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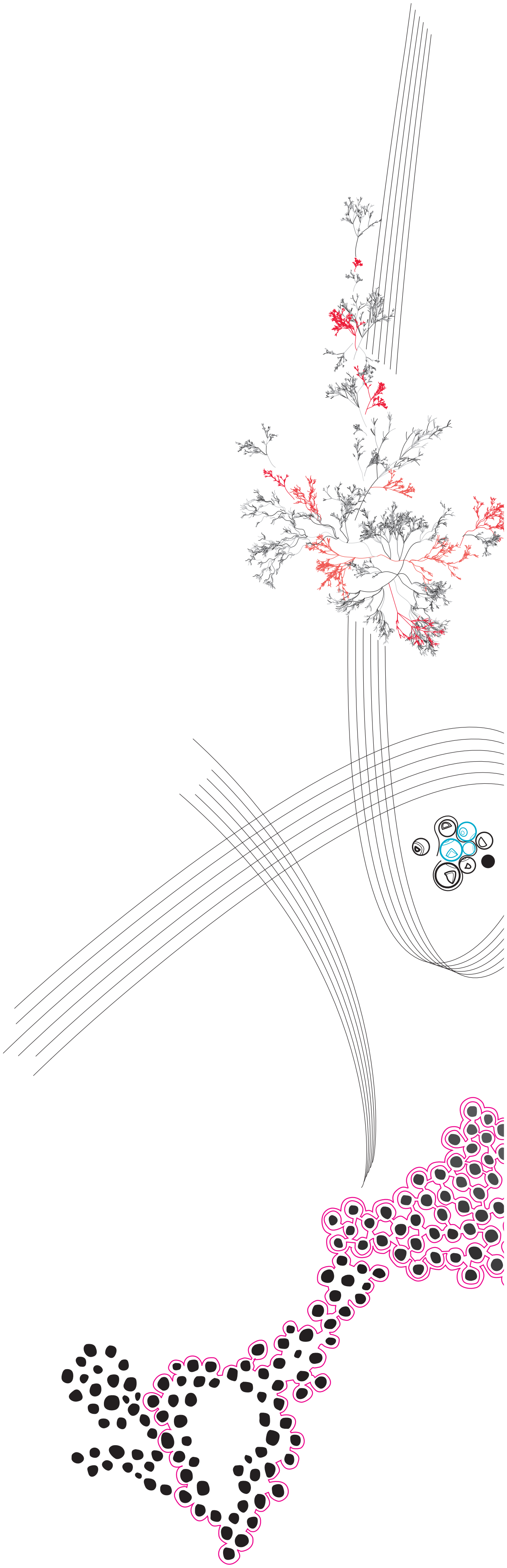

BACHELOR THESIS CREATIVE TECHNOLOGY

DEVELOPING A SMART RAINWATER BUFFERING SYSTEM FOR THE CITIZENS OF ENSCHEDE

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Abstract

Recently, more frequent and heavier rainfall has occurred in the Netherlands. This caused issues especially in the city of Enschede that is built on a gentle slope where rainwater will runoff, causing damage in the city centre. The sewerage system of Enschede is not built to handle this amount of rainwater. Therefore, the municipality of Enschede is looking for a solution to reduce the strain on the sewerage system; a smart rainwater buffer meant for implementation on the private properties of the inhabitants of Enschede.

Literature research showed many different uses for harvested rainwater. These range from outdoor uses, doing the laundry and replacing other potable water sources. In addition to this, already existing smart systems were found during background research. However, these were not designed for usage on private properties. The target area, the neighbourhoods de Bothoven and Velve-Lindenhof, has been analysed. From this analysis can be concluded that there is little space available for implementation of a buffer at the street side of the house where often the downspout is located. By conducting surveys and interviews with the target users, the citizens of the two neighbourhoods and the municipality of Enschede, requirements have been set-up. This was followed by a functional system architecture, serving as building blocks after which a prototype was developed.

The smart rainwater buffering system, Tonnie, consists of a smart buffer, a database and an interface. The smart buffer has several components including two solenoid valves for automatic and manual discharge towards the sewerage system or the garden, a faucet for tapping water, five flow sensors to measure in- and outgoing flows and an ultrasonic sensor to measure the water level inside the buffer. The interface has been programmed with JavaScript and contains almost all the user interaction with the system. By using this interface, citizens are able to select valves, set an amount of water that the system should discharge and open the valves. Furthermore, the buffer's performance is visualised including the current capacity, future catchment data, history data and precipitation data.

Finally, the system has been tested with five citizens. Overall, the test participants seemed to understand the interactions with the system and liked the interface. However, the system lacks feedback and a guide on how to interact with the system when using it for the first time. In addition, further testing should be done with a larger test group.

Acknowledgements

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1. Introduction

This chapter describes a detailed description of the situation, goal and challenges that are related to this graduation project. Afterwards a research question along with sub questions will be formulated which will be treated in this thesis. The final part of this chapter contains the document structure for the remainder of this thesis.

1.1 Situation

Due to global warming our climate is changing which causes more frequent and excessive rainfall. The traditional sewerage system that is used in the Netherlands cannot cope with sudden large amounts of rainwater, as it was not designed to do so [1]. A consequence of the excessive rainwater is that streets will be flooded more often which may cause houses and shops to get flooded as well. In addition to causing a lot of damage to buildings, water on the streets can be very dangerous for people. Manhole covers could come loose leaving a gap in the street where people or animals could get stuck. Furthermore, dirty sewage water that enters streets or buildings is hazardous for the health of inhabitants of the city.

The city of Enschede East is built on a gentle slope with a height difference of 40 meters between Enschede East and the rest of the city as can be seen in Figure 1. During heavy rainfall, the rainwater will flow downhill into the city centre where it can cause a lot of damage. To reduce the hazard of excessive water in the streets it is of great concern that the strain on the sewerage system is reduced. The municipality of Enschede is therefore looking for a smart solution to reduce the strain on the sewerage system at de Heurne and Oldenzaalsestraat, two streets close to the city centre of Enschede.

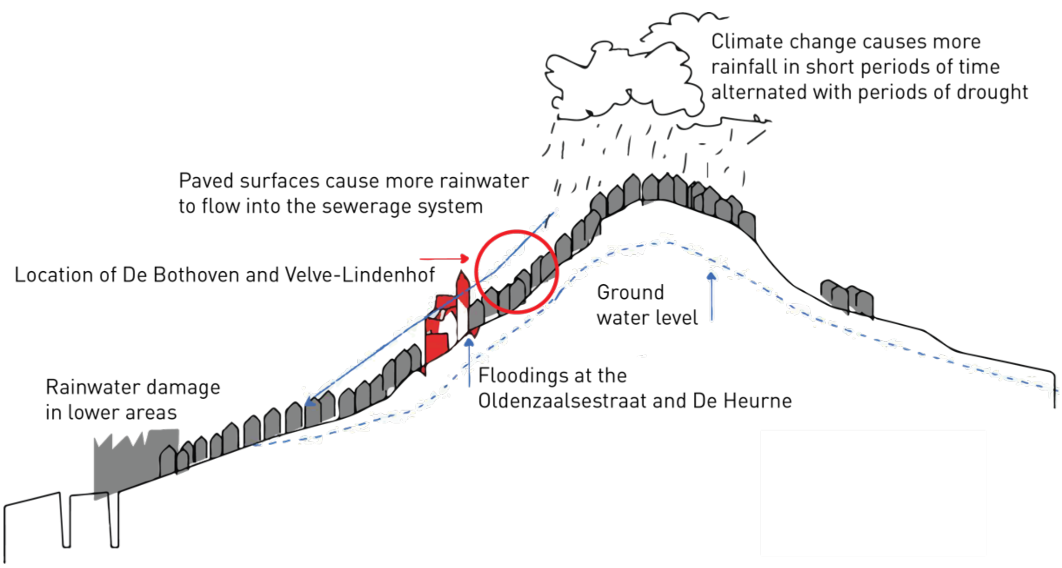


Figure 1. Situation and location of Enschede, image by Gemeente Enschede

De Heurne and Oldenzaalsestraat are marked by Hartemink and Meijer [2] as a risk area since these two streets enclose a shopping area in the city centre of Enschede. This area is very flat and the public buildings have no doorstep, making it easy for excessive water on the streets to penetrate these public buildings. This makes the impact of a certain heavy rainshower worse than on other locations, assigning a high risk to this area.

The municipality of Enschede is therefore looking for solutions to retain rainwater at de Bothoven and Velve-Lindenhof, two neighbourhoods located in the runoff area between Enschede East and the city centre, reducing the strain on the sewerage system at de Heurne and Oldenzaalsestraat.

1.2 Challenges

The goal of this graduation project is to develop an intelligent solution for rainwater buffering during rainfall, where both governance and technical aspects have to be taken into account, to reduce the strain on the existing sewerage system in Enschede with in particular the Oldenzaalsestraat.

It is very important for inhabitants of de Bothoven and Velve-Lindenhof to be closely involved to solve the problem of excessive rainwater on the streets and reducing hazardous situations for fellow citizens close to the city centre. The inhabitants of the two neighbourhoods live in the runoff area, in between the higher and the lower parts of the city, and might together be able to reduce the strain on the sewerage system at the lower parts of the city. Therefore, the main challenge is involving the inhabitants of the two neighbourhoods in the design process of a rainwater buffering system and raising awareness towards rainwater buffering.

1.3 Research Questions

Continuing the previous presented situation and challenges, a research question was setup that will be covered by this thesis: *How to develop a smart rainwater buffering system that reduces the strain on the sewerage system of the municipality of Enschede?*

To give an elaborate answer to this question two sub questions were identified to support the main research question.

- What solutions are feasible if system elements are located on the private properties of the inhabitants of 'de Bothoven' and 'Velve-Lindenhof'?
- What control functionality is needed to optimize buffering capacity of this system?

The two sub questions will help finding an answer to the main research question and will be answered throughout this report.

1.4 Report Outline

First, a background study containing a literature review about rainwater harvesting systems and its uses and a state of the art review will be discussed. After this, the methods will be explained that will be used for the remainder of the project in the report. Then the design process for Creative Technology will be applied, where each phase consists out of one chapter; Ideation, Specification, Realisation and Evaluation where the prototype will be tested. Finally, conclusions will be given, answering the research question and recommendations for future research will be discussed.

2. Background Research

This chapter will cover a literature research which will describe what would attract urban citizens to harvest rainwater themselves and covers a state of the art review that describes relevant, already existing systems concerning rainwater harvesting. Furthermore, this chapter describes the target area and target user with the final part of this chapter an overall conclusion of the background research.

2.1 Literature Review

The literature research covers a study on rainwater harvesting, trying to answer the question: *What would attract urban citizens to harvest rainwater themselves?*

The literature review starts by discussing different ways of rainwater retention, how a rainwater harvesting (RWH) system works, the uses of harvested rainwater and a study to different places in the world where it describes in what way different continents and countries apply rainwater harvesting. It is especially important to know the uses and implementations of other countries on rainwater harvesting since the Netherlands is rather lagging behind and not implementing rainwater harvesting on a large scale yet. Finally, the literature review tries to give an answer to the previously formulated question which will be discussed in the conclusion of this section.

2.1.1 Different ways of rainwater harvesting

Rainwater is most commonly harvested via rooftops, however its storage technology can differ. Urban areas generally have a large density of buildings which usually all have a roof. Therefore, according to Mehrabadi et al. [3] and Farreny et al. [4] the most common way to harvest rainwater is utilising roofs in urban areas since the runoff is less polluted than the runoff of other impermeable surfaces. However, GhaffarianHoseini et al. [5] state another, less common, way of rainwater harvesting where land surfaces and rock catchments can be utilised. As a result, to be able to utilize the collected rainwater, rooftops are most frequently used to harvest rainwater as its runoff is the least polluted.

Another distinction can be made in the storage technology where the harvested rainwater can be stored in varying tanks from above ground rain barrels to above or below ground cisterns. The rain barrels are containers that are usually made out of plastic or metal and have a capacity of only a few cubic meters. The cisterns however, are of larger size and usually made out of metal or plastic when above ground and concrete for below ground use [5]. Furthermore, a combination of a tank module with an infiltration system can be used, as well as rain gardens or bio retention cells for managing tank overflows. However, according to Campisano et al. [6] more advanced technological options are recently being implemented in the tank module which increases its complexity. Sensors are added to the tank to improve the control and automation of RWH systems for optimal management of the harvested rainwater. Therefore, many options are available to store harvested rainwater as various tanks can be applied depending on their usage.

2.1.2 Rainwater harvesting system

In literature, the core components of a RWH system are described in three different ways where some authors describe the same core components and other authors have additional parts added to the core components. According to Ghaffarian Hoseini et al. [5], Campisano et al. [6] and Haque et al. [7], a RWH system consists of three core components: collection system, storage system and application system. The first core component of a RWH system is the collection surface, which is as mentioned before, most commonly a rooftop. The second core component is the tank that stores the rainwater during rainfall that is delivered via a system of downspouts and gutters from the rooftop. The third core component is the application of the harvested rainwater, like a tap for rainwater use in the garden, to which the tank is connected by an infrastructure of separate pipes. These three components make the basis for a rainwater harvesting system.

Contradictory, Ward et al. [8] claim the rainwater delivery system to the tank a separate core component and does not mention the treatment of the water whereas Vieira et al. [9] divide a RWH system into five core components: A collection system, treatment system, storage system, distribution system and a water backup system.

Furthermore, for the various applications that are possible several additional modules can be used. Pumps are commonly used to get the water out of the tank to the usage destination whereas supplementary modules as filters, debris screens and a first flush diverter can be added to the RWH system for rainwater quality control. The filters and screens are used to intercept solids like debris, leaves and sediment in the harvested rainwater where the diverter separates and transports the most contaminated part of the rainwater to the sewerage system [6]. Pumps, filters, screens and diverters are no core components of a RWH system but can be added for usages applications.

2.1.3 Uses of harvested rainwater

There are four different uses of harvested rainwater in urban areas which nearly all aim to reduce usage from supplied (potable) water sources. The first and main use of harvested rainwater is using the collected water for toilet flushing, doing laundry and outdoor uses [6], [7], [9], also called the ''halfway house'' by Ghaffarian Hoseini et al. [5]. Outdoor uses for which rainwater can be used are for example garden irrigation, car washing and terrace cleaning. Ward et al. [8] state that toilet flushing, the laundry and outdoor uses account for 80% of the overall water consumption of a single household. By using harvested rainwater for toilet flushing, the laundry or outdoor uses, a significant amount of (potable) water can be conserved.

The second use for harvested rainwater is replacing potable water by the collected and treated rainwater, reducing the usage of the supplied potable water source. The replacement of potable water by treated rainwater is especially used in peri-urban areas where a source of water supply is not available in both developed and developing countries [7], [10].

The third use of harvested rainwater is local temperature control when rainwater is harvested on rooftops [10]. The rainwater on rooftops contributes to better isolation as it cools down buildings in summer if a layer of water is present.

The fourth and last use of harvested rainwater is using the rainwater as a thermal energy source for heating domestic water in the Nordic countries [11]. In contrast to an air cooling effect during rainfall, urban impermeable surfaces can absorb excessive heat within catchments to cool down the surfaces [10]. Furthermore, Scholz and Grabowiecki [13] and Novo et al. [14] studied how harvested rainwater from the urban environment can be combined with sustainable energy solutions by using storm water management techniques. To determine the thermal energy that will be available for an individual building's hot water usage, the temperature of the rainwater plays a significant role. Furthermore, the energy potential of the harvested rainwater can vary due to seasonal meteorological conditions as the needed heat at a specific location and the frequency of rainfall at catchments [11]. Therefore, using rainwater as a thermal energy source could be beneficial for heating domestic water as it reduces the energy costs.

2.1.4 Applications of rainwater harvesting in different continents and countries

Rainwater harvesting is widely used over the world in many different countries with varying purposes. Study by Handia et al. [15] shows that a substantial water source could be provided by rainwater harvesting across the continent of Africa. Rainwater harvesting is often used as a result of economic scarcity rather than physical scarcity in different parts of the continent. Meaning there is a sufficient amount of water available, however sufficient storing, treatment and transport are missing [6]. Furthermore, rainwater harvesting in ponds and storage tanks to provide water for households or large public buildings are widely used in Africa as well. Industrial and commercial companies have recently shown interest in rainwater harvesting as an alternative water sources for cooling and irrigation [16].

Rainwater harvesting plays an important role in Asia where it raises a lot of awareness. Local governments in Japan started promoting water recycling in the early 1980s for cities that were facing urban flood problems and water scarcity as an effective mitigation countermeasure [6]. According to Gould et al. [17], a rainwater harvesting project in China in 2000 has led to 2 million rainwater tanks that have been build supplying potable water for almost two million residents and supplemental irrigation. Furthermore, rainwater harvesting has been included in the Taiwanese Water Law as alternative domestic water supply source. This policy requires new buildings larger than 10.000 square meters to implement rainwater harvesting to cover at least 5% of the water that is required by the building [6].

Australia, where about 1.7 million households were in possession of rainwater tanks, widely used implementations of RWH systems which provided 8% of the household water use from 1 July 2013 till 30 June 2014. However, Campisano et al. [6] claim that limited data is available on rainwater harvesting usage in Australia where Silva et al. [18] state that rainwater is used for drinking in certain peri-urban and rural areas where no water sources is available. According to Campisano et al. [6] experience shows that rainwater harvesting is used for irrigation of gardens and sportsgrounds in public areas.

In European countries, the implementation of RWH systems is varied where the UK and Germany are leading in re-using rainwater. GhaffarianHoseini et al. [6] discuss that residents in the UK are collecting and storing rainwater for household use as the laundry and other cleaning purposes. Schools, office buildings and supermarkets are currently implementing more RWH systems due to their greater financial viability over household systems. However, Melville-Shreeve et al. [19] state recent innovation causes smaller systems to increase in popularity. Due to the promotions of rainwater harvesting in Germany, about one third of the new buildings in the country are provided with a RWH system. The uses of harvested rainwater are strictly limited to non-potable uses as toilet flushing, the laundry and garden irrigation due to strict drinking water regulations and air pollution [6]. Lately the popularity of RWH systems is also increasing in other European countries as Austria, Belgium, Denmark and Switzerland where the main driver is the potable water price [20].

In the USA rainwater harvesting is being used with the purpose of conserving potable water. The cities of San Antonio and Austin give subsidies to encourage usage of RWH systems for conserving water. The cities of New Mexico and Oregon also allow rainwater harvesting from rooftops which however need strict requirements for re-using the harvested rainwater. Systems in these cities vary from tanks for fire suppression to do-it-yourself rain cisterns for food garden irrigation [6].

In South America, rainwater harvesting is used as a potable water source replacement. A program in 2001 in Brazil helped about two million people living in semi-arid rural settlements where more than 350.000 cisterns have been constructed as the people had no access to nearby potable water [21].

2.1.5 Conclusion

Literature research done in the previous paragraphs describes rainwater harvesting in various ways with rooftop rainwater harvesting the most common and efficient way, as the roof runoff is less polluted than the runoff of other impermeable surfaces. A rooftop could therefore be part of a RWH system which consists of three core components: collection system, storage system and the application system where a delivery system and distribution system can be described as a piping infrastructure and several extra modules can be added to improve the RWH system.

To get to an answer to what would attract urban citizens to harvest rainwater themselves, it is important for urban citizens to gain something when they would implement rainwater harvesting. One of the main uses of harvested rainwater in urban areas is using the collected water for toilet flushing, doing laundry and outdoor uses. By doing so, a significant amount of water can be conserved and therefore the costs on potable water sources can be reduced. Another significant implementation of the harvested rainwater in urban areas is using the harvested rainwater as replacement source for drinking water. This however needs additional treatment which would make a RWH system more complex and expensive, making it less attractive for users. Implementing rainwater harvesting for local temperature control or as a thermal energy source reduces the costs on potable water sources less and the latter needs further research before it can be widely implemented.

It can be concluded that the main benefit of implementing rainwater harvesting is that the costs on potable water sources can be reduced as the collected water can be used for household activities and therefore replace the potable water sources.

In addition, further research has to be done to determine which size an urban catchment area is required to collect the amount of rainwater satisfying the demands for individual domestic hot water use as the size of the catchment area and the storage tank will depend on the availability of free space and the usage of water.

In section 2.3 the target area will be investigated, which should give more insights in the available options concerning the available space of the properties of inhabitants of de Bothoven and Velve-Lindenhof.

2.2 State of the Art Review

This chapter describes the already available or being developed products related to smart rainwater harvesting and buffering. The first four sections describe developed smart rainwater buffering systems ranging from do it yourself programmable rainwater buffers to a smart controllable valve that can be placed on a rooftop. Furthermore, non-intelligent systems will be described which might be able to offer opportunities to be made intelligent.

2.2.1 Rainwater Harvesting by LOXONE

LOXONE is aiming for a smart home, where daily activities become automated and energy is being saved [22]. The company is selling miniservers and smart accessories that can be operated through the miniserver.

LOXONE wants to make rainwater harvesting smart by connecting an ultrasonic sensor in a tank to their miniserver. According to LOXONE, an app that displays the tank volume at any time on a smartphone or tablet is essential for smart rainwater harvesting.

Furthermore, LOXONE recommends automatic email notifications to notify the user when the water level inside the tank is low and an additional alert if the pump stops working for any given reason. The ultrasound sensor has a built-in 0-10V transmitter and senses the level of rainwater inside the tank and sends the data over to the miniserver. With the LOXONE software configuration users can implement the system in just a few minutes. Using the correct overall setup and the function block for the sensors provided with the software saves the user a lot of time monitoring and programming.

2.2.2 De Slimme Regenton by Bas Sala

De Slimme Regenton is a smart rainwater barrel that buffers and retains rainwater which is currently under development by Bas Sala [23]. This rainwater barrel is designed to offer a customised solution to reduce the strain on the sewerage system in dense urban areas that have many paved streets and therefore a water storage shortage. By using a monitoring system, water authorities can get access to the available collection capacity of the rainwater barrels which makes De Slimme Regenton suitable for a combined use with other climate adaption systems. Bas Sala aims to implement 5 components that can be seen in Figure 2.

In addition, Bas Sala is developing a portal which powers the barrels and receives data from the barrels. The portal will be linked to the weather forecast to anticipate on predicted rainfall and will also be able power other systems, monitor them and acquire data. However, the data analysis is still very limited at this moment.

Figure 2. Components De Slimme Regenton by Bas Sala

De Slimme Regenton is vandalism proof and can be implemented at participation projects where it raises awareness for inhabitants concerning excessive rainwater. It is intentionally designed for public spaces and in the summer of 2017, De Slimme Regenton will start serving as a water reservoir for irrigation of public green. Furthermore, the goal is to implement De Slimme Regenton in projects where the municipality, water authorities, companies and housing associations work together with inhabitants working on a future with rainwater buffers.

In Figure 3 the Memphis Rainbarrel can be seen which is especially designed for implementations in public spaces. De Slimme Regenton comes in different variations, depending if it will be implemented in public or private spaces.

Figure 3. Memphis Rainbarrel by Bas Sala

2.2.3 Tank Talk by IOTA

Tank Talk is a rainwater tank network developed by IOTA [24], which is owned and managed by South East Water Australia. Tank Talk is developed to minimise the risk of flooding and damage by excessive storm water, and dramatically reduce water pollution. It is designed to find an automated solution that optimizes the storage capacity of multiple tanks in a catchment and ensure that the tank network remain operational at all times, reducing network maintenance costs. Users can limit the possibility of floods and storm water overflows themselves by using the system. Tank Talk will anticipate on the weather forecast when discharge is required to provide enough capacity to harvest the predicted rainfall [25].

Tank Talk monitors water levels inside a rainwater tank and automatically releases tank water at chosen set points by the user and a controlled rate, creating storage capacity in the system and preventing excessive overflows. When rainfall is predicted by the Bureau of Meteorology, a weather institute in Australia, the system will receive these predictions via a communications link and will pre-emptively discharge the water level in tanks to provide the capacity to capture and hold the incoming rainwater. Tank Talk works by forward analysing and predicts weather patterns five days in advance.

The system is designed to give centralized control to storm water infrastructure owners such as councils and is very simple in usage. Users can monitor and operate tanks remotely by using a web based application on the computer or by using the Tank Talk app on a tablet or smartphone. The cumulative capacity can be monitored and controlled in real time, being able to change the collective storage volume. Furthermore, the tank's drain valve can be operated manually, releasing the harvested water in dryer periods to return flow to rivers and creeks.

The tank data is stored so users can view the performance history at any given time. The Tank Talk app and web application provide easy to read graphs giving historical information about daily rainfall, daily drain volumes, performance results and tank levels. Screenshots of the app provided by AppAdvice [25] can be seen in Figure 4.

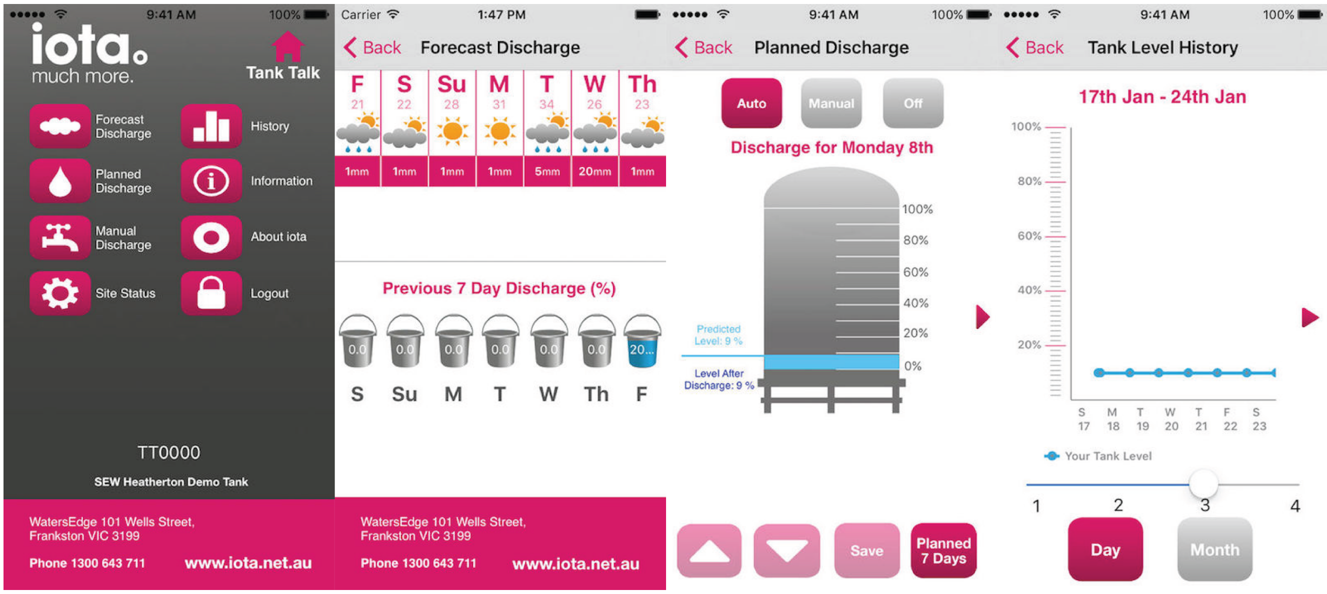


Figure 4. Tank Talk iPhone app screenshots by IOTA

According to Sustainability Matters [26] the software is designed to learn and self-correct from rain events as varying tank and roof combinations react differently to the intensity and volume of the rainfall. By using an algorithm, it can be analysed how successful the harvesting of rainwater was and adjust accordingly for future rainfalls. IOTA aimed to use software and products that could monitor local weather forecasts and anticipate on these by controlled releasing water in the tank before predicted rainfall.

Tank Talk was tested at Dobson's Creek Australia, which was severely impacted by storm water flows. To manage the water inside the tank, a microprocessor was linked to a solenoid valve at the outlet of the tank. These units were linked via a telemetry unit, which also monitored the weather forecasts, and were controlled by South East Water's SCADA network, a supervisory control and data acquisition which is a monitoring and controlling system architecture.

The residential rainwater tanks had dual and conflicting purposes which added complexity to its development. The first purpose was leaving space within the tank to harvest heavy rainfall. However, the second purpose was retaining water in the tank for private household uses for inhabitants. The microprocessor was only used to release a sufficient amount water from the tank in order to be able to harvest the predicted rainfall. This means that a smaller rain shower would not necessarily require all the harvested water inside the tank to be released again, but only a smaller volume. Therefore, the microprocessor's software algorithm needed to be able to self-correct and learn, reacting to each rain event to ensure both purposes were fulfilled. The algorithm checked the success rate of the harvested rainwater for each rain event and how the volume inside the tank should be changed for rainfall in the future.

By implementing Tank Talk, South East Water was able to retain control over multiple tanks and monitor their performance via the SCADA system. By accessing the SCADA Tank Talk web application, the user would retain control over the harvested rainwater by controlling the tank's set points and release valve.

2.2.4 Smart Flow Control by Optigreen

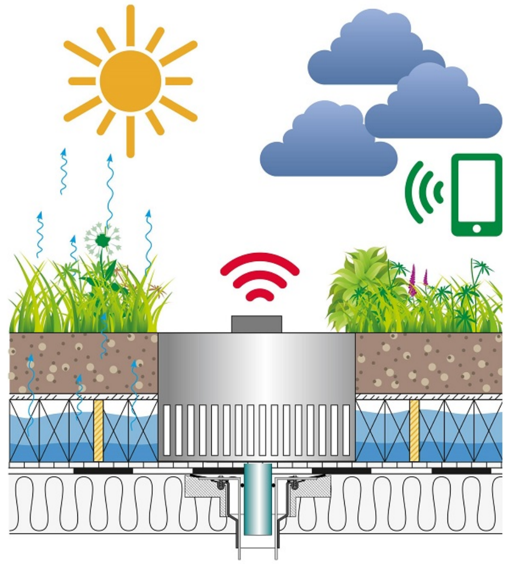


Figure 5. Smart Flow Control by Optigreen

Developed by Optigreen, Smart Flow Control is a computer powered outflow valve that is controlled via a weather forecast app and can be placed on top of the waterspout outlet on a flat rooftop [27], [28]. Smart Flow Control can be seen in Figure 5. The Smart Flow Control analyses weather forecasts and determines, based on the storage capacity of the rooftop, whether or not the next predicted rainfall is can be stored on the rooftop.

Smart Flow Control works best in combination with water retention boxes. Vegetation can be placed top of these retention boxes that will have access to the buffered water via vertical capillary tubes. When rainfall is predicted via an internet linked weather app, Smart Flow Control will open the outflow valve and makes storage capacity available for the predicted rainfall.

For example, if rainfall is predicted, the system discharges prior to the rainfall but only just enough to have space for the next rainfall. Therefore, outflow of the rainwater only happens prior to rainfall, when there is no strain yet on the sewerage system. During rainfall, rainwater will be buffered and the strain on the sewerage system will be reduced.

Furthermore, with Smart Flow Control the water level on the roof can not only be automatically controlled. It is possible to manually or remotely control the system, creating opportunities for institutions to link multiple Smart Flow Control systems in a network to control rainwater buffering in a larger area.

2.2.5 Other Rainwater Buffering Systems

In addition to smart rainwater buffering systems, there are many other rainwater buffering systems that are not intelligent. An example of available rainwater buffering systems in a garden are illustrated in Figure 6. This example includes a rainwater pond, a roof surface as catchment and retention area, a rainwater barrel, underground infiltration crates, a rainwater harvesting fence and furniture.

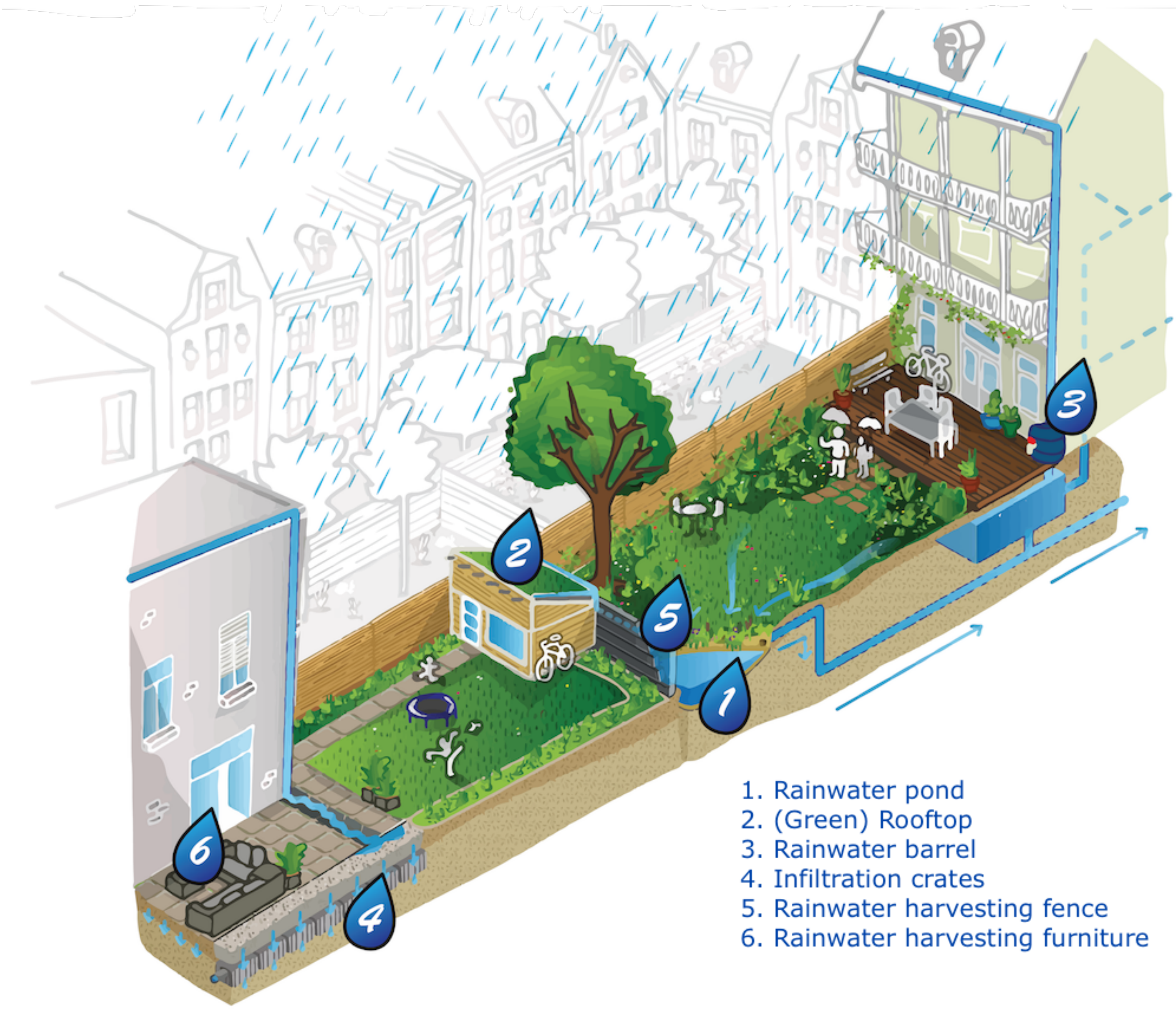


Figure 6. Rainwater buffering systems for garden implementation by Amsterdam Rainproof

An overview of the above-mentioned systems and other non-intelligent water buffering systems can be found in *Appendix A*.

2.2.6 Conclusion

State of the art research done in the previous paragraphs describes only four smart rainwater buffering systems that are under development or already existing. The first system that was described is LOXONE which offers a do-it-yourself style rainwater harvesting system that can be integrated in a smart home. With their components and software, users themselves are able to programme a system that measures tank water levels amongst other things and receive this data in an app.

The second system, De Slimme Regenton by Bas Sala, is a rainwater buffer that is currently still under development. The system aims to anticipate predicted rainfalls and empties its tank prior to rainfall, reducing excessive water on the streets. Furthermore, the user will be able to monitor the system by using an app and re-use the harvested water for public green. The goal is to raise awareness and participation towards rainwater buffering with the inhabitants of the Netherlands.

The third system is a smart network of tanks, Tank Talk. It is designed to find an automated solution that optimizes the storage capacity of multiple tanks in a catchment and ensure that the tank network remain operational at all times, reducing network maintenance costs. The tested residential rainwater tanks had two purposes; leaving space within the tank to harvest heavy rainfall and retaining water in the tank for private household uses for inhabitants. A microprocessor was used to release a sufficient amount water from the tank in order to able to harvest the predicted rainfalls and its software algorithm was able to self-correct and learn, reacting to each rain event to ensure both purposes were fulfilled.

The fourth and final system is Smart Flow Control, a computer powered outflow valve that is controlled by a weather forecast app and can be placed on top of the waterspout outlet on a flat rooftop. Smart Flow Control analyses weather forecasts and determines, based on the storage capacity of the rooftop, whether or not the next predicted rainfall is able to be stored on the rooftop. When this is not the case, the exact amount of water that is predicted will be discharged via the valve, leaving room on the rooftop for harvesting the predicted rainfall and therefore reducing the strain on the sewerage system.

From this state of the art research, it can be concluded that there are only a few developed smart rainwater buffering systems, creating many opportunities for own development. However, there are many non-intelligent rainwater buffering systems as infiltration crates, water buffering furniture and more. All these non-intelligent rainwater buffering systems have potential to be made smart.

2.3 Target Area

The target area for this research is defined by the municipality of Enschede and can be seen in Figure 7, a screenshot taken from Google Maps [31]. As was described in the introduction, this area was chosen to reduce the strain on the sewerage system at the Oldenzaalsestraat and Heurne, which is marked as a high risk area. This is because water from Enschede East will flow towards the city centre during heavy rainfall as Enschede East is 40 meters higher in altitude than the city centre.

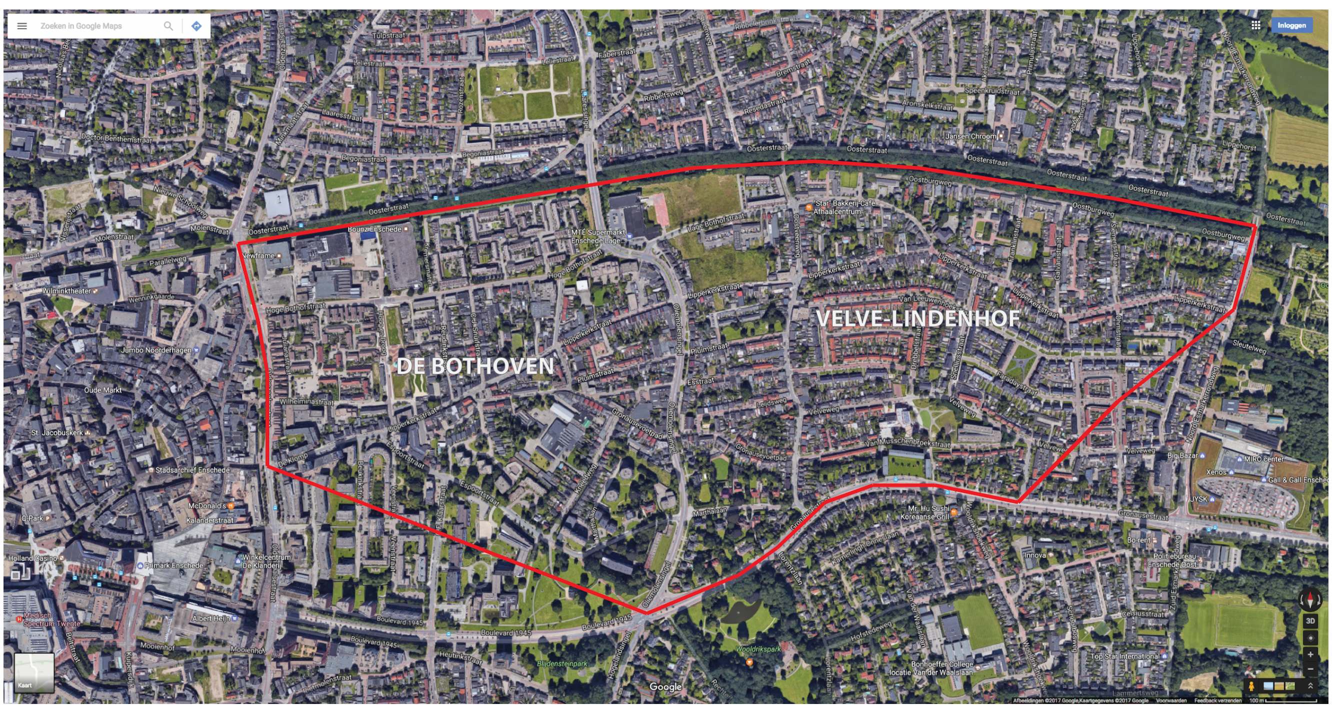


Figure 7. De Bothoven and Velve-Lindenhof via Google Maps

There is a total of 5845 households in de Bothoven and Velve-lindenhof which will be roughly rounded to 5000 households to fit the target area, as it is not containing both neighbourhoods completely. The household data of de Bothoven and Velve-Lindenhof can be found in Table 1.

According to Erik Dekker [32], about 7.000.000 litres of water need to be buffered to significantly reduce the strain on the sewerage system during a heavy rain shower.

Observations in the neighbourhoods showed that the houses range from old semi-detached to newer semi-detached buildings as can be seen in *Appendix B*. Only a few large buildings like flats and senior housings were present and the same goes for detached houses of which only a few have been found.

In addition, some houses have a garden as part of their property. In these neighbourhoods, the front yards are very small if there is a front yard at all (which was often not the case.) Google maps data [31] shows however that most houses do have a reasonable backyard often paved or with grass which can be derived from Figure 7.

During the observation of the two neighbourhoods, a handful of houses with a green roof have been found which is already a form of rainwater retention and could be well combined with a smart rainwater buffering system. Therefore, a roof can be considered a very important actor where the distinction can be made between pitched roofs and flat roofs. Most semi-detached houses in the neighbourhoods have a pitched roof, where the flats, senior housings and larger companies have a flat roof.

The final important actor for rainwater harvesting are downspouts that lead the rainwater on roofs into the sewerage system. Many houses in these neighbourhoods had the downspouts in the front of their house, running from the roof into the ground.

Table 1. Household data de Bothoven and Velve-Lindenhof 2016

Neighbourhood	De Bothoven	Velve-Lindenhof
Households		
Number of households	3 575	2 270
Single Household	65 %	46 %
Household without children	22 %	25 %
Household with children	12 %	30 %
Average household size	1,5	2
Area		
Land	65 ha	74 ha
Water	0 ha	0 ha
Density		
Address density	3 962 addresses / km2	2 421 addresses / km2

2.4 Conclusion

From the literature review in section 2.1 was concluded that the main benefit of implementing rainwater harvesting is that the costs on potable water sources can be reduced as the collected water can be used for household activities and therefore replace the potable water sources. The goal of this project is developing a smart rainwater buffering system rather than a smart rainwater harvesting system. However, it would be a very positive side effect if the system is designed in a way that the inhabitants will be able to re-use the buffered rainwater. In addition, the literature review concluded that it is important to determine which size an urban catchment area is required to collect the amount of rainwater satisfying the demands for individual domestic hot water use as the size of the catchment area and the storage tank will depend on the availability of free space and the usage of water. For developing a smart rainwater buffering system it is important as well that the sizes and available spaces for the urban catchment areas are researched which was globally done in section 2.3.

In section 2.3. research was done to the target area. It became apparent that some houses have a garden as part of their property. In these neighbourhoods, the front yards are very small if there is a front yard at all (which was often not the case.) Google maps data showed however that most houses do have a reasonable backyard, often paved or with grass. Knowing most houses have significant space in their back yards is encouraging for developing a smart rainwater buffer. However, roofs can also be utilised for buffering rainwater which can be assumed, all houses have. The distinction is made between pitched and flat roofs where flat roofs are a great buffering surface.

Finally, the state of the art review concluded only a few smart rainwater buffering systems that have already been developed. However, there are many non-intelligent rainwater buffering systems as infiltration crates, water buffering furniture and more. Together, this creates many opportunities for the development of a smart rainwater buffering system as there are only a few systems existing and some of the non-intelligent rainwater buffering systems have great potential to be made intelligent. Examples could be water buffering roofs, furniture, fences and underground crates that could all be easily placed in a garden.

It is important that further research should involve the inhabitants of the two neighbourhoods in developing a smart rainwater buffering system and research if they would be interested in buffering rainwater at all.

3. Methods and Techniques

This chapter describes the methods and techniques that are applicable for this bachelor thesis with emphasis to the design process for Creative Technology.

3.1 Design process for Creative Technology

Throughout the bachelor study Creative Technology, the design process for Creative Technology [33] has been implemented thoroughly during the execution of projects [33].
The design process for Creative Technology is based on two models. Jones [34] described a classical model for creative design process in 1970 that consists of a divergence phase followed by a convergence phase. Furthermore, spiral models have been described as a process where all design steps are interconnected and can be rearranged in any suitable order where each step concludes with a reflection phase.
The design process for Creative Technology has the same aspects as the classical model for creative design where it consists of a divergence phase followed by a convergence phase. This implies that all the possibilities are explored as the design space is opened up and defined before creating a solution by reducing the design space. With the characteristics of a spiral model, the process of exploring possibilities before creating solutions is repeated several times to create different solutions. The structure of the design process for Creative Technology can be seen in Figure 8.

3.1.1 Ideation

The first phase of the design process for Creative Technology is the ideation phase. The ideation phase is characterised by its design question. The design question is the starting point of the design process for Creative Technology which in this case are the research questions mentioned in chapter 1. The goal of the ideation phase is generating a creative idea by finding the user needs, stakeholder requirements and finding a technology. By doing observations and interviews on users and experts the user needs can be defined and to find the stakeholder requirements a story board, sketches, mock-ups and prototypes can be made. By knowing the technology that is used for a project, tinkering can be applied with the goal to identify new applications for the chosen existing or new technology [35]. Combining all these aspects, the ideation phase results in a more elaborate project idea in combination with the problem requirements.

3.1.2 Specification

The second phase of the design process for Creative Technology is the specification phase where the requirements can be denoted that have been discovered during the Ideation phase. The specification phase is characterised by exploring the design space by using several prototypes after which feedback loop and a short evaluation is applied. To find the experience specification, a use scenario and story board can be made. Next to an experience specification a functional specification must be identified which both together lead to early prototypes. Functionality and user experience influence each other which can lead to new prototypes. Here, the prototypes are often reduced to only a few aspects of the to be designed product.

3.1.3 Realisation

The third phase of the design process for Creative Technology is the realisation phase. The realisation phase is characterised by the decomposition of the start specification, realisation of the components followed by the integration of components and the evaluation of these components.

3.1.4 Evaluation

The fourth and final phase of the design process for Creative Technology is the evaluation phase. The evaluation phase is characterised by more elaborate functional testing, of which some already might have taken place in the realisation phase. The goal of the evaluation phase is to evaluate if all the requirements that have been set-up in the Specification phase are met, usually done by user testing which verifies whether the decisions taken facilitate the intended experience and satisfy the defined user requirements. However, prior to the user testing, it should be validated that the subsequent specifications are met by the end prototype, typically done by functional testing. Furthermore, the created result can be placed in the context of existing work. The methods used for the evaluation user test protocol will be described in section 7.3.

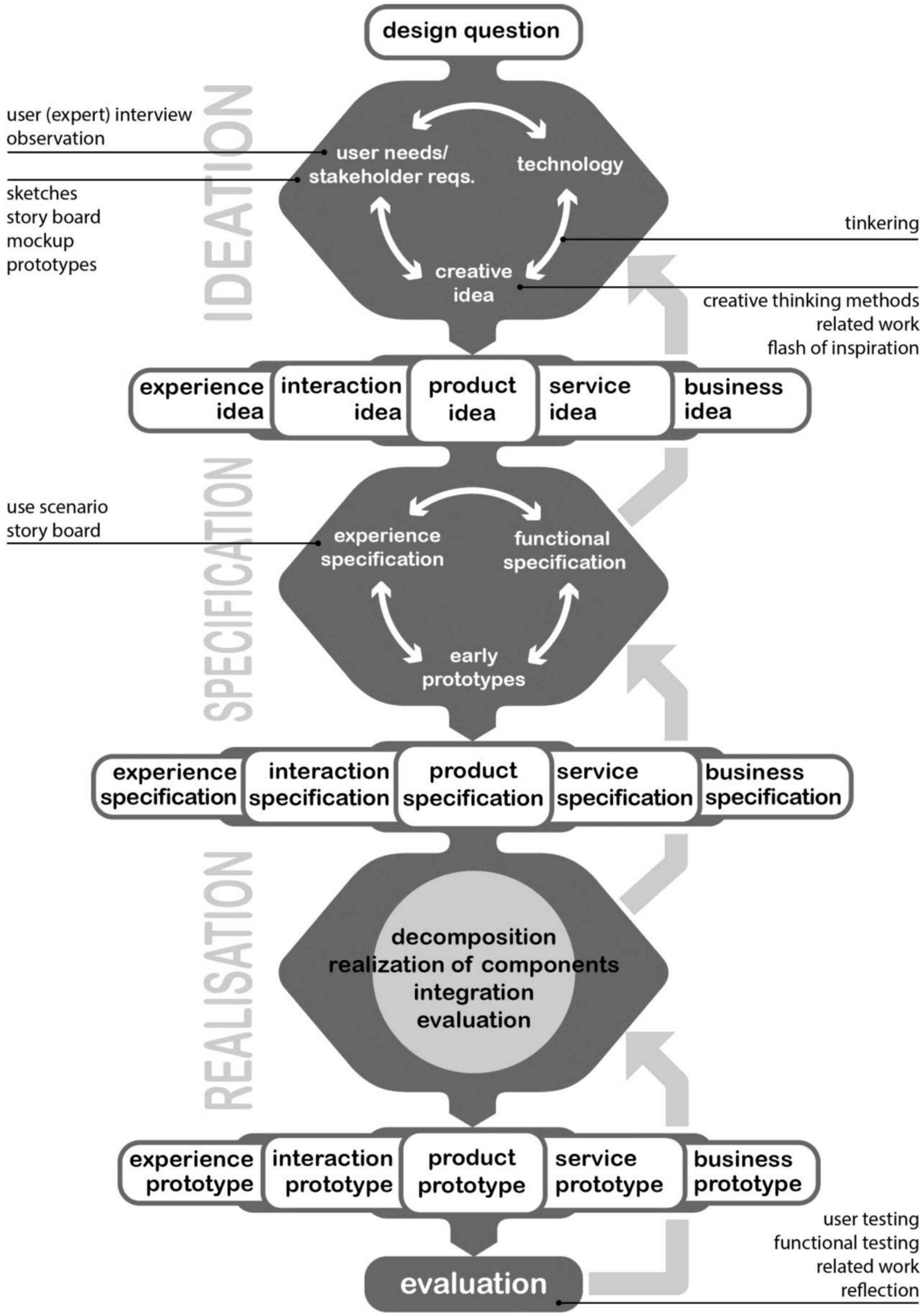


Figure 8. Design process for Creative Technology by A. Mader and W. Eggink

3.2 Requirement Analysis

The requirement analysis for this project consists of setting up user requirements and categorise them as functional and non-functional requirements. A functional requirement specifies something the system should do like a behaviour of function. A non-functional requirement describes how the system should behave and how it works where it specifies the system's quality attributes and characteristics [37].
Furthermore, the set-up user requirements will be transcribed to system requirements. The system requirements will be the basis upon which the system can be built.

3.2.1 MoSCoW

In addition, the requirements will be prioritised to find the most essential requirements and the least essential requirements. The prioritisation of requirements will be done by using MoSCoW which can be categorised in four types and stands for must have, should have, could have and won't have. The 'must' requirements are most important and need to be implemented for the basic functionality of the system.

3.3 Stakeholder Analysis

The stakeholders will be analysed by questionnaires and interviews. By doing this, insights will be gathered on the needs of the stakeholders.

3.3.1 Interviews

There are five different techniques possible for conducting interviews [37].

Informal interviews
The interviewer talks informally with the interviewee which resembles a normal conversation since it lacks the usage of an interview guide. An informal interview fosters low pressure and allows interviewees to speak more openly and freely.

Unstructured interviews
The interviewer defines the goal and focus prior to the interview which guides the discussion. It lacks the usage of a structured interview guide but it lets interviewees express themselves in their own ways and open-up.

Semi-structured interviews
An interview guide is developed which lists topics and questions in a specific order that need to be covered during the interview. The interviewer follows the guide but when appropriate, is also able to follow different trajectories in the conversation that stray from the guide.

Structured interviews
Questions are created prior to the interview with an interview guide that is closely followed. Little room for variation is present and questions are standardized and kept consistent for each interview.

Focus groups
Data is collected by conducting a semi-structured interview on a specific topic to explore new research areas, difficult observable topics or sensitive topics.

For this project, both a mix of informal interviews and unstructured interviews will be used during appointments with the municipality. These techniques are chosen to keep the conversations open and freely as well as being able to discuss relevant questions and topics. Furthermore, semi-structured interviews will be conducted with other stakeholders that are less well-known with the project.

3.4 PACT Analysis

The aim of the design of the system is to achieve harmony between the needs of people who execute specific activities in specific context using specific technologies. The PACT analysis can be used for understanding the current situation or improving the situation for the future. PACT is an acronym where the P stands for People, the A for Activities, the C for Context and the T for Technologies. PACT is a framework that can be used to describe the user's perspective [38], [39].

To find the variety of people, activities, contexts and technologies, interviews of stakeholders will be conducted along with surveys. Furthermore, from the PACT analysis scenarios can be created to get a clear vison on the people that are involved at this design process.

People
The people contain all the various stakeholders that should be considered for the designed product.

Activities
It is very important to consider the possible complexity of the activity, cooperative features, the temporal features and the nature of the data. The activity can for example be difficult or simple, many steps or only few steps and focused or vague whereas the temporal features should consider frequency, peaks and can be interruptible or continuous.

Context
The context implies the social, physical and organisational settings of the system.

Technologies
The technologies concentrate on in- and output, content and communication.

3.5 FICS

To describe the designer's perspective, FICS can be used which is an acronym and stands for functions and events, interactions and usability issues, content and structure and style and aesthetics. In chapter 5, both PACT and FICS will be combined to design a combined user's and designer's perspective scenario [40].

3.6 Functional Architecture

To identify the system's functions and interactions, a functional architecture model can be made that defines how functions are operating together to execute the system's missions [41]. In order to create a functional architecture, the functional requirements that will be described in chapter 5 will be decomposed, and put into sub functions where they are related to the system elements that will make up the final design.

4. Ideation

This chapter describes the initial ideation phase of this project with the goal to come up with feasible ideas that will be further developed in chapter 5.

4.1 Idea Generation

Chapter 2 described some already existing smart and non-smart products that are able to harvest rainwater. Some extra ideas have been generating by brainstorming that consist of existing products and non-existing products and can be found in *Appendix C.*

In addition, the developers of the Tank Talk system as described in section 2.2.3 have been contacted and interviewed about a few features of their system. This interview can be found in *Appendix D.* From this interview can be concluded that the Tank Talk system discharges one day before anticipated rainfall and its technology is now being reused in another system where rainwater is being converted to hot water. In the Netherlands however, the precipitation prediction is not accurate enough to predict rainfall one day ahead.

4.1.1 Interviews

In chapter 2 it was mentioned that according to Erik Dekker, about 7.000.000 litres of water needs to be buffered to significantly reduce the strain on the sewerage system during a heavy rain shower. However, according to Hendrik-Jan Teekens from the municipality of Enschede, 1.000.000 litres of water needs to be buffered at private property of the citizens. This was concluded from an interview which can be found in *Appendix E*. This would imply that each household roughly needs to buffer 200 litres of water since the estimated number of households in the target area was five thousand (1.000.000 litres / 5000 = 200 litres, taking roughly 0.2 cubic meters of space.)

4.2 Stakeholder Analysis

For this project, the two main end users can be defined, the municipality of Enschede and the inhabitants of de Bothoven and Velve-Lindenhof. This section includes a background research towards the inhabitants of these two neighbourhoods after which the inhabitants will be further analysed by conducting surveys. These two main end users are also the two most important stakeholders, however two extra stakeholders will be discussed in section 4.2.1 that could have a great potential interest in the system as well.

4.2.1 Stakeholder Descriptions

Stakeholders are defined by Freeman [42] as:

'A stakeholder in an organisation is (by definition) any group or individual who can affect or is affected by the achievement of the organisation's objectives.'

Stakeholders can interact with each other and be related to each other. These interactions vary from exchanging product, instructions, information or providing tasks [43]. This section will describe the possible stakeholders related to this project and how the stakeholders are related to each other.

Citizens

The citizens are defined as the inhabitants of the two neighbourhoods de Bothoven and Velve-Lindenhof. These are the most important stakeholder since the smart rainwater buffering system is designed for their usage on their private property and the citizens are the targeted main end users for the smart rainwater buffering system. Due to their age and educational differences, the cognitive and physical characteristics of the citizens can differ a lot as well as their personal interests and hobbies.

However, it might be interesting to notice that these citizens can be categorised in two categories. These are citizens who rent their house and citizens who own a house. Therefore, the housing association will be described as a separate stakeholder as well.

Municipality
The municipality of Enschede is another very important stakeholder and main end user of the system. The municipality of Enschede is actively searching for a solution to buffer rainwater in the city on a local level and plays an active role when it comes down to the functionalities of the smart rainwater buffering system. The municipality is responsible for the sewerage system in the city and it is in their favour that the strain on the sewerage system is reduced during heavy rainfall by buffering rainwater on a local level at the citizen's properties. People who work for the municipality are often adults between the age of 20 and 67, master the Dutch language very well and can be considered more homogeneous than heterogeneous.

Water Authorities
The water board Vechtstromen is another stakeholder that might be very interested in a smart rainwater buffering system. They could be another potential end user that controls the water treatment, water quality and water quantity. Just like the municipality of Enschede, they plead for less rainwater in the sewerage system and want rainwater to be returned into nature.

Housing Association
There are three main housing associations present in Enschede, Domijn, Ons Huis and de Woonplaats. These housing associations own buildings and rent out houses to people who want to live in the city of Enschede. A housing association can sometimes be responsible for severe changes on the house like re-painting the window frames outside and smaller maintenance like changing locks. The smart rainwater buffering system can be placed in the same category and installing such a system or maintenance can be placed under activities that have to be executed by the housing association.

4.2.2 Background Research

Population data, taken from Centraal Bureau voor de Statistiek [30], of the inhabitants of de Bothoven and Velve-Lindehof about age distribution, marital status and origin can be found in Table 2. It is notable that the largest group of inhabitants of the two neighbourhoods are between 25 and 45 years old, the man to woman distribution is about equal and the majority of the people are originally from the Netherlands.

Table 2. Population data de Bothoven and Velve-Lindenhof 2016

Neighbourhood	De Bothoven	Velve-Lindenhof
Inhabitants		
Number of inhabitants	5 700	4 550
Male	2 835	2 300
Female	2 860	2 245
Population density	8 810 inhabitants / km2	6 155 inhabitants / km2
Age distribution		
Up to 15 years old	9 %	15 %
From 15 to 25 years old	18 %	16 %
From 25 to 45 years old	29 %	29 %
From 45 to 65 years old	19 %	25 %
From 65 years old	25 %	14 %
Marital Status		
Unmarried	56 %	55 %
Married	25 %	33 %
Divorced	10 %	8 %
Widowed	9 %	5 %
Origin		
Western countries	13 %	13 %
Non-western countries	17 %	16 %
Morocco	2 %	1 %
Dutch Antilles and Aruba	1 %	1 %
Surinam	1 %	1 %
Turkey	5 %	7 %
Other non-western countries	8 %	6 %
Dutch	53 %	55 %

4.2.3 Surveys

To get better insights on the inhabitants of the target area and wishes of these citizens, a survey was conducted. The questions of the survey and the results can be found in *Appendix F* and *Appendix G* respectively.

Thirteen participants have filled in the survey, all from De Bothoven of which 62% of the participants were female against 38% male. Roughly half of the participants once experienced problems caused by excessive rainwater, both in their own street as well as in the city centre. When asked if they wanted a rainwater buffer on their property only 8% answered yes whereas 69% answered maybe and 23% answered no. Interesting is that when people were asked if they wanted a rain water buffer to contribute to less rainwater problems 31% answered yes whereas 38% answered maybe and 31% answered no. When asked if they wanted a rainwater buffer when the harvested rainwater could be re-used 69% of the people answered yes whereas 23% answered maybe and 8% answered no. It is therefore important for the system to have the possibility of rainwater re-usage. In addition, the majority of the people had no trouble if the municipality would use their buffer information to improve the system.

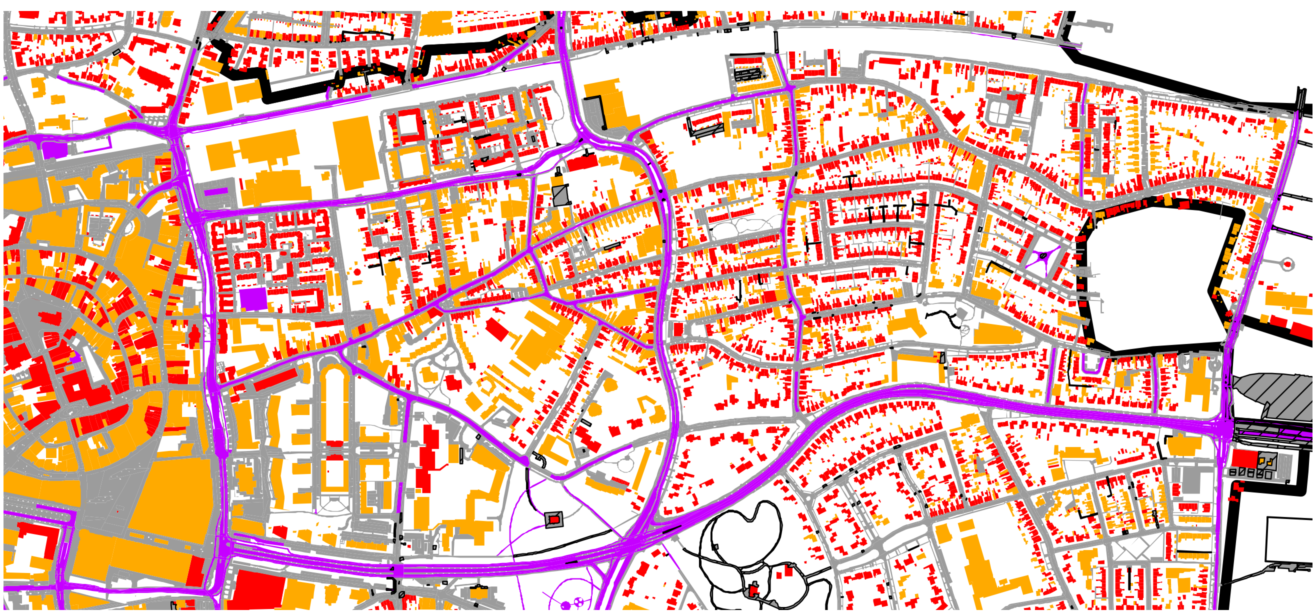
Finally, people were asked what type of rainwater buffer they liked most. From high to low their votes went to a rainwater buffering/green roof, rainwater harvesting fence, rainwater planter and lastly a rain barrel.

4.3 Target Area Analysis

Section 2.3 provided a global analysis on the target area, based on observations. To get a clearer understanding of the target area, two topics will be researched. Research will include the types of roofs present in the target area and a property analysis to find out if placing a rainwater buffer is possible.

4.3.1 Roof Analysis

A rooftop can not only be used as a catchment area but could function as harvest area as well. The two types of roofs can be distinguished from Figure 9, where red implies a pitched rooftop and orange implies a flat rooftop.



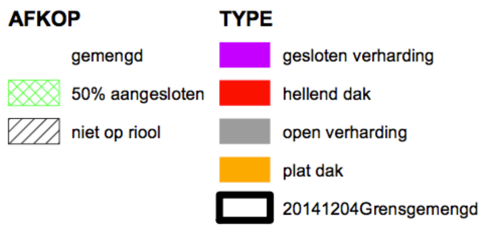


Figure 9. Roof types and pavement in target area. Image by Witteveen+Bos

According to an interview with a representative for the housing association Domijn, every rooftop of a house would be able to withstand at least 70kg/m^2 for a longer period of time. However, rainwater can be only harvested on flat rooftops. In addition, these rooftops have to contain a special roofing, as the standard roofing for flat rooftops is often gravel which will contaminate the rainwater. The interview with Domijn can be found in *Appendix H*.

From Figure 9, it can be seen that most houses have a pitched rooftop whereas larger buildings often have a flat rooftop. This makes it seem that the distribution of flat and pitched rooftops is about equal in the target area but unfortunately for rainwater buffering purposes, most houses have a pitched rooftop which is unsuitable for harvesting rainwater.

4.3.2 Property Analysis

By using google maps, it can be quickly analysed that especially in de Bothoven, many houses have no front yard. This would imply that there is no opportunity to install a rainwater buffer as the downspout is often located at the street side of the house. However, as mentioned in section 2.3, most houses do have a back yard. This brings the opportunity to install an extra downspout in the back yard or divert the original downspout to the garden where it connects to a buffer and divert it back again to the front of the house.

Fortunately, there are more houses with a front yard in Velve-Lindenhof which often are large enough to house a rainwater buffer.

4.4 Conclusion and Feasible Application Selection

Since approximately 200 litres of rainwater have to be buffered per household, it is important that the buffer is of significant size to actually be able to capture 200 litres of rainwater at once. However, due to fact that downspouts are located at the street side of houses, the buffer has to be placed close to the downspout which will be assumingly in the front yard of the houses if there are any front yards at all. It is therefore necessary the buffer takes little space but is large enough to capture approximately 200 litres of rainwater.

The most feasible applications that would apply to these 'requirements' would be a rain barrel, a rainwater harvesting planter, a rainwater harvesting fence, a rainwater harvesting screen or simply buffering rainwater on a flat rooftop. As for the technologies that will be used for this project and defined in chapter 5, the shape of the buffer is irrelevant. This holds for the rain barrel, a rainwater harvesting planter, a rainwater harvesting fence and a rainwater harvesting screen, where the same technology can be implemented in any of these applications. However, only for buffering rainwater on a rooftop, the technology would be slightly different as a different design and components would be needed. Furthermore, since there is only a small section of houses with a flat rooftop, this option will be discarded.

This leaves a rain barrel, rainwater harvesting planter, rainwater harvesting fence and a rainwater harvesting screen as the most feasible applications to be made smart and implemented into the smart rainwater buffering system.

5. Specification

This chapter will describe the functionalities the envisioned system should fulfil. From the Ideation phase, requirements can be set-up upon which a system can be built. Furthermore, the functions of the envisioned system can be described by a functional system architecture. Finally, a PACT analysis followed by a combined PACT-FICS scenario will be written to describe the system in terms of user and functionality interaction.

5.1 Requirements

Requirements for both end users have been set-up and categorised in functional and non-functional requirements with a further distinction between user and system requirements. Furthermore, all the requirements have been prioritised with MoSCoW.

From the first interview with the Hendrik-Jan Teekens of the municipality of Enschede, functional and non-functional requirements can be set up. The municipality is interested in an automated system that is able to store and release rainwater without any input from their side. However, when designing a system for both the municipality and the citizens of Enschede, both stakeholders should be satisfied. Therefore, the system must be able to function automatically but must also be able to be controlled by the citizens of the two neighbourhoods as they otherwise might feel the municipality is controlling them.

In order to make the system more attractive for citizens, the harvested rainwater should be re-usable for private use by the citizens, providing them an extra purpose to harvest rainwater. If possible, this rainwater should not be contaminated and therefore the water should be filtered prior entering the buffer.

Mentioned by Hans Koetsier from the municipality of Enschede, rainwater can take up to two to three hours entering the sewerage system and leaving the sewerage system via the water treatment plant. To reduce the strain on the sewerage system as much as possible, buffers must create enough space to buffer the predicted rainfall at least up to two hours ahead.

Finally, it is not necessary for the municipality to see real time data as the system will be used for analysis purposes only. However, for the citizens of Enschede, real time data is preferred as it is not desirable to see the buffer completely filled in the interface while it is in fact empty.

5.1.1 Functional Requirements

The functional requirements can be seen in Table 3. In this table, data is defined as: historic discharge date, future discharge date, planned water catchment, system performance, current water level inside the buffer, historic garden discharge and buffer history.

* = requirement verified with municipality
** = requirement verified with a citizen

Table 3. Functional user and system requirements

Functional User requirements	Functional System requirements
Must	
The buffer is able to store and release rainwater automatically. *	
The rainwater captured by the buffer is re-usable by the citizens.	The buffer is connected to a downspout diverter. The buffer contains a faucet to retrieve water and has a sensor to measure the flow rate.
The user is able to see the weather prediction data up to 2 hours ahead. *	The system is able to fetch weather prediction data by communication with a weather station (KNMI, Buienradar). The system uses weather prediction data up to 2 hours ahead.
The user is able to see data generated by the system every 15 minutes. *	The system's sampling rate is 15 minutes. The system's synchronization rate is 15 minutes.
The interface of the municipality shows the overall system performance consisting of the historic and current buffer volume, future discharge data and rainfall prediction. *	The buffer contains sensors that measure the water level. The data of the buffers is stored in a central database. The buffers communicate with each other and with the central server via Wi-Fi.
The interface of the citizens shows own system performance that includes catchment and history (request for one year) **, future catchment overview, current water level inside the tank and show the precipitation forecast.	The data of the citizens is stored for a month on the local node (aka. buffer system).
The buffer discharges through a pipe that is connected to the downspout.	
The buffer can be discharged independently of other buffers. *	
The citizen is able to use the roof as a catchment area for the buffer.	The buffer is connected to the downspout of the roof.
The buffer does not cause excessive rainwater in the gardens of the inhabitants.	The buffer has a downspout diverter that acts as an overflow.
Discharging the system does not result in excessive water in the sewerage system.	

The user information will be treated confidentially and anonymously.	The system anonymizes the data from the citizen's buffers in the interface of the municipality, meaning that the municipality cannot see to which person which buffer belongs.
Should	
	The buffers communicate with each other and with the central server via LoRa.
The buffers notify the user in case of malfunctioning or dangerous situations.	The system should send error messages/notifications in case of malfunctioning or dangerous situations (leakage, no contact with server, clogged, freezing).
The buffer has an overflow to the garden that will only be used between April and October. *	
The citizen is able to see recent data (almost real time) generated by the system at any time. **	Sampling rate of the sensors is lower than the synchronization rate (<15 min) and higher than the sensor accuracy. The system is able to send new data to the interface of the citizen with the same rate as the sampling rate.
The rainwater captured by the buffer is not contaminated by leaves, debris (sand etc.) and insects.	The system must filter the water before it is stored in the buffer.
The citizen is able to choose whether his/her buffer data will be shared with the municipality.	
Could	
The municipality is able to test the system's performance with model rain showers. *	The system could be tested using virtual data/models.
The buffers each contain a weather station that measures local weather statistics. *	The buffers contain sensors for measuring and predicting temperature, wind speed and humidity.
The interface of the citizen only shows the data corresponding to that citizen's buffer.	The interface stores the buffer data on a local server.
Won't	
The interface of the inhabitants shows an overview on potable water savings.	
The user is able to connect an existing rainwater buffer to the system.	

5.1.2 Non-Functional Requirements

The non-functional requirements can be seen in Table 4. In this table, data is defined as: historic discharge date, future discharge date, planned water catchment, system performance, current water level inside the buffer.

* = requirement verified with municipality
** = requirement verified with a citizen

Table 4. Non-functional user and system requirements

Non-Functional User requirements	Non-Functional System requirements
Must	
The interface of the users shows the water level with a high accuracy.	The accuracy of the buffer is 1L.
The buffers discharge ahead of a predicted rain shower. *	The buffer must have a discharge of at least 67L/hour (~1L/min).
The user does not need to operate the system (manually) in order for the system to fulfil its purpose. *	The system functions autonomously and not require intervention from the user in order to fulfil its purpose.
The citizen is able to operate the system manually.	The interface of the citizens contains buttons with which the citizen can control the buffer's capacity.
The user is able to operate the interface of the system with ease.	
The buffer fits in the garden of the citizens.	
The system is safe (does not fall over, protecting user from the electronic components).	
Should	
The buffer network should have enough capacity to buffer a medium-large rain shower.	The joint capacity of all buffers is 1000000L of rainwater. *
The system does not use a substantial amount of power.	The system is energy efficient. The sampling frequency of the system adopts to the current weather state and re-usage of rainwater by the citizen.
The user needs the system to function at any given weather condition, all year round. *	The system should function whether it has been in contact with water.
The system is durable (lasts a long time.) *	
The buffer's design is unobtrusive and aesthetically pleasant.	

5.2 Functional System Architecture

Three functional system architectures have been designed to create a better overview of the system and its different subsystems. These architectures include an overview, the smart buffer and the monitor and control applications. Prior to discussing the functional system architecture, the symbols used in these diagrams will be elaborated to understand the types of interaction.

Closed arrow: Indicates interaction in de direction of the arrow (i.e. A → B implies an interaction between component A and B) within the (sub)system itself.
Open arrow: Indicates interaction in the direction of the arrow (i.e. A → B implies an interaction between component A and B) to or from a (sub)component outside the (sub)system itself.
Square: Indicates a joint, joining data streams together to make the diagrams clearer.
Diamond: Indicates a split, splitting data to send to the right (sub)components or duplicate the data.
[*]: Indicates multiple data streams (i.e. sensor data [*] indicates multiple data streams which could be derived from different sensors and is therefore different data.)

5.2.1 Overview

The overview of the system can be seen in Figure 10 where three main components of the system are identified. These three components include the smart buffer system, the central server and the monitor and control applications. The smart buffer system and the monitor and control applications will be discussed in section 5.2.2 and 5.2.3 respectively.

The main input to the smart buffer system is defined as the outside world, describing the measurements from sensors measuring events in the outside world. The main input to the monitor and control applications is defined as the end user input, describing the interaction between the end user and the interface where users can control the system. Both the smart buffer and the monitor and control applications get time-dependent precipitation predictions as input.

The output of the system is the end user output, which is generated by the central server and verifies the efficiency and actual state of the system.

Within the system itself, several interactions are present which include notifications, commands, requests and updated and stored data. Commands from the user could include discharging water from the buffer whereas the requests are made to visualise data in an interface.

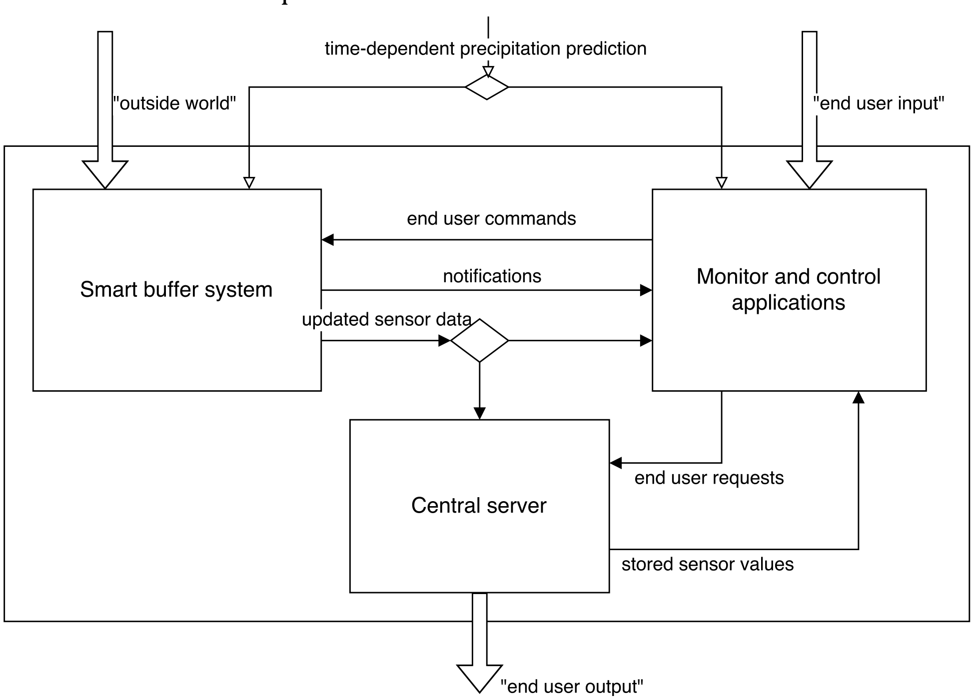


Figure 10. Overview Functional System Architecture

5.2.2 Smart Buffer

The main function of the smart buffer is to apply logic to the sensing world and taking care of opening and closing valves in the buffer when necessary. Its functional system architecture can be seen in Figure 11. The outside world is being sensed after which the sensor data is pre-processed (i.e. filtered and checked for errors) and logic is applied. The logic of the buffer determines the state of the buffer and future actions it should take.

The pre-processing requests new data from the sensor system which replies by sending a data stream of sensor data from either one or multiple sensors. After pre-processing, data is sent to the smart buffer logic and the central server. Data is split between actual values that go to the central server and filtered most important values that go to the smart buffer logic. When dangerous states or errors are detected during pre-processing, the event handler receives a notification.

Furthermore, two types of interactions are present between the smart buffer logic and the pre-processing. These interactions include update request and commands. The update request receives the most recent or relevant sensor data where the command interaction lets the smart buffer logic send a command to the pre-processing, which it should obey.

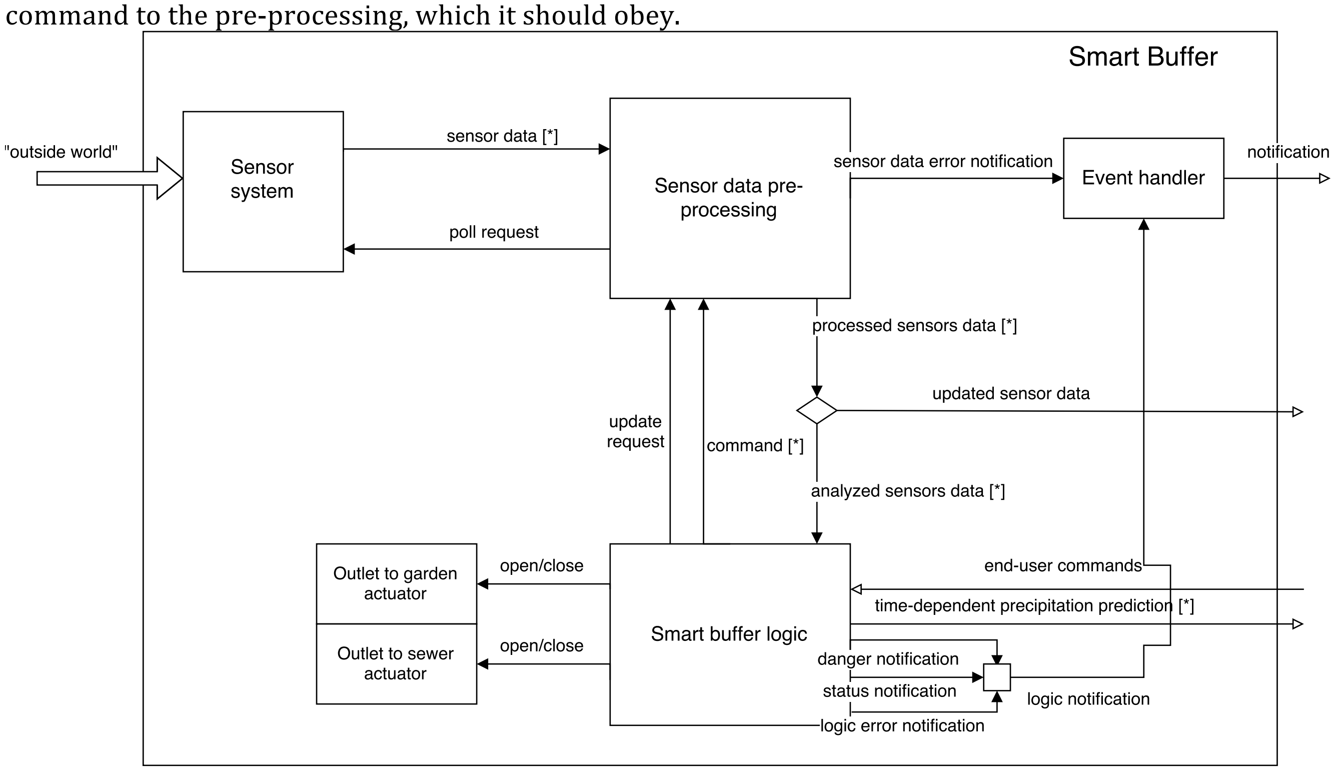


Figure 11. Smart Buffer Functional System Architecture

5.2.3 Monitor and Control Applications

The monitor and control applications block consists out of three main components and can be seen in Figure 12. These components include a logger, application logic and a visualiser. Notifications and sensor data are stored in the logger, which sends on requests of the user (through the interface) data to the visualiser. The visualiser gets the time-dependent precipitation prediction from the outside world but also receives time-dependent precipitation data from the application logic, along with real-time sensor data. The end-user input to the visualiser is defined as selecting date ranges, setting the amount of water that should be discharged and where this water should be discharged to. Both data selection and discharge request go to the application logic and the logger, where it is stored. The application logic, translates these request to commands and sends these to the smart buffer logic.

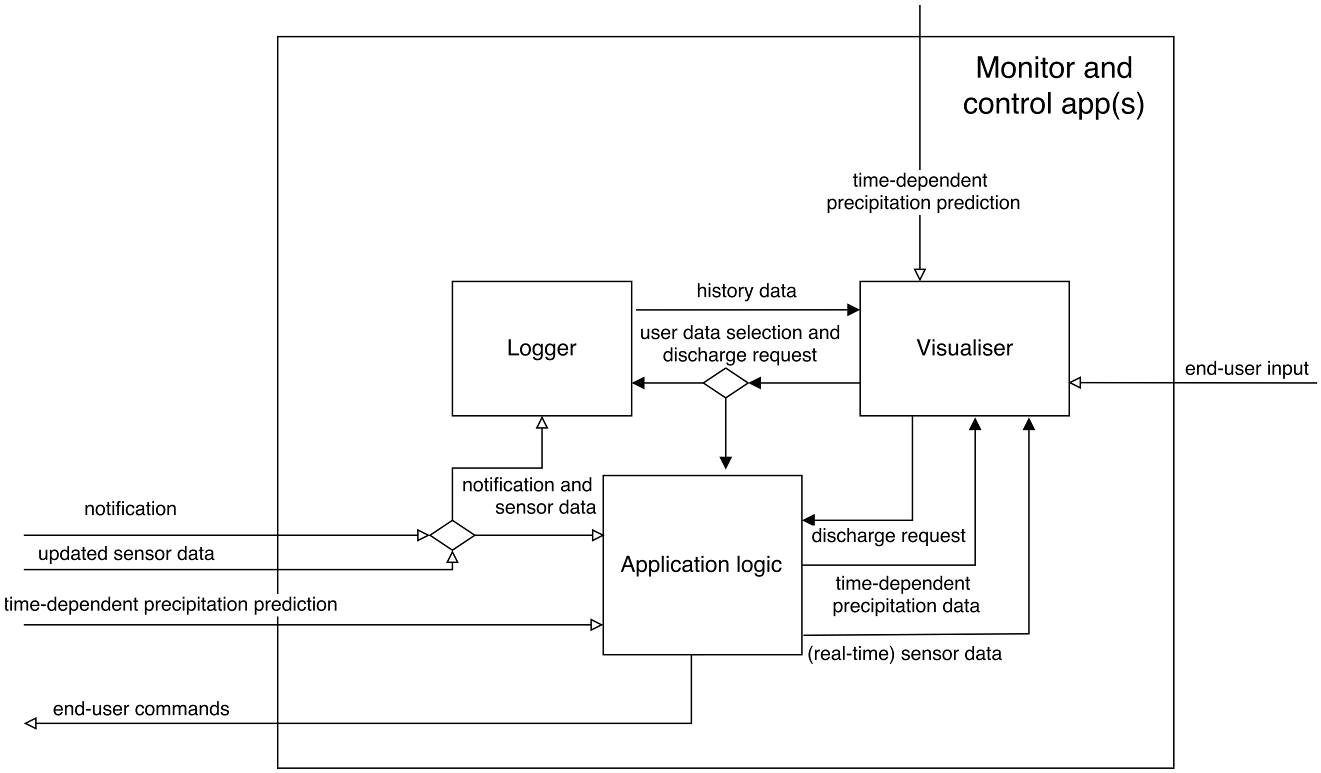


Figure 12. Monitor and Control Applications Functional System Architecture

5.3 PACT Analysis

To describe system in the user's perspective, a PACT analysis has been set-up.

5.3.1 People

Two different types of end user groups can be considered:

1. The inhabitants of de Bothoven and Velve-Lindenhof
2. The municipality of Enschede

Since both groups have their own skills and characteristics, each will be described in their own section.

The citizens

The system will be placed in the neighbourhoods de Bothoven and Velve-Lindenhof. These neighbourhoods are the home of a very diverse group of citizens. These people will have dissimilar cognitive and physical characteristics. There will also probably be a substantial difference in age and educational level of these citizens. However, it is expected that children and minors will not be actively using the system, but mostly adults older than 18 years. Although using the system does not require a lot of physical strength or fitness, it does have a graphical user interface. This means that blind people will not be able to use the system and colour-blind people might be hindered.

In addition to these differences, there is a large variety in the ethnic groups that live in these neighbourhoods. This means that some users will not understand Dutch very well. This could lead to issues in understanding the interface as it will be designed in Dutch. Furthermore, this ethnic diversity might lead to a division in the neighbourhood. Some people will never interact with others and therefore might not care about the problems excessive rainwater causes other people. This might cause them to not be motivated to put a rainwater buffer on their property. On the other hand, if someone is active in their community, it can be assumed they care more about their fellow community members. This might lead to them feeling more motivated to install a smart rainwater system on their property.

In addition to this, the hobbies and personal interests of people have to be taken into account. If someone is already very interested in climate changes and actively working on decreasing this or the effects of this, they might feel more motivated to invest in the system. Finally, if someone already has some other smart home technology, such as the Nefit Easy smart thermostat [44], they might be more willing to invest in another smart system like the smart rainwater buffer.

The municipality
The municipality of Enschede will also be using the system. The people working at the municipality that will use the system are assumed to be similarly educated and to have similar interests. Their ages, however, are expected to range from approximately 20 years old to 67 years old. This means there are big differences in physical and possibly cognitive abilities that have to be taken into account. Physical strength is not important in using this system, but cognitive abilities are. Older people can have more trouble seeing or hearing. This could be problematic while viewing the interface, especially because the interface monitors the rainwater buffers. Older people can also be expected to have more trouble using a computer than younger people which also applies to the citizens. This could also prove to be a problem, but this can be partially solved by using terminology to which they are acquainted in this interface. This could make it easier for them to use and navigate.

Most people working at the municipality are either Dutch or have mastered the Dutch language. Therefore, it is expected that there will not be many cultural differences within this end user group. Furthermore, it is expected that most employees at the municipality have similar interests and that they will be interested in using the rainwater as it is directly related to their work.

5.3.2 Activities

The smart rainwater buffering system has several different functions. The main goal of the smart rainwater buffer itself is buffering rainwater and the interface gives the users insight in the buffers' system performance. Tasks that can be executed by the users individually depend on the type of users described above, the citizens and the municipality.

The citizens
The smart rainwater buffering system will be able to function completely autonomously. However, if needed the users will be able to operate the system manually by using the interface. The three main tasks the citizens can execute is getting insights in their own smart rainwater buffer's performance, manually operating the smart rainwater buffer by deciding the amount of water that the buffer should discharge into the sewerage system or garden and re-using the harvested rainwater for private uses. Actions that cover the first task, getting insights in the user's own smart rainwater buffer, are visiting the webpage on a computer or smartphone on which the interface is being displayed. This web page displays several graphs on the precipitation forecast, the system's performance, planned catchement and history. The user can display the graphs on a specific date range by selecting this date range on the web page. Since the smart rainwater buffering system is able to function completely autonomous, the user can execute this task as frequently as they prefer.

The actions that cover the second task, also include using the interface. The user can set an amount of water that should be discharged into the sewerage system or garden by typing the amount of water in litres into a text input field on the interface and then clicking the discharge button. The discharge request can be cancelled any time by clicking the cancel button.

Finally, the actions that cover the third task involve using the faucet of the rainwater buffer. To re-use the harvested rainwater, the user can place a watering can or a bucket underneath the faucet or attach a garden hose to water the plants etc. When the user opens the tap, water will flow out if the buffer is filled.

The municipality
For the municipality, the smart rainwater buffering system is a completely autonomous system and therefore the only task that can be executed is getting insights on the smart rainwater buffering system's total performance. Actions that cover this task are visiting the web page on a computer on which the

interface is being displayed. On this web page, several graphs on the precipitation forecast, the system's total performance, planned discharge and history can be displayed. Additionally, the user can display the graphs on a specific date range, by selecting this date range on the web page. Since the smart rainwater buffering system is an autonomous system, this task can be as frequently executed as the user prefers.

5.3.3 Context

The buffer will be placed outside a citizen's home, most likely in a front yard because of the presence of a downspout. Therefore, the buffer will be exposed to any weather condition (i.e. snow, heat rain.) However, the social environment where interaction takes place with the system is different for both citizens and the municipality.

The citizens
The interaction with the system happens via an interface that is a website that can be accessed on a computer of mobile phone. The interaction can take place any time of the day at any place as long a computer of mobile is present with a working internet connection. Additionally, the citizens can tap water directly from their own buffer for re-usage.

The municipality
Again, the interaction with the system happens via an interface that is a website that can be accessed on a computer. Most likely, the employees of the municipality will only use the interface during work hours at their office. However, since the interface is a web application, the interface can be accessed via any computer. The employees of the municipality are, unlike the citizens, unable to interact with each individual buffer and have no control over discharging water.

5.3.4 Technologies

The technology used in the smart rainwater buffering system is for both end users the same. The buffer gets its input from the sensors which sense the outside world and the precipitation prediction that is taken from Buienradar, a weather forecast site which (as accurately as possible) predicts the amount of rainfall for the coming two hours. User input to the system will go via the interface where the interface fetches the precipitation prediction on its own and visualises the predicted precipitation for the next two hours. The output the system delivers is opening and closing valves after applying its own logic or when discharge requests have been sent via the user and visualising graphs depending on the selected data. The user interaction with the system happens solely via the interface. However, the citizen is able to manually open the faucet attached to the buffer, draining water from it.

The buffers from the citizens are all connected to the main server that will be located at the municipality. Finally, the buffers are functioning at all times, but they do not send real-time data the majority of the time.

5.4 PACT-FICS Scenario

The results of the PACT analysis are combined with FICS in order to create a scenario that captures both the user and the designer's perspective.

The citizens
Martin is a 22 year old citizen of Velve-Lindenhof. Together with his Labrador Vanessa, he lives in a semi-detached house. Martin works in IT support for a large chain of stores that sell electronic devices. Martin has little contact with the other people living in the neighbourhood. His house is also not affected or damaged in any way when heavy rain falls.

Martin enjoys having some plants in front of his house, but hates gardening. He wanted to have a system that automatically waters his plants for him, which led him to searching Google for automatic watering systems. The automatic text correction system on his iPhone changed this to automatic rainwater systems which made Tonnie, the smart rainwater buffer appear on his screen. Martin was quickly convinced by Tonnie's website and enthused by the fact that he could contribute to decreasing the street floods in Enschede while being able to have his plants automatically watered.

Tonnie was quickly ordered and delivered to Martin's door in a couple of days. It was easy for Martin to install Tonnie, which took him approximately 30 minutes. He checked the interface and was impressed by its looks. To no surprise, the system showed his Tonnie was empty. Martin went to work and noticed some rainfall on the skylights of the store. During his coffee break he checked his personal Tonnie website to see the buffer had already stored its first litres. Rain continued to fall all day and when Martin returned home, the interface told him Tonnie was filled for ten percent.

Some months later, Tonnie was half full, but a dry period was starting. To prevent his garden from drying out, Martin set Tonnie to water his plants with fourteen litres of water. Tonnie also made Martin more conscious about his water use and even helped him lower his water bills because he no longer waters his garden using potable water.

The municipality

Kees is 46 years old and active as a civil engineer at the municipality of Enschede. He lives with his 40 year old girlfriend who is an artist, a passion Kees shares in his spare time. They met at a technology and art festival in Enschede. Kees is looking for solutions for the water problems in Enschede. Rainwater often causes floods in this city, which causes a lot of damage and other hindrances. His main goal is to reduce the strain of rainwater on the sewerage systems.

For some time, Kees has been working on implementing a system called Tonnie. Tonnie consists of a system of smart rainwater buffers that are placed in the neighbourhoods de Bothoven and Velve-Lindenhof. These buffers can be monitored through a central server placed at the municipalities offices. These systems work autonomously, but Kees prefers to check in on them quite often because he wants to make sure they function well.

Kees especially likes the monitoring functions of this system during heavy rain days. On these days, Kees always checks if the system is able to buffer the coming rain. Tonnie has not failed him yet, even on days with one of the heaviest rainfalls the sewerage system can handle. On the monitoring interface, Kees sees the systems will be preparing for such rainfall by discharging some water so they are ready to capture the coming rain. Later in the afternoon, Kees sees that all buffers are almost full, which is denoted by the system status in the monitoring interface.

By using Tonnie, Kees gained a lot of insight in the rainfall and rainwater management in the city of Enschede. Tonnie has also successfully decreased the damage and trouble caused by water in Enschede.

6. Realisation

This chapter describes the technologies that were used to build the prototype and shows insights on why certain technologies have been chosen as well on how the system was built.

6.1 Hardware

The hardware in the system makes the user interaction possible with the interface that will be described in section 6.4. The hardware components are chosen based on the requirements for the system to fulfil its purpose.

6.1.1 Raspberry Pi 3B

A Raspberry Pi is a microcomputer which runs on an operating system by choice [45]. The operating system that is chosen for this project will be explained in section 6.1.1. The Raspberry Pi 3B contains amongst other things an Ethernet port, built in Wi-Fi and 8 General-Purpose Input/output (GPIO) pins which are able to process data and can for example be connected to sensors.

However, due to the lack of PWM pins to power the Water Flow Sensor that will be described in section 6.2.3, the decision has been made to use an Arduino for the data processing of all the necessary sensors.

6.1.2 Arduino Mega

An Arduino board contains a microcontroller that is able to read inputs and turn these into an output [46]. The Arduino's GPIO pins are able to process both digital and analogue data and be connected to several sensors.

Chosen was to use the Arduino Mega as it has 54 digital input/output pins of which 15 can be set as PWM pins and 16 analogue inputs compared to 14 digital input/output pins of which 6 can be set as PWM and 6 analogue inputs for the Arduino Uno of which the latter has frequently been used during the Bachelor Creative Technology.

6.1.3 Water Flow Sensor

Several water flow sensors are being used for the prototype. The water flow sensors could measure the amount of water that gets into the buffer, the amount of water that flows out of the faucet, valve to the garden and valve to the sewerage system, the amount of water that flows back to the sewerage system and the amount of water that overflows into the garden or sewerage system. The water flow sensor works on 5V and is connected to a PWM Arduino pin which reads out the sensor values. The water flow sensor can be seen in Figure 13.

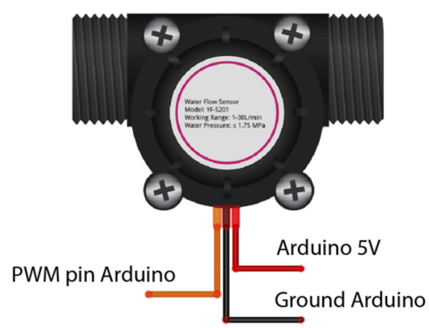


Figure 13. Water flow sensor

6.1.4 Ultrasonic Sensor

One ultrasonic sensor module will be placed in the lid of the water buffer to measure the water level. The sensor operates on 5V and has two ground pins. Furthermore, two digital pins are present for sending and receiving ultrasound signals. The ultrasonic sensor can be seen in Figure 14.

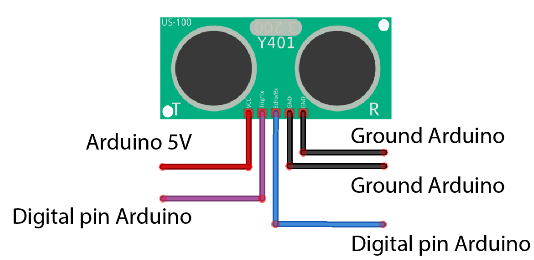


Figure 14. Ultrasonic sensor

6.1.5 Solenoid Valve

A solenoid valve is used to control water when discharging and can be seen in Figure 15. The solenoid valve is closed by default and when 12V is applied, the valve opens as long as this high voltage is supplied. Since the Arduino only supplies 5V by default, the Arduino will be powered with a 12V adapter which will also be the voltage output on the Vin pin on the Arduino that will be connected in a circuit of a transistor, resistor and diode to the solenoid valve. This circuit contains a Buzz-11 N-Channel Mosfet, 100KΩ resistor and a 1 ampere diode. When the Arduino supplies 5V over the digital pin, the channel in the transistor will open and 12V will be applied to the solenoid which opens the valve.

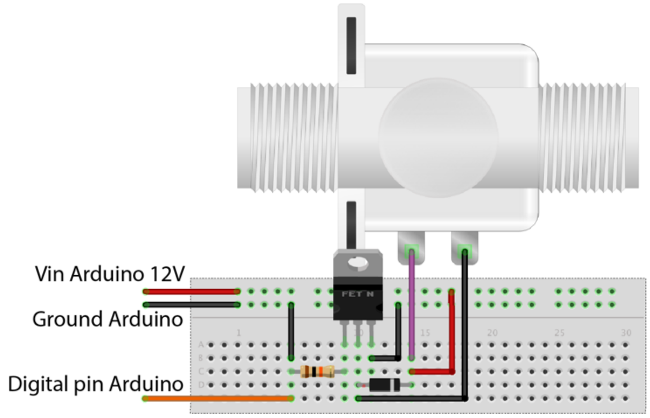


Figure 15. Solenoid valve

6.2 Software

The software in the system makes the user interaction with the system possible. The specific software is chosen based on own experiences and assuming what would work best for the prototype.

6.2.1 Operating System

The operating system that runs on the Raspberry Pi 3B for this project is Raspbian. The operating system is the Raspberry Pi Foundation's official supported operating system and can be downloaded from the official Raspberry Pi website. Raspbian comes with pre-installed programming tools and software like Java, Python, Scratch and Sonic Pi.

6.2.2 Interface

The interface will be used by users to interact with the system. To visualise the data that is being obtained by the sensors in the buffers, different data visualisations were made with D3.js. This is a JavaScript library that can be used to manipulate documents based on data using HTML, SVG and CSS. D3 allows to bind data to a Document Object Model (DOM) after which data-driven transformations to the document can be applied [47]. For example, data can be used to create an interactive SVG bar chart or an HTML table can be created.

6.3 Database

The database is an important component of the smart rainwater buffering system. The data from the sensor is read and processed by the Arduino after which it is sent to the Raspberry Pi. The Raspberry Pi sends this data to the database where it is stored. For this project, another Raspberry Pi 3B is used as server that hosts the database.

From the interface, users will be able to access new data at least every 15 minutes and let it be visualised in graphs. The data in the database will be at least stored for one year.

The database consists out of seven different tables of which the database structure can be seen in Figure 16. In this database structure PK stands for Primary Key and FK stands for Foreign Key. A table is qualified as a relational table once it has a primary key which is a set of columns which contain a unique identifier. A foreign key is a set of columns as well but refers to a primary key in another table.

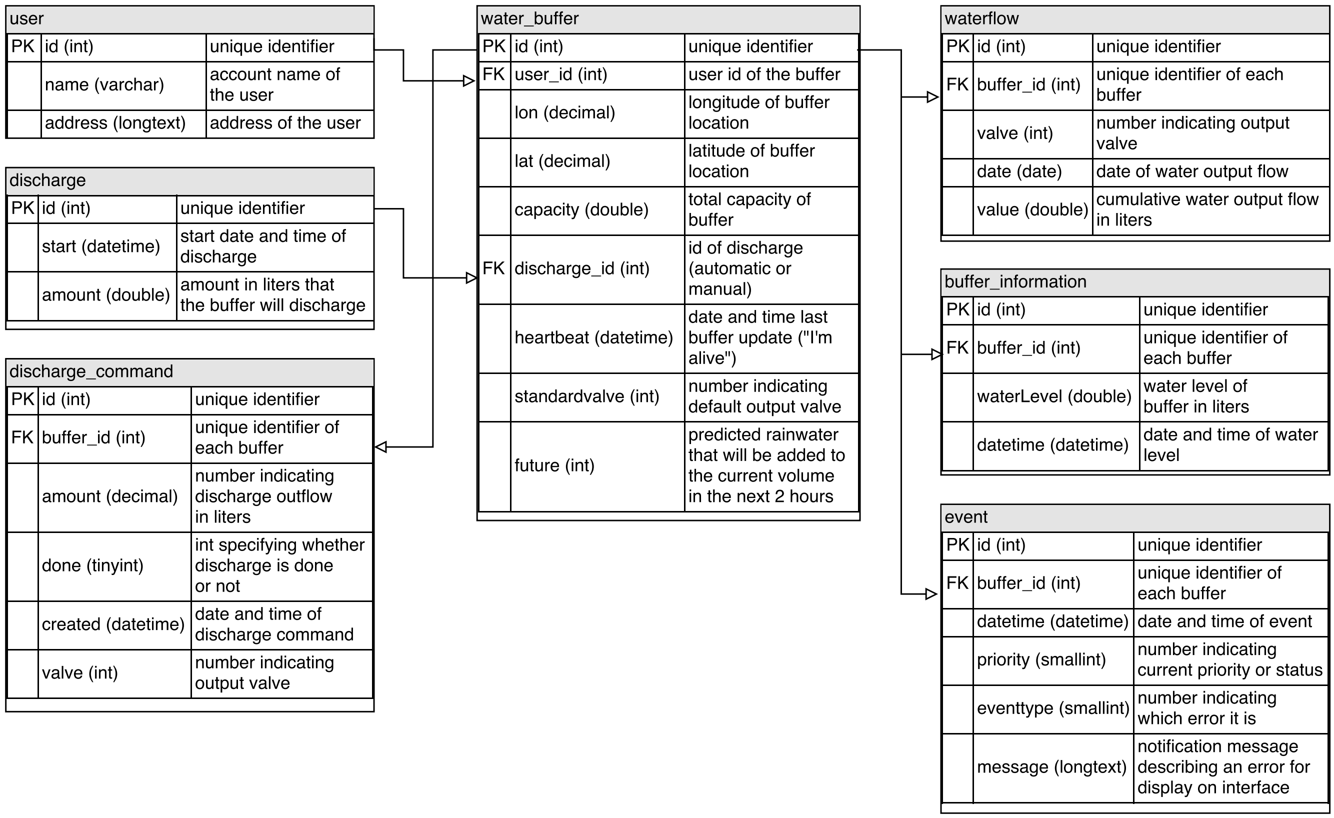


Figure 16. Database structure

6.4 Smart Rainwater Buffer

This section will describe two different iterations of Tonnie, the smart rainwater buffer which is the main element of the total system. By using the requirements, sketches have been made to combine elements into a smart buffer. For now, the design of the buffer will be a plain rain barrel since the technology matters the most. As explained in chapter 4, this technology could in further research be applied in any type and different buffer form.

6.4.1 First Buffer Iteration

A sketch of the first buffer iteration can be seen in Figure 17. In order to be able to buffer a significant amount of rainwater, the buffer will be connected to a downspout which can be accomplished with a downspout diverter. A downspout diverter catches water at the inside of the downspout, directing it to the buffer and acts as an overflow as well. In addition, for users to get the least contamination in the buffer, a filter should be added to the downspout diverter and a first flush diverter could be used. A first flush diverter lets the first part of a rain shower flow to the sewerage system instead of directing it to the buffer. This could be beneficial since the roof runoff could be very contaminated prior to a rain shower. The first part of a rain shower could wash away the contamination, leaving a cleaner runoff for the rest of the rain shower.

Having as little contamination as possible in the rain buffer is not only to prevent in and outflows from clogging but also gives citizens cleaner water for re-usage. Rainwater can be re-used by opening a faucet that is attached to the buffer. This would make it possible for citizens to fill up a watering can with harvested rainwater and water indoor plants with it.

Inside the buffer's lid, a microcontroller will be installed that is connected to a sensor that measures the water level. This microcontroller can connect to a database and store the sensors' data to it.

Lastly, the buffer is connected to the downspout again with an outlet for automatically and manually discharging water. This outlet is controllable with a valve, where the micro controller can send signals to open or close the valve.

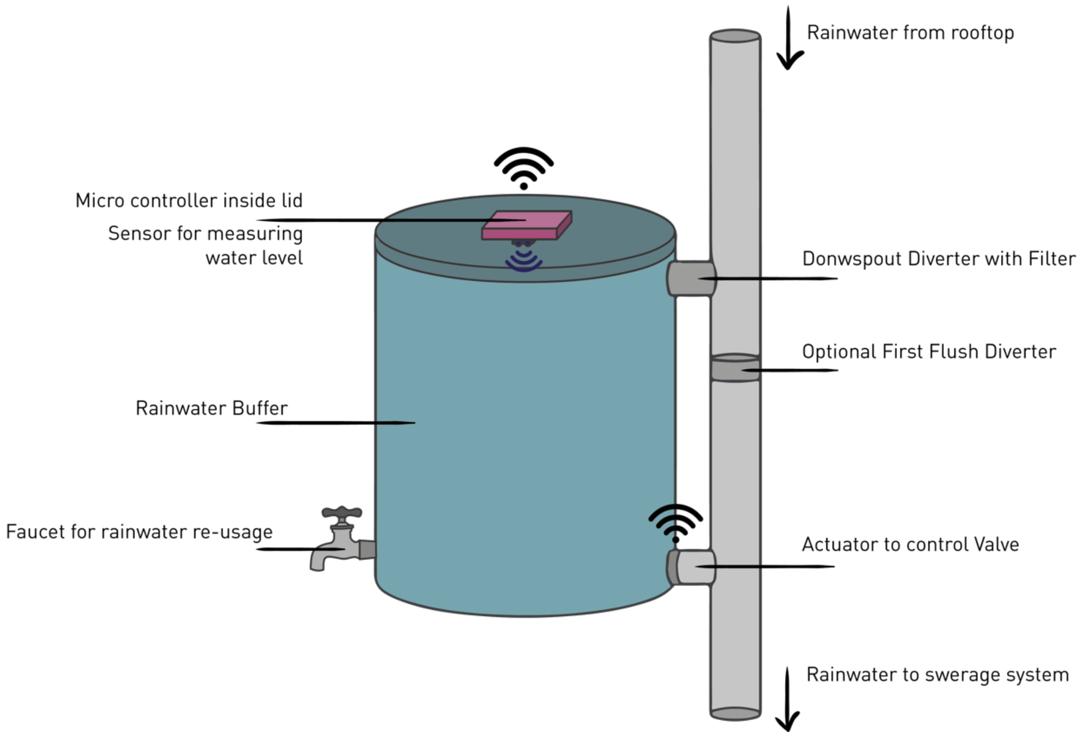


Figure 17. First buffer iteration

6.4.2 Final Buffer Iteration

The first iteration has been changed by taking into account the needs of the stakeholders as an extra controllable outlet to the garden has been added to the buffer. The municipality of Enschede wants to reduce the strain on the sewerage system as much as possible which can be done by discharging water into the garden instead of the sewerage system. This was said during an interview which can be found in Appendix I. When users would attach a garden hose or a sprinkler installation to this outlet, watering the garden could be made a lot easier.

Experience showed that a downspout diverter is not working properly in this setup and therefore it was chosen to replace the downspout diverter and have a separate inlet and overflow. In order to measure the water level very accurately and detect leakages, water flow sensors have been added to every in- and outlet.

Therefore, the smart rainwater buffer consists out of 5 water flow sensors that measure the in- and outflow of the rainwater, one ultrasonic sensor that measures the water level inside the buffer and two solenoid valves that control the discharge of the harvested rainwater to the sewerage system and to the garden. The final buffer iteration can be seen in Figure 18. When for example a water flow sensor measures a water flowing through when a valve is closed according to the microcontroller, the system can detect this as a valve malfunctioning.

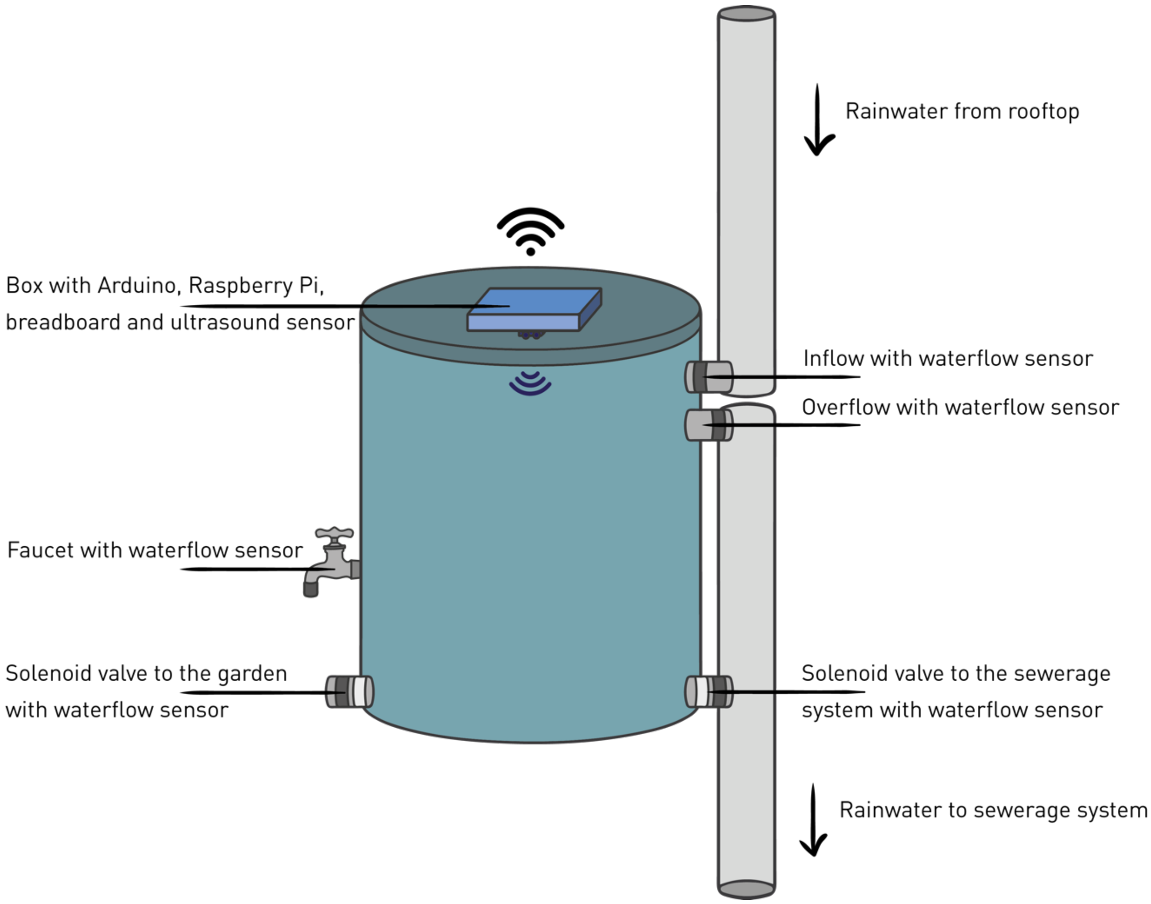


Figure 18. Final buffer iteration

Unfortunately, the water flow sensors are not very accurate and not capable of measuring the in- and outflow in litres correctly. Therefore, they have been given the sole purpose to detect if water flows into or out of one of the in- and outlets and detect potential malfunctions of the valves and faucet.

Finally, a box has been attached inside the lid of the buffer. This box contains a microcontroller, the Arduino Mega and a microcomputer, the Raspberry Pi 3B, a breadboard with the circuits for the solenoid valves and an ultrasonic sensor for which holes have been cut out of the box for the sensor to fit in.

The connections between the hardware components can be seen in Figure 19. The Raspberry Pi is powered with a micro USB cable and has a wireless internet connection with which it can connect to the database. The Arduino is powered by a 12V power plug which also supplies the Vin that switches the transistors.

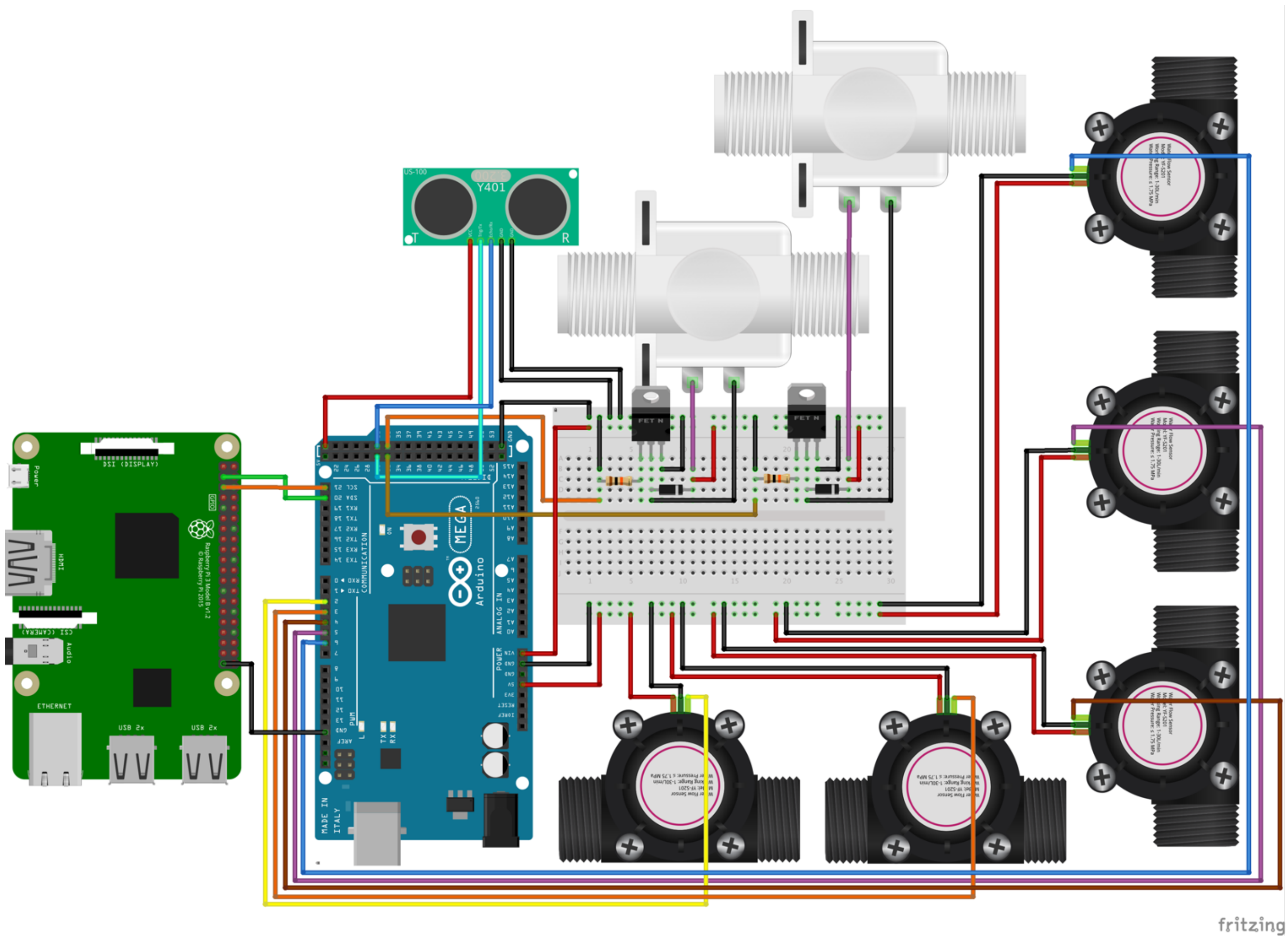


Figure 19. Components overview

Prototype

For the prototype, a rain barrel was bought at a physical store and adjusted to fit the requirements and the sketch. A radiator faucet has been installed on the place of the original faucet, because of its screw-thread, making it easier to attach a water flow sensor to this type of faucet.

In addition, two extra holes have been drilled in the bottom of the buffer where a solenoid valve has been installed in each hole, one for the garden outlet and one for the sewerage system outlet. To both valves, two water flow sensors have been connected.

Unfortunately, due to restrictions of the university building, the downspout could not be altered. To fit a water flow sensor into a downspout, a top part of a plastic bottle has been transformed and melted around a downspout pipe, acting as a funnel. Furthermore, the downspout was not connected to the sewerage system. Therefore, pipes have been installed at the overflow outlet, directing the water towards the ground with pipes. At the end of these pipes, a water flow sensor has been installed.

Finally, wires for the sensors and valves have been cut and soldered to fit the breadboard and Arduino pins. The wires have been directed into the box with the Raspberry Pi, Arduino, breadboard and ultrasonic sensor where everything has been connected. The box has been attached to the barrel with cable ties for easy assembly and de-assembly. Photos of the prototype can be seen on the next page in Figure 20.

Figure 20. Photos of the buffer prototype

Top left: Inlet with funnel and flow sensor. Top right: Smart rainwater buffer. Bottom left: Solenoid valve with flow sensor and faucet with flow sensor. Bottom right: Blue box with hardware components.

6.5 Interface

For the smart rainwater buffering system project, two different end users have been defined; the citizens of de Bothoven and Velve-Lindenhof and the municipality of Enschede. For both end users, a different interface will be designed to interact with the smart rainwater buffer. However, this report focusses solely on the design of the interface for the citizens of the two neighbourhoods[1].

This section will describe three different iterations of interface mock-ups after which the final interface has been programmed. The third iteration of the interface has been tested with test participants which will be described in chapter 7. All text present on the interfaces are written in Dutch, the native language of the majority of the target users.

6.5.1 First Web Iteration

By taking the functional must requirements into consideration, a first iteration for the web interface has been made as can be seen in Figure 21. The interface of the citizens must show its own system performance that includes catchment history and future catchment overview, current water level inside the tank and show the precipitation forecast. Furthermore, it is necessary that the citizen is able to operate the system manually if wanted.

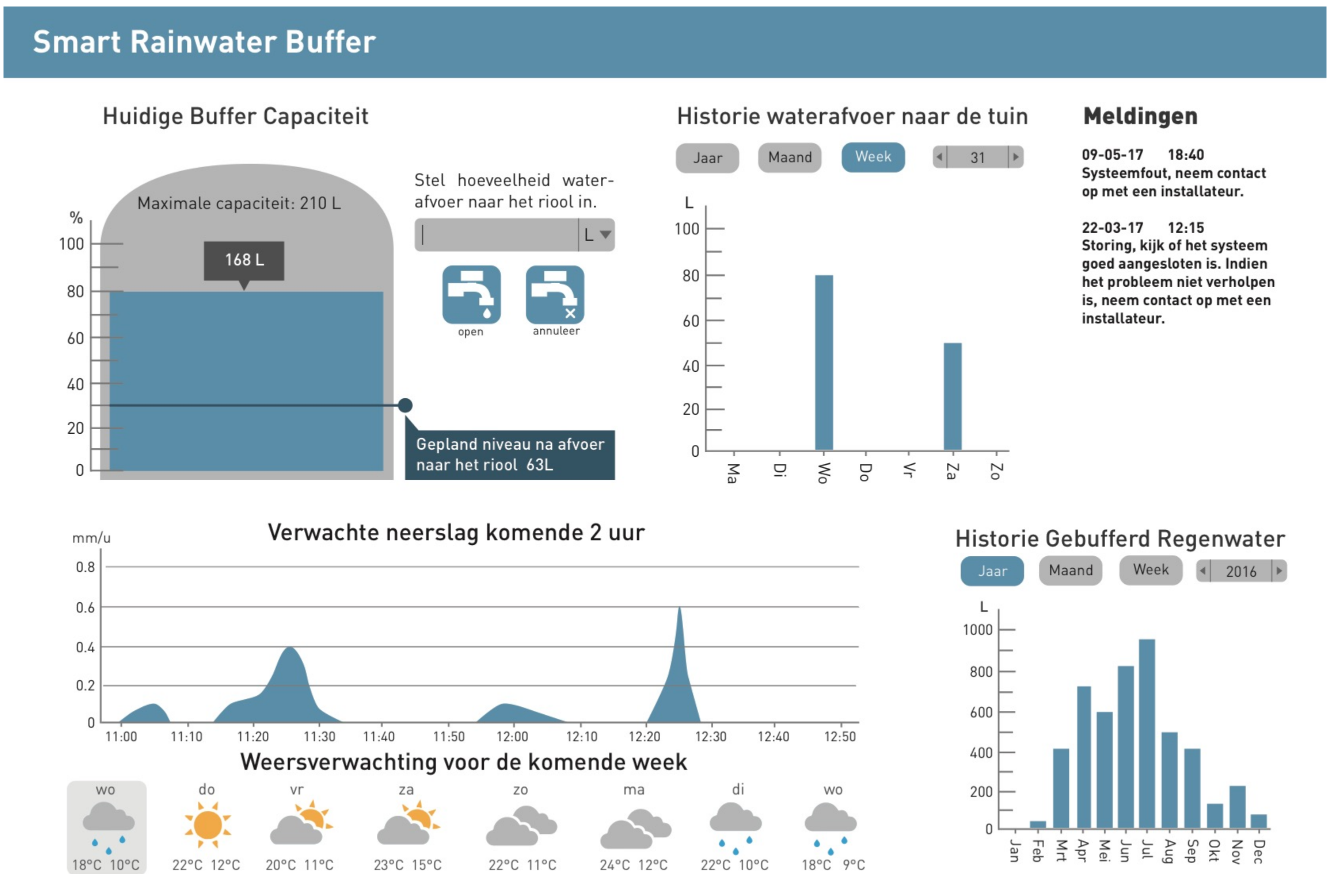


Figure 21. First interface iteration

The top blue row shows the header of the interface with the name of the system. From left to right, the first row contains the current buffer capacity, water discharge history towards the garden and notifications. The bottom row consists of a two-hour precipitation prediction with the weather forecast for the coming week underneath and buffered rainwater history.

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[1] The municipality interface can be found in the Bachelor Thesis Creative Technology by Gelieke Steeghs, 2017

To visualise the current buffer capacity, an image of a rainwater buffer has been made which functions as background to a bar chart with one single bar. This bar has been given a blue colour to resemble the actual water level inside the buffer. On the left-hand side of the bar, the y-axis displays a scale in percentages, making the bar chart readable. In addition, the value of the bar chart has been converted into litres, shown on top of the bar chart. The number of litres is shown in a box with a triangle pointing towards the bar, showing that this value is connected to the data of the bar. The maximum capacity of the buffer is denoted in the top of the buffer. In addition to the bar chart, a line graph shows the water level after the planned discharge to the sewerage system within the next two hours.

Directly next to the buffer on the right-hand side, the amount of water that can be discharged manually can be set. In a text field the user can set the amount of water and open the valve by clicking on the open button. This can be cancelled by clicking on the cancel button, next to the open button on the right-hand side. The amount of water to be discharged manually can be either set in litres or in percentages.

The discharge history towards the garden is visualised by a bar chart. A bar chart has been chosen because of its easy to read capabilities and the colours of the bar kept the same as the previous described bar chart, for the consistency of the interface. The bars visualise how many litres of water have been discharged towards the garden were selections can be made to either visualise the data for years, months or weeks. When hovering over the bar chart with a cursor, the user should get to see a tooltip with the data value and timestamp for that point.

The notifications section in the top right show errors and notification messages when something is not functioning right, along with a date and timestamp.

The second row shows an area graph on the predicted precipitation for the coming two hours and the weather forecast for the coming week. It was chosen to visualise the precipitation data in an area graph as this data gets updated every five minutes and consists out of five minute samples. When transferring this interface to a mobile device, a bar chart with 24 bars (two hours, every five minutes) will become too cluttered. Therefore, it has been chosen to show the precipitation data in an area chart. When hovering over the area chart with a cursor, the user should get to see a tooltip with the data value and timestamp for that point. The weather forecast consists out of eight days that show the weather type (i.e. sunny, cloudy, rainy) and the minimum and maximum temperature of that day.

The final graph is a bar chart on the buffered rainwater history. This graph has the same design as bar graph on the discharge history towards the garden, to keep the interface consistent. The bars visualise how many litres of water have been buffered over the years, months or weeks.

6.5.2 First Phone Iteration

To increase mobility, a mock-up of the interface was designed for mobile platforms as well and can be seen in Figure 22. The interface consists out of the exact same elements as the interface in section 6.5.1. but each element displayed on a different page rather than one dashboard to get a clearer, readable overview.

The only addition to this phone interface in comparison to the web interface is an added menu to the interface. From this menu, users will be able to navigate between different pages of the interface. The menu can be accessed via the menu icon on each page, located in the top left corner. Via this menu, other pages from the interface can be visited. The menu consists out of a list containing: settings, notifications, buffer capacity, buffer history, discharge history and the predicted precipitation.

Figure 22. First phone iteration

6.5.3 Second Web Iteration

The second iteration only contains some minor changes compared with the first iteration and the mock-up can be seen in Figure 23. The weather forecast for one week has been left out of the interface because this data is not used nor useful for any of the graphs. Furthermore, there are already many existing other options to view the weather forecast for one week and is therefore superfluous for this interface. However, it was chosen to keep the predicted precipitation graph in the interface even when, just like the one week weather forecast, there are already several other existing applications that show this. The reason to keep the two hour precipitation forecast in the interface is due to its relation to the planned discharge. When there is more rainfall predicted than space in the buffer, the buffer will automatically discharge some water to make space for the coming rainfall.

The final change that has been made is the date selection for both bar graphs. Where users first had to click either a year, month or week, this has now been combined in one date range picker.

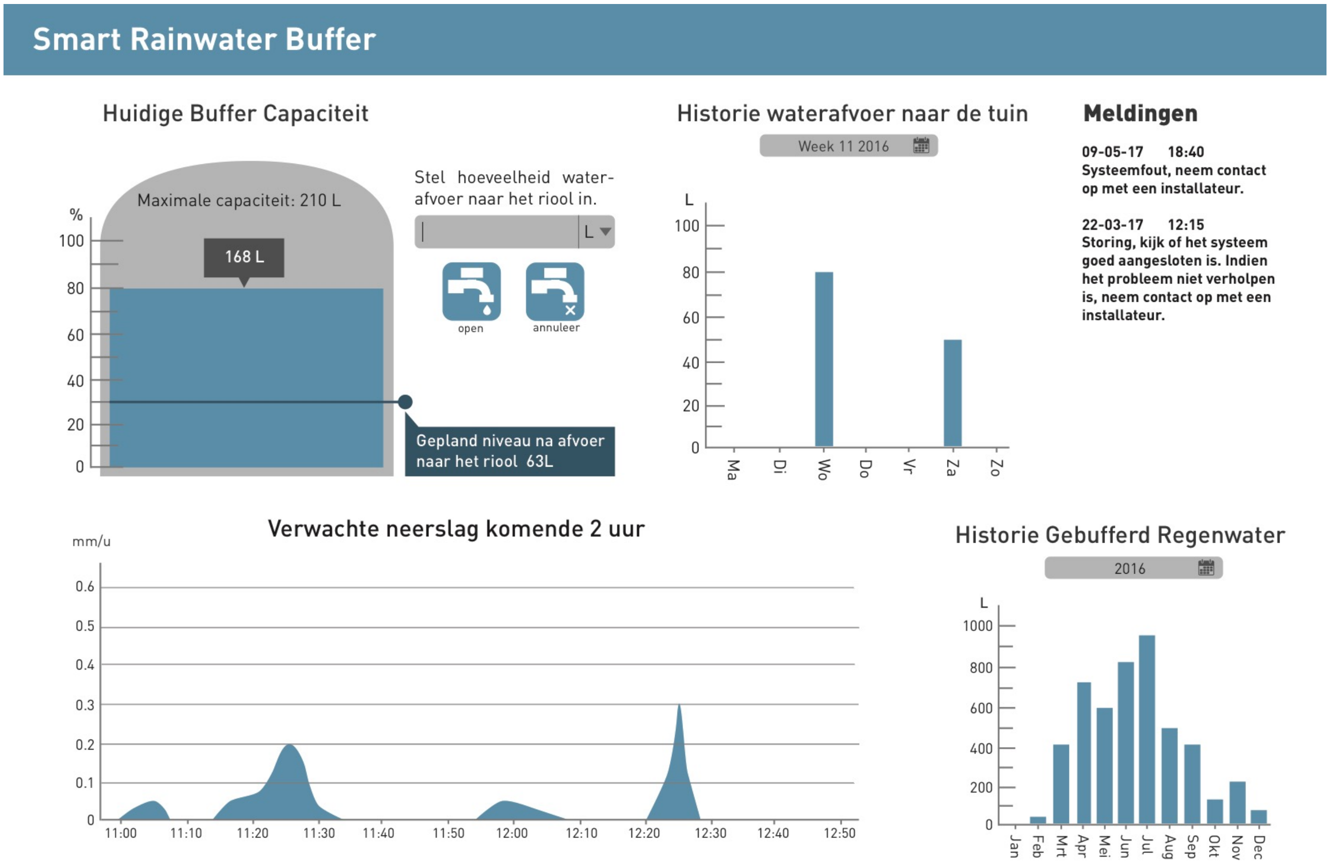


Figure 23. Second interface iteration.

6.5.4 Second Phone Iteration

The phone interface has been changed along with the second web iteration. The changes of the phone interface can be seen in Figure 24. Just like the second web iteration only some small changes have been made where the one week weather forecast has been left out, leaving only the predicted precipitation for the coming two hours. Additionally, the date selection for both bar graphs have been updated as well into a date rage picker.

Figure 24. Second phone iteration

6.5.5 Third Web Iteration

The second iteration on the interface was shown to the supervisors of this project upon which feedback was given. This feedback included adding a name for the system; Tonnie, which will replace Smart Rainwater Buffer in the header. Furthermore, instead of showing the water level after discharging, the predicted water level after a rain shower should visualised. After all, the buffer will only automatically discharge when a lot of rainwater is expected that will not entirely fit inside the buffer. The third iteration of the web interface can be seen in Figure 25.

Other changes that have been made is the addition of today's date in the header. Furthermore, the notifications are hidden and have been replaced by the status of the system.

In addition, a distinction has been made between automatic water discharge and manual water discharge. The user is now able to choose whether the automatic water discharge will be set to the sewerage system or the garden where the manual water discharge can be set to the sewerage system or garden as well. This interface has been tested with target users, which will be discussed in section 7.3.

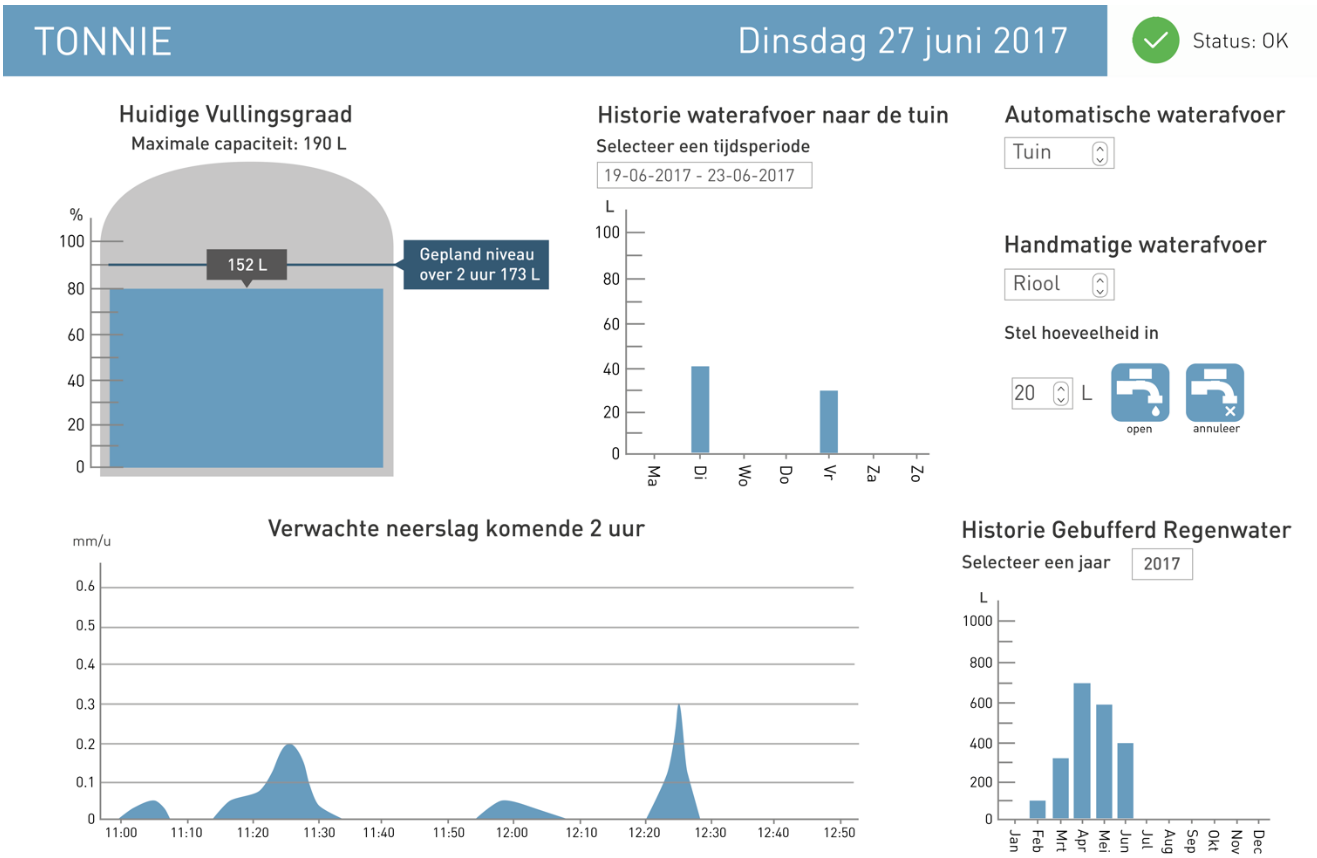


Figure 25. Third interface iteration.

6.5.6 Third Phone Iteration

The phone interface has been changed along with the third web iteration as well. Discussed before, instead of showing the water level after discharging, the predicted water level after a rain shower is visualised. In addition, the notifications page has been deleted and replaced by a water discharge page. Here, the user could set the automatic discharge to either the sewerage system or the garden and manual discharge can be set to the sewerage system or garden as well. The updated pages from the phone interface compared to the second phone iteration can be seen in Figure 26. Note that the pages on the histories and precipitation remained the same as the second phone iteration.

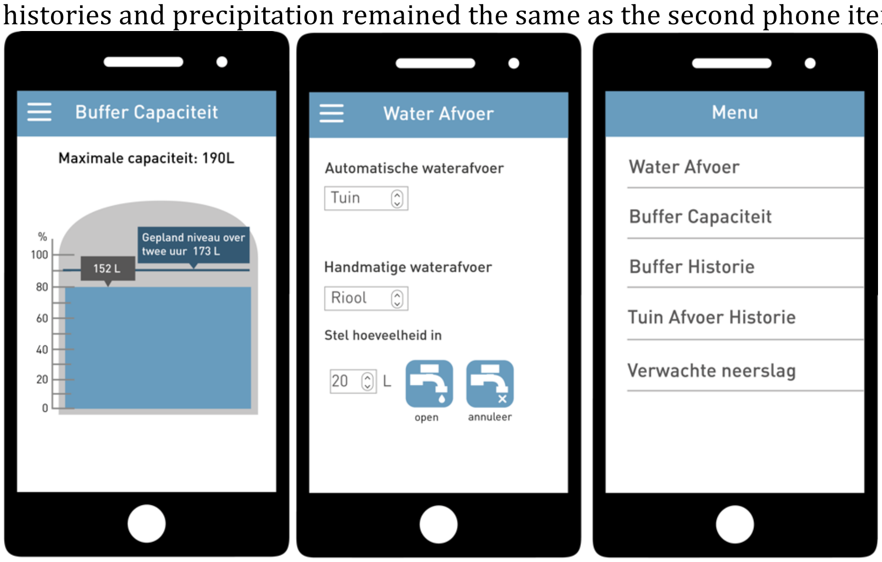


Figure 26. Third phone iteration

6.5.7 Final Interface

The final interface is similar to the third iteration with only aesthetic changes made. The final iteration can be seen in Figure 27. Due to time constraints, only the web interface has been programmed. The graphs of the interface were programmed by using D3.js, a JavaScript library. The largest change that has been implemented in this interface is the change in position of the water discharge section with the bar chart on the discharge history to the garden. This was implemented so both bar charts would be aligned together and the water discharge section would be closer to the capacity of the buffer, implying a closer connection between the two sections since the water discharge is related to the current water level of the buffer. The code of the final interface can be found on GitHub[2].

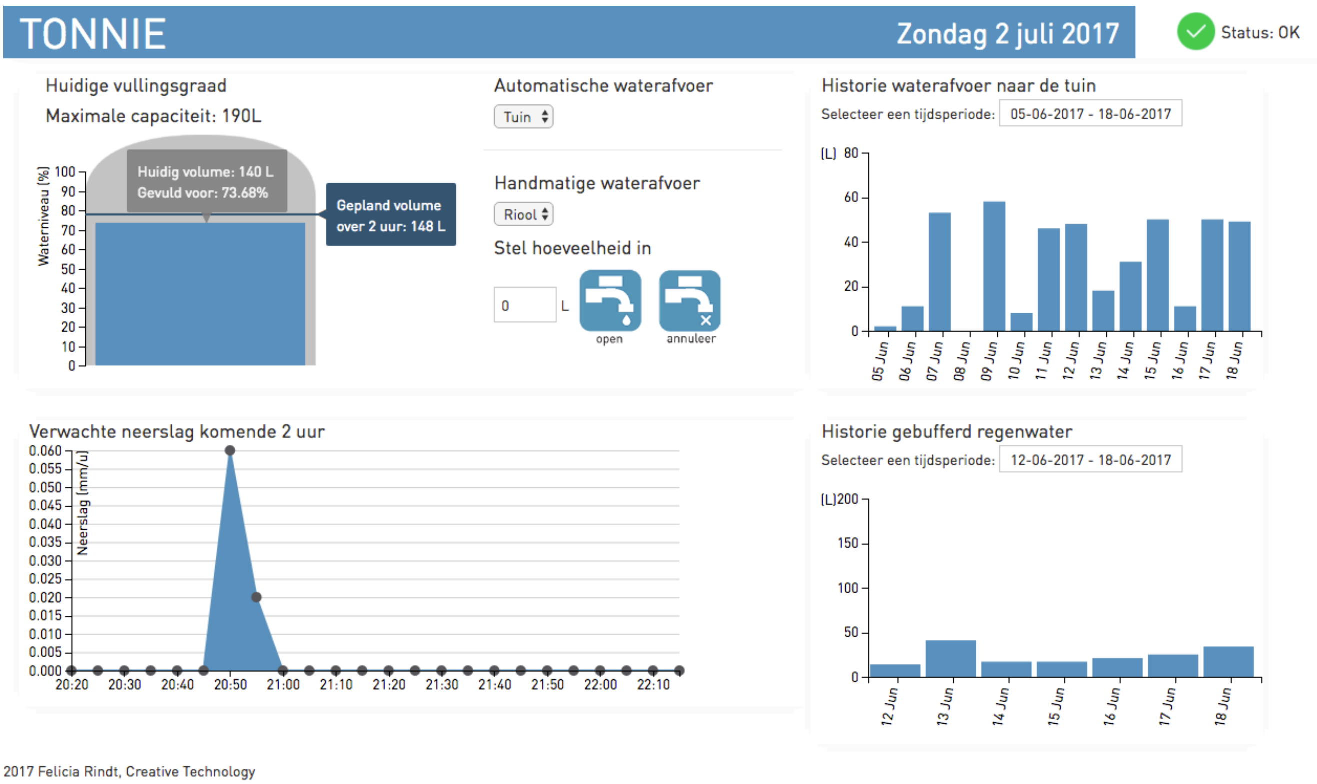


Figure 27. Screenshot final interface

In order to implement tooltips in an area chart, dots have been drawn over the area chart at every data point. When hovering over one of the point with a cursor, a tooltip will appear which can be seen in Figure 28.

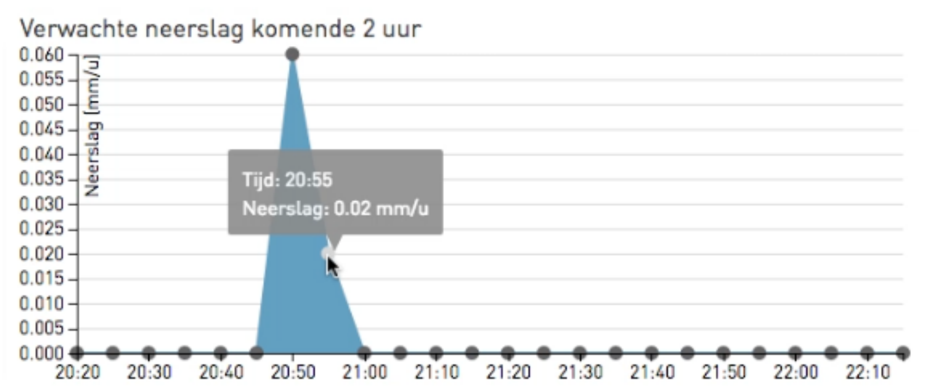


Figure 28. Tooltip example

[2] https://github.com/FeliciaRindt/SmartRainwaterBuffer

In the third iteration of the interface, a system status had been added. This status can be either critical, OK, and notification as can be seen in Figure 29. For example, when everything functions alright, the status will be OK. When there is a malfunction in the system, the status changes to critical.

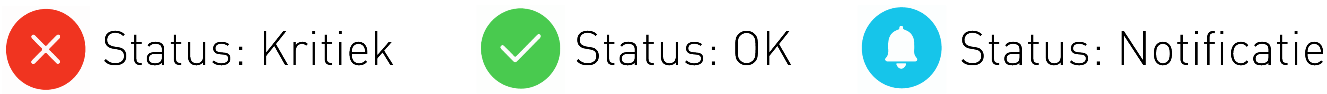


Figure 29. System status

Another change that was made is the date selection. For this interface, an existing date range picker has been used for easy implementation. This date range picker gives users more freedom in selecting a range themselves and display data from specific chosen dates. A screenshot from this date picker in the interface can be seen in Figure 30.

In addition, the bar charts have been changed so the width of the bars will always fill the chart area. This means when only a few dates are selected the bars are larger and when many dates are selected the bars are smaller in width. The text on the x-axis has also been slightly rotated to make it better readable when a large date range is selected.

Finally, the fixed textbox with the number of litres present in the buffer has been changed with a more detailed description. Instead of displaying only the number of litres, text has been added which says: 'Current volume' in litres and 'Filled for' in percentages. This makes the data of the bar graph more easily readable.

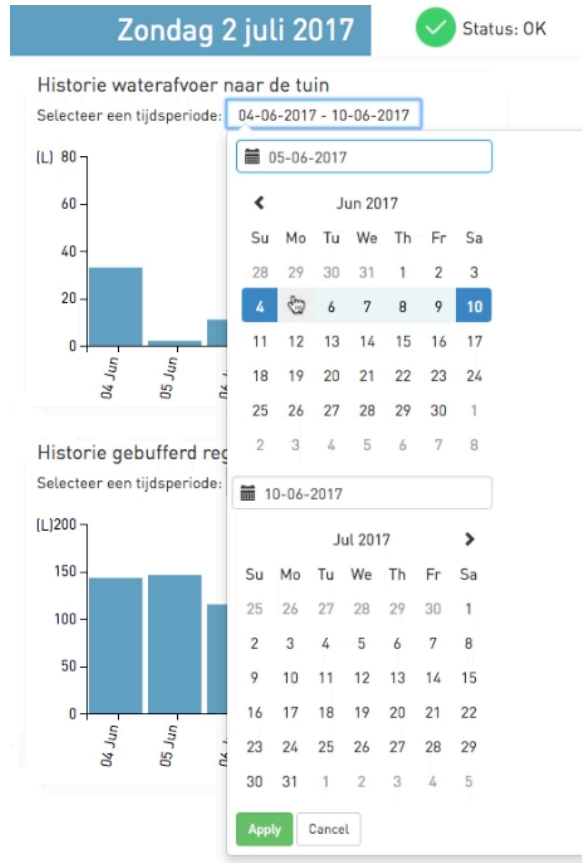


Figure 30. Date picker

7. Evaluation

The goal of the evaluation protocol is making sure that testing the prototype happens quickly, smoothly and consistently. It includes an overview of the technology's most crucial functionalities, functional testing, a user test protocol and a conclusion.

7.1 Crucial Functionalities

The goal of the smart rainwater buffering system is buffering rainwater to reduce the strain on the sewerage system and its most crucial functionality is to provide users with insight to its real-time performance, history performance and precipitation data. Interaction with the system takes place via an interface that displays graphs that can be adjusted to the user's selected date range. When it rains, the system should respond by giving the user feedback by updating its data and graphs that are being visualised on the system's interface.

7.2 Functional Testing

Before user tests were conducted, the system needed to be tested on its functional requirements. The system could be user tested when all the "must" functional requirements, specified in section 5.1.1, were fulfilled. When the system did not fulfil one of the requirements, the prototype had been adjusted accordingly. At the end of the functional test, the system fulfilled all the functional "must" requirements specified in section 5.1.1.

7.2.1 Discharge Time

One of the requirements was that the buffers should be able to empty within 2 hours. The time it takes for the water to flow out of the buffer can calculated theoretically. For this Bernoulli's principle will be used [48].
Bernoulli's principle is as follow:

$$\frac{v^2}{2} + g \cdot z + \frac{P}{\rho} = constant$$

Herein v is the flow speed of a fluid through a point, g is the gravitational constant, which in this case will be $9.81\frac{m}{s^2}$, z is the height from the reference point in meters, P is the pressure and ρ is the density of the fluid, water in this case.

For the rain barrel used in this system, this equation can be used to calculate the outflow time of the water. This is done by using Bernoulli's equation for two points in this system, first at the surface of the water in the rain barrel, which is point 1 in Figure 31. The second point is located at the opening of the nozzle of barrel, which is point 2 in Figure 31. For ease of calculation, it is assumed that the rain barrel is a perfect cylinder and that the bottom of the nozzle pipe is located exactly 0.05 meters (5cm) above the bottom of the rain barrel. The initial water height is assumed to be 0.9 meters above the bottom of the rain barrel, or 0.85 meters above the bottom of the nozzle. The variable h is the height difference between the water surface in the rain barrel and the bottom of the nozzle. The initial value for this, h0, is thus also 0.85m. d1 is the diameter of the rain barrel, which is 0.57m. d2 is the diameter of the nozzle, which is 0.01m (1cm).

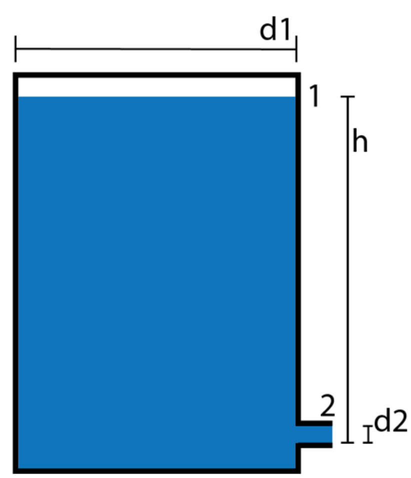


Figure 31. Rainbarrel dimensions

Because Bernoulli's equation results in a constant, this can be compared for the two points on the rain barrel. This leads to the following;

$$\frac{v1^2}{2} + gz1 + \frac{P1}{\rho} = \frac{v2^2}{2} + gz2 + \frac{P2}{\rho}$$

Because z2 is the reference point, this is set to 0 whereas z1 is equal to h. Furthermore, because both points are in contact with air, there is no pressure difference, therefore this can be negated. Finally, the equations are divided by g, the gravitational constant to make them simpler. The equation then looks like this;

$$v1^2 = v2^2 + 2gh$$

It is safe to assume that v2 is much bigger than v1, because d2 is much smaller than d1. Thus;

$$v1^2 = 2gh$$

And

$$v1 = \sqrt{2gh}$$

However, although it is much smaller than v1, v2 is not equal to 0. Instead;

$$v2 = \frac{-dh}{dt}$$

The mass flow through the two points is equal (because the same amount of water will flow through these points, albeit at different speeds.) Mass flow rate is given as the flow speed of something multiplied by the area through which this flows. This means that the following holds true;

$$v1A1 = v2A2.$$

With v1 and v2 being the flow speed at their respective points and A1 and A2 being the area of the pipe at their respective points. if the earlier calculated equations for speed are plugged into this equation, this leads to the following equation. R is the radius of the rain barrel and equal to half d1, r is the radius of the faucet and equal to half d2.

$$\sqrt{2gh} \cdot \pi \cdot r^2 = \frac{-dh}{dt} \pi R^2$$

After moving isolating dh/dt

$$\frac{dh}{dt} = -\sqrt{2g}\, \frac{r^2}{R^2} \sqrt{h}$$

Because everything, except for h, in this equation is a constant, we define a placeholder constant k as follow;

$$k = -\sqrt{2g}\, \frac{r^2}{R^2}$$

Which turns the equation into;

$$\frac{dh}{dt} = k\sqrt{h}$$

By changing this equation around a little more and then integrating, this equation can be used to give a formula for the time it takes to empty the barrel. This integration goes from h0 to h1, with h0 being the initial water height and h1 being the final water height (when the barrel is empty) where t is time in seconds.

$$\int_{h0}^{h1} \frac{1}{\sqrt{h}}\, dh = k \int_{o}^{t} dt$$

Which turns into

$$2\left[\sqrt{h1} - \sqrt{h0}\right] = kt$$

Dividing this by k gives the equation which can be used to calculate the time it takes for the barrel to empty itself.

$$t = \frac{2\left[\sqrt{h1} - \sqrt{h0}\right]}{k}$$

k was defined as follow;

$$k = -\sqrt{2g}\,\frac{r^2}{R^2}$$

When filling in the values for these constants ($g = 9.81 m/s^2$, r = 0.005m and R = 0.285m), the value for k is found.

$$k = -\sqrt{2 * 9.81}\,\frac{0.005^2}{0.285^2} = -0.0013633$$

Now t, which is the time it takes to empty the barrel, can be calculated. The initial water height, h0 is 0.85 meters above the reference point. The final height h1 is 0cm above the reference point. Filling this into the earlier given equation together with k results in the following;

$$t = \frac{2\left[-\sqrt{0.85}\right]}{-0.0013633} = 1352.5\ seconds = 22.56\ minutes$$

Therefore, in theory it should take 22.56 minutes for the barrel to empty. However, due to friction of the sensors and valves, the time it takes to empty completely the barrel would be longer but will most probably stay under two hours, fulfilling the requirement.

7.3 User Test Protocol

The test protocol is a predefined plan for a testing session with the goal of making testing smooth and consistent. The user test protocol consists of an interaction device, interaction method, usability and acceptance criteria. Prior testing, the test participants had to sign a consent form that can be found in *Appendix J.*

7.3.1 Interaction Device

The interaction device used for evaluation is the system's interface for the municipality and the system's interface and buffer for the citizens. Test persons will interact with a laptop that shows the interface of the system on a website. They are expected to be able to gain insights into the system's real-time performance, history performance and precipitation data by clicking on the specific date ranges of the graphs they want to be visualised for the chosen dates. Furthermore, the citizens will be able to manually discharge the buffer by setting the volume in litres of rainwater the buffer has to discharge, select either the sewerage or garden as discharge option and then clicking on the corresponding button in the interface to open the valve.
Feedback to the test person will be given by updating all the graphs after date selections and after the buffer's capacity has been changed due to (extra) rainfall, automatic or manual discharges.
The interface that will be tested is the interface from section 6.4.3. This interface has been recreated using Axure RP 8, a prototyping software [49]. It was chosen to test the interface within Axure RP so the interface can be tested without an internet connection and no dummy data has to be inserted in the database for the interface to work. The interface that has been made in Axure RP for testing can be seen in Figure 32.

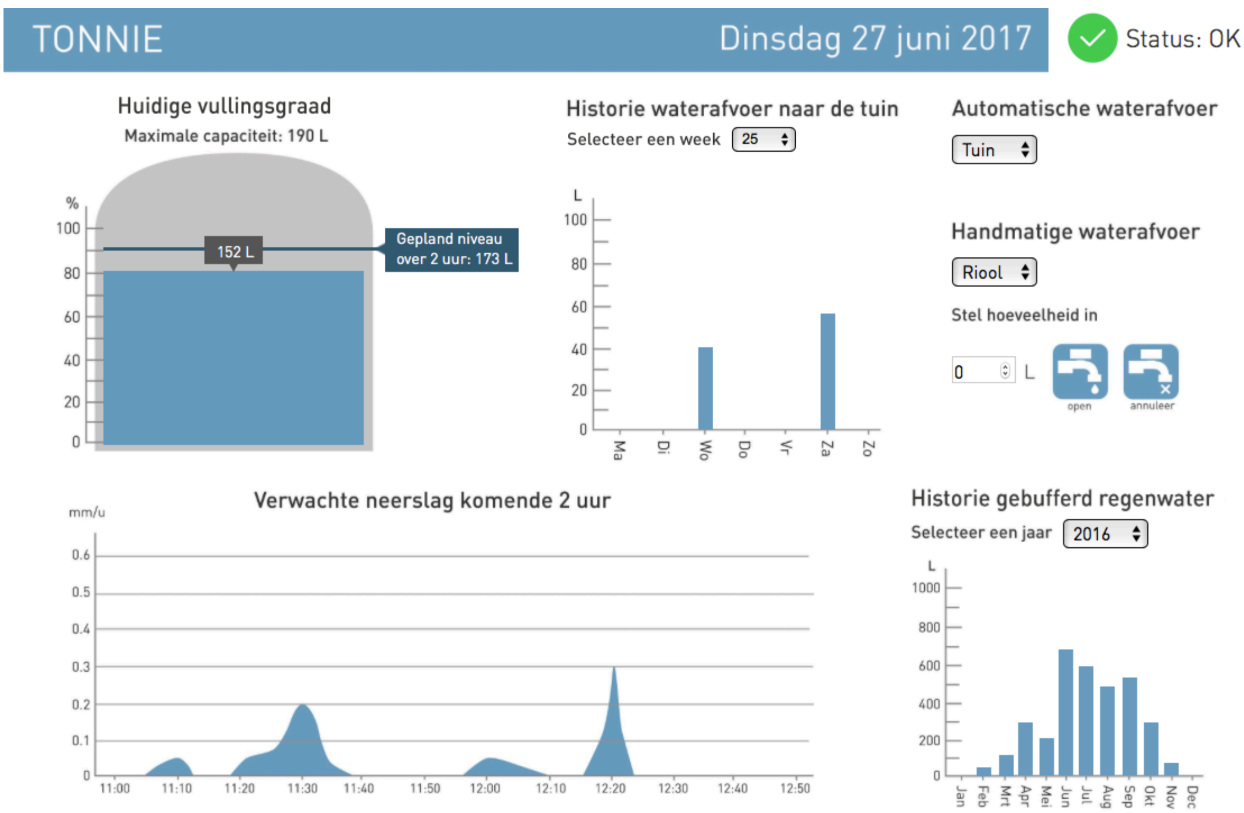


Figure 32. Interface made in Axure RP for testing.

7.3.2 Interaction Method

Two different interaction methods can be defined as free interaction and task based interaction. For free interaction, the test person can freely interact with the prototype without any goals that need to be achieved. Whereas task based interaction provides the test person with predefined tasks they need to execute.
For testing Tonnie, a task based interaction has been used. This interaction method has been chosen to test how well test participants were able to interact with the system when they wanted to gain insights into specific data and perform specific tasks. During the task based interaction, it was sometimes necessary to interrupt the testing and give the test participant a hint when they did not understand how

to perform a certain task. When the test participant did not show any sign of understanding the system and or the task they needed to perform, the test session was interrupted and guidance was given to the test participant.

7.3.3 Data Collection Method

During the test sessions, the data collection methods that have been used are thinking-aloud, observations and screen recordings which allow to gather the thoughts and experiences of the test persons. In addition, the test participants were asked to fill in a survey during and after the test and give feedback on the system. The survey can be found in *Appendix K*.

By letting test persons think aloud, two different sub methods were considered, a concurrent method and a retro perspective method. The concurrent method is meant to make the test participants tell about their experiences out loud during test session and the retro perspective method is meant to make the test participants share their experiences after the test session. By letting the test participants say out loud during the test session what they thought instead of afterwards, the thinking-aloud method was used in a concurrent way. It happened that test participants forgot the thoughts they had during the test session shortly afterwards. Therefore, the concurrent method was preferred over the retro perspective method, but as not every test participant was willing to speak out loud constantly, thoughts were discussed afterwards as well.

By observing the test participants, additional information was gathered by taking notes of important discoveries. These discoveries included the emotion test participants showed when interacting and if they were interacting enthusiastically with the system.

Combining all three methods, the experiences and thoughts of both the researcher and the test persons were gathered as well as the execution of the task based interactions.

7.3.4 Usability

Usability of the system will be tested with ten usability heuristics, developed for user interface design [50]. These heuristics include:

Visibility of system status

Feedback within reasonable time is necessary to keep users informed about what is going on with the system at any given time.

Match between system and the real world

The system should use familiar words, icons and concepts to the user rather than system-oriented terms. Information should appear in a logical and natural order that follows real-world conventions.

User control and freedom

When a mistake has been made by a user, an undo and redo function need to be implemented rather letting users go through extended dialogue. An emergency exit should be implemented.

Consistency and standards

Platform conventions should be followed where no confusion exist if different situations, actions or words mean the same thing.

Error prevention

Error-prone conditions should be eliminated or being checked and present to the users with a confirmation option before committing to the action.

Recognition rather than recall
When objects, options and actions are made visible, the user's memory load can be minimized. It is recommended that users should not have to remember too much information and instructions should be easily retrievable or visible for use of the system whenever appropriate.

Flexibility and efficiency of use
Frequent actions should be able to be tailored for experienced users so both experienced and inexperienced users are catered.

Aesthetic and minimalist design
To achieve a minimalist design, irrelevant or rarely needed information should not be contained in dialogues since it diminishes their relative visibility.

Error recognition, diagnosis and recovery.
Error messages should precisely indicate the problem and be expressed in plain language. Furthermore, they should constructively suggest a solution.

Help and documentation
In some cases, the provision of documentation can be necessary. This documentation should be easy to search, list steps the user can carry out, focus on the user's task and overall, not be too large.

These ten heuristics were tested by setting up a statement for each individual heuristic. Test participants gave their opinion on these statements by filling out a likert scale where people could completely disagree, disagree, are neutral, agree or completely agree with these statements. The statements and the results on the usability test will be discussed in section 7.3.6.

7.3.5 Acceptance

Acceptance criteria helped in making sure the prototype will actually be used by the users for which the system is designed, as well if the design of the final prototype corresponds with the wishes and demands of the end users. The acceptance criteria for testing the interface is defined as:

- Does the system encourages the user to buffer rainwater?

To test on acceptance, unstructured interviews have been conducted with the test participants which consisted of asking questions related to the acceptance criteria of the system.

7.3.6 Results

This section describes the results on the user evaluation where the usability will be evaluated through the tasked based interaction and heuristic evaluation. The acceptance criteria will be evaluated through unstructured interviews. The interface has been tested with 5 citizens from de Bothoven.

Tasked based interaction
The fifteen tasks and accompanied questions that have been executed as well as the results of the tasks and questions can be found in Figures 33-47.

1. What is the current status of the system?

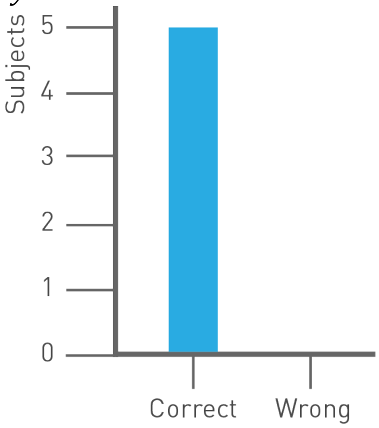


Figure 33. Task 1

2. How much is the buffer filled at this moment in percentages?

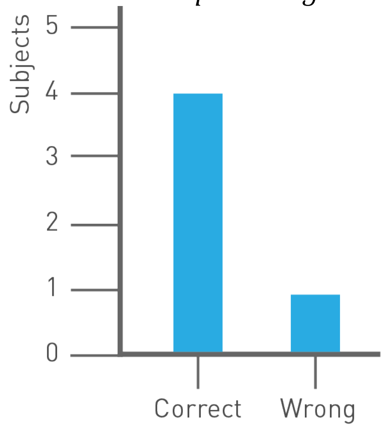


Figure 34. Task 2

3. How many litres of water does buffer contain at this moment?

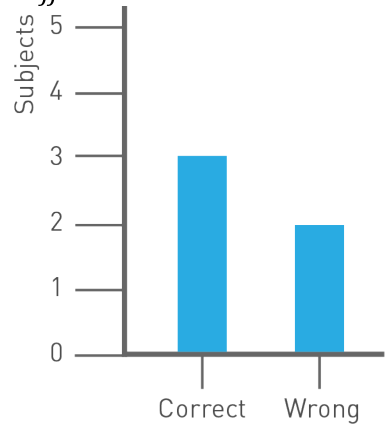


Figure 35. Task 3

4. What is the maximum capacity of the buffer in litres?

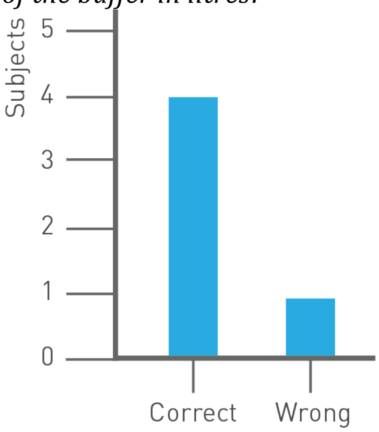


Figure 36. Task 4

5. Is there precipitation predicted for the coming two hours?

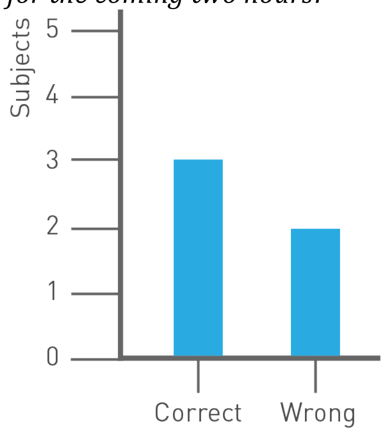


Figure 37. Task 5

6. How many litres of water will be in the buffer in two hours?

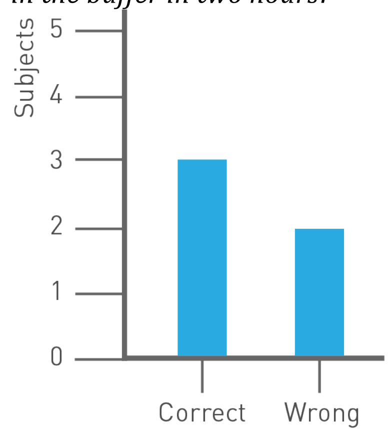


Figure 38. Task 6

7. What percentage is this?

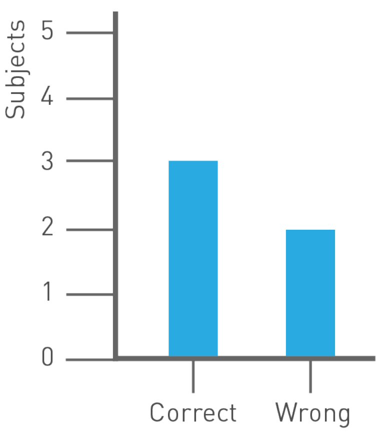


Figure 39. Task 7

8. How many litres of water did the system buffer in April 2016?

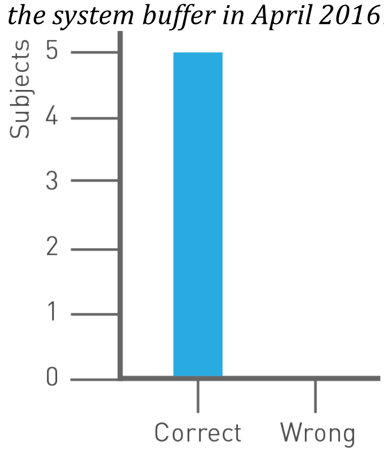


Figure 40. Task 8

9. How many litres of water did the system buffer in June 2017?

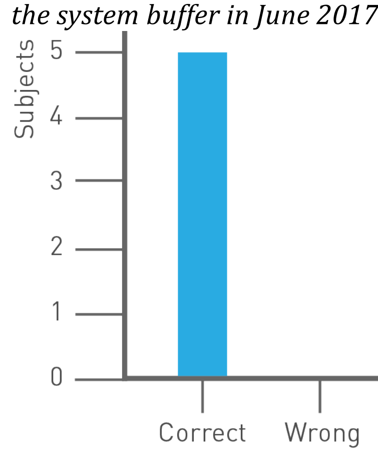


Figure 41. Task 9

10. How many litres of buffered rainwater went to the garden on Saturday in week 25?

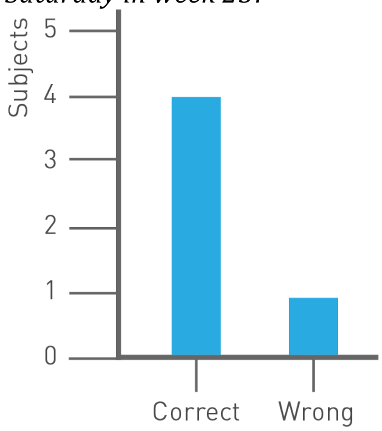


Figure 42. Task 10

11. How many litres of buffered rainwater went to the garden on Tuesday in week 26?

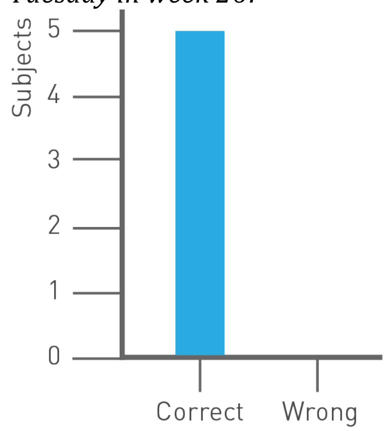


Figure 43. Task 11

12. Change the automatic discharge to the sewerage system.

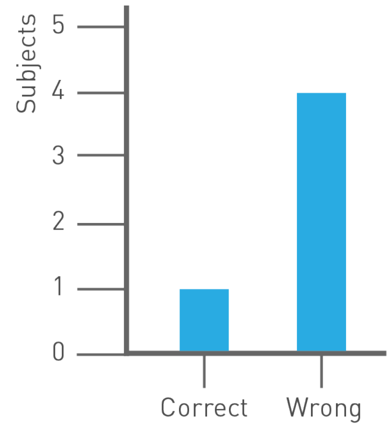


Figure 44. Task 12

13. Manually discharge 50 litres of water into the garden.

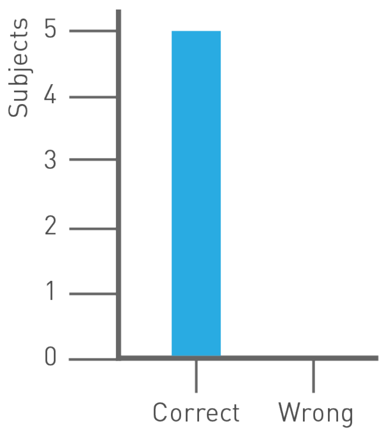


Figure 45. Task 13

14. How many litres of buffered rainwater went to the garden on Tuesday in week 26?

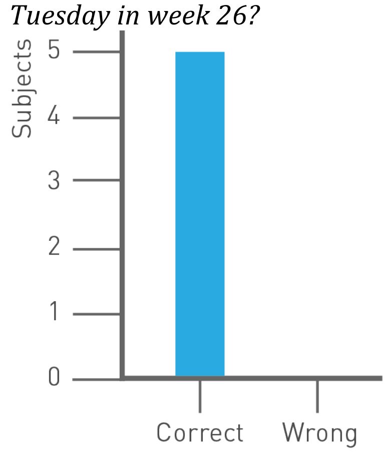


Figure 46. Task 14

15. How many litres of water does the buffer contain at this moment?

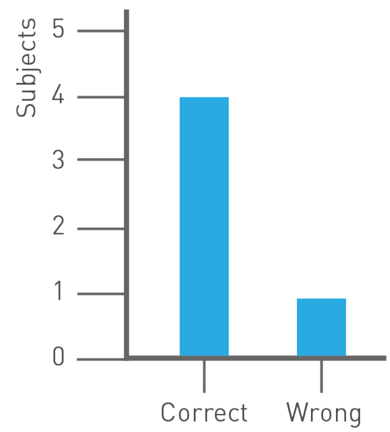


Figure 47. Task 15

Overall, the task based interaction went well. The majority of the test participant were able to execute the tasks properly.

To execute the first task, the test participants were asked to find the current status of the system. The first test participant had no trouble in finding the status of the system whereas the other four people were slightly confused about the word 'status.' They were uncertain whether this would imply if the system was performing well, that it was not working, or that is was about the amount of water present in the buffer etc. When the test participants were being told that the system's status should be readable from the interface, they eventually all found the system's status. They mentioned that they were overthinking what the system's status could be but they found the location of the status clear once they knew where to find it. Another factor that could have contributed to the test participants not seeing the status of the system could be the colour of the icon. During the user test the status of the system was 'OK' which contained a green icon. If this icon would for example be red, when the system status would be critical, it might have been more noticeable for the test participants.

The second task was finding out how much the buffer was filled with water at that specific moment during the test in percentages. Four out of five test participants had no trouble reading the bar graph. However, one test person found it really difficult to grasp that the tasks and questions in the survey were about the interface shown to her rather than an existing buffer which she did not have and therefore she thought she could not answer the question. After explaining several times that the questions can all be answered with the interface and are not related to existing buffers in the test participant's garden, it was still unclear for the test participant what to do and she guessed an answer based on what she thought the water would be when she would have a buffer at home.

The third task was almost the same as the second task, but participants now had to find the volume in litres. Unlike during the previous task, only three out five participants answered the question correctly.

The fourth task was finding the maximum capacity of the buffer. Four out of five participants did this correctly. Again, one test participant could not grasp that the question was about what was shown in the interface rather than a buffer standing in the test participant's garden at that moment. The test participant assumed that her potential buffer had a different maximum capacity than was written in the interface, therefore deviating from the correct answer.

The fifth question was if there was any predicted precipitation for the coming two hours. Three out of five test participants answered this question correctly by making use of the precipitation graph in the interface. However, two test participants were recalling the weather forecast for the day of testing and remembered that it was not going to rain that day. Therefore, they ignored the precipitation graph plotted in the interface.

The sixth task was to find out what the volume of water inside the buffer would be in two hours. This was also visible in a combined bar and line graph but only answered correctly by three out of five test participants. The same test participants that answered the question on the predicted precipitation wrong, answered this question wrong as well. When people answered that there was no precipitation predicted in the coming two hours, they said the volume of the buffer would remain the same as they answered in question three, rather than reading the answer off the line graph.

The seventh task was converting this volume into a percentage which was also readable from this same line graph. The same people who answered question six wrong answered this question wrong as well, all due to the wrong insights on the predicated precipitation.

The eighth task was reading off a bar chart, for how much water the system buffered in April 2016. All test participants answered this question correctly. By analysing the videos, it can be seen however that the test participants did not use the tooltip to read off the needed value. This is probably because they did not know there were tooltips present when hovering over bars or they were not comfortable using the trackpad of a laptop.

The ninth task was similar to task eight, but for this tasked the test participants needed to select a different year. No test participant had difficulties doing so and all answered the question correctly. Again, for this question, the tooltip was not used to read off the value more easily.

The tenth task was reading off a bar chart, how much buffered rainwater had been discharged into the garden in week 25. Four out of five test participants were able to answer this question correctly. One test participant asked when week 25 was, which was the week prior to the user test. The test participant then said that her garden did not get any rainwater that week and filled in the wrong answer. Again, the tooltip was not used to find the answer to the question.

The eleventh task was similar to task ten, but then the test participants had to select a different week. All test participant answered the question correctly as the graph showed no buffered rainwater was discharged into the garden.

The twelfth task was setting the automatic discharge to the sewerage system. However, this task was skipped by all participants, simply because they read over the question. One test participant was asked to execute the task while he was ready to execute task thirteen but the test participant did execute the task well.

The thirteenth task was similar to the twelfth task but then setting the manual discharge to the garden and discharging 50 litres of water. This task was not skipped by the test participants and executed well. The test participants had to fill in the amount of water in a type box where two out of five test participants were a bit hesitant but turned out to fill out the amount just fine. After filling out the text field, two out of five test participants were hesitant about what they had to do next. They knew they had to approve something to confirm that 50 litres of water would discharge into the garden and after giving it some thought, they were all able to press the button to open the valve.

The fourteenth task was the exact same as task eleven, but now with updated data. All test participants were able to answer the question correctly and understood why the answer was different from question eleven.

The fifteenth and final task was the same as task three, but again with updated data. When 50 litres had been discharged into the garden, the bar and line graph were updated every half second to simulate a real situation when the volume inside the buffer changes due to manual discharges. However, due to the time limit these updates were set to half a second to speed up the process. Three test participants really liked the feedback of the updated bar and line graph as it seemed they were animated. Four out of five test participants answered this question correctly where again one test participant was confused about the buffer in the interface and a potential buffer in one's garden.

Heuristics

After the task based analysis, a heuristic evaluation with ten questions was performed by the test participants. The results of this heuristic evaluation can be found in Figures 48-57.

1. I find the status of the system clearly visible

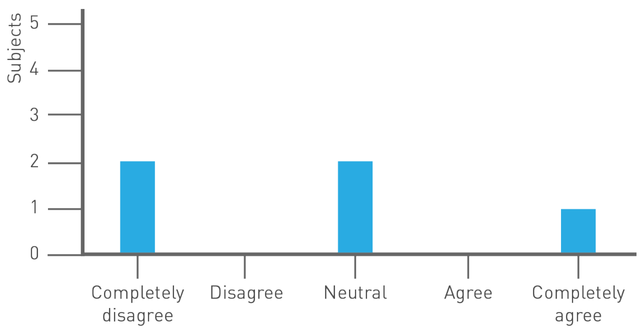


Figure 48. Heuristic 1

2. The meaning of the used icons and symbols were completely clear

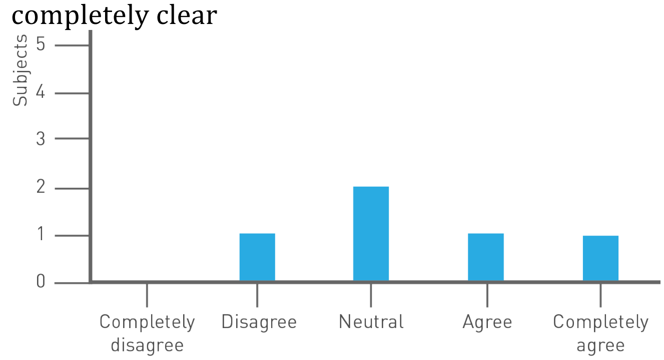


Figure 49. Heuristic 2

3. I feel like I am in control over the interaction with the system

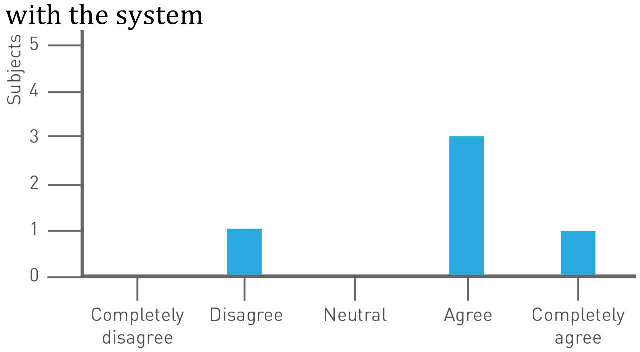


Figure 50. Heuristic 3

4. The design of the interface is consistent

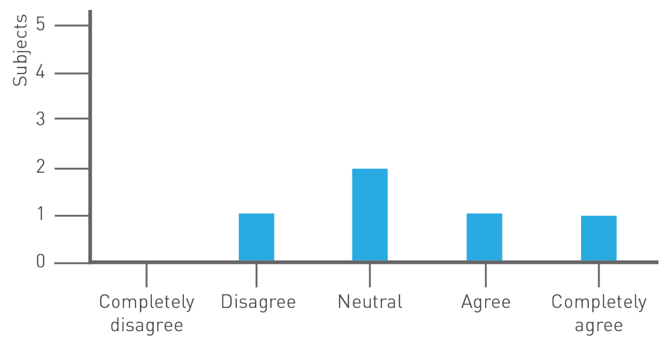


Figure 51. Heuristic 4

5. There are no mistakes in the interface

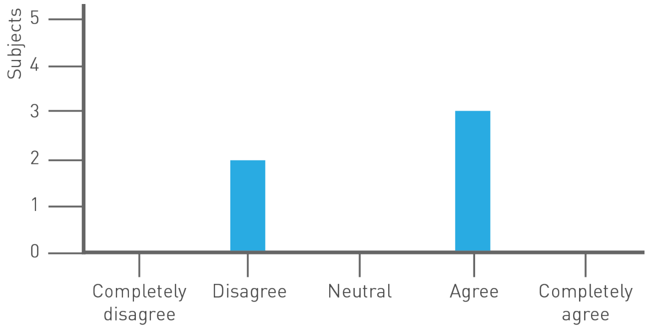


Figure 52. Heuristic 5

6. The interface is easy to use

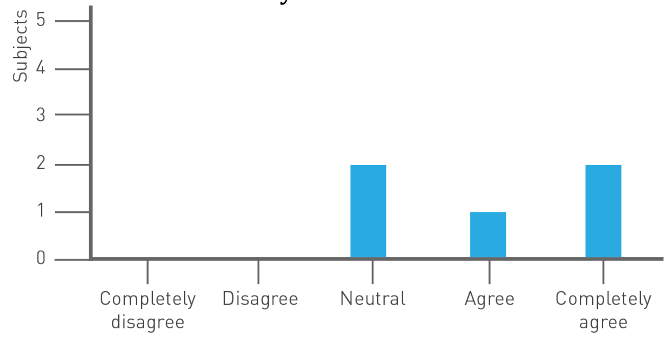


Figure 53. Heuristic 6

7. I can navigate efficiently through the interface

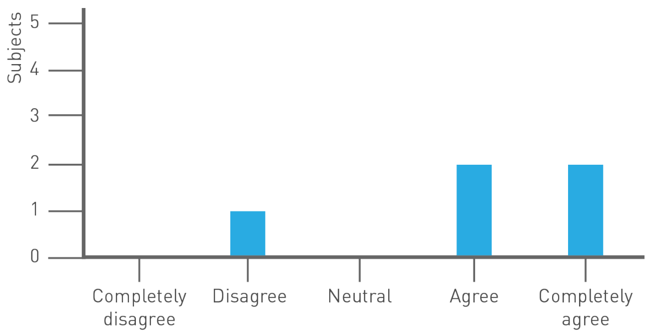


Figure 54. Heuristic 7

8. I find the interface pleasantly looking

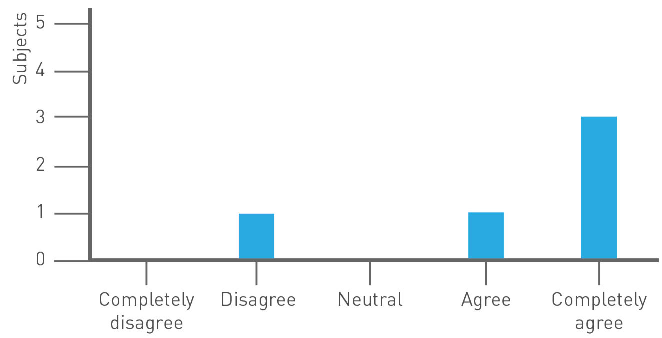


Figure 55. Heuristic 8

9. It is clear when I made a discharge selection

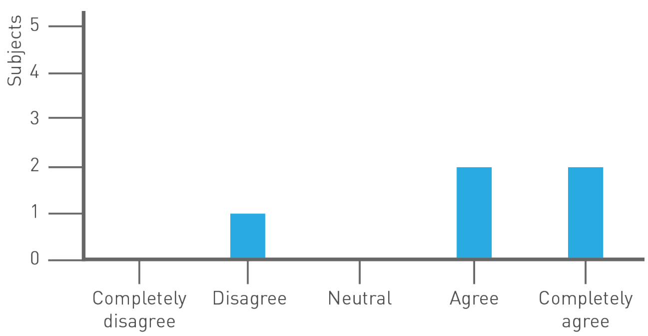


Figure 56. Heuristic 9

10. I can easily find help when needed using the interface

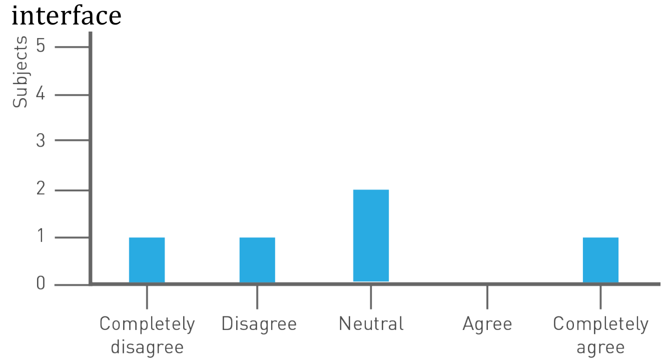


Figure 57. Heuristic 10

1. I find the status of the system clearly visible.
The first task, during which test participants had to find the status of the system, was also the task that took most time because test participants did not know what to look for. When they eventually saw the status they told that they were looking in the wrong place or were overly thinking the question. Because only one test participant could immediately find the status of the system, the majority of the people completely disagreed or were neutral about the statement.

2. The meaning of the used icons and symbols were completely clear.
Since there are only a few icons present in the tested interface, the question refers to the icons used for manually opening and closing the valve. Most test participants were neutral or agreed/completely agreed with the statement whereas only one test participant disagreed. This was probably because the test participant was visually impaired and the icons with the text were too small and difficult to read.

3. I feel like I am in control over the interaction with the system.
Only one test participant disagreed with this statement where the majority agreed and completely agreed with the statement. The test participant who disagreed took the longest time interacting with the system and was not completely comfortable with using a laptop.

4. The design of the interface is consistent.
One out of five test participant disagreed with the interface being consistent whereas the others were either neutral, agreed or completely agreed.

5. There are no mistakes in the interface.
Two out of five participants disagreed with this statement whereas the others agreed. This was caused by the precipitation forecast that showed it was going to rain in the next two hours while no rain was predicted that day.

6. The interface is easy to use.
Two test participants were neutral about the interface being easy to use whereas one test participant agreed with the statement and two others completely agreed.

7. I can navigate efficiently through the interface.
One test participant could not navigate efficiently through the interface as they had trouble understanding it. The other four test participants were evenly divided over agreeing with the statement and completely agreeing.

8. I find the interface pleasantly looking.
Four out of five test participants found the interface pleasantly looking where one of them agreed with the statement and three of them completely agreed. However, one test participant disagreed with the statement and therefore did not find the interface pleasantly looking.

9. It is clear when I made a discharge selection.
Four out of five test participants found it clear when they made a discharge selection with half of the participants agreeing with the statement and the other half completely agreeing with the statement. Again, it was unclear for one test participant when a discharge selection was made and disagreed with the statement. The discharge selection could be made in a dropdown list with two options, the sewerage system and the garden.

10. I can easily find help when needed using the interface.
The expected outcome for this heuristic would have been that all participants would disagree or completely disagree. However, one participant completely agreed with the statement since according to their thoughts, the researcher was the help during testing. The other test participants had a divided opinion between completely disagreeing with the statement and being neutral.

Unstructured interviews

Prior to testing, it was intended to test both citizens of de Bothoven as well as citizens of Velve-Lindenhof. Mentioned before was that all test participants were citizens of de Bothoven which were all happy to help and test the interface. However, citizens from Velve-Linenhof were not willing to test the interface when they were asked to. Roughly eight people have been asked to test the interface. 50% of the test participants said they were not comfortable using a laptop. One potential tester said she knew the problem of damage by excessive rainwater as her toilet would overflow during heavy rainfall. This was recently fixed by cutting down the downspout and letting rain water flow into the garden, reducing rainwater to flow into the sewerage system at her own property. However, even with the knowledge of the rainwater problems in Enschede, this potential tester was not willing to test the interface. This was because she did not experience the problems of excessive rainwater herself anymore and did not feel the need to help others by testing this interface. All the other potential test participants were simply not interested in testing the interface since they never experienced problems with excessive rainwater due to the location of the neighbourhood (Velve-Lindenhof has a higher altitude than the city centre.) Resulting that rainwater will flow away from Velve-Lindenhof and collect in the city centre.

Unlike the citizens in Velve-Lindenhof the test participants from de Bothoven were very enthusiastic about the system and liked the interactions with it. One of the problems that arose was what should happen when no space would be available for a rainwater buffer on one's property when they have no garden. This would imply that these citizens would not be able to buffer rainwater even when they do like the system.

By testing the interface, four out of five participants sometimes needed some guidance to get started. One of the test participants suggested to include a manual to the interface, which can be consulted prior the first time using the interface or when users do not know how certain things work or what they are.

7.4 Conclusion

From the test results, it can be concluded that four out of five people had no trouble with the tasked based interactions and overall the test participants seemed very enthusiastic about the interface. Their enthusiasm increased when they were able to interact with the interface and actually see changes happen when new data selections have been made or when the bar and line graph of the buffer capacity changed.

When people would understand the interface was meant as a test and not something that was attached to a buffer in their gardens during testing, the test participants most of the time executed the tasks well and knew how to perform these task without significant help. However, a manual for the interface would not be superfluous for most test participants.

Only one task, to set the automatic discharge to the sewerage system, was wrongly performed by the majority of the test participants whereas all the other tasks and accompanied questions were performed correctly by the majority of the test participant. This was not due to the task itself but that the test participants read over the task and therefore skipped it. Furthermore, the task that was most difficult for most participants was finding the status of the system. The test participants were simply overthinking the task or looking at the wrong places.

No test participants could be found for the neighbourhood Velve-Lindenhof where some potential test participants declined since they were not interested in buffering rainwater or were anxious of interacting with a laptop.

Concluding, due to a very small test group, the results described in section 7.3.6 are not representative for the whole target area which consists out of roughly five thousand households. Therefore, no-well founded conclusion could be made but from the people that tested the interface, the majority liked it and were able to interact well with it.

8. Conclusion

This chapter will provide the answers to the research questions stated in section 1.3 and other conclusions of this graduation project.

At the beginning of the report, a research question has been defined along with two sub questions. In order to find an answer to these questions, a literature research towards rainwater harvesting was set-up, defining the potential uses of rainwater. Furthermore, several smart and non-smart applications have been researched that harvest rainwater to get insights on already existing systems.

The first sub question was defined as: *What solutions are feasible if system elements are located on the private properties of the inhabitants of 'de Bothoven' and 'Velve-Lindenhof'?* To find an answer to this question, the target area has been analysed. It was found that there are approximately 5000 households present in the target area in total. Most of the houses in the target area have a pitched rooftop which is unfortunately unsuitable for rainwater harvesting. However, pitched rooftops can still be used as catchment area. Houses in this target area mostly consist out of detached and semi-detached buildings where a front yard is not that common. When using a rooftop as catchment area, the buffer has to be placed close to the downspout which is often located at the street side of the house, usually at the front. Unfortunately, most houses in de Bothoven do not have a front yard making it difficult to place a rainwater buffer. However, most houses do have a significant backyard (compared to the front yard) leaving options for diverting the downspout or assembling a new downspout in the backyard for rainwater buffering. In Velve-Lindenhof, more houses with a front yard are present, making rainwater buffering via a rooftop and downspout possible.

The second sub question was defined as: *What control functionality is needed to optimize buffering capacity of this system?* By conducting a survey with the inhabitants of de Bothoven, it became clear that some people would like to have an autonomous system where others would like to control the system manually. Therefore, it was decided that the system is able to function autonomously but can be controlled by the user as well if the user has this need. Also noted from the survey was people showing more interest in buffering rainwater when they would be able to re-use the harvested rainwater for their private usage. Therefore, the control functionality provides users the opportunity to discharge water to either the sewerage system or the garden, where the latter could make watering plants in the garden a lot easier if a hose is attached to the buffer. To maximise the buffering capacity, water will only be discharged if the predicted precipitation is more than the empty space in the buffer. When more rainfall is anticipated, the buffer will discharge to either the sewerage system or garden (that can be set by the user) to make enough space to harvest the rainfall. This causes the smart rain buffer to be filled for most of the time (unless water is manually discharged or used) leaving the user with plenty of rainwater which can be re-used.

Finally, an answer can be given to the main research question: *How to develop a smart rainwater buffering system that reduces the strain on the sewerage system of the municipality of Enschede?* By interviewing the municipality of Enschede, requirements were set-up for the system. From these requirements, a functional system architecture was derived which identified the functionalities of the system and translate these to realisable subsystems. By using both the requirements and the functional system architecture, a prototype was built; a smart rainwater buffer with sensors, valves, micro-computers and controllers and an interface which has been programmed in JavaScript. The interaction takes place via the interface where users can select date ranges to visualise the data they want to see. Furthermore, the citizens are able to set the automatic and manual discharge of the system to either the sewerage system or the garden and manually discharge a chosen amount of water by opening the valve via a button in the interface.

Finally, the interface was tested with users which led to new recommendations for further development of the system.

9. Recommendations

This chapter will provide recommendations for future development of the system. Firstly, the system was only tested with five test participants who are not representative for the total target area. Therefore, it is recommended to test the system with a larger group of test participants from the target area. Secondly, better sensors should be used which are more accurate (but also more expensive.) Thirdly, to improve the safety and quality of the water, a temperature sensor should be implemented in the buffer. When temperatures are getting too low, the buffer should discharge its water before it freezes and when temperatures are too high, the buffer should discharge its water to reduce the chance of contamination which hinders re-using the captured rainwater.

9.1 Usability

In order to improve the usability of the system, the system should have more feedback implemented. When a discharge selection has been made and water is set to discharge, the user gets no feedback whether the system is still discharging or when the system finished discharging. This could be implemented by either showing a pop-up screen which says 'discharging', or having a drop-down menu where the discharging requests are shown. In addition, the status should also provide the user feedback in the form of text when something is wrong with the system and how to fix the issue.

Furthermore, a manual should be implemented when users are using the system for the first time or when people are not sure how to use the system. This manual could be implemented in the form of a walkthrough or a telephone number could be added for people to call if they are completely clueless about the system.

In addition, the interface should be adapted for people with an impaired vision. As the target users consist out of different aged people, a significant part of this group consists of elderly people. Some elderly people are a bit hesitant when it comes down to interacting with a computer. However, if they are willing to do so, the interface should be clearly readable for them. It should therefore be an option to tailor the font size and graph size to users' own needs.

Finally, the interface should be available on different platforms. For many people, it is easier to look on an app on their smartphones, rather than on their computer. Furthermore, a different platform should be researched since many potential test participants did not want to participate during the test because they did not feel comfortable interacting with a computer.

9.2 Acceptance

To improve the acceptance of the system, the smart rainwater buffer itself should become more visually attractive. Since the system would most likely be installed at the front of a house, people would not be interested in the system when all the wires are visible. Furthermore, from the survey could be concluded that people would prefer a rainwater harvesting planter over a normal rain barrel. Since the technology would remain the same, only the outside barrel would need adaptation.

In addition, people could be persuaded by the municipality to get a rainwater buffering system if they get something in return. One could think of reducing the taxes on the sewerage system, or giving a financial funding. Furthermore, the same applies for the water board. It is of their interest that rainwater flows back into nature rather than the sewerage system and therefore the water board taxes could be reduced if for example people let their rainwater buffer discharge the rainwater to the garden for more than 60% of the time.

Finally, the system could be expanded towards a larger system, increasing sustainability. With additional filters and water treatment, harvested rainwater could be re-used for more things, replacing potable water sources. This is not only beneficial for nature but could also reduce more costs on potable water sources making the system more attractive for the citizens.

References

[1] *Gemeentelijk Rioleringsplan 2016-2020, Veilig en op maat*, 1st ed. Enschede: Drukkerij Gemeente Enschede, 2016.

[2] J. Hartemink and R. Meijer, *Proeftuin Enschede: risicogestuurd (afval)waterbeheer*, 1st ed. [Ede]: Stichting RIONED, 2015.

[3] M. Rashidi Mehrabadi, B. Saghafian and F. Haghighi Fashi, "Assessment of residential rainwater harvesting efficiency for meeting non-potable water demands in three climate conditions", *Resources, Conservation and Recycling*, vol. 73, pp. 86-93, 2013. DOI: 10.1016/j.resconrec.2013.01.015

[4] R. Farreny, T. Morales-Pinzón, A. Guisasola, C. Tayà, J. Rieradevall and X. Gabarrell, "Roof selection for rainwater harvesting: Quantity and quality assessments in Spain", *Water Research*, vol. 45, no. 10, pp. 3245-3254, 2011. DOI: 10.1016/j.watres.2011.03.036

[5] A. GhaffarianHoseini, J. Tookey, A. GhaffarianHoseini, S. Yusoff and N. Hassan, "State of the art of rainwater harvesting systems towards promoting green built environments: a review", *Desalination and Water Treatment*, pp. 1-10, 2015. DOI: 10.1080/19443994.2015.1021097

[6] A. Campisano, D. Butler, S. Ward, M. Burns, E. Friedler, K. DeBusk, L. Fisher-Jeffes, E. Ghisi, A. Rahman, H. Furumai and M. Han, "Urban rainwater harvesting systems: Research, implementation and future perspectives", *Water Research*, vol. 115, pp. 195-209, 2017. DOI: 10.1016/j.watres.2017.02.056

[7] M. Haque, A. Rahman and B. Samali, "Evaluation of climate change impacts on rainwater harvesting", Journal of Cleaner Production, vol. 137, pp. 60-69, 2016. DOI: 10.1016/j.jclepro.2016.07.038

[8] S. Ward, F. Memon and D. Butler, "Performance of a large building rainwater harvesting system", *Water Research*, vol. 46, no. 16, pp. 5127-5134, 2012. DOI: 10.1016/j.watres.2012.06.043

[9] A. Vieira, C. Beal, E. Ghisi and R. Stewart, "Energy intensity of rainwater harvesting systems: A review", *Renewable and Sustainable Energy Reviews*, vol. 34, pp. 225-242, 2014. DOI: 10.1016/j.rser.2014.03.012

[10] K. An, Y. Lam, S. Hao, T. Morakinyo and H. Furumai, "Multi-purpose rainwater harvesting for water resource recovery and the cooling effect", *Water Research*, vol. 86, pp. 116-121, 2015. DOI: 10.1016/j.watres.2015.07.040

[11] M. Kollo and J. Laanearu, "An optimal solution of thermal energy usage in the integrated system of stormwater collection and domestic-water heating", *Urban Water Journal*, vol. 14, no. 2, pp. 212-222, 2015. DOI: 10.1080/1573062x.2015.1086006

[12] B. Janke, W. Herb, O. Mohseni and H. Stefan, "Case Study of Simulation of Heat Export by Rainfall Runoff from a Small Urban Watershed Using MINUHET", *Journal of Hydrologic Engineering*, vol. 18, no. 8, pp. 995-1006, 2013. DOI: 10.1061/(asce)he.1943-5584.0000696

[13] M. Scholz and P. Grabowiecki, "Combined permeable pavement and ground source heat pump systems to treat urban runoff", *Journal of Chemical Technology & Biotechnology*, vol. 84, no. 3, pp. 405-413, 2009. DOI: 10.1002/jctb.2054

[14] A. Novo, J. Bayon, D. Castro-Fresno and J. Rodriguez-Hernandez, "Temperature Performance of Different Pervious Pavements: Rainwater Harvesting for Energy Recovery Purposes", *Water Resources Management*, 2013. DOI: 10.1007/s11269-013-0270-y

[15] L. Handia, J. Tembo and C. Mwiindwa, "Potential of rainwater harvesting in urban Zambia", *Physics and Chemistry of the Earth*, no. 28, pp. 893–896, 2003. DOI: 10.1016/j.pce.2003.08.016

[16] Dobrowksy, H et al. "Quality Assessment And Primary Uses Of Harvested Rainwater In Kleinmond, South Africa". *Water SA* 40.3 (2014): 401. DOI: 10.4314/wsa.v40i3.2

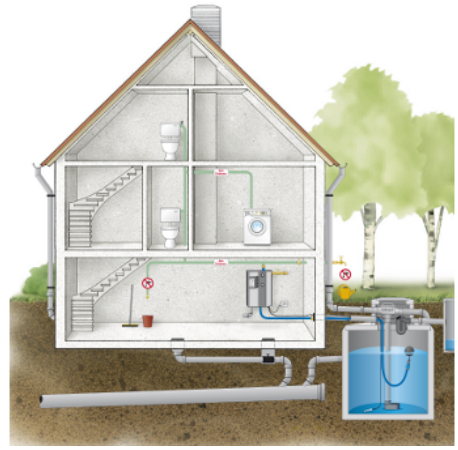
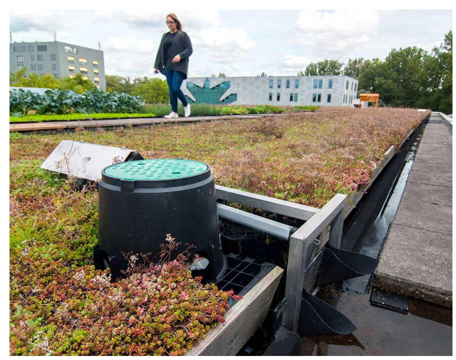
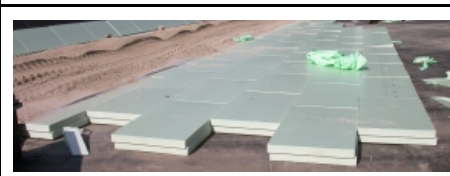
[17] J. Gould, Z. Qiang and L. Yuanhong, "Using every last drop: rainwater harvesting and utilization in Gansu Province, China", *Waterlines*, vol. 33, no. 2, pp. 107-119, 2014. DOI: 10.3362/1756-3488.2014.012

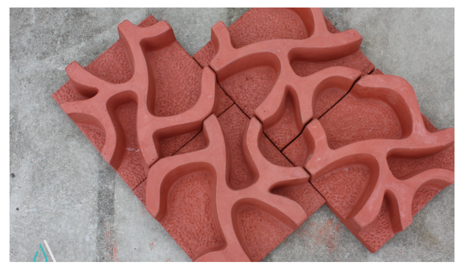
[18] Silva, Cristina Matos, Vitor Sousa, and Nuno Vaz Carvalho. "Evaluation Of Rainwater Harvesting In Portugal: Application To Single-Family Residences". *Resources, Conservation and Recycling* 94 (2015): 21-34. Web. DOI: 10.1016/j.resconrec.2014.11.004
[19] P. Melville-Shreeve, S. Ward and D. Butler, "Rainwater Harvesting Typologies for UK Houses: A Multi Criteria Analysis of System Configurations", *Water*, vol. 8, no. 4, p. 129, 2016. DOI: 10.3390/w8040129
[20] B. Godskesen, M. Hauschild, M. Rygaard, K. Zambrano and H. Albrechtsen, "Life-cycle and freshwater withdrawal impact assessment of water supply technologies", *Water Research*, vol. 47, no. 7, pp. 2363-2374, 2013. DOI: 10.1016/j.watres.2013.02.005
[21] A. Moraes and C. Rocha, "Gendered waters: the participation of women in the 'One Million Cisterns' rainwater harvesting program in the Brazilian Semi-Arid region", Journal of Cleaner Production, vol. 60, pp. 163-169, 2013. DOI: 10.1016/j.jclepro.2013.03.015
[22] *LOXONE*, 2014. [Online]. Available: https://www.loxone.com/enen/rainwater-harvesting/. [Accessed: 30- Mar- 2017].
[23] *Bas Sala*, 2017. [Online]. Available: http://www.bassala.com/slimme-regenton. [Accessed: 02- Mar- 2017].
[24] *IOTA*, 2016. [Online]. Available: http://www.iota.net.au/. [Accessed: 11- Apr- 2017].
[25] *AppAdvice*, 2016. [Online]. Available: https://appadvice.com/app/tank-talk/1081704452/. [Accessed: 11- Apr- 2017].
[26] *Sustainability Matters*, 2016. [Online]. Available: http://www.sustainabilitymatters.net.au/content/water/article/monitoring-rainwater-with-talking-tanks-789774949/. [Accessed: 11- Apr- 2017].
[27] *Architecten Web*, 2016. [Online]. Available: https://architectenweb.nl/producten/product.aspx?ID=26272/. [Accessed: 15- Apr- 2017].
[28] *Optigroen,* 2016. [Online]. Available: http://www.optigroen.nl/nieuws/in-de-pers/innovatives-regenwassermanagement-wetter-app-steuert-abfluss-vom-gruendach/. [Accessed: 15- Apr- 2017].
[29] *LandschapOverijssel*, 2017. [Online]. Available: http://www.landschapoverijssel.nl/water-en-kristalbad. [Accessed: 10- Apr- 2017
[30] *Centraal Bureau voor de Statistiek*,, 2017. [Online]. Available: http://www.cbsinuwbuurt.nl/. [Accessed: 24- Apr- 2017].
[31] *Google Maps*, 2017. [Online]. Available: https://www.google.nl/maps/place/De+Bothoven,+Enschede/. [Accessed: 03- Apr- 2017].
[32] E. Dekker, "Witteveen+Bos Nieuws 101", no. 24, 2016.
[33] A. Mader and W. Eggink, A Design Process for Creative Technology, 2014.
[34] J. Christopher Jones, Design methods. Wiley-Interscience, London, 1970.
[35] Michael Resnick & Eric Rosenbaum. Design, Make, Play: Growing the Next Generation of STEM Innovators, chapter Designing for Tinkerability. Taylor & Francis, 2013.
[36] Reqtest.com, 2017. [Online]. Available: http://reqtest.com/requirements-blog/functional-vs-non-functional-requirements/. [Accessed: 19- May- 2017].
[37] "RWJF - Qualitative Research Guidelines Project | Interviewing | Interviewing", Qualres.org, 2017. [Online]. Available: http://www.qualres.org/HomeInte-3595.html. [Accessed: 13- May- 2017].
[38] D. Benyon and C. Macaulay, "Scenarios and the HCI-SE design problem", Interacting with Computers, vol. 14, no. 4, pp. 397-405, 2002.
[39] V.Trulock, "Designing Interactive Systems A comprehensive guide to HCI, UX and interaction design", 2008.
[40] I. Widya, R. Bults, M, Huis in 't Veld and M. Vollenbroek-Hutten, "Scenario-based requirements in elicitation in a pain-teletreatment application", 2009.
[41] "AcqOps", AcqNotes, 2017. [Online]. Available: http://www.acqnotes.com/acqnote/careerfields/functional-architecture. [Accessed: 22- May- 2017].
[42] Freeman, R.E. "Strategic Management: A stakeholder approach", Pitman, Boston, 1984.
[43] H. Sharp, A. Finkelstein and G. Galal, "Stakeholder Identification in the Requirements Engineering

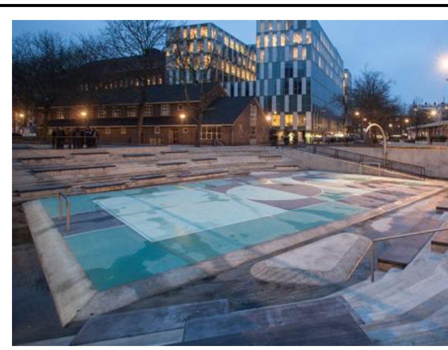
Process", 1999.
[44] "Nefit Easy: de slimste thermostaat!", Nefit.nl, 2017. [Online]. Available: https://www.nefit.nl/consument/service/easy/easy. [Accessed: 20- Jun- 2017].
[45] "Raspberry Pi - Teach, Learn, and Make with Raspberry Pi", Raspberry Pi, 2017. [Online]. Available: https://www.raspberrypi.org/. [Accessed: 07- Jun- 2017].
[46] "Arduino - Home", Arduino.cc, 2017. [Online]. Available: https://www.arduino.cc/. [Accessed: 07- Jun- 2017].
[47] M. Bostock, "D3.js - Data-Driven Documents", D3js.org, 2017. [Online]. Available: https://d3js.org. [Accessed: 19- Jun- 2017].
[48] D. Brilman, M. van der Hoef, "Transport Phenomena"
[49] "Prototypes, Specifications, and Diagrams in One Tool | Axure Software", Axure.com, 2017. [Online]. Available: https://www.axure.com. [Accessed: 25- Jun- 2017].
[50] "10 Heuristics for User Interface Design: Article by Jakob Nielsen", Nngroup.com, 2017. [Online]. Available: https://www.nngroup.com/articles/ten-usability-heuristics/. [Accessed: 15- Jun- 2017].

Appendix

A. Overview of Rainwater Buffering Elements

Product	Scale	Image
GEP regenwater IRM™ rainwater systems from GEP can be combined with rainwater tanks from GEP and rainwater can be re-used for doing the laundry, toilet flushing and garden irrigation. When the rainwater tank is empty, the system automatically switches over to the potable water source for refilling the rainwater tank, so users consume less potable water. Source: www.regenwater.com	Garden	
Retention Roof Retention Roof by Optigreen reduces water discharge during rainfall whilst retaining good drainage. The roof provides both discharge delay and water storage and is generally suitable for inverted roofs and blue roofs. Source: http://www.optigreen. co.uk	Roof	
Polderdak The Polderdak exists of the Smart Flow Control an underground buffer system. The Polderdak makes a roof a water storage component which can be controlled and it retains rainwater during rainfall and discharges the rainwater afterwards. Polderdak could be a basis for a green roof, roof garden or roof park. Furthermore, the harvested rainwater could be re-used for household activities. Source: www.polderdak.nl	Roof	
Green facades Green facades absorb rainwater by water buffering in plants and its substrate. It slows the discharge into the sewerage system, cleans the rainwater and the plants cause the water to evaporate. Source: www.sempergreen.com	Building	
Roofdrain The drainage mats contribute to buffering of rainwater which can be placed underneath any type of green roof. Source: www.intercodaminfra.com	Roof	

Rainwinner Garden elements are converted to water suppliers and is a perfect solution for rainwater buffering in gardens. Empty modules can buffer up to 110 litres of rainwater and can be assembled next to or onto each other like Lego bricks. Furthermore, the harvested rainwater can be re-used for household activities. Source: www.rainwinner.nl	Garden	
Kristalbad Kristalbad can be seen as a water machine and combines water storage with water purification on a natural way. The total area stretches about 40 hectares which can store 187.000 cubic meters of water. Source: http://www.landschapoverijssel.nl/water-en-kristalbad	Landscape	
Flood Rain(a)Way's 'Flood' is a tile that stores rainwater in a visual way and attractive way. The tiles are only meant for decoration and not for walking. The lower layer of the tile is completely closed making water only being able to flow out via joints. Source: www.rainaway.nl	Garden	
Hydroblob/Hydrorock Hydroblob, also known by Hydrorock, protects a garden from excessive rainwater by absorbing rainwater and discharging water to the surrounding area. Source: www.hydroblob.com Source www.hydrorock.nl	Garden	
MultiBouwSystemen Rainwater can be harvested in water storage cellars made from prefab concrete underneath squares and parking lots after which water will be discharged into the sewerage system of the municipality, to surface water or into the soil. In addition, the collected rainwater can be retained for re-usage. Source: www.mbswaterberging.nl	Neighbourhood	
Smart Station The smart station offers electricity outlets that are powered by renewable energy. Furthermore, with the wind and solar energy. The rainwater that will flow from the roof into the tank will be purified and offered to the users. Source: www.coroflot.com/saeid-kh/Smart-Station	Neighbourhood	

Waterfix Waterfix is a cellular water storage block which is lightweight and uses injection moulded recycled material. The modular system provides a sustainable and versatile drainage system, buffering rainwater and therefore reduces the risk of flooding. Source: www.bera-bv.com/waterfix	Garden	
Urbanscape Landscaping System Urbanscape can be implemented in gardens and has a high water retention capacity. The Urbanscape Green Roles are made of wool fibres which have a high water absorption and retention property. Additional water storage is provided by virgin mineral fibres which release water when required. Source: http://www.bera-bv.com/urbanscapegreenroll	Garden	
Wadi A wadi is a planted ditch consisting of permeable soil. The top layer is planted improved ground with underneath a geotextile box that is filled with stones through which rainwater can flow. An infiltration pipe is present at the bottom of the box to which overflow elements are attached. Source: www.groenblauwenetwerken.com/measures/bioswales/	Neighbourhood	
Infiltra Rainwater Crates One Infiltra unit consists out of 2 modular crates of 125 litres each. Infiltration crates prevent rainwater flowing in a short time period into the sewerage system. The crates buffer the water before releasing it again. Source: www.acogarden.be/nl/product/infiltra	Garden or Street	
Water Square A water square makes water storage facilities visible and enjoyable for inhabitants as in dry periods the square can be used as a recreational space. The rainwater is collected in the surroundings of the square where it is being transported via gutters into the basins. These gutters are made out of stainless steel and designed to fit for skaters. Source: www.urbanisten.nl/wp/?portfolio=waterplein-benthemplein	Neighbourhood	

B. Photos of Buildings at de Bothoven and Velve-Lindenhof



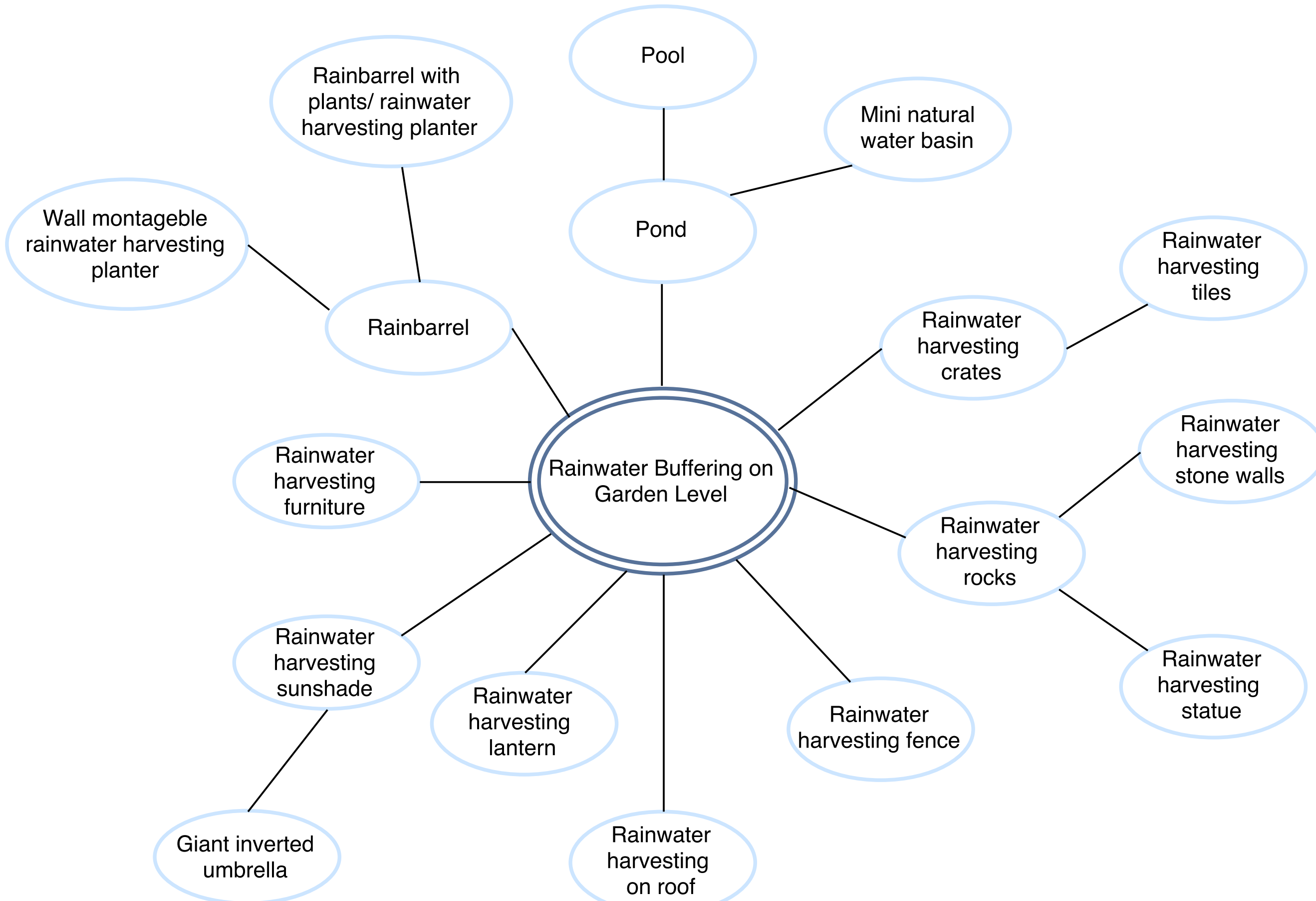









C. Application Brainstorm



D. Interview with South East Water

A fellow student and I are working on our Bachelor Thesis for the University of Twente and researching intelligent rainwater buffers. I stumbled upon Tank Talk but unfortunately, I was only able to find some news articles, a YouTube video and the app in the iTunes store. The webpage from IOTA about Tank Talk also seems to have been removed. From the video I saw it seemed that Tank Talk is the most advanced system to date and I was wondering the following.

The news articles talk about 'the system' but what exactly is the system? Should I think of a pre-made tank that is being installed at properties or is it a device that can be placed in an already existing tank that measures water levels and regulates in and outflow?

The latter. It can be installed in a standard tank to regulate flows. Control is managed through South East Water's OneBox® device, which can use any number of comms platforms to connect with a network operations centre.

In the video was mentioned that Tank Talk was powered by OneBox which is meant to monitor (pressure) sewer systems. I am not sure how this works in Australia but are Tank Talk and OneBox systems that are used by governmental organisations or is it designed for inhabitants to use (or both?)

The Talk Talk® solution, and South East Water's intelligent pressure sewer systems are quite separate, although both are installed and maintained by South East Water (a government owned utility). The former optimises storage in rainwater tanks and mitigates flood risk, while the latter manages waste water flows by storing wastewater in a tank at individual properties, and releasing it into a reticulated network when there is capacity (this removes diurnal peaks). Both use OneBox® as the monitor and control device.

Is Tank Talk already being implemented by users (and who are these users? Inhabitants? Government? Others?)

Yes. The most significant of these is Aquarevo, a 460 lot estate currently being built through a partnership between South East Water and a developer. South East Water will install and maintain the Tank Talk® solution. You can find out more on this here:
http://southeastwater.com.au/CurrentProjects/Projects/Pages/Aquarevo.aspx

And finally, from the app screenshots I could distinguish 3 types of discharge. Forecast, planned and manual. Would it be possible to explain the difference between planned discharge and manual discharge?

Planned discharge – This is what the Tank Talk program controls. Using forecast data (rainfall depth and probability), site information (tank size, volume and inflow from the roof catchment area) and daily usage patterns (based on historic data) it uses inbuilt calculations to determine if there is sufficient space in the tank to capture the forecasted rainfall. It shows data for the week and updates daily. The day before a forecasted rainfall event it will discharge tank water if there is insufficient space to capture all of the forecasted inflow into the tank.

Manual discharge – This is what the user/operator controls. Through the iPhone app/web interface there is a button that allows a user/operator to discharge water from the tank.

E. First Interview with the Municipality of Enschede

On May 8 2017, some basic questions regarding the system design were asked in order to guide the brainstorming process and select the most promising ideas. This was a semi-structured interview that allowed for exploration of other (related) topics. This interview is written in the Dutch language.

Welke tools en programma's op het gebied van waterbeheer gebruiken jullie al?
We gebruiken RainTools, daarmee kun je verschillende buien simuleren met de huidige riolering en eventuele waterberging.

Hoe werken jullie huidige regenwaterbuffers?
We hebben nu gewoon een watertank waarbij je kunt zien hoe die zich vult en leegloopt. Dat systeem werkt met telemetrie, met inbellen. De klep naar het riool wordt handmatig bediend door een persoon, die de weersvoorspelling checkt en aan de hand daarvan bepaalt of de klep open of dicht gaat (en het water dus in de tank blijft of wegstroomt.)

Als ik een slim regenwaterbuffersysteem zou ontwerpen, welke data willen jullie dan hebben? (Bijv. het waterniveau of het weer.)
We zouden de totaalcapaciteit van het systeem willen weten, dus een gezamenlijk getal van alle buffers bij elkaar. En hoeveel water er opgevangen is van de bui: als er bijvoorbeeld 40 mm regen is gevallen, hoeveel daarvan is er dan in de buffer gekomen? Details omtrent de waterkwaliteit, zoals de pH-waarde en mineraalgehalte zijn minder belangrijk voor ons (de gemeente). Het gaat ons om het totaalplaatje.

Wat zouden jullie willen kunnen controleren en beheren in het systeem?
We hoeven zelf niet per se actief iets te controleren, als het systeem gewoon goed werkt dan gaat dat automatisch. Aan de hand van de verwachte regenval kan het systeem bepalen welke buffers water opvangen en hoeveel, het 'verdeelt de pijntjes'. We willen het niet afzonderlijk per huis aansturen, dus niet specifiek gaan kijken wat we doen met de buffer van mevrouw Jansen. Qua privacy is dat ook geen goed idee.

Welk onderhoud aan het systeem zijn jullie bereid te plegen, en wat verwachten jullie van de bewoner?
We willen de garantie dat het gewoon werkt. We kunnen de bewoner subsidie geven (betalen uit de rioolbelasting) voor het aanschaffen van de buffer, maar dan moeten ze wel zelf aantonen dat ze die buffer hebben staan. We kunnen eventueel weleens in de zoveel tijd (bijvoorbeeld om de 4 jaar) een controle uitvoeren.

Welke eigenschappen moet het systeem zeker hebben?
Het moet vooral een simpel en robuust systeem zijn. Eenvoudig en overzichtelijk, en het moet gewoon werken. Het mooiste zou zijn als het werkt van april tot oktober, wanneer de meeste regen valt. Dat er dan gegarandeerd overloop is en er water wordt opgevangen bij de mensen (en eventueel de tuin in gaat). In de winter is het wat anders, dan wil je het water niet in de tuin infiltreren omdat de grond dan al verzadigd is en het grondwater vrij hoog staat.

Wat zou de voertaal van de interface moeten zijn, Nederlands of Engels?
Nederlands is handiger voor de interne communicatie, omdat dat ook in het Nederlands gaat.

Heb je verder nog toevoegingen of opmerkingen?
Gebruik de 'neerslag duurlijnen' om de werking van je systeem aan te geven. Een wadi kun je tekenen als een aflopende lijn, eerst alles opvangen en daarna afvoeren. Bij jullie buffer, die werkt met geknepen afvoer, laat je direct een deel weglopen en vang je een deel op. Dit resulteert dan juist een stijgende lijn.

Misschien kunnen jullie ook nog kijken naar waar in de wijken de kansen het gunstigste zijn. Sommige gebouwen en huizen zijn al erg oud en daar kun je simpelweg niet zo veel meer mee. Kijk of je de beste plekken, de interessantste mogelijkheden eruit kunt halen. Een scan van de wijk met getallen, waar kun je hoeveel water bufferen? Je kunt ook woningcorporaties meenemen in je onderzoek. Het is handig om de werking van het systeem te testen met standaardbuien, dat zijn buien die echt gebeurd zijn, zoals bui Herwijnen, Kopenhagen of Apeldoorn.

F. Survey Questions

This survey is written in the Dutch language.

1 Wat is uw geslacht?
- ❍ Man
- ❍ Vrouw
- ❍ Anders

2 Wat is uw leeftijd?
- ❍ 0-19
- ❍ 20-39
- ❍ 40-59
- ❍ 60-79
- ❍ 80+

3 In welke wijk woont u?
- ❍ De Bothoven
- ❍ Velve-Lindenhof
- ❍ Andere wijk

4 Wat voor woning heeft u?
- ❍ Koop woning
- ❍ Huur woning

5 Heeft u wel eens last gehad van regenwateroverlast in uw tuin of straat?
- ❍ Ja
- ❍ Nee

6 Heeft u wel eens last gehad van regenwateroverlast in het centrum van Enschede?
- ❍ Ja
- ❍ Nee

7 Kent u andere mensen in uw buurt die last hebben gehad van regenwateroverlast?
- ❍ Ja
- ❍ Nee

8 Hoe zou u uw tuin omschrijven?
- ❍ Klein
- ❍ Gemiddeld
- ❍ Groot
- ❍ Geen (eigen) tuin aanwezig

9 Heeft uw huis een plat dak?
- ❍ Ja
- ❍ Nee
- ❍ Ik woon in een flat/gedeelde woning

10 Heeft uw garage een plat dak?

- ❍ Ja
- ❍ Nee
- ❍ Geen garage aanwezig

11 Heeft uw tuinhuis een plat dak?

- ❍ Ja
- ❍ Nee
- ❍ Geen tuinhuis aanwezig

12 Zou u een regenwaterbuffer in uw huis of tuin willen?

- ❍ Ja
- ❍ Nee
- ❍ Misschien

13 Waarom wel of niet?

14 Stel nou dat u een regenwaterbuffer (bijv. een regenton) in uw tuin kunt zetten om bij te dragen aan een oplossing. Zou u hier zonder tegenprestatie toe bereid zijn?

- ❍ Ja
- ❍ Nee
- ❍ Misschien

15 Zo nee, wat zou er voor u tegenover moeten staan? U kunt hierbij denken aan minder kosten voor water, of subsidie van de gemeente.

16 Stel dat u het gefilterde regenwater dat u opvangt kunt hergebruiken, bijvoorbeeld voor uw tuin, uw wasmachine of het doorspoelen van het toilet en hierbij leidingwater kunt besparen. Zou u dan wel een regenwaterbuffer willen?

- ❍ Ja
- ❍ Nee
- ❍ Misschien

17 Welke buffer zou u aanspreken? Een regenton, regen plantenbak, regenschutting of regendak? Meerdere antwoorden zijn mogelijk.

- ❑ Regenton
- ❑ Regen plantenbak
- ❑ Regenschutting
- ❑ Regenwater bufferend dak/groendak

18 Het systeem is 'slim', het verzamelt data. Welke informatie over uw regenwaterbuffer systeem zou u het liefste kunnen inzien? Meerdere antwoorden zijn mogelijk.

- ❑ Huidige waterniveau in buffer (bijv. 60% gevuld)
- ❑ Lokaal weerbericht
- ❑ Historie van opslag en leegloop (bijv. wat het waterniveau in de afgelopen dagen was)
- ❑ Aanbevolen leegloop (bijv. laat het met 20% leeglopen voor optimale prestatie)
- ❑ Hoeveel regenwater hergebruikt is voor eigen doeleinden (bewateren van de tuin etc)

19 Hoe zou u deze informatie het liefste kunnen inzien? Meerdere antwoorden zijn mogelijk

- ❑ Via een app op de mobiele telefoon
- ❑ Via een website of programma op de computer
- ❑ Een scherm in uw huis vergelijkbaar met een thermostaat

20 Zou u (sommige van) deze informatie anoniem ter beschikking willen stellen aan de gemeente? Om hiermee regenwateroverlast in het centrum te beperken?

- ❍ Ja
- ❍ Nee
- ❍ Misschien

21 Waarom wel of niet?

22 Zou u ermee akkoord gaan als de gemeente deze data gebruikt om het systeem zo efficiënt mogelijk te besturen? U heeft er dan zelf geen omkijken meer naar. Dit kunt u vergelijken met slimme energiemeters, die op afstand worden uitgelezen door energiemaatschappijen.

- ❍ Ja
- ❍ Nee
- ❍ Misschien

23 Waarom wel of niet?

24 Welk onderdeel van de buffers spreekt u aan om zelf te willen besturen? Meerdere antwoorden zijn mogelijk.

- ❑ Hoeveel water er maximaal opgevangen kan worden in de buffer
- ❑ Wanneer het water in de buffer leegloopt in het riool
- ❑ Hoeveel water in de buffer leegloopt in het riool
- ❑ Hoeveel water in de buffer wordt gebruikt voor andere doeleinden

25 Wat lijkt u aantrekkelijker, een plug-en-play product waar u zelf niks aan hoeft te doen, of een product dat u zelf kunt monitoren en besturen?

- ❍ Plug-en-play
- ❍ Zelf monitoren en bestuderen
- ❍ Beide opties zijn mogelijk

G. Survey Results

Here, the results of the survey of Appendix F can be found. The survey results are written in the Dutch language.

1	2	3	4	5		7	8
Man	20-39	De Bothoven	Huur woning	Nee	Nee	Nee	Klein
Vrouw	20-39	De Bothoven	Huur woning	Nee	Ja	Ja	Geen (eigen) tuin aanwezig
Vrouw	20-39	De Bothoven	Koop woning	Ja	Ja	Ja	Gemiddeld
Vrouw	20-39	De Bothoven	Huur woning	Nee	Ja	Ja	Geen (eigen) tuin aanwezig
Vrouw	40-59	De Bothoven	Koop woning	Ja	Nee	Nee	Gemiddeld
Vrouw	20-39	De Bothoven	Koop woning	Nee	Ja	Ja	Klein
Vrouw	60-79	De Bothoven	Huur woning	Nee	Ja	Ja	Gemiddeld
Man	40-59	De Bothoven	Huur woning	Nee	Nee	Ja	Groot
Vrouw	40-59	De Bothoven	Koop woning	Ja	Nee	Ja	Gemiddeld
Vrouw	40-59	De Bothoven	Huur woning	Ja	Nee	Ja	Gemiddeld
Man	40-59	De Bothoven	Huur woning	Nee	Nee	Nee	Gemiddeld
Man	20-39	De Bothoven	Koop woning	Ja	Ja	Ja	Gemiddeld
Man	40-59	De Bothoven	Koop woning	Ja	Ja	JA	Groot

9	10	11	12
Nee	Geen garage aanwezig	Ja	Nee
Ja	Geen garage aanwezig	Geen tuinhuis aanwezig	Ja
Ja	Geen garage aanwezig	Geen tuinhuis aanwezig	Misschien
Ik woon in een flat/gedeelde woning	Geen garage aanwezig	Geen tuinhuis aanwezig	Nee
Nee	Geen garage aanwezig	Geen tuinhuis aanwezig	Misschien
Nee	Nee	Nee	Misschien
Nee	Geen garage aanwezig	Geen tuinhuis aanwezig	Nee
Ik woon in een flat/gedeelde woning	Geen garage aanwezig	Geen tuinhuis aanwezig	Misschien
Nee	Geen garage aanwezig	Ja	Misschien
Nee	Nee	Nee	Misschien
Ik woon in een flat/gedeelde woning	Geen garage aanwezig	Geen tuinhuis aanwezig	Misschien
Nee	Ja	Geen tuinhuis aanwezig	Misschien
Ja	Geen garage aanwezig	Geen tuinhuis aanwezig	Misschien

13	14	15	16	17
Weinig ruimte in tuin...	Nee	Minder kosten voor water	Ja	Regenwater bufferend dak/groendak
	Nee	Ik woon in een huurflat, is afhankelijk van de eigenaar	Nee	Regen plantenbak, Regenschutting, Regenwater bufferend dak/groendak
	Misschien		Ja	Regenwater bufferend dak/groendak
Niet van toepassing, bovenwoning	Nee	Onkostenvergoeding voor aanschaf, minder kosten voor water, subsidie gemeente	Ja	Regenschutting, Regenwater bufferend dak/groendak
	Misschien		Misschien	Regenton, Regen plantenbak
kosten ongemak	Misschien		Ja	Regenton, Regen plantenbak,Regenwater bufferend dak/groendak
De waterbuffer zit achter ons huis, onder de parkeerplaats	Ja		Ja	Regenschutting, Regenwater bufferend dak/groendak
Het ligt eraan of ik hierdoor overlast krijg.	Ja	nvt	Ja	Regenton, Regen plantenbak
	Misschien		Ja	Regen plantenbak, Regenschutting, Regenwater bufferend dak/groendak
	Ja		Misschien	Regenschutting
Niet echt nodig.	Ja		Ja	Regenton, Regenschutting
mischien	Nee	Subsidie	Misschien	Regenwater bufferend dak/groendak
	Misschien		Ja	Regenschutting, Regenwater bufferend dak/groendak

18	19	20
Huidige waterniveau in buffer (bijv. 60% gevuld), Historie van opslag en leegloop (bijv. wat het waterniveau in de afgelopen dagen was), Aanbevolen leegloop (bijv. laat het met 20% leeglopen voor optimale prestatie), Hoeveel regenwater hergebruikt is voor eigen doeleinden (bewateren van de tuin etc.)	Via een app op de mobiele telefoon, Via een website of programma op de computer	Ja
Huidige waterniveau in buffer (bijv. 60% gevuld), Lokaal weerbericht, Historie van opslag en leegloop (bijv. wat het waterniveau in de afgelopen dagen was), Aanbevolen leegloop (bijv. laat het met 20% leeglopen voor optimale prestatie), Hoeveel regenwater hergebruikt is voor eigen doeleinden (bewateren van de tuin etc.)	Via een app op de mobiele telefoon	Ja
Historie van opslag en leegloop (bijv. wat het waterniveau in de afgelopen dagen was)	Via een app op de mobiele telefoon	Ja
Huidige waterniveau in buffer (bijv. 60% gevuld), Aanbevolen leegloop (bijv. laat het met 20% leeglopen voor optimale prestatie), Hoeveel regenwater hergebruikt is voor eigen doeleinden (bewateren van de tuin etc.)	Via een app op de mobiele telefoon, Via een website of programma op de computer	Ja
Lokaal weerbericht, Hoeveel regenwater hergebruikt is voor eigen doeleinden (bewateren van de tuin etc.)	Via een app op de mobiele telefoon	Misschien
Huidige waterniveau in buffer (bijv. 60% gevuld), Lokaal weerbericht, Historie van opslag en leegloop (bijv. wat het waterniveau in de afgelopen dagen was),Aanbevolen leegloop (bijv. laat het met 20% leeglopen voor optimale prestatie),Hoeveel regenwater hergebruikt is voor eigen doeleinden (bewateren van de tuin etc.)	Via een app op de mobiele telefoon	Ja
Hoeveel regenwater hergebruikt is voor eigen doeleinden (bewateren van de tuin etc.)	Via een app op de mobiele telefoon	Ja
Huidige waterniveau in buffer (bijv. 60% gevuld)	Een scherm in uw huis vergelijkbaar met een thermostaat	Nee
Huidige waterniveau in buffer (bijv. 60% gevuld), Lokaal weerbericht, Hoeveel regenwater hergebruikt is voor eigen doeleinden (bewateren van de tuin etc.)	Via een app op de mobiele telefoon, Een scherm in uw huis vergelijkbaar met een thermostaat	Ja
Hoeveel regenwater hergebruikt is voor eigen doeleinden (bewateren van de tuin etc.)	Via een website of programma op de computer	Misschien
Huidige waterniveau in buffer (bijv. 60% gevuld), Aanbevolen leegloop (bijv. laat het met 20% leeglopen voor optimale prestatie)	Een scherm in uw huis vergelijkbaar met een thermostaat	Ja
Lokaal weerbericht	Een scherm in uw huis vergelijkbaar met een thermostaat	Ja
Huidige waterniveau in buffer (bijv. 60% gevuld), Historie van opslag en leegloop (bijv. wat het waterniveau in de afgelopen dagen was), Hoeveel regenwater hergebruikt is voor eigen doeleinden (bewateren van de tuin etc.)	Via een app op de mobiele telefoon	Misschien

21	22	23	24	25
Data-deling leidt tot betere resultaten.	Ja	Data-deling leidt tot betere resultaten.	Hoeveel water er maximaal opgevangen kan worden in de buffer, Hoeveel water in de buffer wordt gebruikt voor andere doeleinden	Plug-en-play
	Ja		Wanneer het water in de buffer leegloopt in het riool, Hoeveel water in de buffer wordt gebruikt voor andere doeleinden	Zelf monitoren en bestuderen
	Misschien		Hoeveel water er maximaal opgevangen kan worden in de buffer	Beide opties zijn mogelijk
Ter verbetering mag de gemeente dat zeker inzien.	Ja	Maakt het makkelijker voor alle partijen	Hoeveel water in de buffer wordt gebruikt voor andere doeleinden	Plug-en-play
	Misschien		Hoeveel water in de buffer wordt gebruikt voor andere doeleinden	Beide opties zijn mogelijk
	Ja		Hoeveel water in de buffer wordt gebruikt voor andere doeleinden	Beide opties zijn mogelijk
Meewerken aan een probleem	Ja		Hoeveel water in de buffer wordt gebruikt voor andere doeleinden	Plug-en-play
Het valt bij de gemeente wel op of ik wel of geen regenwater opvang	Nee	Het water wordt opgevangen, dat moet voldoende zijn voor de gemeente	Hoeveel water er maximaal opgevangen kan worden in de buffer	Plug-en-play
	Ja		Hoeveel water in de buffer wordt gebruikt voor andere doeleinden	Beide opties zijn mogelijk
	Ja		Hoeveel water in de buffer wordt gebruikt voor andere doeleinden	Plug-en-play
	Ja		Hoeveel water er maximaal opgevangen kan worden in de buffer	Plug-en-play
Met subsidie	Ja	subsidie	Hoeveel water er maximaal opgevangen kan worden in de buffer, Wanneer het water in de buffer leegloopt in het riool, Hoeveel water in de buffer leegloopt in het riool, Hoeveel water in de buffer wordt gebruikt voor andere doeleinden	Plug-en-play
	Misschien		Hoeveel water er maximaal opgevangen kan worden in de buffer, Wanneer het water in de buffer leegloopt in het riool, Hoeveel water in de buffer leegloopt in het riool, Hoeveel water in de buffer wordt gebruikt voor andere doeleinden	Zelf monitoren en bestuderen

H. Interview Representative Housing Cooperation Domijn.

On May 22 2017, a semi-structured interview was conducted with a representative from the housing cooperation Domijn in Enschede. This interview is written in the Dutch language.

Heeft Domijn weleens klachten gehad over wateroverlast? Zo ja, in welke mate?
Ja, voornamelijk over vochtige kelders/vloeren, maar dat is meer een grondwaterverhaal. Toen hebben we weleens maatregelen moeten nemen, met betrekking tot de drainage.

Heeft Domijn zelf al maatregelen genomen tegen wateroverlast? Zo ja, welke? Kunt u deze toelichten?
Zijn er al mee bezig, ook met de gemeente Enschede en Vechtstromen (Watervisie):

- Waterretentie op *hellend* groendak bij Transburg (gedeelte in De Bothoven), pilot project. Met hellende daken is dit nog niet echt gedaan, dus vrij nieuw.
  Al sinds 1982 "groendak" boven de parkeerplaats hier.
- Sterrenbuurt afkoppelen hemelwater (in Twekkelerveld)

Proefprojecten staan er al sinds 2011
Regenton in bak met grind (i.p.v. klei) zodat het water goed kan weglopen.

Gebruiken jullie ook (slimme) technologie in die maatregelen?
Er wordt wel gemeten bij het pilot project van de groene daken (STOWA doet dat), zoveel kan er opgevangen worden op zo'n groot dak, berekeningen.

In hoeverre zouden huurwoningen een regenwaterbuffer mogen hebben?
Huurders mogen gewoon een regenton aansluiten, dat is geen probleem.

Zouden jullie betrokken willen worden bij ons project?
Misschien in verband met als je een bestaande huurwoning 'op-plust', dus hoger energielabel eraan geeft, dat je dan direct ook zo'n systeem aanlegt. Hergebruiken in de tuin. Ik zie het nog niet zo 1-2-3 bij bestaande woningen op grote schaal in de nabije toekomst. We staan er wel zeker open voor.
Hergebruik van water e.d. voor wasmachine is meer voor nieuwbouw of grootse renovatie. Dan krijg je energie neutrale woningen, die hun eigen grijswatercircuit opslaan.

Zou Domijn bereid zijn hieraan mee te betalen op het terrein van huurwoningen?
Dat is wel heel vroeg om nu te zeggen. Maar stel je wil meer isolatie dan kun je als bewoners naar Reimarkt en die leggen dan uit wat je kunt verbeteren aan je woning om je energielabel omhoog te halen. Dus het gaat met name om energiemaatregelen. Evt. kun je hier het afkoppelen van hemelwater bij halen. Overzichtsplaatje waar je regenwater voor kunt gebruiken, niet alleen de plantjes maar het grijswatercircuit.

Er is een bedrijf, Optigroen, dat een systeem bedacht heeft voor een retentie dak. Dit systeem kijkt naar de weersvoorspelling en bepaalt aan de hand daarvan of er water opgevangen kan worden of af wordt gevoerd. Wat denkt u van zo'n systeem?
Dat kan alleen bij platte daken, en dan moet je het platte dak ook zo voor ingericht hebben. Want de meeste daken hebben allemaal grind erop, dus dan moet je naar een heel ander dak systeem.
Meestal kan een dak de ballast wel aan, 70kg/m^2 dus 70L water zou wel moeten kunnen voor een normaal bestaand plat dak. Maar je moet naar een ander dak systeem, het mooiste is een dak systeem met EPDM, dat is een soort rubber. Dan kun je dus echt water gaan bufferen op je dak. Want grind ligt er zo los op. Je zou hiernaar kunnen kijken bij de vervanging van je daklaag.

Wat vinden de mensen in de wijk van groene daken en dergelijke maatregelen, voor zover u weet?
Oude mensen en buitenlandse mensen hebben er vaak nog wat problemen mee, maar jonge mensen zijn er vaak wel enthousiast over. Maar die begrijpen het ook water beter en die kennen het principe al wel.

Heeft u nog tips/suggesties voor onze regenwaterbuffers?
Het mooiste zou zijn als je het water gewoon tijdelijk vast kunt houden op het gebouw zelf. Daar zijn niet zo heel veel mogelijkheden voor, dat zou dan gaan om een groen dak of opslaan bij de woning zelf.

Je hebt ook 'blauwe' daken, die zijn wat simpeler, die slaan alleen water op (zonder groen dus).
Het zou wel heel mooi zijn om een kaart te hebben om te weten waar wat allemaal mogelijk is qua waterbuffering, waar platte daken zijn en zo. Het zou wel mooi zijn om te weten bij welke complexen je zo'n (slim) systeem toe kan passen.

I. Second Interview with the Municipality of Enschede

On May 18 2017, a structured interview was conducted with Hendrik-Jan Teekens from the municipality of Enschede. A few questions in this interview were answered by Hans Koetsier, who works for the municipality of Enschede as well but is specialized in the sewerage system. This interview is written in the Dutch language.

Hoeveel procent van de huishoudens zouden potentieel een regenwater buffer willen en hoe groot zouden deze moeten zijn?
Dat is lastig te zeggen, je kunt het beste een soort 'kansenkaart' maken van het gebied waarbij je verschillende straten en huizen in kaart brengt. Je kunt dan categorieën toewijzen op basis van de mogelijkheden die er op de kavels zijn, bijvoorbeeld of het heel moeilijk gaat worden, of dat er juist wel veel opties zijn. Daaruit kun je dan een soort percentage of getal van de hoeveelheid huishoudens afleiden. De grootte van de buffer hangt heel erg af van de mogelijkheden op de kavel, dus ook dan kom je weer bij een soort overzichtskaartje terecht. Bij het ene huis kun je nu eenmaal meer opvangen dan bij het andere huis.

Hoe lang van tevoren moet de buffer leeglopen? Wat is de tijd die er nodig is om de buffer(s) te legen?
Voor het leeglopen van de buffer heb je twee opties:

- Geknepen afvoer naar het riool
- Eerst de buffer laten vollopen, daarna nood overflow naar het riool.

Dat laatste is waarschijnlijk het handigste voor jullie. De tijd die nodig is om een buffer te legen zal pakweg 10 minuten zijn, afhankelijk van hoeveel water erin zit.

Hans Koetsier: de looptijd van het rioolstelsel van het hoogste punt van de stad naar de rioolwaterzuiveringsinstallatie is ongeveer 2-3 uur. Dus je zou de buffer ook 2-3 uur van tevoren kunnen laten leeglopen. 3 uur kun je nemen om aan de veilige kant te zitten, maar 2 uur geeft meer accurate weerdata.

Hoe vaak zouden jullie de data in willen zien?
Het is voldoende om elke 15 minuten nieuwe data te krijgen, real-time is niet nodig. Eventueel elke 10 minuten.

Maakt het uit hoe snel een buffer leegloopt? Hoe snel/langzaam?
Hans Koetsier: Bij bergbezinkbassins is het zo dat de vulsnelheid en ledigingssnelheid afhankelijk zijn van metingen in het riool. Je kunt daar dus niet één getal aan vastplakken dat voor elke situatie geldt. Om aan de veilige kant te blijven kun je de buffer zeker wel laten leeglopen 24 uur na een bui, want dan heeft het rioolstelsel genoeg kans gehad om te stabiliseren.

Is een overloop naar de tuin te realiseren?
Een overflow naar de tuin is niet verplicht, maar wel zeer gewenst. Dit kun je weer aangeven in een overzichtskaartje, waarin je kunt zien waar er een tuin is met infiltratiemogelijkheden en waar er betegeling is (of geen tuin). Je kunt een beeld schetsen van waar de overflow wel en niet mogelijk is op basis van:

- Verhouding verhard/niet verhard oppervlak.
- Hoogteverschil (AHN hoogtebestand), is het huis hoger dan de tuin? (Niveau bouwpeil)

In het geval van een tuin kun je aangeven hoeveel % in de tuin terecht komt naast wat de buffer opvangt. Dat schept mogelijkheden voor extra opvang.

Wat moet het system van oktober tot april doen?

De rest van het jaar moet je het water niet in de tuin laten lopen, omdat de grondwaterstand dan erg hoog is. Het mag wel gewoon het riool in. Je kunt dit mooi zien aan de statistieken van de grondwaterstand in Enschede.

J. Informed Consent - Dutch

Titel onderzoek: Smart Rainwater Buffer - Tonnie

Verantwoordelijke onderzoekers: Gelieke Steeghs, Felicia Rindt

In te vullen door de deelnemer

Ik verklaar op een voor mij duidelijke wijze te zijn ingelicht over de aard, methode, doel en belasting van het onderzoek.
Ik weet dat de gegevens en resultaten van het onderzoek alleen anoniem en vertrouwelijk verwerkt zullen worden en al mijn vragen zijn naar tevredenheid beantwoord.
Ik begrijp dat film-, foto, en videomateriaal of bewerking daarvan uitsluitend voor analyse zal worden gebruikt.
Ik stem geheel vrijwillig in met deelname aan dit onderzoek. Ik behoud me daarbij het recht voor om op elk moment zonder opgaaf van redenen mijn deelname aan dit onderzoek te beëindigen.

Naam deelnemer: ....

Handtekening deelnemer: ....

Datum: ....

In te vullen door de uitvoerende onderzoeker

Ik heb een mondelinge en schriftelijke toelichting gegeven op het onderzoek. Ik zal resterende vragen over het onderzoek naar vermogen beantwoorden. De deelnemer zal van een eventuele voortijdige beëindiging van deelname aan dit onderzoek geen nadelige gevolgen ondervinden.

Naam onderzoeker: ....

Handtekening onderzoeker: ....

Datum: ....

K. Usability Survey

Survey Tonnie for testing with the citizens. The survey is written in the Dutch language. The correct answers have bold typeface.

Voor ons afstudeerproject hebben we systeem van slimme regenwater buffers gemaakt, genaamd Tonnie. Het systeem bestaat uit meerdere buffers die bedoeld zijn om op privé terrein te worden gebruikt door bewoners. Een buffer heeft verschillende sensoren die meten hoeveel water in de buffer zit, hoeveel water er in en uit gaat en maakt automatisch water vrij voor een heftige regenbui indien nodig. Iedere eigenaar van een buffer kan inzicht van de eigen buffer krijgen op een interface. Om de interface te testen moeten er enkele eenvoudige taken worden uitgevoerd, waarna een aantal vragen worden gesteld. Het invullen duurt slechts enkele minuten.

In het eerste gedeelte worden een paar korte vragen gesteld, die u moet beantwoorden door de interface te gebruiken. Als u er echt niet uitkomt, kun ons om een hint vragen. Veel succes!

Wat is de huidige status van het systeem?

- ❍ **OK**
- ❍ Melding
- ❍ Waarschuwing
- ❍ Error
- ❍ Kritiek

Voor hoeveel procent zit de buffer nu ongeveer gevuld?

- ❍ 90%
- ❍ **80%**
- ❍ 70%
- ❍ 60%

Hoeveel liter water zit er nu in de buffer?

- ❍ 190 L
- ❍ **152 L**
- ❍ 90 L
- ❍ 80 L

Hoeveel liter water kan er maximaal in de buffer?

- ❍ **190 L**
- ❍ 152 L
- ❍ 90 L
- ❍ 80 L

Wordt er neerslag verwacht de komende twee uur?

- ❍ **Ja**
- ❍ Nee

Hoeveel liter water zit totaal er in de buffer over twee uur?
- ❍ 190 L
- ❍ **173 L**
- ❍ 152 L
- ❍ 90 L

Hoeveel procent is dit ongeveer?
- ❍ 100 %
- ❍ **90 %**
- ❍ 80 %
- ❍ 70 %

Hoeveel liter water heeft het systeem gebufferd in april 2016?
- ❍ 500 L
- ❍ 400 L
- ❍ **300 L**
- ❍ 200 L

Hoeveel liter water heeft het systeem gebufferd in juni 2017?
- ❍ 800 L
- ❍ 700 L
- ❍ 600 L
- ❍ **500 L**

Hoeveel liter water heeft de tuin op de zaterdag in week 25 gekregen?
- ❍ 60 L
- ❍ **58 L**
- ❍ 48 L
- ❍ 40 L

Hoeveel liter water heeft de tuin op dinsdag in week 26 gekregen?
- ❍ 40 L
- ❍ 30 L
- ❍ 10 L
- ❍ **0 L**

Stel de automatische afvoer van het water in op het riool.

Het systeem is gekoppeld aan het weerbericht en reageert hier op. Het kan een neerslag verwachting lezen die twee uur vooruitkijkt. Als er meer regen wordt verwacht dan er in de buffer bij kan, wordt er capaciteit vrij gemaakt door water af te voeren via de gewenste uitlaat (riool of tuin) zodat er zo min mogelijk water tijdens de regenbui zelf in het riool komt.

Voer handmatig 50 liter water af naar de tuin.

Hoeveel liter water heeft de tuin nu op dinsdag in week 26 gekregen?

- ❍ 60 L
- ❍ **50 L**
- ❍ 40 L
- ❍ 30 L

Hoeveel liter water zit er nu in de buffer?

- ❍ **123 L**
- ❍ 102 L
- ❍ 72 L
- ❍ 63 L

Nu gaan we de taken die je zojuist volbracht hebt langs aan de hand van 10 design principes ("heuristics"). Geef voor elke stelling aan in hoeverre je ermee (on)eens bent.

	Volledig mee oneens	Mee oneens	Neutraal	Mee eens	Volledig mee eens
Ik vind de status van het systeem duidelijk zichtbaar.	❍	❍	❍	❍	❍
De betekenis van de gebruikte iconen en symbolen waren voor mij volstrekt helder.	❍	❍	❍	❍	❍
Ik heb het gevoel dat ik controle heb over mijn interactie met het systeem.	❍	❍	❍	❍	❍
Het ontwerp van de interface is consistent.	❍	❍	❍	❍	❍
Er zitten geen fouten in de interface.	❍	❍	❍	❍	❍
De interface is eenvoudig in gebruik.	❍	❍	❍	❍	❍
Ik kan efficiënt navigeren door de interface.	❍	❍	❍	❍	❍
Ik vind de interface mooi.	❍	❍	❍	❍	❍
Wanneer ik een waterafvoer selectie heb gemaakt, wordt dit duidelijk weergegeven.	❍	❍	❍	❍	❍
Als ik hulp nodig heb bij het gebruik van de interface, kan ik die gemakkelijk vinden.	❍	❍	❍	❍	❍