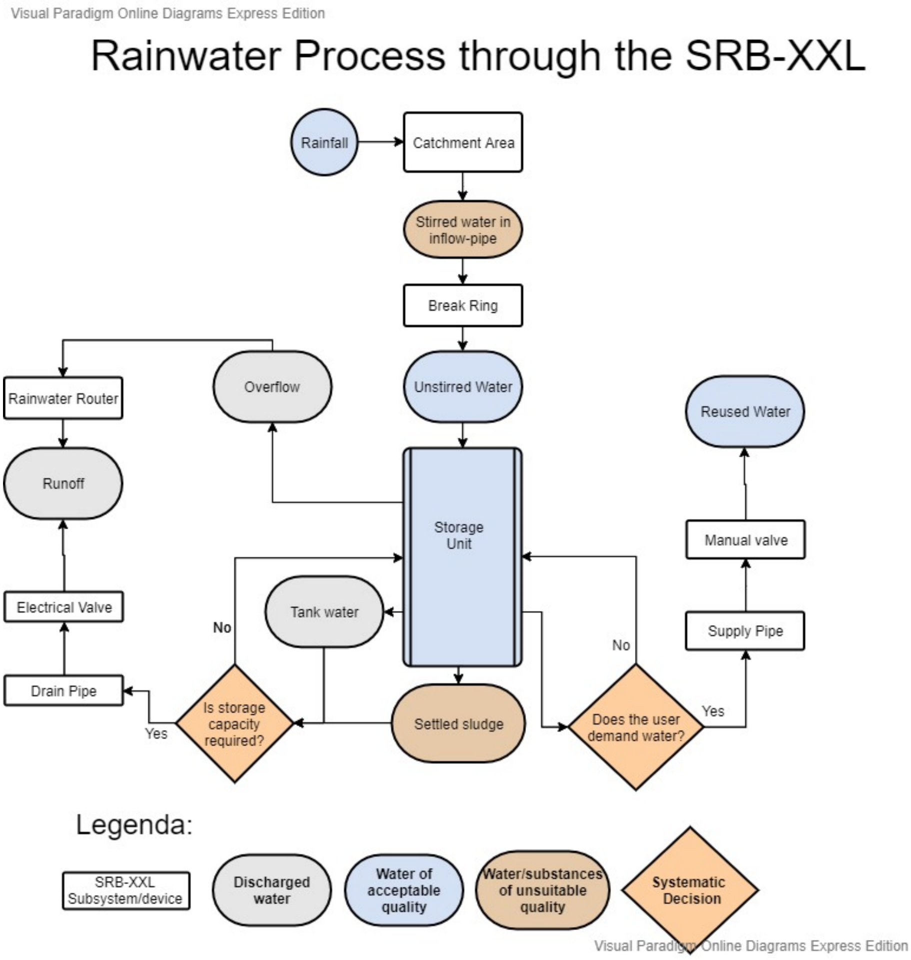


Figure 33: Rainwater Process Flowchart

The water level and water temperature (a.k.a. the outside sources described in the black box overview) are measured through the pressure and temperature sensors placed within the storage unit. This sensor data gets sent to the User Interface Dashboard and as a reaction to receiving this information, the user sends commands to the system's Back End Server to modify the SRB's decision-making. For example, the *"Is storage capacity required?"* decision in the flowchart depends on the water volume limit set by the user and dictates the drain pipe whether or not to release water. Next to playing a role in influencing system behaviors, the data received from the outside sources and displayed on the dashboard inform Krinkels on the possibility to withdraw water from the tank. This particularly regards the *"Does the user demand water?"* decision. If there is enough water to fulfill Krinkels needs then they can visit the SRB's location to drain the tank, however at an insufficient amount of water no action will have be taken which relieves the user from an unnecessary trip.

5.2 Rainwater Router

One of the requirements set by the stakeholders was to keep the construction required to alter the composition of the storage tank as minimal as possible. This entails that it is essential to avoid drilling unnecessary holes in the tank to make pipe connections, such as the inflow and overflow pipes. The tank already has an opening on the roof from which the inflow water could enter the tank (see 4.4 Sportcentre Interview), however the problem of where to direct the overflow water in case the tank reaches full water capacity persists. As a solution, the Rainwater Router was designed.

5.2.1 RWR Concept Design

As prementioned, the overall goal of the Rainwater Router (RWR) is to direct inflowing rainwater into the tank while also redirecting overflowing water into the runoff location with as little tank-alteration as possible. This goal is made possible by having the inflow pipe work as an overflow pipe once full capacity is reached. At the other end of this pipe connected to the SRB-XXL is the RWR, a triangular pipe construction acting as a Y-junction between the inflow pipe, SRB pipe and outflow pipe. The setup of this piping connection can be seen in **Figure 34**.

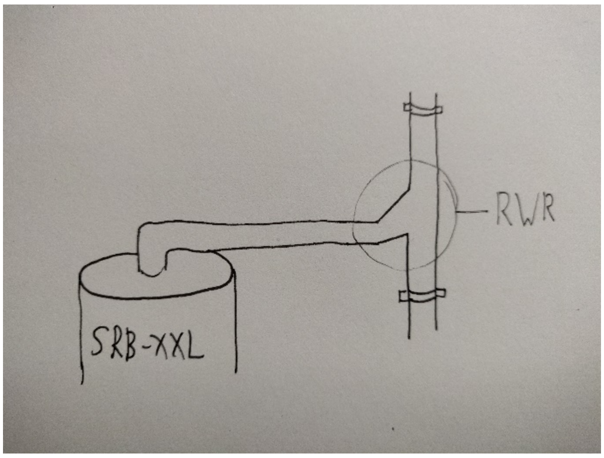


Figure 34: SRB-XXL & RWR Setup

There is also the matter of assuring that the inflowing water gets directed into the water tank instead of immediately plummeting into the runoff location. This is resolved by placing a separating wall in the center of the triangular space, routing incoming rainwater to the SRB-XXL (see **Figure 35**). There is a slight slope towards the SRB pipe to ensure full flow towards the tank, making it as efficient as possible. Once the tank has then reached full capacity and the overflow limit is reached, the water level within the pipe will rise and find a means of escape through the overflow pipe The RWR is considered a success if ALL the incoming water flows towards the SRB-XXL and if, at full tank capacity, all the overflowing water travels into the overflow pipe.

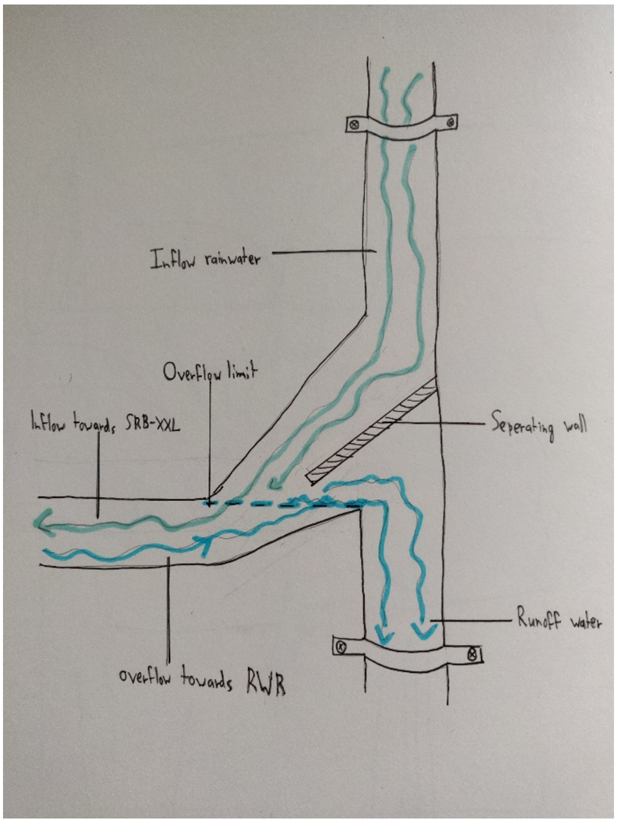


Figure 35: Rainwater Router Design

5.2.1 RWR Specification

For a successful execution of the rainwater router design, a number of demands need to be met. First of all, the essential building parts of the RWR are; the three pipes, the triangular space, and the separating wall. The measurements of the pipes and triangular space must be in accordance with the flow-rate of in- and outgoing water. The diameter of the rain pipes currently installed at the Sport Centre are approximately 12.5 cm, which means that the cylindrical pipes installed in the RWR are required to have the same diameter leading to an area of 122.7 cm^2 (from the $A = r^2 * \pi$ equation). The triangular space, however, needs enough space to both direct inflow into the tank and the runoff into the sewage system in order to avoid clogging. The space above and under the separating wall will therefore have to match the 122.7 cm^2 area of the pipes, acquiring a V-like shape. The separating wall is a straight platform made from durable and strong material (PVC or metal) to withstand the pressure of rainwater dropping down the inflow pipe. The wall has to be long enough to act as a roof over the runoff opening so the water flows in direction of the SRB-XXL.

The next requirement regards waterproofing of the RWR to prevent leakage during the water transfer from inflow to the SRB-XXL and outflow towards the runoff. Therefore, the connections between the SRB-XXL, the pipes and the triangular space have to be sealed off. For example, wrapping rubberized waterproof tape (e.g. “Flex Tape” **[61]**) over these connection areas are a reliable way to ensure a sealed water distribution system.

Following these specifications, in Chapter 6: Realization a proof of concept prototype of the Rainwater Router will be presented in Chapter 6: Realization and the construction process and end results will be discussed.

5.3 User Interface Dashboard

This paragraph discusses in detail the User Interface Dashboard layout and its capabilities. These capabilities include providing the user(s) with information regarding the SRB-XXL, interaction possibilities with the system, and user-to-user interaction.

5.3.1 UI Dashboard Flowchart

To understand how the UI Dashboard fits together, the flowchart in **Figure 36** acts as a guideline depicting the various menu screens the user sees on the dashboard, the relations between them, and the information/activities that can be found within these screens. When the user first opens the dashboard he is met with the "Login Screen" which is essential to distinguish the various users signing in. The users consist of the admin, the owner of the dashboard who has access to all privileges and holds the power to grant them to others, and the rest of the users involved in the SRB-XXL project (e.g. Krinkels & UTwente members). These privileges that grant the user a level of authority over the SRB-XXL entail; the ability to view the SRB's Background Information, the possibility to alter or override the SRB's decision-making and lastly, the ability to grant others the role of admin.
Once the user is signed in, he enters the "Home Screen" and with the use of the "Navigation Bar" gains the possibility to travel along the other three main-menu screens; "Settings", "Help", and "About SRB-XXL". On each main-menu screen the user sees a Notification Alert Box which notifies the user of (semi-)important information that the dashboard has received. This entails events regarding storage capacity fluctuations, user-to-user requests, rain forecast notifications or errors within the SRB-XXL.
The **Home Screen** gives the user basic information of three menu screens regarding relevant data on the SRB-XXL that the user immediately sees upon signing in. The user has the ability to click on a zoom-button to visit a menu screen giving a more detailed view of these three topics:

- **Water Level**: where the user receives data showing the storage tank's water level over a period of time in the form of chart containing a linear xy-graph. Depending on the scope in which the user wants to see water level data, he can switch between charts of a 24 hour, a week, and a month time period.
- **SRB Status**: where the user can find current information regarding the SRB. All users can view basic information such as water temperature and water level, but with the privilege of viewing the SRB's Background Information, the user beholds a detailed overview of the essential parts which make up the SRB-XXL system. This entails static information, such as what kind of valve is used in the Supply Pipe, and dynamic information which constantly changes over time (e.g. Control Box configuration data). Within the SRB's Background Information exists the pre-mentioned privilege to alter the SRB's decision-making. If granted by the admin, the user can interact with the SRB-XXL by changing the water level limit when the tank empties itself and the minimum water level up to which the tank is not allowed to go under, manually overriding the SRB-XXL to flush the tank

(e.g. for tank-cleaning purposes), and re-configurating Control Box to clean up internal storage.

- **Rain Forecast**: in which one perceives future precipitation data on an xy-graph, similar to the Water Level screen, but also observes a local satellite view rain/storm clouds hovering above the SRB's area on a Weather Radar. The precipitation data can be viewed in time stamps until the next 2 hours or the next 5 days. If the user wishes to obtain more details surrounding the weather radar data, he clicks on an icon and visits the precipitation source's webpage (in this case "Buienradar.nl").

Opening the **Settings** main-menu gives the user an overview of their own User information, which is seen by other users and can be edited upon if necessary, the Home Menu Options, allowing the user to turn on or off which home menu screens he wants to see upon logging in, the List of Contacts who have access to the UI Dashboard, and an (admin-only) matrix of all the users and their dashboard privileges. Visiting a user-specific page in the List of Contacts gives, next to their contact information, an overview of their Privilege Settings where the admin can turn them on or off thus giving (or taking away) user access to different parts of the UI dashboard. If signed in as a non-admin user, the List of Contacts page gives the user the possibility to request the admin for privileges to which the admin receives the request in their account's Notification Alert Box.

The **Help** main-menu screen exists to guide the user through the dashboard to clear up any misunderstandings while exploring the user interface. This includes a detailed explanation of the various menu buttons, what the navigation bar is and how to work with it and the layout of a basic menu-screen.

Lastly, **About SRB-XXL** informs the user of the origins and end goal of the Smart Rainwater Buffer project. This includes the situation of extreme weather (e.g. droughts and heavy rain) occurring in the municipality of Enschede and the need for the SRB to act as a solution for these unfortunate weather conditions.

In the Realization chapter, a detailed description is given on the execution of the UI dashboard design-process, which is based on the information given in this section.

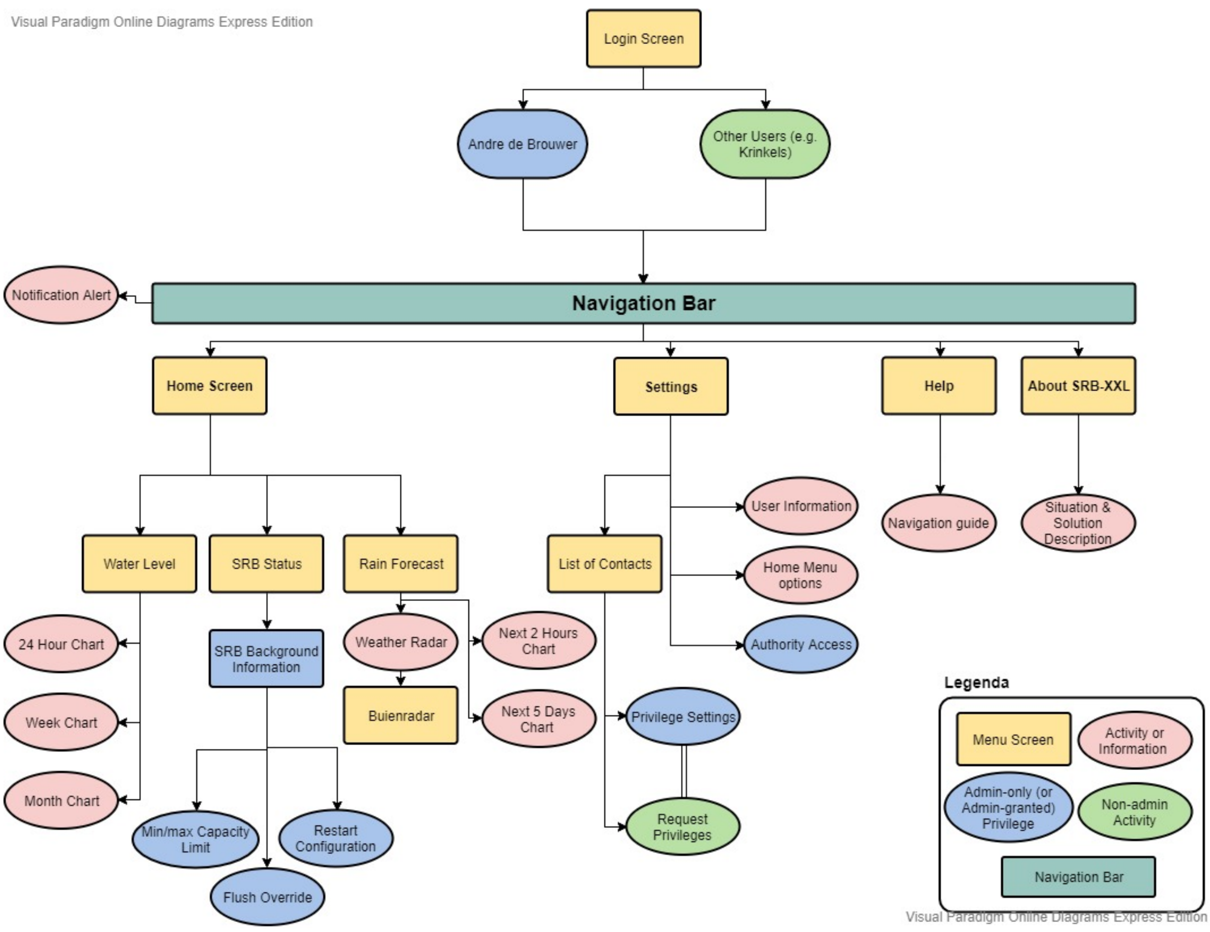


Figure 36: UI Dashboard Screen flowchart

5.4 Finalized Requirements

By laying out the systematic decomposition levels of the SRB-XXL and introducing the concept design of the Rainwater Router, new requirements have been added to the list of (non-) functional requirements. The requirements depicted in a green table-cell are the ones that will be realized and will thus be discussed in the Realization chapter. This resulted in the table of finalized requirements:

Functional Requirements	Non-Functional Requirements
Must	
The system must be able to store a large amount of water	The system must be viewable to the public
The system must be able to act as a buffer for its surroundings by capturing and storing incoming rainfall	The system must be placed on a sturdy platform to hold the silo tank, including the weight of stored water.
The amount of roof area must be decided accordingly to the rainfall intensity	The public must be able to see where the outflow/overflow of the water goes.
The tank must work according to the weather analyzed predictions and make room at least 2 hours prior to the incoming rainfall	There must be a rainwater catchment area in close vicinity of the SRB-XXL

The water supply must be opened by a manually controlled valve and only be accessible by authorized people	The storage tank must be made of stainless steel.
The system must accurately measure the water level inside the tank	The outflow port should be at a low point of the tank
The tank's original state must be preserved as much as possible concerning the in- and outgoing piping connections	The SRB-XXL must be sturdy, meaning it has to work properly for a long time
The system must be fitted with an automated outflow tap which is always functional	The water supply valve must be protected by a lock
The tank must have a drain at the bottom to remove settled sludge from the tank.	The tank must be fitted with a fenced-platform on the top-surface exclusively accessible by a lifting ramp
The discharge flow-rate must be controllable	There must be a failsafe present in case of hardware failure to route overflow into the runoff location.
The supply pipe should be placed on a low height	
Any overflow water must be able to be distributed without disturbing the water inside the system	
The tank must be able to flush out dirty water and built up sludge at the bottom of the tank	
The overflow water must not flow over the tank's outer surface.	
The user interface must show the water level and temperature of the tank	
The user interface must show how the SRB functions: - How many times did the tank have to empty? - How much water was in the tank before and after a certain rain period?	
The user must be able perform system commands to the SRB-XXL from the user interface.	
The user must be able set the required minimum storage capacity of rainwater.	
The UI Dashboard must show the water level history in varying time periods.	
The UI Dashboard must allow the admin to create or take authority or privileges to the other users.	
The RWR must direct all incoming water towards the SRB-XXL and all overflowing water into the overflow pipe.	
Should	
The tank should be able to discharge 5 cubic meters for watering sessions in a short amount of time.	The SRB-XXL should use a hydrostatic pressure sensor to measure the water level.
The system should show to the public when the tank is full and directing overflowing water into the runoff location	The outflow pipe should be controlled by an electrical valve

The tank should be isolated in such a manner that it prevents outside temperatures from changing the temperature of the stored water	
The water inflow should enter the SRB-XXL without disturbing the settled sludge in the tank	
The water level should be observable when standing in front of it.	
The water outflow rate should be able to be regulated	
The system should monitor the water temperature to warn the user of legionella risk	
The SRB-XXL should not overflow with a continuous inflow of water coming from the RWR.	
There should be no water-leakage present through the pipe or wall openings of the RWR.	
Could	
The system could filter out smaller substances, such as sand, before entering the tank	The SRB-XXL information could be displayed on a screen attached to the tank
The information screen could show the benefits of the SRB: what the tank specifically does in certain situations, future prospects and water preservation details	The system could be fitted with a coarse leaf filter
The information screen could show information regarding water recycling, e.g. how much potable water is saved.	
The water level could be measured using a magnetic float sensor	
Would not	
The system would not have thorough filters that eliminate bacteria or viruses	

Chapter 6: Realization

The initial goal of the realization phase was to build a proof of concept prototype of the SRB-XXL on the UT campus, based on the final concept created in the ideation phase, and the functional system architecture and requirements developed in the specification phase. Unfortunately, due to the unforeseen circumstances created by COVID-19, it was decided to make a change in plans and instead direct the focus towards designing a prototype of the Rainwater Router and a fully interactive User Interface design based on their designs and final requirements in the Specification phase.

6.1 Rainwater Router Prototype

In the previous chapter, a detailed description was given on the concept of the Rainwater Router and how it would benefit the SRB-XXL setup by redirecting in- and outflowing rainwater in an efficient and autonomous manner. Using the concept design as reference, a prototype has been created to act as a proof of concept and determine whether or not practice follows theory.

6.1.1 Prototype Parts

Realizing the prototype required gathering the necessary parts at the local hobby/construction store “Praxis”. The proof of concept prototype required the following parts **[62-A to F]**:

- Regular straight pipes: acting as the inflow, outflow and SRB-pipes.
- T-split pipe (45 degrees): The triangular space where the rainwater is rerouted to the SRB-XXL and the overflow to the runoff source.
- Elbow pipe: the piping-connection between the SRB-pipe and T-split pipe.
- Water-storage unit: a bucket with a 20 liters capacity would act as the SRB-XXL storage unit.
- Separation wall: a piece of 2.5 mm thick polystyrene plastic was used to separate the triangular space.
- Rubberized tape: to close the hole in the water bucket and prevent water from escaping in the piping connections.

Although the realization of the SRB-XXL would require pipes with a diameter of 12.5 cm (see 5.2.2), the proof of concept would work just as well with smaller measurements. It was therefore decided to work with PVC-pipes with a diameter of 50 mm. The T-split of 45 degrees was used for its triangular shape and its ability to replicate the concept design from the Specification chapter.

6.1.2 Constructing the Prototype

The construction of the rainwater router prototype began with inserting the separation wall into the T-split. This was done by sawing a 30 degree cut from the straight side of the junction towards the center of the bended pipe (the one leading to the water container) far enough until it reached further than the diameter of the inflow pipe, affirming total blockage from water falling straight down. The polystyrene plate was then cut to a 10 x 10 cm square and fitted into the cut.

From the 2 meter long straight PVC pipe three flow-pipes were made with 10 cm, 20 cm and 30 cm lengths (outflow, SRB and inflow respectively). The inflow pipe had to be a margin longer than the other pipes to test the RWR's ability to efficiently catch the force of water dropping from a high entering point. The elbow pipe was fit into the T-split's 45 degree pipe, turning it horizontal, and the flow-pipes were connected to their respective endings. The piping connections were then made waterproof by sealing them with the rubberized tape.
Finally an X-cut was made into the water-bucket at two-third of its height where the SRB-pipe was pushed through (and sealed with tape) creating the connection between the RWR and the storage unit. The end result can be seen in **Figure 37** but also in a proof of concept video on YouTube **[63]**.

Figure 37: Rainwater Router Prototype

6.2 User Interface Dashboard

Using the computer software "Adobe XD", a dashboard design was created for the SRB's user interface. The flowchart in sub-chapter 5.3 was used as a reference for the overall structure of the web design. This section describes the thought and design process through multiple iterations wherein between supportive feedback was given from the supervisors to further improve structuring details and how to properly navigate through the interface.

6.2.1 1st Iteration

The first iteration of the UI Dashboard mostly entails the Home Screen design. The reason for this, is that this design acts as a basis proposing how the rest of the interface will look like and what features it would include.

Home Screen Design
It was decided that the designing process should start by creating the "Home Screen" of the dashboard (see **Figure 38**), since this will include the basic information that the client would like to see when he logs in (e.g. Water Level & SRB Status). The first version of the home screen was primarily based on the design created in the brainstorm phase (see **Appendix A1-1**). The intention from this design was to put different subjects in their respective "boxes" on which the user could view information, but also had the possibility to click on the "+"or zoom-icon, where it would bring them to a menu screen that would give the user a full range of detailed information surrounding the subject in question.
The SRB-Status involved a simple depiction of the storage tank including information involving the water temperature, the current water volume in the tank in cubic meters and the percentage in which the tank's capacity was full. The Water Level was depicted in a bar graph giving the capacity percentage of the tank at the end of each day in the last week. The Rain Forecast is displayed in a line graph, because weather sources such as Buienradar.nl use these to depict their precipitation data as well. The idea was to have the user visit the Water Level or Rain Forecast screen and view different time intervals of the SRB's water level or future rain events, however this wasn't designed yet in the current iteration. The Weather Radar was used as a visual representation of the current weather situation above the region of Enschede and, by clicking the zoom-icon, would give the user the possibility of visiting the web source for more information.

Navigation Bar
The home screen was also fitted with a navigation bar to visit different main menu screens. These were created to view specific data in "Data Selection", customize the interface to the user's liking in "My Profile", seek tips on how to navigate through the dashboard in "Help" and to look into background information on the SRB-XXL project in "About SRB-XXL".

Title Bar & Alert
The home screen was also fitted with a title screen giving, on the left, the name of the menu page the user was currently on and, on the right, the time and date to compare measured data with the current status of the SRB-XXL. Next to the title bar is the "Notification Alert"-box which brings info such as system errors or precipitation events to the attention of the user. It was decided to use a bright green color to give prominence to any important information the user might need to know.

Supervisors Feedback
With the first iteration of the UI dashboard came a feedback session which involved suggestions from Richard Bults and Hans Scholten on what needed to change or be added in the next version. The resulting feedback included the following main points:

- Redesign the navigation bar into a horizontal bar just below the Title Bar.
- Put the Weather Radar within the Rain Forecast, as it both bases its information on precipitation.
- Give the SRB Status screen detailed information on the integral parts with static information (e.g. describing the type of valves used) and dynamic information (such as configuration data).
- Turn "My Profile" into "Settings" containing information and authority privileges regarding the other users.
- Use line graphs in the Water Level chart for a more appealing vision
- Create a "Login Screen".

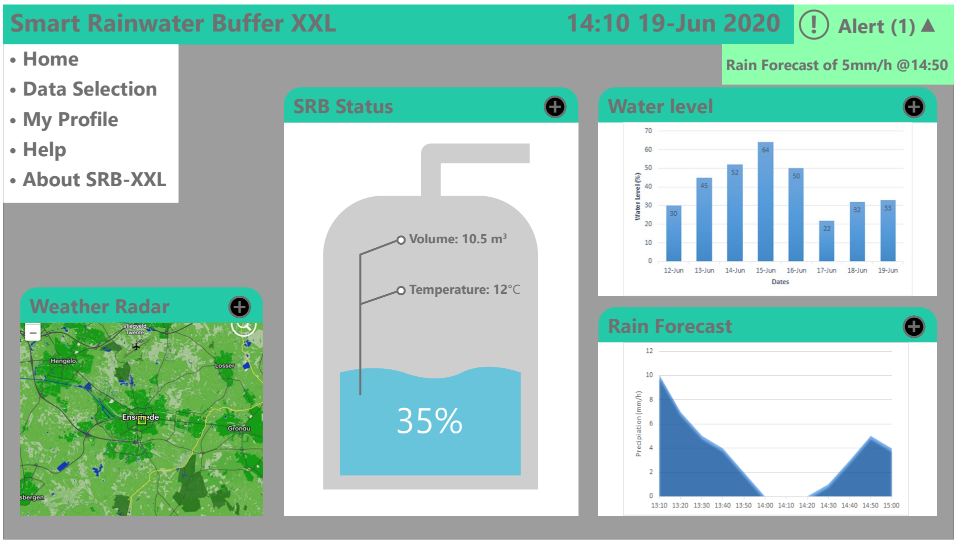


Figure 38: Dashboard Home Screen v1.0

6.2.2 2nd Iteration

Using the feedback of the first iteration, the 2nd Iteration of the UI dashboard consisted of a new home screen along with all the menu screens mentioned in chapter **5.3.1** which were intended to be put into the interface. These include the main menu screens; Settings, Help and About SRB-XXL. Furthermore, the built in screens respective to each of these main menus are added as well (e.g. Water level, Rain Forecast, Contact Information). This version of the dashboard has been reviewed by the intended user Andre de Brouwer and major stakeholders Hendrik Jan Teekens, Richard Bults and Hans Scholten of which the presentation and feedback results can be seen in **Chapter 7.2** of the Evaluation section.

Login Screen

The Login Screen, which can be seen in **Figure 39**, is first thing the user sees when opening up the UI Dashboard. It was decided to keep the interactive content at a minimum with only the necessary objects required in this screen, in order to keep it simple and straightforward for the user. This screen therefore includes a short introduction, two boxes where the user fills in their email address and password, and a Login button used to enter the dashboard once the user information is filled in. The background is decorated with some protruded and bent shapes to give the screen a more energetic feel and to fill up the empty space. A toned down version of these decorations are also included in the other menu screens for aesthetic purposes.

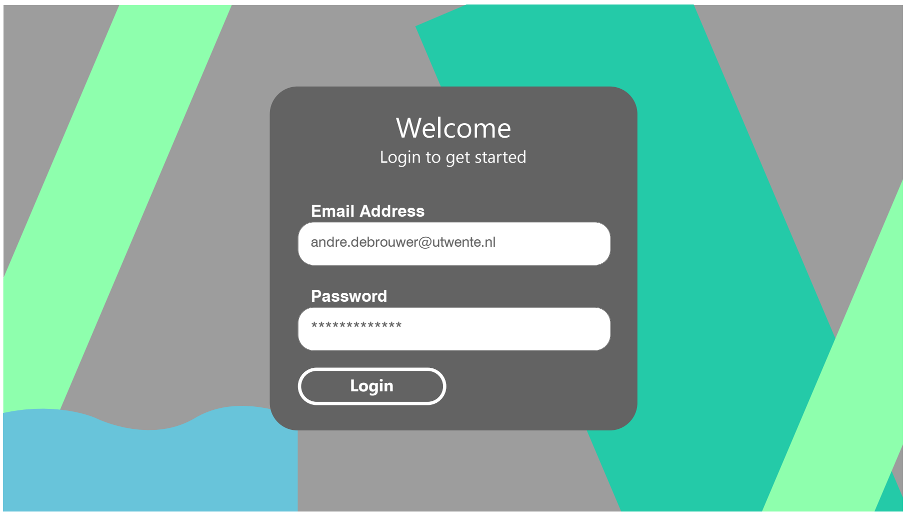


Figure 39: Login Screen

Home Screen v2

Compared to the first version of the home screen, this version was meant to be more polished and structured than its predecessor (see **Figure 40**). The feedback from the supervisors was taken to heart with the navigation bar being more integrated and the weather radar removed from the home screen. In the navigation bar, the user can see on which main menu page he is on by the blue indication line under the menu-screen names. The menu boxes were also lined up in a chronological manner, having the water level representing past SRB-data, the SRB status the current situation, and the rain forecast a prediction of the future. Beside the About SRB-XXL text is a "Sign out"-button allowing the user to log out of the dashboard and potentially sign in as another user.

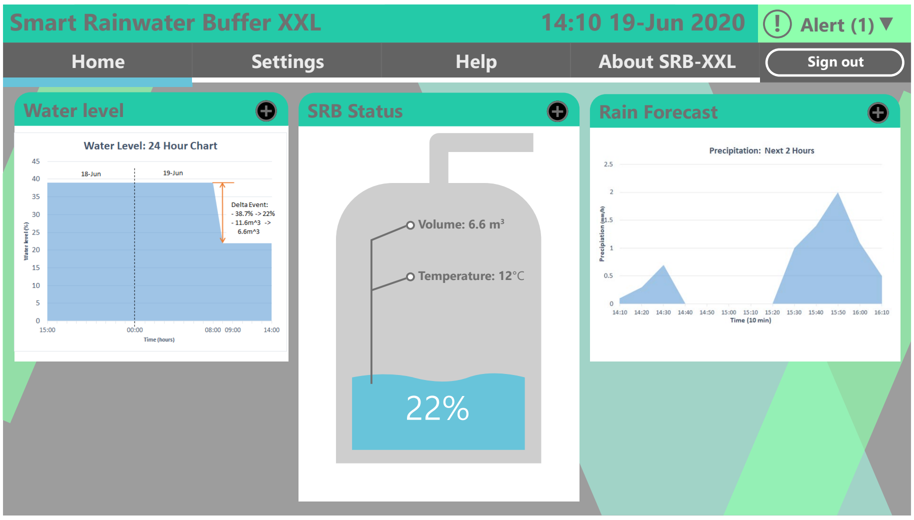


Figure 40: Home Menu Screen v2

SRB Status Screen

The menu page depicting the SRB-XXL's current status included a cartoony version of the water tank with integral parts colored aquamarine in the middle of the screen, and text bubbles on the left and right giving static and/or dynamic information on the parts in question. The SRB Status and each of the menu screens depicted in the Home Screen allows the user to return to the main menu by clicking the "-" button in the top right corner. The text bubbles of the drain pipe and control box include interactive button on which the admin (or users with the authority) can click to change the mannerisms of the SRB's decision-making. The drain pipe has a button where the user can change the minimum and/or maximum capacity limit to which the tank allows water capacity to be held, and how much water should be released once the limit is reached. This allows the user to customize the tank to their specific goals of either prioritizing a full tank to efficiently counter dry periods, or a mostly empty tank to capture as much rainwater as possible to avoid an overworked rainwater treatment system. Next to the capacity limit button, is a Manual Overdrive which exists to let the user issue a command to fully empty the tank for tank-cleaning or maintenance purposes. The Control Box text bubble included a restart-button to reconfigure the wi-fi connection or the data received from the sensors.

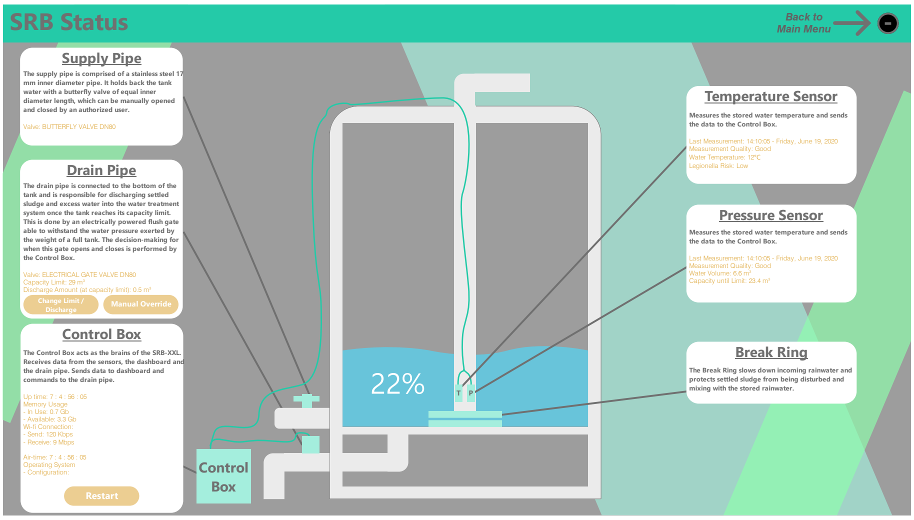


Figure 41: SRB Status screen

Water Level Screen

The water level screen contained three line graphs depicting measured water level data in how full the tank was (in percentage) at certain time instances. These graphs came in a 24 hour chart, a weekly chart and a monthly chart. If a change in water level occurred, these are high-lighted with a "Delta Event" which gives a short overview on the amount of water that was added or removed from the tank.

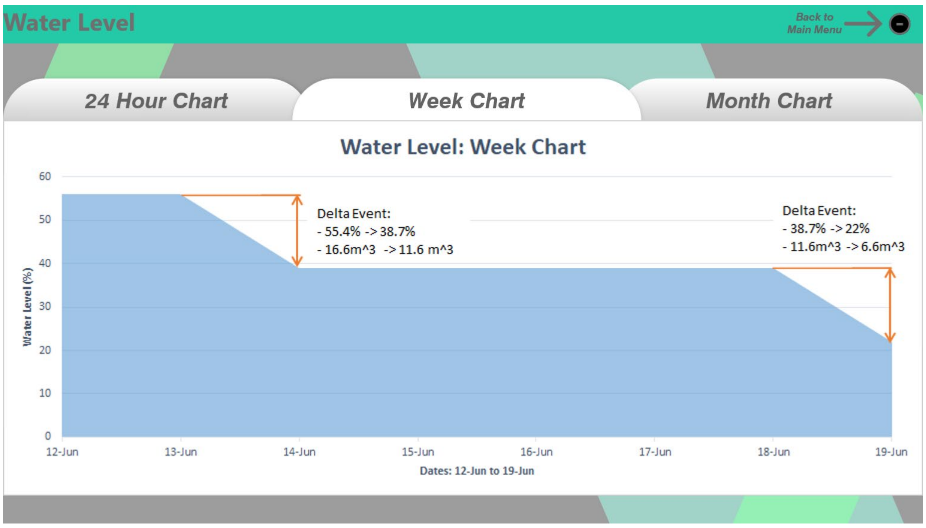


Figure 42: Water Level Screen

Rain Forecast Screen

Just like the water level screen, the rain forecast menu page is fitted with line graphs based on data depicted over different time periods. One graphs shows the precipitation (in mm/h) for the next 2 hours and the other for the following 5 days. As pre-mentioned, the Weather Radar is now placed inside this menu screen and allows the user to visit the Buienradar.nl website by clicking the link-icon in the top right corner.

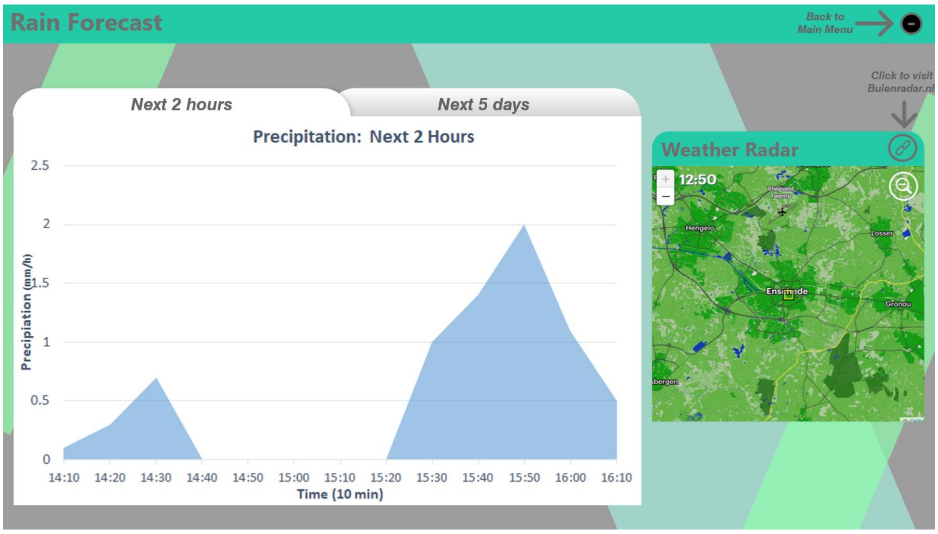


Figure 43: Rain Forecast Screen

Settings menu

In the Settings main-menu the user sees on the left of the screen their personal Contact Information (CI) with an option to change or edit it on the button below. In the middle is the List of Contacts which lists the people who have access to the dashboard with the white CI button to view detailed information or edit their authority privileges. The contacts are divided between the contact groups Krinkels, University of Twente and Others. On the right is an Authority Access matrix of all the users and their dashboard privileges, which is only viewable by the admin, and in the bottom right the Home Menu options to customize the home menu screen to the user's liking in terms of which components he wants to interact with. These components are switched on or off by clicking on the sliding bar depicting whether the component is on or off in terms of viewing.

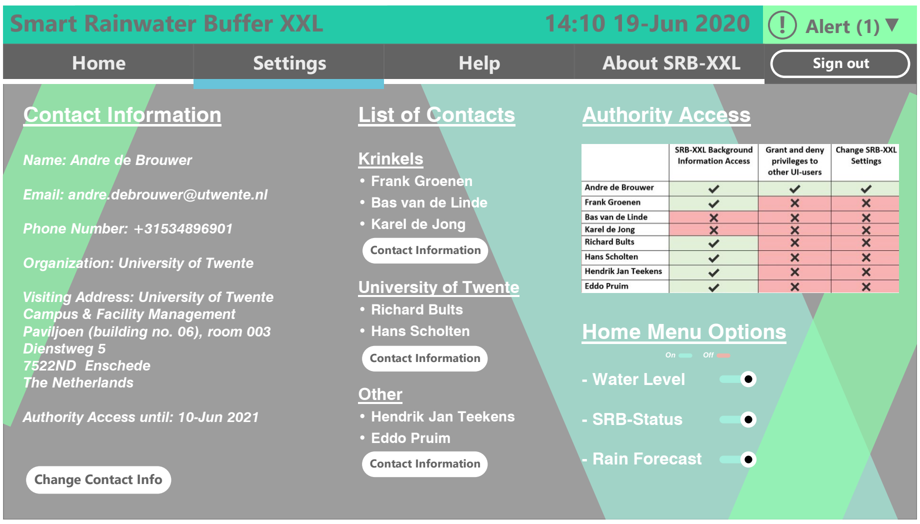


Figure 44: Settings Screen

Admin & Others Contact page

One noticeable difference between the admin and other UI users, is what the users sees when they look into each other's CI. The admin gets a menu page with the other user's information at the top and the status of their interface privileges at the bottom, similar to the Home Menu Options sliders. Only the admin has the power to turn these privileges on or off. When the user visits the CI of the admin, they see the admin's personal info on the left and their own privileges attached to a sliding bar on the right. Unauthorized privileges have a lock on their slider meaning that they can't change these settings without permission from the admin. Permission can be granted after the user makes a request to the admin using the white Send Request button after which the request will show up in the admin's notifications.

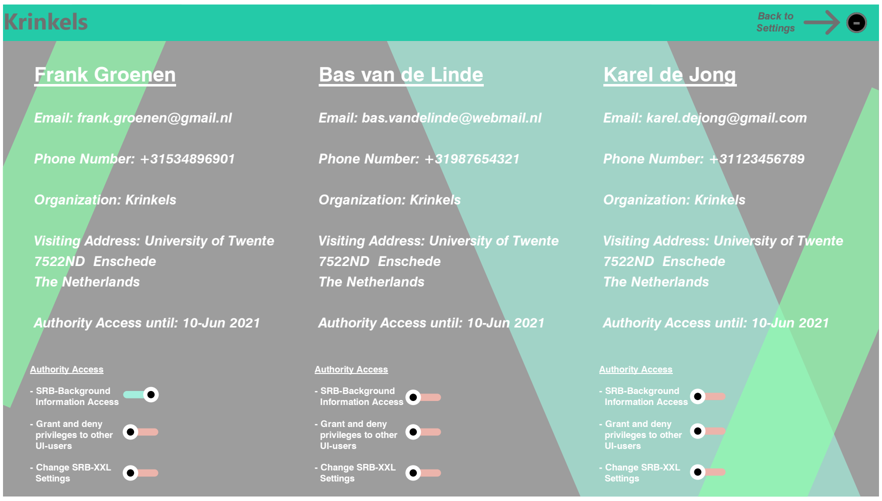


Figure 45: Admin's perspective of other user's CI

Figure 46: Other user's perspective of admin's CI

Help menu

With the goal of guiding the user through the dashboard, the Help-menu includes a detailed explanation of the various menu buttons, what the navigation bar is and how to work with it and the layout of a basic menu-screen. These tips and explanations have arrows attached which can be seen pointing to their respective menu-subjects.

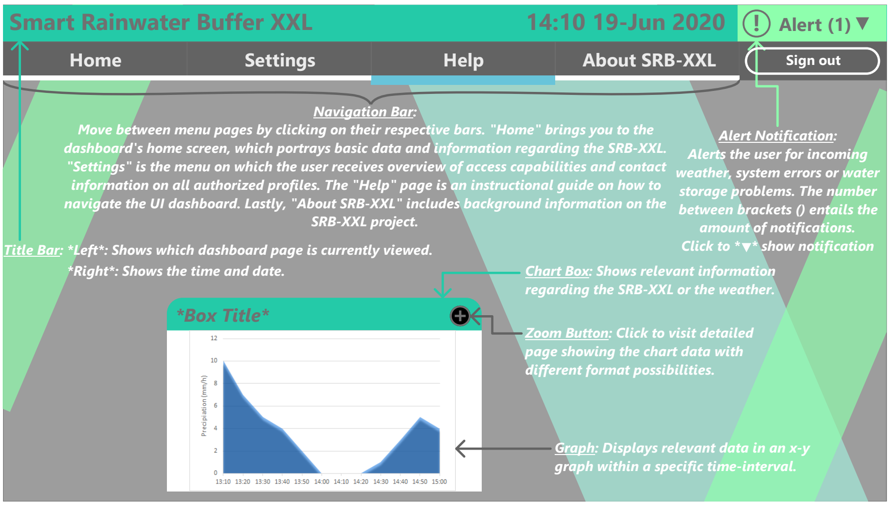


Figure 47: Help Screen

About SRB-XXL menu
This menu screen informs the user of the situation of extreme weather (e.g. droughts and heavy rain) occurring in the municipality of Enschede and the need for the SRB to act as a solution for these unfortunate weather conditions in a short summary on the right side of the screen. On the left is the picture of the final concept design which can also be found in sub-chapter 4.7 of this thesis report.

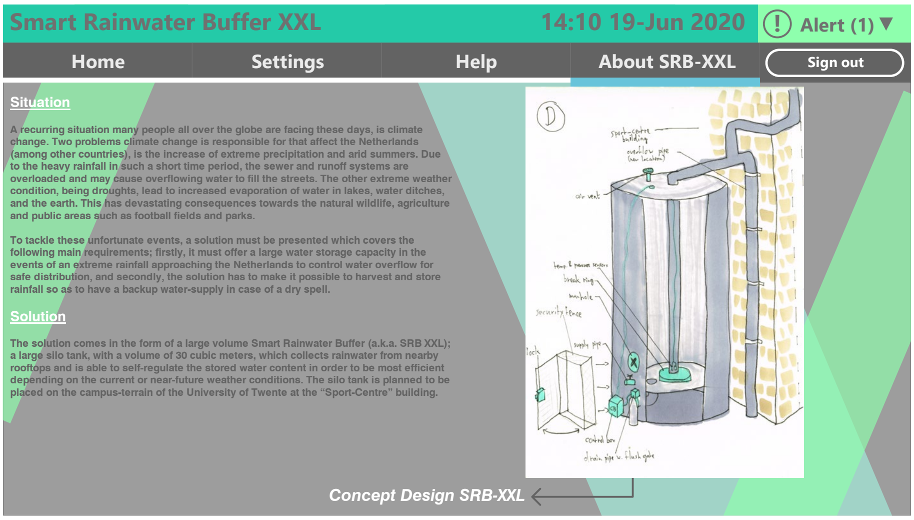


Figure 48: About SRB-XXL Screen

6.2.3 Final Iteration

After presenting the 2nd iteration of the UI design to the stakeholders involved in the User Test, the feedback given on what could be improved was put into the final iteration of the dashboard. A guide explaining the characteristics of this version of the User Interface can be found on YouTube **[64]**.

Drinking Water Savings
One of the most important feedback notes obtained from the final user test, was that there was no noticeable information given regarding the drinking water savings after installing the SRB-XXL on campus. As a result of the feedback, the water level menu box and all Water Level

Screens were attached with a large textbox below the graph depicting the total water savings within a certain time period. The amount of water savings is determined by how much stored water is discharged from the storage tank and used for watering the UT campus plants. The Home Menu shows the savings from the moment of installation to the current date, while the graphs in the Water Level Screens showed the savings relevant to the respective data chart (e.g. daily water savings in the 24 hour chart).

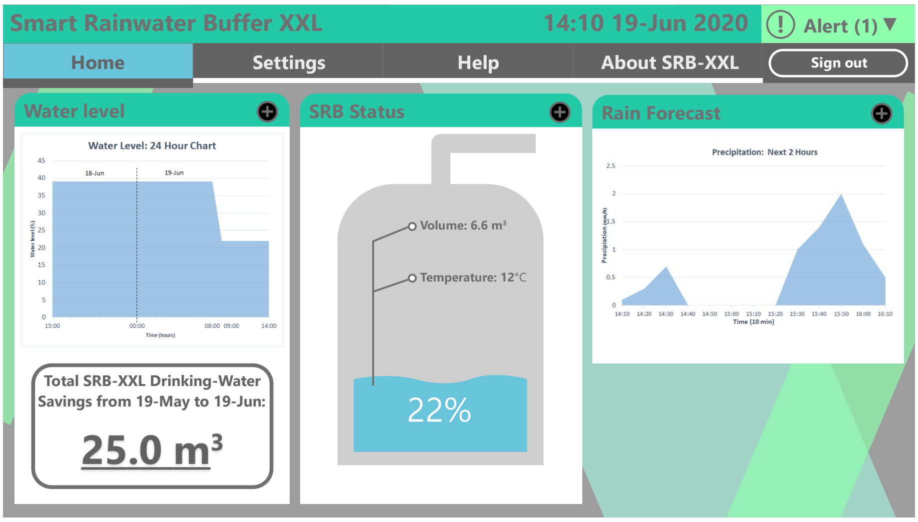


Figure 49: Home Menu screen with Drinking Water savings

Delta Event - Water Level Screen

In the Water Level Screen charts, changes in the water level are depicted with a slope together with a small text box describing the amount of water added or removed from the tank. During the user test of the 2nd iteration, the consulted stakeholders observed that the text box was taking in too much space which would cause difficulties in overseeing the chart if many delta events would occur. A solution to this is replacing the text box with a small "…" symbol which would open more information only when the interface user hovers their mouse over it. This way the water level chart can still show the user delta event information while at the same time keeping a more organized chart.

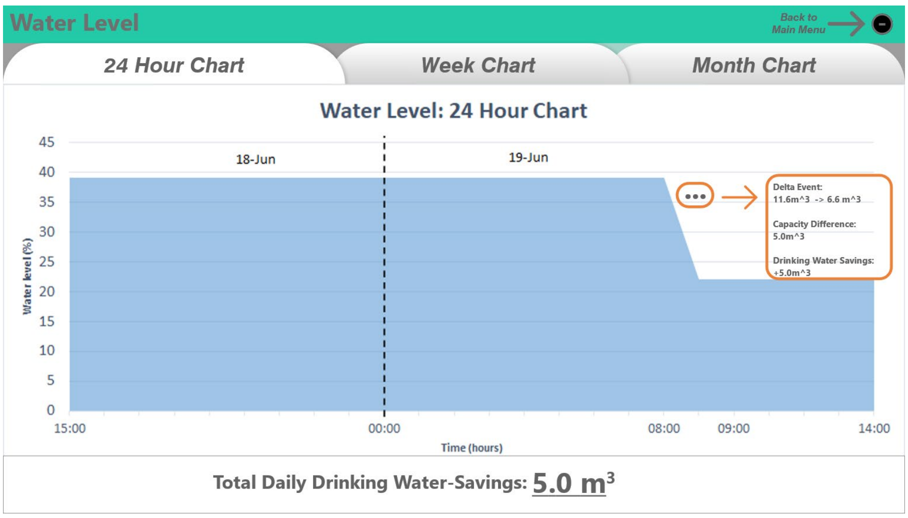


Figure 50: Water Level Screen with hover-locked Delta Event

Capacity Limit Overview

The last feedback subject concerns showing the user the minimum and maximum water storage capacity limit that the SRB-XXL must follow, in line with the client Andre's needs. For the final UI iteration, two lines were added to the SRB Status showing the max. and min. storage limit. These limits can be changed by Andre, or authorized users, in the "Change Max/Min Capacity Limit" button.

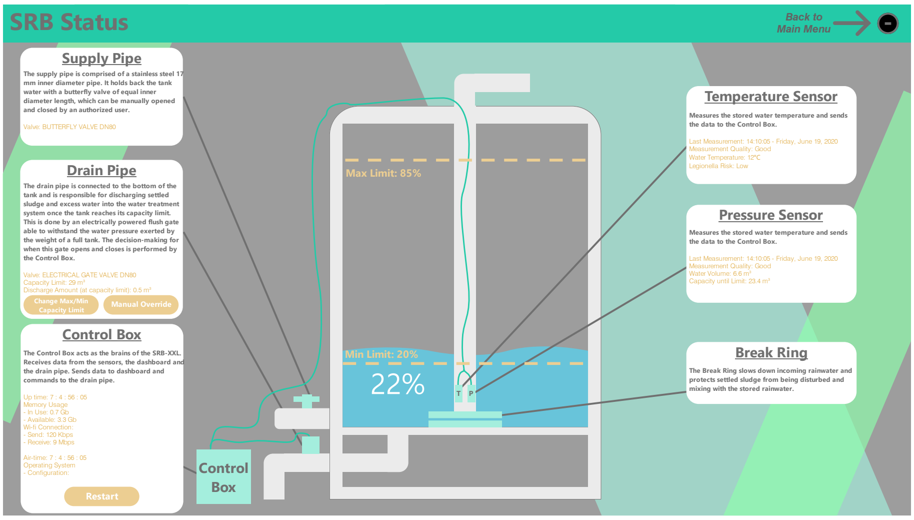


Figure 51: SRB Status with water capacity limits

Chapter 7: Evaluation

The evaluation phase is the last phase in the Creative Technology Design Process and entails a thorough review of the prototypes of the User Interface Dashboard and the Rainwater Router. This section includes a Functional Testing Evaluation, where the prototypes are tested for their fulfillment of the Specification requirements, and a User Evaluation performed by stakeholders where they test the prototype as well as give their final opinion and feedback on it.

7.1 Functional Evaluation

At the end of the Specification chapter, a table was created showing which finalized requirements regarding the UI and RWR prototypes must, should or could reach in order to call the prototype a success in the eyes of the client and stakeholders in the "Manage Closely" stakeholder matrix (see Chapter 4).

7.1.1 Rainwater Router Requirements

The functional evaluation of the RWR was performed to test if the finalized requirements regarding the RWR were met:

- "Must"- requirement: *The RWR must direct all incoming water towards the water-container and all overflowing water into the run-off pipe.*
- "Should" - requirements:
    - *The water-container should not overflow with a continuous inflow of water.*
    - *There should be no water-leakage present through the pipe or wall openings of the RWR.*

The functional test was performed by putting the RWR-prototype outside and pouring water through a garden hose down the inflow pipe. The first noticeable observation was that the water was running completely into the bucket without any of it flowing down the runoff pipe. This checked the first half of the condition that was to be met. After continuously filling the bucket, the water level kept rising until it reached the overflow limit. This is when the water sought escape through the runoff pipe and no longer filled the water bucket. By this stage, it was determined that the "Must" requirement was completely met and the main purpose of the proof of concept was a success.
Furthermore, the first "Should" requirement to test the risk of the container overflowing was also met under the circumstances that the inflow rate was not higher than 11 liters per minute. Otherwise the bucket's water level would slowly continue rising and eventually overflow the bucket. A hypothesis for this occurrence is that there wasn't enough area between the separating wall and the overflow limit for the water to escape faster than there was water coming into the water bucket. For the future SRB-XXL version of the RWR the dimensions would be significantly larger and this problem could therefore instantly be avoided.
Finally, there was no leakage present during the testing, making the RWR setup waterproof and thus meeting the second "Should" requirement's demand.

7.1.2 User Interface Dashboard Requirements

The requirements that the User Interface Dashboard needed to fulfill regard what information is displayed in the dashboard and what user-system interactions are made possible. This functional evaluation test was performed on the 2nd iteration of the UI Dashboard. These are the requirements that the UI Dashboard "Must " fulfill:

1. *The user interface must show the water level and temperature of the tank*
2. *The user interface must show how the SRB functions:*
   - i) *How many times did the tank have to empty?*
   - ii) *How much water was in the tank before and after a certain rain period?*
3. *The user must be able perform system commands to the SRB-XXL from the user interface.*
4. *The user must be able set the required minimum storage capacity of rainwater.*
5. *The UI Dashboard must show the water level history in varying time periods.*
6. *The UI Dashboard must allow the admin to create or take authority or privileges to the other users.*

The first of these requirements is met due to the user interface showing the water level and temperature of the water stored in the SRB-XXL on multiple menu screens: the Home Menu, the Water Level Menu and in the SRB Status menu.
The Water Level Menu shows in the Delta Events at what times rainwater entered the tank or when storage water was discharged, but also the difference in water level after such an event, fulfilling the 2nd "Must"- requirement.
In the SRB Status menu, the admin Andre and authorized users are able to perform system that change the capacity limits, manually flush the tank or restart the configuration of the control box, thus checking both the 3rd and 4th of the "Must" requirements of the User Interface Dashboard.
The 5th requirement is fulfilled because the Water Level Menu gives the user the option to view the water level history in periods of 24 hours, a week and a month.
Lastly, he admin has the possibility to give or take privileges to other dashboard users in the Settings menu.

With the results of the RWR and UI Dashboard analyses, it is determined that all the finalized requirements have been fulfilled.

7.2 User Evaluation

The user evaluation involves the stakeholders Andre de Brouwer, Hendrik Jan Teekens, Richard Bults and Hans Scholten performing a user test where they do short exercises navigating through the User Interface and discovering its functionalities. Hereafter, they answer a list of questions while giving their opinion and feedback on the UI Dashboard. This evaluation was executed in an online conference call using screenshare to show the dashboard to the stakeholders.

7.2.1 Exercises

In this phase the client Andre is asked to perform some exercises to navigate through the dashboard through the eyes of himself, the admin, and as a Krinkels employee. These exercises were performed by controlling the mouse to where Andre wanted it go based on his instructions through the conference call.

Andre de Brouwer - Admin

- *Log in to the UI dashboard*
- *Go to the Help menu-page*
- *Please read the instructional texts describing the various functions of the dashboard*
- *Are the instructions clear? If so, please go to the "About the SRB-XXL" menu page.*
- *Now go to the "Settings" page and find out what the Authority Access settings are of Frank Groenen.*
- *Find out what the phone-number is of Frank.*
- *Go back to "Settings" and turn off the option to view the Water Level in "Home Menu Options"*
- *Open the SRB-Status zoom button and find out what the risk is of Legionella in the SRB-XXL*
- *Go back to the "Home" menu and open and close the Alert notification*
- *Find out if it will rain on the 22nd of June*
- *Sign out of the dashboard*

Krinkels

- *Log in to the UI dashboard*
- *Find out what the current water capacity is and when it was the last time the water pressure was measured*
- *Go to the Settings menu page and request the privilege to change the SRB-XXL settings*
- *Find out what the water level was in the 7th of June*

Andre performed these exercises with relative ease making the Exercises phase of the User Evaluation a success.

7.2.2 Questions and Stakeholder Feedback

The second phase of the User Evaluation involves a semi-structured interview where the stakeholders are asked questions, which lead to them answering them and allowing discussions to take place and feedback to be received regarding the UI Dashboard. Below is the translated transcript of the evaluation session involving the questions and stakeholder feedback.

- **Was the layout of the User Interface easy to navigate?**

Andre: I found it so yes. There are pictures that clearly illustrate what you're supposed to do as a user. The most important aspect for me is the information regarding how much water is in the tank. The limit regulation is definitely a plus in this case. For the future it might be worthwhile to look into combining the future rainfall with the limit regulation.

Hendrik Jan: It's nice that when looking at the interface I don't have any questions about what any of the things are as they are logically placed and explained in the Help menu. Although I expect that the Settings menu probably won't be used much, it is certainly a useful function to have once the need arises to give certain people access to the SRB's functions. It also brings clarity to the hierarchy in ownership of the SRB-XXL, which I'm a big fan of.

- Was the Help menu useful in informing the user of navigating through the interface?

Andre: I probably will only look at this menu-page just once, where after it will become a bit purposeless. However, it does fulfill its initial goal of informing the user of the interfaces functions.

Hans: Is the user interface also available on the mobile platform?

Paco: Not currently, no. The goal was to create an interface that would best suit the client Andre, and it was my understanding that the PC platform was more preferable than the mobile one. Another reason is that PC's have a generally bigger platform and shows more functionalities at once on the user's screen.

- What is your opinion of the design of the user interface?

Andre: I was pleased with it, but I found the picture of the tank in the SRB Status page to be somewhat childish. It could have been more technical in my opinion.

Hans: In the navigation bar you indicate on which page you are with a blue line under the menu. I didn't see that very clearly at first, so I would change the whole tab blue to make it more obvious.

Hendrik Jan: About the green bars in the background, I found it a bit too busy for my taste. Did you have trouble with design in this aspect?

Paco: It was actually intended to have this energetic feel because I found just a gray screen in the background to be very boring.

Hans: As a suggestion, there's also the possibility to put blurred photos of the campus in the background, just like the UTwente website.

- Were the graphs in Water Level and Rain Forecast easy to read?

Hans: At the delta event are approx. six rows of information. If the delta events are much smaller and more frequent, do you still have enough space to display that much information or do you have some other measure against this?

Paco: I was still unsure of how Andre would want to see the change in water capacity, either in percentage or cubic meters. This is why I put both up for the time being, but it is good to ask Andre now.

Andre: It's important to explain what amount exactly has been removed (or added) and how much remains in the tank. I'm fine with having the cubic meters as measure, but I would also like to see the relevant delta-event information after you drag your mouse on said event.

Richard: This is a clever solution to the problem of displaying information on a small delta-event, but it's important to explain this possibility in the Help page.

Andre: An essential part of info I would like to see is how much drinking water has been saved by using the SRB's stored water for watering the plants instead.

Richard: This means it's crucial to keep tabs on the total amount of water that has been drained from the supply pipe (so not the drain pipe since this directs the water into the sewage system). Basically, sum up this amount of water savings per day, week or year and display it in the interface.

- **Are you overall pleased with the current design of the User Interface?**

Andre: Despite the delta-event and drinking water savings not being viewed properly in the dashboard, I am satisfied with the end result of this prototype. It meets all the must-have requirements I have given, which is the most important aspect of this evaluation.

7.3 Evaluation Conclusion

The last phase of the Creative Technology Design Process was executed with the goal to assess if the RWR and UI Dashboard prototype met the finalized requirements in the Functional Evaluation and were satisfactory in the eyes of the client Andre de Brouwer, supervisors Richard Bults and Hans Scholten and stakeholder Hendrik Jan Teekens in the User Evaluation. The Functional Evaluation resulted in fulfilling all finalized requirements, with the slight exception of the “Should” requirement regarding the RWR not overflowing with a continuous inflow of water if the flow-rate was to high. The exercises made in the User Evaluation were performed successfully and the stakeholders were pleased with the end-result. After the User Evaluation, the UI Dashboard was remodeled into its final iteration based on the feedback given (see § 6.2.3).

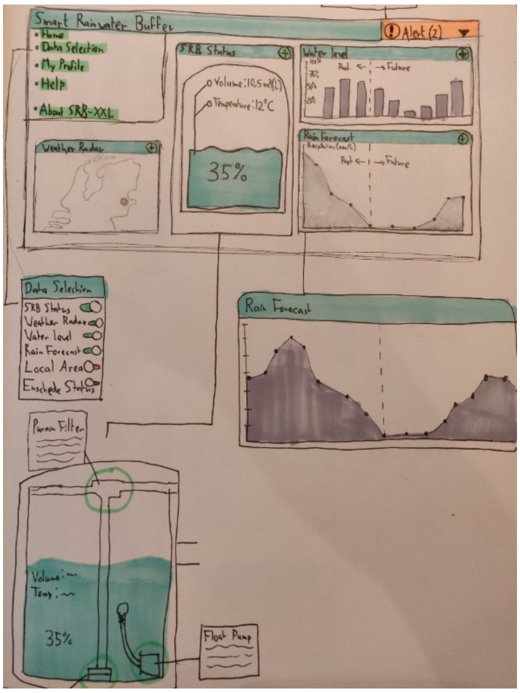
Chapter 8: Conclusions and Recommendations

In this chapter, a conclusion is given by discussing to what extent the research questions are answered and the goal of the SRB-XXL project is reached. Furthermore, recommendations for are given with regards to future projects involving the SRB-XXL.
The SRB-XXL project is concluded by answering the research questions created at the beginning of the project. The main research question reads as follows:
"How to develop a large volume smart rainwater harvesting & buffer system for the UT campus?"
Three sub-questions were created that focus on the sub-systems of the SRB-XXL:

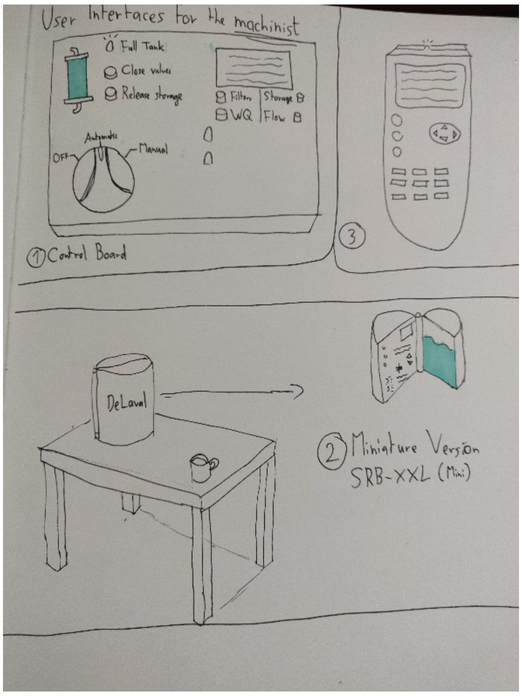
1. "What actions must be taken to control the rate of water in- and outflow of the SRB-XXL?
2. "How is the water quality of in- and outflowing water of the storage tank best purified/maintained?"
3. "What user interface systems can be applied to RWH systems?"

Regarding the main research question, by integrating minimum and maximum capacity limits controlled by the system's smart elements and determined by the user, the SRB-XXL is able to act as both a harvesting and buffer system. This way the SRB-XXL can fulfill the interest of people in control of the system even if they have different goals in mind. The municipality of Enschede wants to use the SRB-XXL to catch as much rainwater as possible, thus setting a low capacity limit, while the client Andre would rather have a full water storage tank, setting the limit higher.
The water in- and outflow rate of the system is controlled by installing flow-pipes of equal diameter with the outflow being released by a manually or electrically controlled valve (supply & drain pipes). These valves make it so that it can open up to a degree that once the water is discharged from the tank it doesn't overload the stress on the destined discharge location (e.g. the sewage system or the 5 m^3 Krinkels tank).
The water quality is managed by desludging the tank using a bottom release system, discharging settled matter through the drain pipe. Although this method of water-quality maintenance is useful for contaminants such as dirt or leaves, it's no solution for purifying the water of micro-organisms.
User interfaces that clearly convey subjects regarding to water level, system status and precipitation data, in this project's case digitally, can be applied to rainwater harvesting systems.
The "SRB-XXL Concept for UT Campus" project was largely influenced by discovering the system architecture with relevant sub-systems (e.g. filters & UI) that would best serve the needs of the client(s).
Due to unfortunate circumstances the realization was mainly focused on the sub-systems. However, the research that has been performed on the base system and its concept design has been set in place for future SRB-XXL projects. For this reason, it is my hope that future SRB-XXL project researchers will use my findings and realized prototypes as a stepping stone to fully realize the SRB-XXL project. Furthermore, I highly advise them to keep the client, supervisors and other stakeholders firmly in the loop to avoid misconceptions and agree on project-decisions.

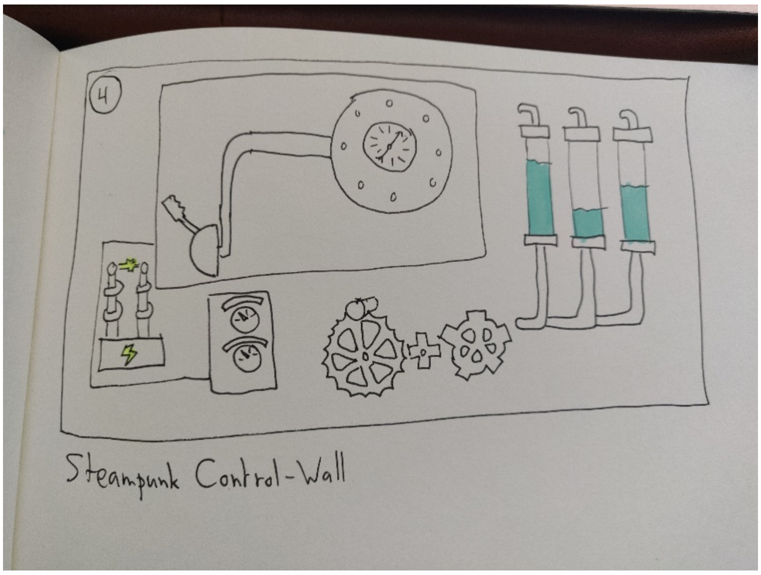
Appendix A: Brainstorm Sketches



1) *Digital UI Design*

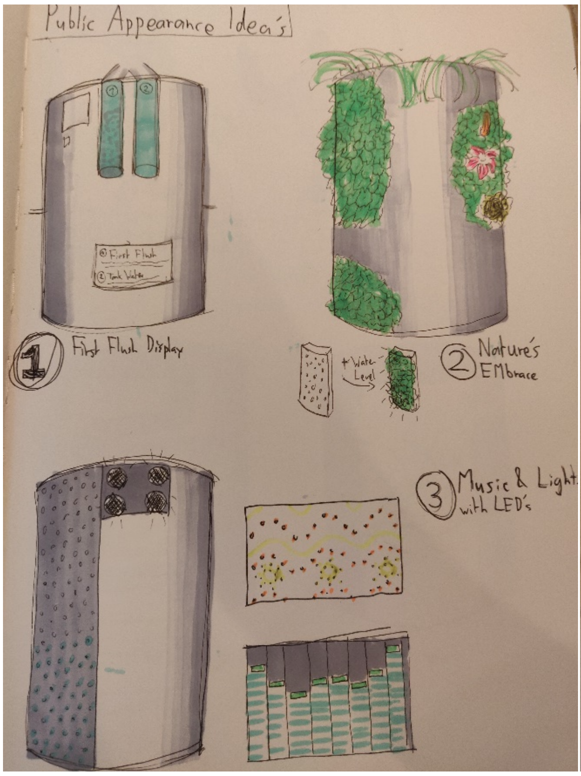


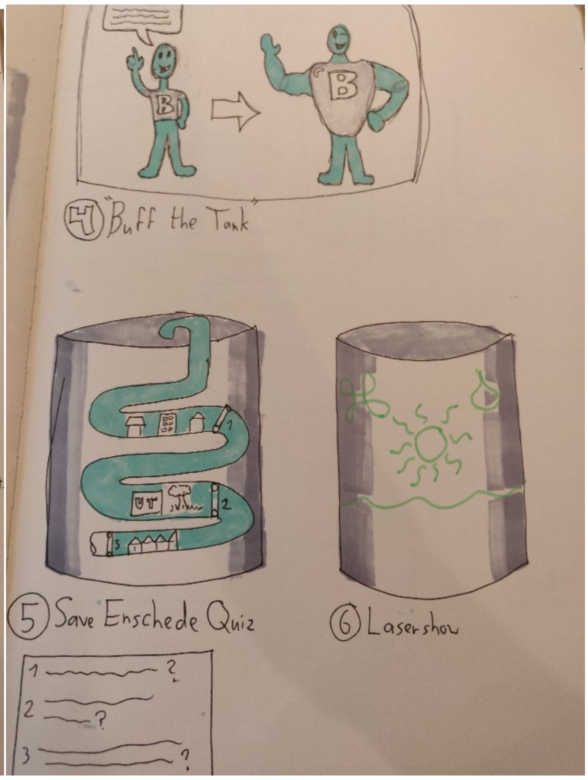
2) *Physical UI Designs*



3) Steampunk Control-Wall

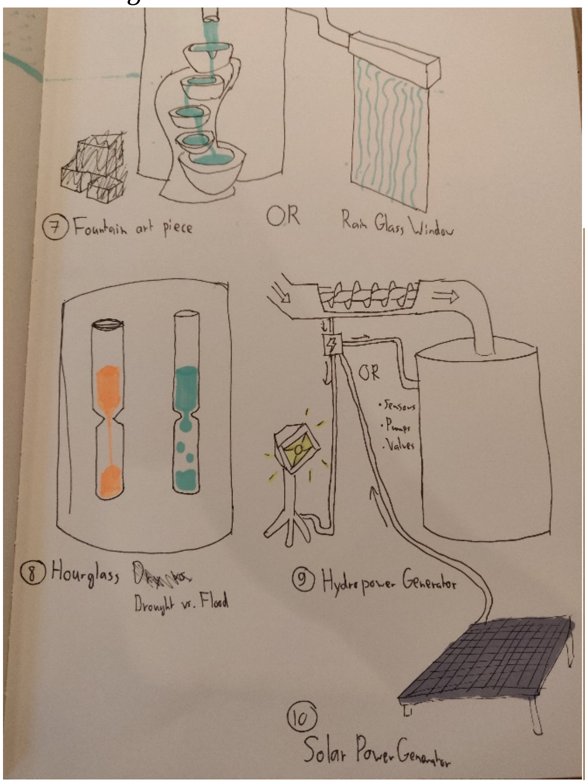
Figure A1: Digital User Interface Design

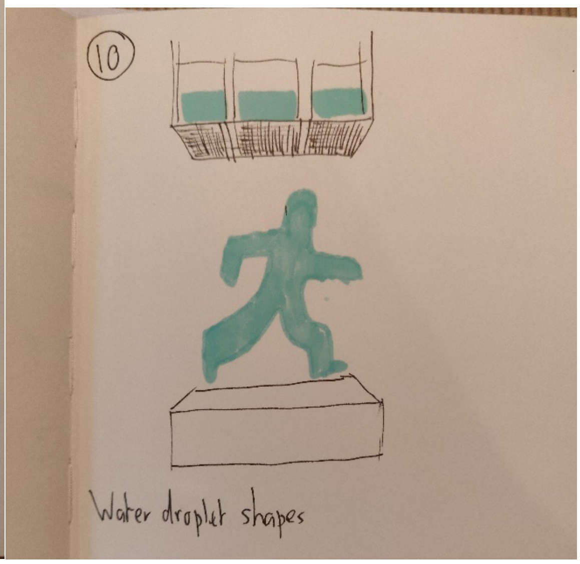




1)First Flush Display, Nature's Embrace, Lasershow
Music & Lights with LED's

2) Buff the Tank, Save Enschede Quiz,

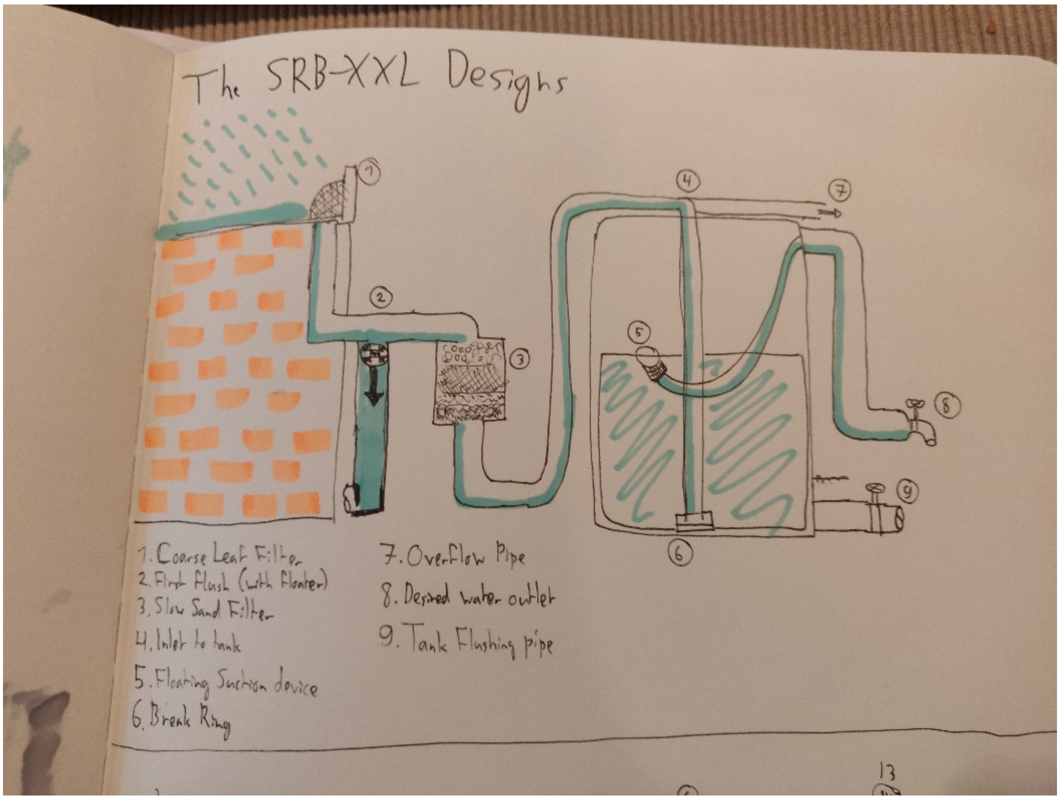




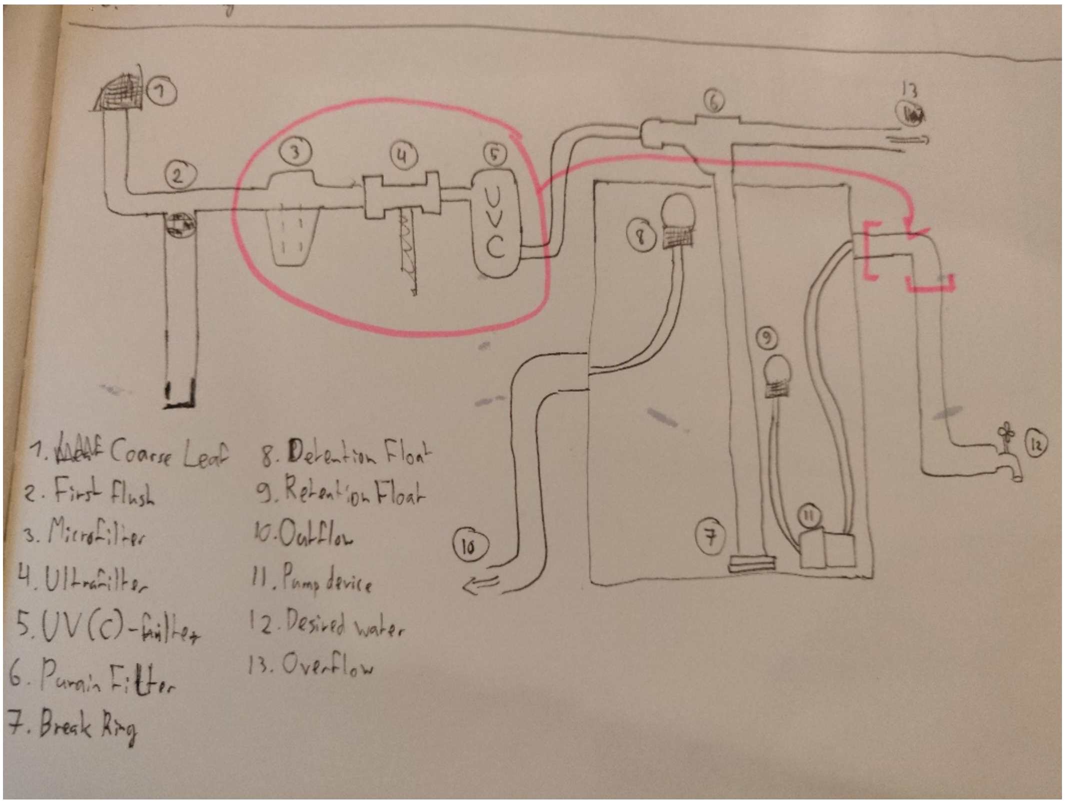
3) Fountain Art Piece / Rain Glass Window
Hourglass Drought vs. Flood, Hydropower Generator, Solar Power Generator

4) Water Droplet Shapes

Figure A2: Sketches of the 10 Public Appearance Concepts



1) SRB-XXL Design #1



2) SRB-XXL Design #2

Figure A3: Sketches of the SRB's Schematic Overview

Appendix B: Stakeholder Interviews

B1. Interview with Andre de Brouwer accompanied by Richard Bults as observer, 12:00-13:00, 27-Nov-2019

Speaker Colors: Andre, *Richard*, **Paco**

Paco: Given that the whole Sportcentre roofs are able to be used, how many square meter of that would you connect to the SRB-XXL, keeping in mind how much rainfall would drop in on the tank?

Andre: A full roof is not possible because the tank would become full in a relatively short time, so the plan is to use half a roof. There's also the intention of installing a Pluvia system on the roof. The Pluvia is a filtering system which uses smaller pipes to distributes the catchment water all into a single collection unit. I don't know the exact area to be connected to the tank, but I'll come back to you on that.

Richard: I have gathered from the municipality of Enschede that when dimensioning buffers, you must work in accordance to a T = 2 and Stormlevel 8. This means an intensity of 18-20 mm of rainfall in an hour. So we would like to base our tank around this number.

Andre: Indeed. This means that if you were to look at the total volume of the tank, 30.000 liters, and the rainfall intensity of 20 mm, then you would have a full tank in an hour if you were to use 1500 square meters of catchment area.

Richard: Precisely, but we must also take into account the possibility of rainfalls with intensities of 40 mm per hour, which increases the possibility of the tank reaching overflow.

Andre: Yes, when this happens it's important to show the public that overflow is currently happening. The tank should work according to the weather predictions analyzed and make room for the calculated incoming rainfall.

Paco: The goal of the SRB-XXL is to have the tank be both a buffer for the sewage system and a water preserve to be used against dry periods. There currently exist some of these "dual purpose" systems such as the one from the company GRAF which could be used in the SRB *shows GRAF movie*

Andre: This is a very good system, but it is unfortunately placed underground making it unviewable for the public. The Technohal uses a similar system where the underground tank, once full, puts a lid on and lets the water flow on. Additionally there's a pump which provides the stored water to the toilet flushing system.

Paco: In such a system, how do you reassure that the water and or the tank stays clean, especially if it's underground, making it harder to clean?

Andre: The sludge collects on the bottom, so when we clean the tank the water is removed and then you can freely suck all the remaining debris out of the tank with a pump. It's also very important to have a sprayer on attached to the Pluvia filtering system on the roof to spray off all the debris. It can work automatically, but it still needs to be maintained. The water used for the plants may still contain some bacteria and viruses, so there's no need to install fancy filtering systems which remove them.

Richard: You say that Andre, but with a large catchment area you have a great amount of dust from dry periods, the Pluvia system might not be enough to handle it all.

Andre: For that you can just let the sand and smaller particles go through the Pluvia and into the tank, where after you let it rest on the bottom of the tank and occasionally clean it up.

Richard: That's one possibility. Another is to install a sand filter somewhere before it enters the tank, keeping the SRB as clean as possible.

Andre: Yes, but you must keep in mind that with those filters you will have to use extra maintenance.

Richard: So Paco, for you it's important to find out what you're going to filter, where are you going to place them, and what will this cost in price but also in maintenance.

Andre: For maintaining the grass fields of the campus with water, using the SRB-XXL is not nearly enough water since the tank will be empty in no time. Plus, you would have to install more filters to prevent algae and such from forming which can damage the fields.

Paco: How does the whole process work for watering the plants on campus?

Andre: Normally, the plant-pots are provided by 1 or 2 cubic meters of water from a truck (or such a vehicle). This water comes from a waterhole containing drinkable water, which is unfortunate because we don't want to use valuable potable water for watering the plants. We could use water from lakes, but this would require to much resources and is difficult to do.

Richard: Indeed. Everything you can do to prevent the UT from unnecessarily using potable water, is a huge benefit for the university.

Paco: Would you rather have the tank be more full, in case of droughts, or more empty to catch enough rainfall?

Andre: Definitely more full. It's better to have more reserve of clean water than an empty one after a faulty weather prediction.

Richard: That's the difference between your interests, Andre, and those of the municipality. Because it costs more money to redistribute more water through the water treatment systems.

Paco: Now that we've discussed the technology portion of the SRB, I would like to talk about the user interface. What would you like to see in terms of how the information about the tank is visualized? Would you rather have it virtual, like on a website or app, or more physical, like a control board?

Andre: I want to know the water level of the tank when I stand in front of it. Using a sensor placed in the tank which directs the information to an app is very pleasurable. It doesn't really matter to me how it's projected, as long as the received information is accurate. However, I would definitely like to see how the SRB functions: How many times did the tank have to empty? How accurate were the predictions? How much water was in the tank before and after a certain rain period? It's also important to show where the outflow goes once the tank is full or when room has to be made. The control system of the tank must be shut off from public use, so that it's only accessible by persons of authority, and so people with ill intentions don't mess with the SRB.

B2. Interview with Hendrik Jan Teekens - Municipality of Enschede, 11:00-11:30 28-Nov-2019

Speaker Colors: Hendrik Jan, **Paco**

Paco: What is your previous experience with the SRB/Ensketon project?
Hendrik Jan: From the beginning Richard and I have been project-partners concerning the SRB. Firstly, expectation of this project is that it has the potential to grow into something big. Secondly, I believe that the process of this project is running smoothly since you have the skills to gain understanding of the technology. The sewer system is sturdy, since it works properly for 80 years, thus the SRB must be sturdy as well. For example the tap at the bottom has to function all the time, even if there is gravel and such in the tank. To summarize, the realization is on its way, but there's still much that has to be thought through.

Paco: What does the SRB-XXL project mean for you personally if it were to be realized?
Hendrik Jan: It would mean very much to me personally, since that would show how serious we are with gaining results, especially through the transition from smaller rain barrels to the bigger and more effective water tanks, but also as physical proof of our hard work.

Paco: If the SRB-XXL were to be installed in Enschede, for what purposes would you use it?
Hendrik Jan: When the SRB-XXL will be realized it will be attached with logos that supported this project, including the Municipality of Enschede, which can be a stepping stone towards other companies in Enschede that would like to have it installed to their rooftops.

Paco: The main goal of the SRB-XXL is to make the tank both a buffer for the sewers and a water-storage space for drought-related issues. What is, according to you, the more important goal, water catchment or water reserve, or are they both of equal importance?
Hendrik Jan: I see the SRB as a measure against extreme weather conditions. Heavy rainfall is responsible for many water damage, such as floods in homes, but the droughts are, in a sense, a silent killer that is just as bad. That's why they're both important. This project may eventually also benefit other parties for potable water.

Paco: There are rainwater harvesting systems out there called "dual purpose" systems that have split the tank into a retention area to be used against the droughts and a detention area as a buffer for rainfall. Would you like to see the implementation of such as mechanism in the SRB?

I see the purposes of both buffer and harvester as equally important. This “dual purpose” system seems intriguing, but you must consider the pressure you’ll put on the sewer system so as to not cause delay in the outflow. The resolution of this delay is in our best interest. A solution for that could be to take the diameter of the pipe into account.

Paco: Next, it’s important to consider the water quality in the tank, such as preventing pollutants from entering. If the tank were to be placed in Enschede, what level of water quality would you like to have (potable or accessible for plants) and what filtering techniques would you use for that purpose?
Hendrik Jan: We aren’t planning to use the stored water for drinking purposes, so using filters such as UV filters would be overkill. Richard and I went to a fair recently and we observed a technique that is currently being used on the University of Twente “Technohal”. If you contact Andre de Brouwer he can tell you more about this filter. It’s a very self-sufficient system placed on location where the water hasn’t reached the tank yet. When the water is let through and debris has surrounded the filter, a sensor senses the debris and sprays it off after which it drains town into a disposable area. Another potential filter is a kind of cloth that catches the water which, when it has become filled with debris, is automatically replaced with a clean cloth (comparable to a paper towel).

Paco: My client Andre de Brouwer intends to use the stored water to take care of the plants on the UT Campus. Do you have any tips in how far the water should be purified for this outcome?
Hendrik Jan: It’s important to remove as much sludge as you can before it has the chance to enter the tank. However, the bottom of the tank is still filled with sludge so it is crucial to have a drain at the bottom that sucks all the sludge out. To prevent reactions that end up in poisonous water and algae, you have to control the temperature of the tank.

Paco: The SRB’s data should be clear for the client, but the public should also have vision on the inner workings or background information of the tank. What information would you like to see displayed on the user interface or public poster/screen?
Hendrik Jan: Once the tank has been realized on campus I would like to see information, not per se on a technical dashboard, on what the tank specifically does in certain situations. Also a future prospect on e.g. what benefits the tank has provided in a years’ time, how much water has been saved, etc. There is “this much” catchment area connected to the tank which produces “so much” water, but with the SRB in place the amount of water discharged to the sewage system has been reduced by “this much”. The calculations on such matters must be accurate, also in terms on money costs for filtering and distribution. In short, I would like to see the exact benefits of the SRB-XXL, but also the actual information on the tank (e.g. water level and temperature). I think putting it online would be a good way to display the information, but I would definitely also like to see it on a screen placed on the tank.

B3. Interview with Jeroen Buitenweg - former Waterschap Vechtstromen, 15:30-16:00 28-Nov-2019

Speaker Colors: Jeroen, **Paco**

Paco: What does the SRB-XXL project mean for you personally if it were to be realized?
Jeroen: It comes down to that the Municipality of Enschede and Waterschap Vechtstromen have the same goal to move from a centralized water storage system to multiple decentralized systems in addition to current water treatment systems. It is also a means to raise awareness for water-use of the public so they realize how precious potable water is.

Paco: The main goal of the SRB-XXL is to make the tank both a buffer for the sewers and a water-storage space for drought-related issues. What according to you the best way to have the tank reach both goals?
Jeroen: It depends greatly on how accurately the tanks actions follow the weather predictions. If the predicted amount of rainfall is matches the free storage, then there is no problem. However this is unfortunately not the case since such an error is inevitable. You can cover this somewhat by making the tank more flexible in storage capacity. By continuously testing the amount of free storage for incoming rainfall, a maximum capacity can be determined thus being better prepared for weather predictions. The intelligent part of the tank must make sure that clean water comes in the tank while old and dirty water is expelled, raising the water quality.

Paco: When making these flexibility constraints, should I lean more towards the free storage or rather to have more water preservation?
Jeroen: That depends highly in the user. The owner of a domestic household with such a tank installed would rather have more water in the tank, even if this causes unnecessary strain to the sewage system. The municipality, however, would benefit more from the tank acting as a buffer since the sewer system is under their jurisdiction. In any case, the homeowner must be made aware of the risk of holding onto water for a long period without flushing it and exchanging it for newer cleaner water.

Paco: Do you have any preferences towards which filtration devices to be installed into water storage systems?
Jeroen: I am pretty easy on this subject. However I noticed how much dust lands on the rooftops, so a mechanism that takes care of this before it enters the tank is essential. Measures that filter bigger debri like leaves and tennisballs is also of great importance. Sludge that rests on the bottom of the tank must be flushed when making more room.

Paco: Do you believe it matters how much catchment area is used from the roof in terms of the amount of water that travels to the tank and thus fills it faster?
Jeroen: I believe that you have to use as much catchment area as possible, since roof-area that isn't connected to the SRB will otherwise direct water to the sewage system. By not doing so you would waste water that could have otherwise been caught in the tank.

Paco: For the public and relevant stakeholders such as yourself, what do you think is important information to be displayed on the user interface or on the tank itself?
Jeroen: From the public's point of view, I would find it interesting to know how much potable water we have saved by using the SRB's water to provide for the plants instead of valuable drinking-quality water. This would reinforce the importance of water-reuse. This comes down to numbers that show, firstly, how much tank water has been used and, secondly, how much water has been harvested and/or released by the tank from incoming rainfall. The last number shows the public how much the tank provides in terms of water storage. Actual information such as current water level and temperature (in relation to Legionella) is also important.

B4. Interview with Eddo Pruim - DeLaval, 10:00-10:45 11-Dec-2019

Speaker Colors: Eddo, **Paco**

Paco: Do you have any former experience with the SRB projects?

Eddo: No I do not. I have mostly been experimenting with my own tank project, but I have come in contact with Hendrik Jan and Richard Bults, thus discussing our ideas and findings.

Paco: How do you make sure that your rainwater tank maintains acceptable water quality?

Eddo: That's a problem I'm still figuring out. With my first project of two tanks, each with a capacity of 200 liters, I installed a "Gootdrain" (gutter-filter), making sure the big materials don't mix with the water. This however still lets smaller material through like birch seeds, which requires a more thorough filter. But even with these filters, small particles such as sand often reaches the storage unit, collecting as a sludge at the bottom layer. You must have a measure against this lower layer.
The upside of the Cilotank being used as a Milk tank, is that it's designed in such a matter that it will discharge every last drop contained within the tank including the debris sitting on the sides and such. Also, when designing the outflow for your water-needs or flush purposes make sure that it's approximately a meter high. This way you have clean outflowing water and leave the dirty water in the lower part of the tank, cleaning it once per year.

Paco: When analysing the Cilotank description-file, I saw information about a cooling system. Is this included into the tank we will be using?

Eddo: The system you're talking about is used to keep the milk cool and is usually placed on the outside of the tank, however this is not included into your tank-system. However, your tank is very isolated and prevents the temperature of the outside reaching the stored water. In my own system the water remained at a fridge temperature (4 degrees Celsius) while it was 35 degrees outside, so you can highly depend on the isolation. This is important to prevent bacteria from growing inside the tank. Another plus is that it also works in freezing temperatures, preventing the water from solidifying and damages the inner hull.

Paco: One of the discussion points on the SRB is how much catchment area of the roof has to be connected to the system. You can either use the whole roof and fill the tank as fast as possible, or use a smaller portion and let the buffer effect last longer but risk not using water-capacity. Do you have an opinion on this matter with your experience with your own tank?

Eddo: I have my tank connected to the roof of the shed, and when it rains the tank fills up rather quickly which is why you need to direct the overflow. What you could do for your rooftop, is connect one part of the roof to the tank and the rest to whatever infiltration or sewage systems you have.

Paco: We have planned to make a user interface for our client Andre so he can monitor the status of the tank. What do you use for your system to check water level or temperature?

Eddo: I have simply installed a transparent tube on the outside of the tank which shows the water level on the inside of the tank. It has one downside though: because of the algae in the water, the tube turns green. But when winter comes, the green goes away. You could also use a sensor that floats on the water within the tube. This tube is then surrounded by a magnetic field which gives the sensor different signals depending on the height of the floating sensor.

Paco: I have made a few initial sketches of the SRB's layout. **explains the workings of each part Do you have any comments?**

Eddo: When releasing the water through the manual float-pipe, you use an electrical pump to discharge the water. I suggest that you make use of gravity as much as possible and make the exit of the outflow at a much lower point.
A problem you might face with your tank concerns the valves or air-valves to be more specific. Normally you have a compressor to control opening and closing the valves, but this is not included with your tank. I think that an electrical valve would solve your problem and I will inform you once I know more about it.

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