Sensor Measurements: An Opportunity To Deal With Flooding's

A case study to examine how sensor measurements can be integrated into adaptive flood risk management in Amsterdam and Rotterdam

ABSTRACT

The goal of this study is to determine how sensor measurements can be integrated into adaptive flood risk management. Sensor measurements are a part of the smart city concepts. This study researches how sensor measurements can link the smart city and resilient city concept. In this research adaptive flood risk management is defined by the multi-layer safety approach. The data collection was done by using in-depth interviews as method to interview several experts on the topic of sensor measurements or flood risks. The data gathered in this report suggest that sensor measurements have the possibilities to accommodate several flood risk related issues in Amsterdam and Rotterdam. Although there have to be made considerations about cost, durability and the circumstances. The future usage of sensors in adaptive flood risk management depends on finding solutions to the earlier mentioned considerations that have to be made in case of integration of sensor measurements in adaptive flood risk management. The results did partly support the expectations that were found beforehand. The results showed more precisely what has to be thought of when integrating sensor measurements in comparison to the expectations.

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Bachelor Thesis

Colophon

Title:	Sensor measurements an opportunity to deal with floodings
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Content

1. Introduction

1.1 Motivation

The Netherlands has a long history with water, so far they have succeeded in protecting themselves against the water (Restemeyer et al., 2016). Although with scientist agreeing in consensus that the climate is changing action is necessary (Oreskes, 2004). The Netherlands can't sit back and has to adapt again, to negate the changes in the climate like increased periods of heavy precipitation, rise of the sea level and heatwaves (Melillo et al., 2014). In the WordRiskIndex (Arcadis, 2016) the Netherlands is ranked as 12th when it comes to the exposure to natural hazards. That makes the Netherlands the most vulnerable country in Europe in regard to exposure of natural hazards. The Netherlands is mostly vulnerable because of the delta position it has. Delta countries often have to deal with flood risks from the sea, rain and rivers. Flood risks can be defined as the probability of a flood multiplied by the damage (Vis et al., 2003).

The vulnerability of the Netherlands to the exposure of natural hazards counts as well for Amsterdam and Rotterdam. Both are in a vulnerable spot when it comes to flooding. The reasons why they are in such a vulnerable spot are different for each case, nevertheless, for both cities and the waterboards in which they are in positioned, the development of strategies about out how to deal with potential flood risks are necessary. Scientific literature about how to deal with flood risks differentiates most of the time between resistance and resilience strategies (Restemeyer et al, 2015; De Bruijn, 2005; Douven et al, 2012; Hooijer et al., 2004; Vis et al., 2003). Resistance is about decreasing the chance of flood risks meanwhile resilience is about minimizing the damage in case of flooding (Restemeyer et al. 2015). Resilience strategies are more integrated approaches in comparison to resistance strategies. This means that in urban planning the most vulnerable land uses are placed outside flood-prone areas (Restemeyer et al., 2015; Godschalk, 2003; Woltjer & Al, 2007). This change is similar to the approach of adaptive flood risk management. In adaptive flood risk management urban planning is also influenced by the risks of flooding (Klijn et al., 2015).

To reduce the consequences of flooding's in Amsterdam and Rotterdam sensors can provide opportunities to help with dealing with flooding's. Sensors which collect data about potential flooding's and how the dikes behave under various conditions and various other applications offer opportunities to not directly reduce the flood risks. Nevertheless measures can be taken as a result of the collected data. However, the raw data has to be analysed first before it can be of use to deal with flood risks. The collected data can in the end influence the decision making process and therefore, the factors of the multi-layer safety approach and resilience. In potential sensors offer a lot of opportunities to deal with flood risks although in practice waterboards and cities are not yet entirely convinced if and where to make use of sensors for adaptive flood risk management. In this research this issue is investigated further. To see in which way wireless sensor networks can be integrated into the flood risk management in the cities of Amsterdam and Rotterdam.

1.2 Societal relevance

The societal relevance of this research mainly comes from the aspect of safety. Many of the Dutch cities have to deal with the risk of a high exposure to natural hazards (WorldRiskIndex, 2016). To protect against these natural hazards an adaptive flood risk management strategy is needed. Rotterdam and Amsterdam are two cities who belong to the top of the world cities when it comes to mitigation of water during disaster situations (Arcadis & Centre for economics and business research, 2016). Sensors should be able to provide accurate and useful measurements which might lead to ways to deal with flood risks in Amsterdam and Rotterdam and their respective waterboards (Erdbrink et al. 2013). However, there are reasons why there is only made use of a limited amount of sensors in dikes and other flood protection related systems. What are those reasons and how can there be dealt with possible problems for the integration of sensors into the adaptive flood risk management. The role of sensors is mainly about how the data they provide can be analysed and lead to reduction in flood risks or a higher safety through decision making.

1.3 Scientific relevance

The resistance strategy against the water has become subject of debate (Vis et al., 2003). This discussion about what is the more suitable approach for flood risk management resistance or resilience has led to an increase in resilience strategies for cities. Nevertheless, in the debate there is consensus that actions is needed to protect the populations of cities to keep them safe from flood risks. IBM and several partners in the Netherlands like Deltares, University of Delft, waterboard of Delfland and Rijkswaterstaat are working together on how to combine data and technology to lead to smarter solutions in managing the water cycle (Environmental protection, 2013). The information provided by sensors can be a part of the data needed for the search for smarter solutions in water management. In the past there has been done research by Simm et al. (2013) about how sensor measures in dikes should be interpreted and can lead to early warning systems. In this report there is taken a look at how the measurements of sensors can be integrated into and contribute to the adaptive flood risk management in Amsterdam, Rotterdam and the waterboards they are in positioned. Further there is a look at how the concepts of a smart city and a resilient city can be connected through the use of sensor measurements in adaptive flood risk management.

1.4 Research Problem

Problem: Flooding is a threat to the safety of cities. Therefore, adaptive flood risk management is necessary to maintain the safety of the cities, in the Netherlands. This is done by making cities prepared so that they can deal with the consequences of flood risk situations. Adaptive flood risk management plays an important role in how to deal with the incoming climate changes and mitigate the effects of flooding. Sensor measurements offer opportunities to mitigate flooding consequences. This can be done by using the information that these sensors provide. Sensor measurements have the potential to act as a tool to decrease the consequences of a flood. The absence of sensors focussed towards flood risk protection in cities might be a missed opportunity to reduce the consequences of flood risk situations. Therefore, it is interesting to see in which way sensor measurements can integrated into the development of adaptive flood risk management in cities which are prone to flooding's like Amsterdam and Rotterdam and what uses sensor measurements can bring toward the future of adaptive flood risk management.
Goal: Investigate in which way sensor measurements can be integrated into adaptive flood risk management for Amsterdam, Rotterdam and the waterboards of those cities.

Main question: *In what way can sensor measurements be integrated in adaptive flood risk management in Amsterdam and Rotterdam?*

Sub questions:
How can sensor measurements contribute in adaptive flood risk management in Amsterdam and Rotterdam?
Which considerations should be taken into mind for using sensors in adaptive flood risk management in Amsterdam and Rotterdam?
How is the future of sensor measurements regarded by people that are concerned with adaptive flood risk management in Amsterdam and Rotterdam?

2. Theoretical Framework

In this chapter will be discussed the themes during this research. There will be a discussion and explanation of the four different themes (sensor measurements, adaptive flood risk management, smart cities and resilient cities).

2.1 Sensor measurements

Sensor measurements are one of the four themes of this research. To understand what contribution sensor measurements can give to adaptive flood risk management, it is important to understand how sensor measurements can be defined and what purpose they can serve.

Definition:
The article by Akyildiz et al. (2002) gives a wide variety of ambient conditions that can be measured by sensors. Examples are humidity, pressure, the presence or absence of certain kinds of objects, mechanical stress levels and the current characteristics of an object. The options sensors offer lead to opportunities for the measurement of factors which are influencing flood risks. Examples of opportunities for flood risks which can be measured by sensors are piping and stability in dikes, weather conditions and water levels (Simm et al., 2013). Measurements by sensors can through measuring the right parameters help with decreasing the consequences of flood risks in area's prone to flood risks. Sensor measurements are in most cases not provided by only one sensor but are part of a broader sensor network. In a paper written by Zhao et al. (2002) sensor networks are seen as "ideally suitable for the detection of low-observable events, tracking moving phenomena, monitoring a large number of objects or events simultaneously. To increase the accuracy of these measurements collaboration and aggregation between sensors is needed. This makes sensors suitable to measure parameters that indicate a potential flood or potential failing of water defence systems. Sensors can also assist in evacuation management during a flood. The information that is provided by the use of sensors can therefore, be valuable in adaptive flood risk management.

Sensor networks can be used together with the Internet of Things (IoT). "The Internet of Things envisions a future in which digital and physical entities can be linked, by means of appropriate information and communication technologies, to enable a whole new class of applications and services (Miorandi et al., 2012, p.1497)". The Internet of Things offers more options in which sensor networks can contribute to society. "For example the Internet of things can facilitate human life in a noteworthy way, including healthcare, automation, transportation, and emergency responses to manmade and natural disasters, under which circumstances it is difficult to make decisions" (Rathore et al., 2016). The Internet of Things connects a lot of devices together, the expectation is that in 2020 50 billion devices in the whole world will be connected to the Internet of Things (Rathore et al., 2016). Sensor networks can play a key role in the future the internet of things envisions. The reason for this is that the sensor networks are often installed relatively cheap which makes them perfect to integrate in the Internet of Things (International Electrotechnical Commission, 2017). Sensor measurements can therefore, easily be integrated into other applications which can be beneficial to the reduction of flood risks or help with evacuation in case of a crisis

2.2 Adaptive Flood risk management

Adaptive Flood Risk management is the second theme of this research. Adaptive flood risk management is a concept with multiple definitions. Therefore, it is important to look in the relevant literature for a definition which is suitable for this research.

Definition: To understand adaptive flood risk management it is necessary to first understand the concept of flood risks. Klijn et al. (2015). Figure 1 gives a clear explanation of the three key factors of flood risk: flooding probability, exposure determinants and vulnerability

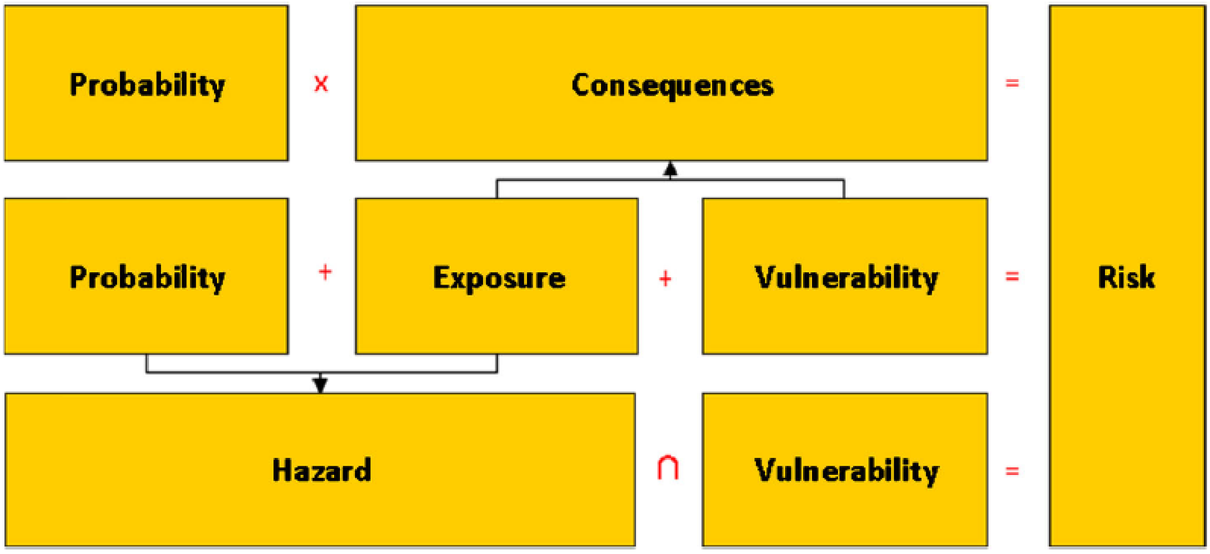

Figure 1: Characteristics of Flood Risk from Klijn et al. (2015)

"The governments of the Netherlands used in the National Water plan a multi-layer safety approach to flood risk management (Klijn et al., 2015)." The multi-layer safety approach consists of three parts namely: Flood protection, Sustainable spatial development as supplement and Disaster management (Klijn et al., 2015). These three parts of the multi-layered safety approach also affect the spatial domain of a city. Flood protection means the "robustness" of a city. A city must have a certain strength to withstand an event of flooding. Most of the time this robustness contain hard measures like dikes and storm surge barriers (Restemeyer et al., 2015).

Sustainable spatial development must deal with flood risks, heat waves, rain water runoff and green-space (Caparros-Midwood et al., 2016). These factors make it difficult to make an optimal sustainable spatial development because each factor has different priorities. In case of flood risk management, the main priority is to reduce the damage flooding cause although at the same time to give the flooding space (Vis et al., 2003). Van de Pas et al. (2012) argues that in case of a flood hazard spatial measures should be done to reduce the vulnerability of flood-prone land.

The last part of adaptive flood risk management is disaster management which consist of how to deal with the consequences of a flood. Important parts of disaster management are preventive evacuation, risks profiles, increasing awareness among the local population and crisis plans (Nederlandse overheid, 2014). These factors all contribute to an increased level of safety and preparation for how to handle a flood.

2.3 Smart cities

Smart cities are the third theme which is being discussed in this report. Smart cities can be defined in various ways. In this report there is made of the definition by Hall et al. (2000). Hall describes smart cities as: “a city which monitors and integrates conditions of the critical infrastructures. This includes roads, bridges, tunnels rail/subways, airports, seaports, communications, water power, even major buildings, to make optimal use of its resources, make plans regarding preventive maintenance activities and finally monitor security aspects while maximizing services to its citizens.” Sensor measurements play a role in the monitoring part. In this research sensors are seen as an opportunity to link the options that smart cities offer for adaptive flood risk management of resilient cities. Therefore it is important to also understand the meaning of resilient cities, which are explained in the next paragraph.

2.4 Resilient cities

Resilient cities are the last theme which is being discussed in this report. Resilient cites are defined according to the flood resilience of cities paper from Restemeyer et al. (2015). Resilient cites can be split up in three different aspects. The first attribute is robustness, by robustness is meant that a city can withstand a flood event by making use of flood protection systems. The second aspect is adaptability, by adaptability is meant that the area behind the flood protection systems is developed so that it is able to withstand a flood without substantial damage. This is mostly done by making use of spatial measures in a planning process. The third and final aspect is transformability is more of a mindset shift in how to deal with flood risks. This shift is from “fighting against the water” to “living with the water”. The three attributes form the resilient city. The aspects of the resilient city are similar to the aspects of the multi-layer safety approach which was mentioned in paragraph 2.2. The multi-layer safety approach is used to link the smart cities and resilient cities. This is done by examining the application of sensor measurements in the multi-layer safety approach.

2.5 Conceptual model

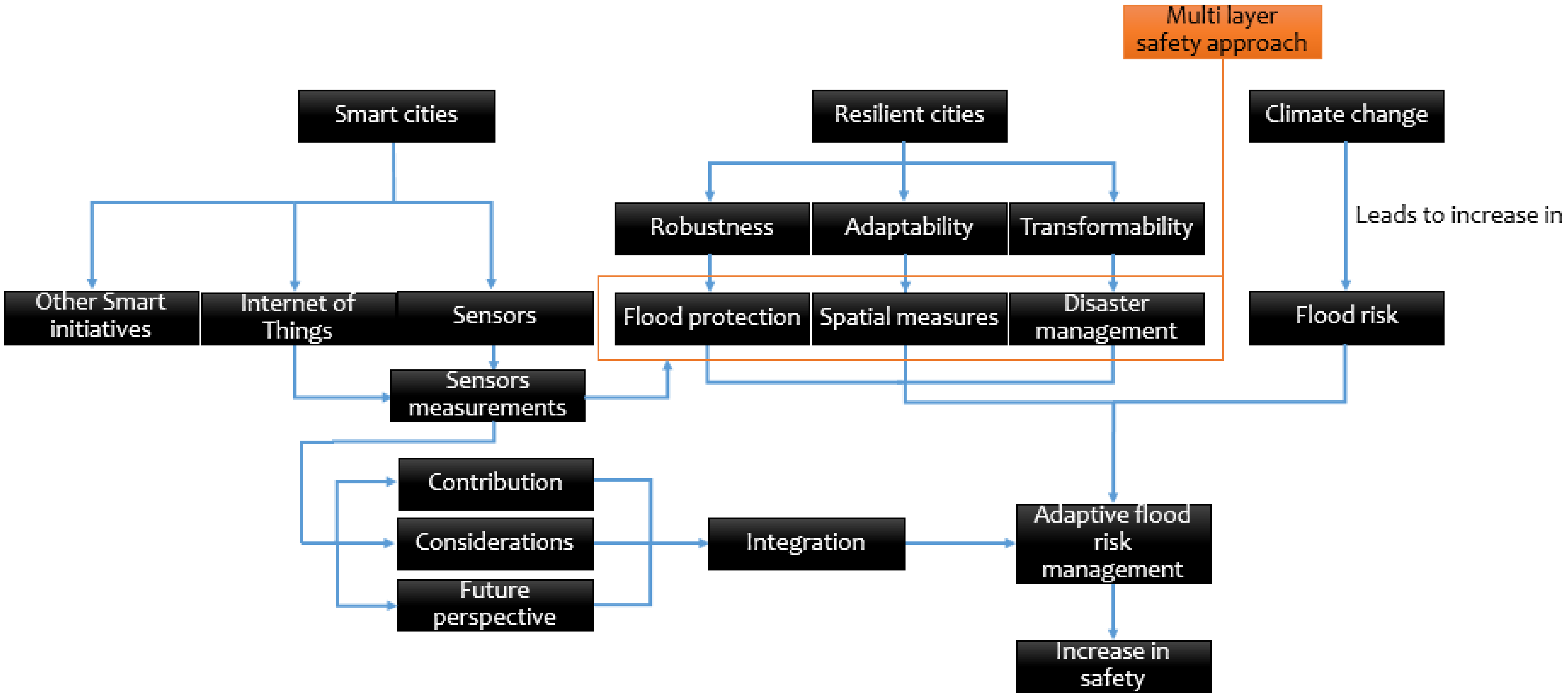

Figure 2: Conceptual model

The conceptual model in figure 2 explains what the important factors are, which are needed to understand in what way sensor measurements can be integrated into adaptive flood risk management. The model exist of three main categories (smart cities, resilient cities and climate change) which explain what is being researched. The first category are smart cities, smart cities consist of sensors, Internet of Things and various other smart ICT related initiatives. Sensors are the most important topic of this research. The Internet of Things can make use of sensor data and is therefore also included. The sensors can collect measurements in the three multi-layer safety approach aspects (flood protection, spatial adaptation and disaster management). To understand how sensor measurements can assist in the multi-layer safety approach, it is important to understand the contribution, consideration and the future perspective of sensor measurements. If this is known, it becomes clear in what way sensors can be integrated in adaptive flood risk management.

Adaptive flood risk management is build out of two aspects, the increasing flood risk which is caused by climate change and the factors of the multi-layer safety approach (flood protection, spatial adaptation and disaster management) which are similar and comparable to resilience factors (robustness, adaptability and transformability). The research should make it clear where integration of sensor measurements can be beneficial in the cases of Amsterdam and Rotterdam. The integration should have an effect which lead to an better understanding, cheaper maintenance and reduced flood risk which should be positive for the safety of the cities of Amsterdam and Rotterdam.

2.6 Hypothesis

Main question:

- *In what way can sensor measurements be integrated in adaptive flood risk management in Amsterdam and Rotterdam?*

- **Hypothesis:** Before the broad instrument of application that sensors offer can be implemented widely some obstacles have to be conquered. After this is done sensor measurements can contribute to digital monitoring which can lead to reduced consequences of flood risks and more awareness of the people for the situation they are living in.

Sub questions:

- *How can sensor measurements contribute in adaptive flood risk management in Amsterdam and Rotterdam?*

- **Hypothesis:** Sensor measurements bring a lot of opportunities about how to deal with flood risks. Sensor measurements can certainly have a positive contribution towards a more adaptive flood risk management strategy. If the sensor measurements are integrated with other digital applications like the Internet of Things, even more possibilities for a contribution to adaptive flood risk management are possible in practice.

- *Which considerations should be taken into mind for using sensors in adaptive flood risk management in Amsterdam and Rotterdam?*

- **Hypothesis:** In practice sensor measurements have some downsides that have yet to be conquered before they can be implemented on a larger scale. For both cities and the waterboards they are in positioned, the circumstances are influential in which way sensor measurements can be used.

- *How is the future of sensor measurements regarded by people that are concerned with adaptive flood risk management in Amsterdam and Rotterdam?*

- **Hypothesis:** Because of the many opportunities that sensor measurements bring, the future of sensors usage in Amsterdam and Rotterdam should be quite bright. Implementation can lead to reduce flood risks which is beneficial for the quality of life in those cities.

3. Methodology

3.1 Methodology

In this report there is a focus on gaining new insights on how sensor measurements can be integrated in adaptive flood risk management in practice. This is mainly done by making use of qualitative methods. Characteristics of qualitative methods are the inductive approach, in which concepts, insights and understandings are collected from the analysed data (Taylor et al., 2015). Another important characteristic of qualitative research is to understand how the perspective is from people their own frame of reference (Corbin & Strauss, 2008). These two characteristics were important to understand how sensor measurements can be integrated in adaptive flood risk management. In the report there were two cases researched. These two cases were studied thoroughly which makes it an intensive research (Clifford et al., 2010). Intensive researches are characterised by having a focus on a small number of cases and the causal process of an item that is being studied. Because of the intensive nature of the research more quantitative methods like surveys are not suited to answer the research questions. Quantitative methods were not suited because of the relative small group that is engaged with sensor measurements and there is no focus on how social phenomena are perceived from the actors own perspective and in what way the world is experienced (Taylor et al, 2015). In this research there has been made a choice for two cities: Amsterdam and Rotterdam. The reasons why these cities were chosen are listed down below:

Amsterdam: Amsterdam is ranked as 3rd in the Arcadis Sustainability cities water Index (2016). This index has a focus on three elements for a sustainable water future: Resiliency, Efficiency and Quality. For this research the first element "Resiliency" is the most interesting because flood risk is a part of that category. When it comes to resiliency Amsterdam is ranked as 2nd.
Another important reason why Amsterdam is such an interesting case to examine is because of Amsterdam's reputation as a smart city and its focus on the Internet of Things (IoT). These two factors make Amsterdam an interesting case to examine in this research.

Rotterdam: Rotterdam is quite a similar case as Amsterdam. Rotterdam is ranked as 1st in the Arcadis Sustainability cities water index (2016). In the category of resiliency Rotterdam is also ranked as 1st which gives Rotterdam an even better position in the rankings as Amsterdam. Rotterdam reputation internationally is good when it comes to pioneering with flood prevention management. In Rotterdam sensors play a role in keeping the city safe from flooding which makes Rotterdam together with the first factor a good city to examine in this research.

3.2 Method of research

In this chapter of the research there is going to be an explanation why there has been made a choice for the use of a certain instrument. In the research the method which was used was in-depth interviews. This instrument made it possible to gather the information needed to form a conclusion. The conducted research was done in an inductive style. The reason there was chosen for an inductive style was that this style made it possible to examine the relations among phenomena that were observed. An deductive style is however, embodied from theories, this was not the case in this research therefore there was chosen for an inductive style. This was because there has not been completed a lot of research in how sensor measurements can be integrated in adaptive flood risk management. Therefore, by using an inductive approach the results will be broader and more open to new suggestions.

3.3 In-depth Interviews:

One of the qualitative methods that was used in this research were interviews. There has been made use of semi-structured interviews because this form of interviewing has a predetermined order but also adds flexibility in what way issues are being addressed (Clifford et al., 2010). Interviews were useful in providing insight that resulted in the answering of all three sub questions. Interviews were a relevant method to use in this research because there are only two cases which were examined. Because of the amount of small cases interviews offered the ability to provide information that consist of facts, descriptions, thoughts or emotions (Clifford et al., 2010). Interviews are often not representative for how the whole population looks at an issue but how individual persons look at an issue (Clifford et al., 2010). In this report there has been examined how sensors can be integrated into adaptive flood risk management. Interviewing experts and other people in this case involved in adaptive flood risk management is often efficient and a concentrated method of data gathering (Bogner et al., 2009. Because the research consisted only of two cases, multiple interviews were conducted per case. This has led to a broader understanding of how sensors can be integrated in adaptive flood risk management. Another important aspect of interviews which has been considered were the ethical considerations. Interviews exist of two main ethical issues which are confidentiality and anonymity (Clifford et al., 2010). Therefore, the interviewed people were told about their rights during the interview and what was going to happen with the information. The information was kept confidential and anonymous with their consent.

3.4 Participants in research

During the data collection part of the thesis, six different people were interviewed. All of those six people worked or worked before in a field related to the subject of this research. The interviewed people gave their insights on how sensor measurements can be integrated into adaptive flood risk management. The list below shows which organisations the interviewed people belonged to:

- Waterboard Hollandse delta (Rotterdam)
- Waterboard Schieland en de Krimpenerwaard (Rotterdam)
- Waternet (Amsterdam)
- Urbanflood
- Municipality of Rotterdam
- TU Delft

With these six interviews, it was possible to collect enough information regarding this research. In each of the interviews people were asked their insights in one or multiple parts of the multi-layer safety approach in how sensor measurements can be integrated.

The waterboards in the list above are selected for the interviews because they mainly deal with flood protection of the cities of Amsterdam and Rotterdam, which is a part of the multi-layer safety approach in which sensors measurements can be used. Therefore, it was interesting for this research to interview them, because it reveals how waterboards integrate sensors measurements into adaptive flood risk management. The city of Rotterdam is positioned in three waterboards however, it was not possible to set an interview with all three waterboard wherein Rotterdam is positioned

Initially it was the plan to set interviews with the municipalities of both Rotterdam and Amsterdam but it was only possible to set an interview with the municipality of Rotterdam. In the interview with the municipality of Rotterdam there was a focus on the spatial adaptation and the disaster management aspect of the multi-layer safety approach.

The persons that were interviewed from the organizations of the TU Delft and Urbanflood were both in the past concerned with projects wherein sensors were used. Therefore, it was an addition to the research to interview them regarding their views on the integration of sensors in adaptive flood risk management.

3.5 Coding

The collected data from the interviews was coded in such a way that the data became clearer and easier to understand. To make the data more understandable the data from the interviews was coded in an open way. That will lead to concepts that seem to fit the data (Clifford et al., 2010). After the coding in an open way was completed axial coding was applied. Axial coding results in the identification of relationships between the earlier open codes (Clifford et al., 2010). This resulted in that the collected data was easier to understand. Out of which conclusions were formed which made it possible to answers the main- and sub questions. The coding was based on the hypothesis of the research questions and on scientific literature. The coding was based on five different themes which each gave an answer to one or multiple sub questions. The five themes that were used were:

- Future perspective
- Disaster management
- Spatial measures
- Flood protection
- Integration

The coding that was used during this research can be found in table 1.

Question	Theme	Coding
How can sensor measurements contribute in adaptive flood risk management in Amsterdam and Rotterdam?	Flood protection	Measurements, application, digital, modelling, calculation, flood risk, water pressure, water level, interaction, critical spots, conservative, information, consideration, alternatives, longevity, limitation, knowledge, organisation, software, risk reduction, failure, uncertainty, added value, priority, challenges, monitoring, implementation, evaluation, norm, understanding, slow process, fast process, parameter, response time, cost, situation, anomalies, temporary, space, flood, risk reduction
	Spatial Measures	Consequences, failure, implementation, norm, water level, situation, outside dikes, flood risk, measurements, cost, natural factors, prediction, planning
	Disaster management	Consideration, consequences, failure, measurements, uncertainty, efficiency, coordination, unpreparedness, human behaviour, decision making, traffic management, integration, consciousness, norm, information, weak spots, response time, flooding, safety, reaction time, pre-defined plan, water level, situation, preparation, Internet of Things, integration, ICT
Which considerations have to be taken into mind for using sensors in adaptive flood risk management in Amsterdam and Rotterdam?	Integration	Knowledge, Motivation, information, measurements, flood risk, simulation, critical points, organisation, focus, consideration, cost, water level, phase, application, longevity, cost, decision making, predictions, traffic management, evaluation, durability, safety, substitute, norm, floods, Internet of Things
How is the future of sensor measurements regarded by people that are concerned with adaptive flood risk management in Amsterdam and Rotterdam?	Future perspective	Measurement, monitoring, challenges, innovation, focus, application, added value, organisation, uncertainty reduction, knowledge, consideration, experimental phase, circumstances, human behaviour, flood risk, communication, Internet of Things, future

Table 1: Different codes regarding the themes and sub questions

4. Results

In this chapter of the research, the results from the interviews and the literature research will be stated and discussed. This has been done by stating the important findings from the interviews within the themes (Flood protection, Spatial measures, Disaster management, Integration, Future perspective) where after they are discussed.

4.1 Flood protection

In this paragraph will be stated and discussed the most relevant findings that were found throughout the analysis of the interviews regarding the theme flood protection. The first finding was that respondents 1, 2, 3, 4 and 6 stated that sensors can be used in dikes to measure various parameters that might indicate ongoing processes inside the dike like piping, macro-stability, temperature changes, changes in position, failure mechanisms, settling flow, pore water pressure, water level. If the right parameters can be measured the condition of a dike can be calculated more precise, which might prove fruitful when it comes to reduce flood risks because the calculations regarding the dikes have to be less conservative. This indicate that in flood protection there is a broad arsenal of possibilities in which sensors can be deployed. Parameters can be measured that indicate any change in mainly dikes and other flood protection related mechanisms. However, there needs to be a reason why sensors are deployed to measure the previously mentioned parameters.

Respondents 1 and 2 stated that sensor measurements can be used in experiments regarding flooding's. These experiments will lead to more knowledge about how dikes perform in such situations. Learning how flood protection systems behave under various circumstances which leads to knowledge is an opportunity where sensors can be used for. The gathered knowledge can be used in maintaining and predicting flood protection systems. Another reason why sensors can be deployed is that sensor measurements can be used at critical locations in the dikes or water works in case there is no budget or space for other measures. In that case sensor measurements act as an extra check of safety which can lead to a decrease in the problem according to respondent 2 and 4. This reason depends on the circumstances and sensors are seen as a temporary solution. If the sensors indicate that other action is necessary plans should be made how to solve this. Therefore sensors do not lower the general flood risk but might give safer margins which can be used during calculations regarding flood protection systems. Another benefit of sensors measurements on the ongoing processes in the dike is that there can be made use of them during any weather condition. Other similar measures are more depended on the weather according to respondent 6. This is a benefit of sensors although the question arises what are the odds that the use of alternative measures to measure the ongoing processes in the dikes is not possible because of weather circumstances.

Finally there was stated by respondent 1 and 2 stated that prevention of a flooding is the most important aspect of the multi-layer safety approach. The reason for this is because, "if a flood occurs it is not possible to reduce the consequences by more than half". Therefore, if the flood risk needs to be reduced, flood protection is the focus. This indicates that the primary focus should be to keep the water out. Measuring the parameters on the ongoing processes inside a dike might therefore be more relevant than spatial measures or measurements during a disaster.

4.2 Spatial measures

In this paragraph will be stated and discussed the most relevant findings that were found throughout the analysis of the interviews regarding the theme spatial measures. One of the findings was that respondent 3 stated that sensor information are not applicable for spatial adaptation because of the slow nature of a planning process. The other respondents who were asked questions regarding this topic did not really have an idea in which sensor measurements could affect spatial measures. Although respondent 5 stated that sensors that measuring water levels in the cities of Amsterdam and Rotterdam outside the dikes daily can help with validating models regarding flooding's. This is however, only possible for places that are located outside of the dikes because of the rate of occurrence of flooding's. Inside the dikes the rate of occurrence would be too low for validation. Therefore the applications and reasons why sensor measurements are needed for spatial adaptation are limited. This is mainly because spatial adaptation does not require continuous information over a long-time period. That is however, the area where sensors would be perfectly suitable for. In areas outside of the dike water level measurements might be of use for the people living in those areas. People who live outside the dikes experience more situations in which extreme circumstances occur. Therefore, they are more prone to the consequences of an disaster situation in case of a flooding.

4.3 Disaster management

In this paragraph will be stated and discussed the most relevant findings that were found throughout the analysis of the interviews regarding the theme disaster management. During the interviews there was a focus in the evacuation part of disaster management. One of the findings was by respondent 1 and 4, they stated that sensor measurements can be used to measure traffic streams and spreading of the flooding, which can lead in case of a small scale disaster to improved efficiency of evacuation of the area. In case of a big scale disaster the system will probably be overloaded. The data sensors provide could be used in traffic models which can be communicated in case of an evacuation. Both respondents however, doubt the practical effect because of human behaviour in case of an emergency. This finding shows the difficulty of how to adapt on the fly. In a disaster situation there is need for a certain speed of a reaction. If the scale of the disaster is to big it becomes difficult to adapt on the fly. Therefore sensor measurements can contribute although the effectivity depends on the scale of the disaster. However, according to respondent 2 and 3 actual information during a flood is still relevant. Actual information might prove fruitful during the disaster for evacuation. Therefore in the heat of an evacuation of a disaster the use of sensor measurements is limited. Sensor measurements might however be used to measure how a flood protection system breaks and provide data for a model of how the flood is going to spread. With this information preventive evacuation might be an option as a result of sensor measurements.

Another finding was by respondent 1, there was stated that the Internet of Things is used for warning people in case of a flood, this has to happen through applications which people use in their daily life. The importance of using applications that people use in their daily life is because of the habits of persons. People will not look for sources during a disaster outside their comfort zone. Further the use of the Internet of Things in disaster management as well as the other themes of this research was limited. This might be a consequence of the upcoming character of the Internet of Things and limited applications related to flood risk management.

4.4 Integration

In this paragraph will be stated and discussed the most relevant findings that were found throughout the analysis of the interviews regarding the theme integration. The first finding was that respondents 1, 2, 3 and 6 stated that the implementation of sensor measurements into adaptive flood risk management is a costly decision to make. Implementation of sensors in adaptive flood risk management have a high initial cost. These high initial costs may form a problem regarding the policy for flood risk management. Respondent 6 stated that the main priority of waterboards is to keep people safe from water for a price as low as possible. The priority of waterboards to maintain the safety for a price as low as possible results in that the implementation of sensors is not often done. There needs to be a valid reason on why sensors should be implemented in adaptive flood risk management. The high cost of sensors in adaptive flood risk management can result in the use of alternative measures. Respondent 2, 3 and 4 stated that alternatives for sensor measurements like Lidar and radar measurements might be just as effective meanwhile cheaper to execute. Therefore, there should be good reasons why sensor networks are chosen instead of alternative measures. Gaining knowledge by sensor measurements as was mentioned before might therefore be the main focus. Alternative measures might be more suited for noticing anomalies regarding dikes. There may be other reasons why sensors measurements are not used that often yet. Respondent 6 noted in a cynical way that he thought that waterboards were not ready yet for serious dike monitoring. Because of a lack of essential infrastructure and knowledge. If that is the case, there should be a transition in the way adaptive flood risk management is done. Waterboards should work together to share knowledge and infrastructure to gain a better understanding on how sensor measurements can be made proper use of.

Another important point which should be considered when the decision needs to be made about the implementation and integration of sensors in adaptive flood risk management is the durability. Respondent 1, 2, 3, 4 and 6 stated that the durability of sensors at the moment is to short. If a sensor fails, there is no data collection anymore and the sensors need to be replaced. This makes sensors measurements unreliable at the moment and not suited for long durations of measurements. If this problem is not solved, there must be more maintenance to replace sensors which can led to negative impacts in the infrastructure where the maintenance is going on. This is a crucial point in the decision needs to be made about the implementation and integration of sensors in adaptive flood risk management. For sensors to be of value long measurements are needed. If that is not the case the information that is gathered by the sensor does not consist of enough extreme situations. Which therefore makes it difficult to form good conclusions out of the sensor gathered information. This is directly linked to the next finding. Respondent 2, 3, 4 and 6 stated that the circumstances wherein a sensor operates determines its efficiency and effectivity. The range of water levels around Amsterdam is quite constant, in an extreme situation only 20 centimetres of water is added in comparison to a normal situation. Because this stability sensors are not often used for flood protection. The range of water levels around Rotterdam is quite different, Rotterdam varies a lot more because of the influence of the sea. Because of the rare occurrence of extreme situations sensor measurements are not often used to validate models regarding floods. This finding states that in each case of sensor usage there should be made decisions if sensors can provide the information which is needed to answer the question that needs an answer.

There need to be made a lot considerations about the implementation and integration of sensors in adaptive flood risk management. At the moment sensor measurements, do not seem the appropriate tool to deal with issues in adaptive flood risk management. Therefore, in the next paragraph there is taken a look at the future perspective of sensor measurements.

4.5 Future perspective

In this paragraph will be stated and discussed the most relevant findings that were found throughout the analysis of the interviews regarding the theme future perspective. At the moment the integration and implementation of sensors are used on limited small scales. For this research it is interesting in how the interviewed people look at the use of sensor in the future. The visions people had with sensors in mind varied. Respondent 6 envisioned that that in the future every dike will be monitored but at the moment we have just started. He sees digital monitoring as a part of the future wherein organisations who deal with flood risks have to work more efficient and effectively together. Respondent 2 stated that he thinks the use of sensor measurements in dike monitoring is a development that will develop gradually but it depends on the need in practice. Both expect that in the future there will be made more use of sensor for dike monitoring only the speed this will develop itself differs between them. Respondent 6 brought up also a challenge which needs to be solved before there can be made proper use of sensor measurements. Respondent 6 stated that organisations who deal with flood risks don't have the necessary expertise and ICT infrastructure to make proper use of sensor measurements. This is a challenge in which organisations regarding flood risk management should cooperate with other organisations. Sharing of knowledge and ICT infrastructure could lead to the property of the needed skills to use sensor measurements. Respondent 1,2, 3 and 4 see sensor measurements as complementary and thinks that increasing knowledge is much more effective in the future. Therefore, respondent 3 and 4 stated that there are some future plans regarding sensor measurements going on or on the line. These tests have a focus on getting new knowledge regarding dikes. The interviewees see potential for the use of sensor measurements to use as an additional tool for adaptive flood risk management in the future. Only in what way this will develop the opinions differ.

The way sensor measurements are viewed also depend on the level of innovation present in organizations that deal with digital applications of dealing with flood risks where sensor measurements are a part of. The city of Amsterdam is often labeled as a smart city, so there is more of a focus on digital innovation. Rotterdam is more focused on climate adaptation, digital innovation plays a role in the climate adaptation of Rotterdam but in comparison to Amsterdam, Rotterdam is less innovative in the use of digital measures to deal with flood risks.

6. Conclusion

In this chapter of the research there is formed a conclusion and an answer to the main research question. The answers of the three sub questions will lead to an answer on the main question. First will the main research question be stated again where after an answer to it will be given.

Main question: *In what way can sensor measurements be integrated in adaptive flood risk management in Amsterdam and Rotterdam?*

Sensor measurements can be of added value in adaptive flood risk management. The most added value is in flood protection or in disaster management. In those two factors of the multi-layer safety approach are several applications where sensor measurements can be beneficial. The possibilities for sensor measurements in spatial adaptation are limited. This is mainly because the flood protection is of such a high quality that the rate of occurrence is low in the spot where spatial adaptation takes place. Another important aspect is the length of measurements, measurements should be long enough before they can be of worth for the end-users. Before sensors can be of worth for Rotterdam and Amsterdam there should be made several considerations. The considerations that should be made vary from the circumstances, the goal, the cost, durability and alternative measures. Currently there is a focus on sensor measurements for gaining knowledge about how to deal with flood risks in the three factors of the multi-layer safety approach. The future of sensor measurements varies from whom is asked. The goal of how innovative an organization wants to be, also plays a factor in how the future of sensor measurements are viewed. In the hypothesis was stated that the Internet of Things could play a role in adaptive flood risk management nevertheless the role of the Internet of Things as was indicated in the results was quite limited at the moment.

Sensor measurements are at the moment not an application that can be used on a wide scale level. Although sensor measurements can help with dealing with flood risks mainly in flood protection there have to be made several considerations. These considerations don't make it interesting to adapt sensors on a large scale in adaptive flood risk management at the moment. However, sensors are at the moment interesting for gaining knowledge which leads to a better understanding on how to deal with floods. Sensor measurements can be a tool to connect the concepts of smart cities and flood resilient cities. The ICT technology which operates in smart cities can assist with finding opportunities to make cities more resilient. Sensor measurements are one of these tools, they can measure the conditions of critical infrastructure which can lead to a better decision making regarding flood risk safety.

As a result of this research it would be good for cities and waterboards to collaborate more and synchronize the systems which are being used to validate and monitor flood protection systems. If the systems are synchronized information and knowledge can be transferred easier between different organizations. This can hopefully partly solve one of the obstacles, the lack of knowledge and ICT infrastructure with which sensor measurements have to deal to be of efficient and effective use.

Another recommendation is that it might be interesting to stimulate policy regarding innovation in flood risk management. There is need for a focus on a wider scale meanwhile maintain the local scale level. To reach this collaboration between different organizations who are dealing with flood related risks are therefore, necessary.

For future research it might be interesting to research how some of the obstacles of sensor networks can be removed in the future. Examples are how to make the sensor networks more durable and how to reduce the cost of implementing a sensor network.

7. Reflection

In this chapter there will be reflected on how the research went and where there was room for improvement. First there is looked at the theoretical framework in which this research was conducted. Second the methodology and the data collection will be reflected. As last the research results are reflected.

The theoretical framework in this report was quite sturdy throughout the writing of this report. There haven't been a lot of changes in the theoretical framework during the execution of the research, although there have been made quite some adaptations to the research question. The changes were made because the research question was not researchable in a proper way or the collected data was not fitting. The data collection itself went okay, there were some problems with finding the right people for the interviews. However, if I would do this research again, I would improve the data collection instrument. Throughout the interviews there were different questions asked to each of the interviewees. In a future research, I would adjust the data instrument in a way that the same questions can be asked. The reason for the different questions was that different interviewees were engaged in different parts of the multi-layer safety approach. Therefore, some questions were not fitting for different interviewees. In retrospect, I should have put more thought into that. As last are the research results reflected, the results partly overlapped with the hypothesis that were made. Most of the research were more complex than initially was shown in the hypothesis. The idea's that were presented in the theoretical framework also came back in the results section. Although in the theory section there was a focus on the Internet of Things working together with sensor measurements but in the interviews was concluded that the implementation of the Internet of Things was quite minimal.

Initially during the writing of this report there was a focus on Amsterdam and Rotterdam for flooding specifically. This was changed during the research to Amsterdam and Rotterdam and their respective waterboards they are in positioned because the safety of those cities starts with the flood protection which is mainly done by the waterboards. Therefore, it made no sense to just research at how sensor measurements can be integrated into those two cities. It made more sense for the topic of the research to increase this a bit to also integrate the waterboards of those cities.

The results answer mainly the main question of the research. However the goal of this research was also to focus on how smart cities and resilient cities are linked together by sensor measurements. There should have been more of a focus on this part during the data collection which has led to a lack in how these two concepts, smart cities and resilient cities are linked together.

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