How uncertainties impact municipal decision-making processes about urban quay walls: An Amsterdam case study

Master Thesis Project:

M.Sc. Civil Engineering and Management

Daniel Bejarano Macias
Student number: S2922347
d.a.bejaranomacias@student.utwente.nl

Supervision by:

University of Twente:

Dr. ir. Vinke-de Kruijf, Joanne
Dr. Hartmaan, Andreas
Dr. Alvarado Vazquez, Sergio

Gemeente Amsterdam:

Environmental and Communications Manager
Bours, Jiska

Summary

Amsterdam's extensive network of canals, comprising 1,800 bridges and 600 kilometres of quay walls, plays a vital role in the city's infrastructure and heritage. However, many of these structures require renovation due to their lifespan, increased traffic, and evolving city conditions. To address these issues, the municipality launched the "*Programma Bruggen en Kademuren (PBK)*" in 2019, focusing on the safety and renovation of 830 bridges and 200 kilometres of quay walls.

This study identifies the municipality's challenges in renovating these structures through the PBK, particularly when implementing interventions for quay walls in poor structural conditions. The complexity of these quay walls introduces various uncertainties that impact the decision-making process of determining such interventions and affect interactions between the municipality and the users of the quay walls. Therefore, the research explores the uncertainties surrounding the decision-making process for interventions on urban quay walls in Amsterdam. It focuses on their impact on risk management and stakeholder participation, especially the communication of risks and the interactions between asset users and the asset owner.

The research adopts a case study approach, analysing the *Waalseilandsgracht* canal in Amsterdam's city centre, where interventions on the *Binnenkant* and *Oude Waal* quay walls led to conflicts between the municipality and the users living along the canal. This study examines how incomplete knowledge, unpredictability, and ambiguity affected these interactions in the case study and how the municipality can improve its risk communication and stakeholder engagement. Resulting in the importance of developing a systematic approach for interacting with stakeholders in uncertain scenarios.

Data were collected through documents exchanged during the case study and interviews with stakeholders involved in the project. The analysis was structured around three phases of the decision-making process for quay wall interventions: (1) the monitoring phase, when gathering and analysing data; (2) the decision-making phase, when determining the type of interventions needed; and (3) the implementation phase, where interventions are carried out.

The study resulted in the effects of incomplete knowledge and unpredictability on assessing the structural condition of quay walls, the effectiveness of interventions, and the users' willingness to support such interventions. The results also reveal the importance of early engagement with stakeholders, effective risk communication through the perception of the experts assessing the risk and those affected by it, and structured stakeholder participation that includes flexibility to adapt to uncertain scenarios.

In conclusion, the study emphasises the need to avoid ambiguity between asset owners and users during decision-making processes for quay wall interventions. It proposes a three-step flexible approach for interacting with asset users, showing the importance of taking into consideration the input of the stakeholders and the early and ongoing stakeholder participation, particularly in urban projects.

Content

List of Figures

List of Tables

1 Introduction

1.1. Background

Amsterdam is a city worldwide known for its intricate canal system, which comprises two primary structural components: quay walls and bridges. Quay walls act as retaining structures along the canals, while bridges are built to link, support, and facilitate passage across these waterways (Voortman, 2021). The municipality of Amsterdam features 1,800 bridges and 600 kilometres of quay walls, making these structures part of an extensive asset network that significantly contributes to Amsterdam's vibrancy by offering scenic views and UNESCO heritage values while also playing a role in the dynamics of the city's tourist attractions through sightseeing cruises and boat tours (Amsterdam, n.d.; Gemeente Amsterdam, 2023; Sasidharan et al., 2022).

However, a considerable amount of these structures demand renovation due to their structural conditions as a consequence of their lifespan, increased traffic loads from heavy vehicles and evolving city conditions (Gemeente Amsterdam, 2023). To address this need, the municipality of Amsterdam launched in 2019 the *"Programma Bruggen en Kademuren (PBK)"*, which in English translates to "Program Bridges and Quay Walls*"*. The PBK aims to ensure the safety of 830 bridges and 200 kilometres of quay walls. Therefore, the PBK focus is on the renovation, innovation, development, and life-span extensions of the "urban bridges and quay walls (UBQs)" of Amsterdam (Gemeente Amsterdam, 2023).

Within the 200 km of quay walls, the PBK has identified certain quay walls that can remain in use without the need for interventions, while other quay walls need urgent renovation due to their poor structural state. However, renovating all the structures simultaneously is impractical and almost impossible due to the large number of structures and budget constraints. For this matter, the PBK has to implement temporary interventions to quay walls that cannot be renovated but are determined to be in poor condition to ensure their safety and reduce the possibility of a quay wall collapse until future renovation can be achieved. To this date, several quay walls are still being monitored and assessed due to their evolving condition. This means that some quay walls, which were initially deemed to be in good structural condition, can start to deform as time goes by, making them in need of temporary interventions (Gemeente Amsterdam, 2021).

Ensuring the safety of all structures within the PBK is expected to take approximately 20 years to complete. For this reason, the PBK also aims to prioritise the accessibility and quality of life of users of the UBQs, such as citizens, tourists, businesses, etc., allowing them to maintain their daily activities and lifestyles throughout the renovation process and implementation of temporary interventions. The municipality does this by monitoring the structures, conducting technical assessments to determine the risk of a collapse, re-evaluating the function of the structures, determining when to implement interventions and interacting with the users of the UBQs, while trying to accelerate production by standardising and innovating more efficient working methods (Gemeente Amsterdam, 2023).

The monumental number of structures within the scope of the PBK and the complexities of a major European tourist destination like Amsterdam, including factors such as tourism, historical and cultural values, annual events, etc., make the task of renovating and/or implementing temporary interventions without compromising the accessibility and the quality of life of users of the UBQs a significant challenge for the PBK (Kavaratzis & Ashworth, 2007).

1.2. Problem context

For now, the PBK must rely mostly on temporary interventions for UBQs identified as being in poor condition and unable to undergo immediate renovation. These interventions are thought to be necessary to ensure the safety of users until future renovations can occur. However, the interventions can create conflicts between the municipality of Amsterdam, who is the owner and manager of the UBQs, and the citizens of Amsterdam, who are one of the primary users of the UBQs (Antonisse, 2021; Miltenburg, 2021).

For example, in 2020, the municipality of Amsterdam determined that the "*Waalseilandsgracht*" quay walls in Amsterdam's city centre were in poor structural condition due to cracks and deformations. The municipality of Amsterdam decided through the PBK to start monitoring the quay walls. When the risk of a collapse was becoming significant, the decision to implement interventions in the form of sheet piles was taken (Gemeente Amsterdam, 2021). While the municipality determined the sheet piles as a "temporary" intervention and the safest measure to protect the users of the quay wall from a possible collapse, the users saw the sheet piles as an intrusive and "long-term" intervention that would affect their quality of life and accessibility until the final renovation of the quay wall, which is scheduled for 2027 (Gemeente Amsterdam, 2024; Miltenburg, 2021).

The differing views from the users of the UBQs and the municipality of Amsterdam regarding the use of quay wall interventions led the users to look for alternatives that would not jeopardise their life quality and to seek legal assistance to raise their voices against the temporary measures used by the PBK on the quay walls. The different points of view created a conflict between the municipality of Amsterdam and the UBQ users who lived in the *Waalseilandsgracht* that delayed the implementation of quay wall interventions for almost half a year (Antonisse, 2021; Miltenburg, 2021).

In order to avoid conflicts like the ones mentioned in the *Waalseilandsgracht*, the municipality of Amsterdam now seeks to collaborate with the users of the UBQs, e.g., Amsterdam's citizens, businesses, entrepreneurs, etc., to achieve the best possible outcome that benefits the parties involved when implementing interventions. This collaboration aims to achieve the goals set by the PBK: to ensure the safety of quay wall users while also prioritising their accessibility and quality of life (Gemeente Amsterdam, 2023a, 2023b).

However, to understand where problems originate when renovating or determining interventions for quay walls, it is important to understand the complexity of these structures. The design and construction of a quay wall depends on various factors, such as soil and subsoil conditions, water levels, load-bearing capacity, construction materials, and functional requirements (De Gijt, 2010). These factors make determining the structural condition of the

quay walls an enormous challenge, especially when gathering information from the quay walls of a historic city like Amsterdam, which has changed over the years (Voortman, 2021).

The complexity of gathering information regarding the various elements that compose a quay wall, combined with their long lifespan and the large number of quay wall structures in Amsterdam, can create significant uncertainties for the PBK as owner and manager of these structures (Chiffi & Chiodo, 2020). Especially when the PBK has to make decisions regarding the structural state of the quay walls and the interventions used to protect the users of such quay walls from a possible risk of collapse (Ward & Chapman, 2003).

1.3. State of the art

While no studies specifically focus on the uncertainties surrounding the UBQs, the associated risks, and the interactions between the owners and users of these structures, some studies have already addressed how to categorise and manage uncertainties in various contexts (Konter, 2023; Kwadijk et al., 2010; Warmink et al., 2017). Other studies have highlighted the importance of effective risk communication in the risk management process to minimise conflicts between experts assessing a specific risk and the people affected by such a risk (Aven, 2016; Frewer, 2004; Hampel, 2006; Olsson, 2007). Additionally, some studies have emphasised the effects of uncertain and risky problems in interactions between decision-makers and stakeholders, especially in construction projects (Böhle et al., 2016; Frewer, 2004).

1.4. Problem statement

Currently, the PBK is investing in developing more efficient working methods to increase the rate of renovations of quay walls or extend their life span until final renovations (Gemeente Amsterdam, 2023b). However, due to the large number of structures and the complexity of addressing the quay walls' condition—due to their structural characteristics and life cycle — there are still many unknown uncertainties the PBK has to face as a decision-maker when determining interventions for quay walls that cannot be renovated (Gemeente Amsterdam, 2023b; Awad, 2023; Ruggeri et al., 2019).

These unknown uncertainties have yet to be identified in the decision-making process for selecting interventions for the UBQs. Additionally, it is unclear whether there is a relationship between these uncertainties and the PBK's interactions between the municipality and the users of the UBQs (Korff et al., 2022).

1.5. Research aim and questions

This research aims to understand the role of uncertainties influencing decision-making processes regarding quay wall interventions and to provide recommendations to the PBK for improving its interactions with stakeholder and their communication of risks associated with the UBQs. To this end, the main research question is: How do uncertainties affect the interaction between the municipality of Amsterdam and the users of the UBQs when making decisions to implement quay wall interventions?

To help answer the main research question, some sub-questions are formulated:

- What uncertainties are present in the decision-making process for determining quay wall interventions?
- How do the municipality and the users of the UBQs perceive and manage quay walls' uncertainties and risks?
- What improvements should the municipality of Amsterdam make in their engagement with stakeholders, particularly in their risk communication?

1.6. Scope

This research makes use of asset management terms described by van der Velde et al. (2013) to identify the main structures and actors involved in this study. It specifically focuses on quay wall structures, which are the assets within the UBQ. It analyses the "interactions" between two main actors: (1) the asset owner and, in this case, also the manager, which is the municipality of Amsterdam through the PBK, and (2) the asset users of the quay walls, which this study takes as the people living along the canal; this means houseboat residents and house residents. Furthermore, any external company subcontracted by the municipality to aid in the PBK is considered a "service provider".

The term "interactions" is taken as any exchange of information between the two main actors that fits in the three categories described by Butt et al. (2016): sending information, retrieving information, and interactively exchanging information. Other terms used in this research are described in Section 2 of this report.

Additionally, within this research, the PBK's "decision-making process" considers only the implementation (or not) of interventions for quay walls; decision-making regarding the final renovation of quay walls and other decision-making processes done by the PBK falls outside this research's scope. Interventions will be considered for this study to be any form of construction (e.g., sheet piles) or limitation applied (e.g., load restrictions) to the quay walls.

To address the decision-making process of quay wall interventions, this study considers three phases taken from planning processes in decision-making systems described by Ning et al. (2011), Song et al. (2017), and Waly & Thabet. The phases for this study are described as (1) the "Input stage", which involves gathering data or information; (2) the "Design stage", which focuses on manipulating these inputs for the design of the project; and (3) the "Output stage", which deals with implementing the project.

Moreover, this research follows a case study approach as described by Cousin, (2005). A specific location within the PBK network was selected for analysis, with data collection focused on documents and actors (asset owners, asset users, and service providers) deemed as relevant by the researcher for the specific case study.

1.7. Reading Guide

The outline of this report is as follows: Section 2 presents the main concepts and elements necessary for decision-making processes regarding uncertainties, risk management, and stakeholder participation. Section 3 describes the research approach used for this study, delving into the specific case study, the data collection tools, and the data analysis process. Section 4 presents the main findings of the case study. Furthermore, Section 5 discusses the main research question of this study using literature and the case study's findings. Finally, section 6 provides the study's conclusion, synthesising the research findings, their significance to the PBK, and further recommendations for future research.

2 Theory

This section outlines the key concepts identified as relevant to this study. The three main concepts explored (based on the introduction) are uncertainty, due to the complexity of assessing the structural condition of the quay walls; risk management, due to the potential risk of quay wall collapse and the PBK's efforts to mitigate it; and stakeholder participation, due to the social concerns surrounding the implementation of quay wall interventions. The key concepts were used to carry out a literature review that focused on how the key concepts have any effect on decision-making processes and or social conflicts between stakeholders. Explaining each concept provides a clearer understanding and facilitates comprehension of the conceptual model (section 2.4) used to analyse the case study.

2.1. Uncertainty in decision-making processes

Uncertainty commonly refers to the lack of knowledge of a situation in which the consequences are known, but the probability of occurrence is not known (Chiffi & Chiodo, 2020). Decision-makers often face uncertainties and risks when executing project activities, which may result in unknown consequences. Specifically, many uncertainties can arise from decision-making processes that exist in interconnected and complex systems such as cities (Chiffi & Chiodo, 2020).

In the field of engineering, uncertainty is often categorised into two types: epistemic uncertainty and ontological uncertainty (Warmink et al., 2017). Epistemic uncertainty presents itself from the lack of information or what is not known at the moment and is commonly reduced by gathering and analysing more information. On the other hand, ontological uncertainty is present in random and chaotic behaviour such as the weather, river systems, and other natural processes; it refers to uncertainty that cannot be known and cannot be reduced (van den Hoek et al., 2014; Warmink et al., 2017). However, when considering social environments and institutional contexts, there is a third type of uncertainty known as ambiguity. Unlike uncertainty about what can or cannot be known, ambiguity originates from different knowledge or perspectives from a specific situation. (van den Hoek et al., 2014).

The three types of uncertainties are commonly identified and treated in specific scenarios (van den Hoek et al., 2014). For example, there is incomplete knowledge in decision-making for flood protection due to the limitations of the models used for weather forecasting (Boelee et al.,

2019). Additionally, there is unpredictability due to the numerous factors affecting the atmosphere and weather, e.g. climate change (Biswas et al., 2014). Finally, depending on the model used, there can be ambiguity in how people interpret results from these models, e.g., in determining safety levels (Palmer, 2000).

Drawing from the list of Konter (2023), several methods can be used to decrease the level of uncertainty depending on the type. Incomplete knowledge can be decreased by enhancing information, e.g. research by experts, and estimating possible effects that could occur on a specific event, e.g. confidence intervals (Brugnach et al., 2008; Kwadijk et al., 2010). Unpredictability can be decreased by using strategies like scenario planning, which forecasts future events by analysing historical trends, and the implementation of measures to adapt to an unpredictable event (Haasnoot et al., 2013; Kwadijk et al., 2010; Pahl-Wostl, 2006). Moreover, communication and negotiation have been validated as effective means to mitigate ambiguity in uncertain situations (Brugnach et al., 2008; Dewulf & Biesbroek, 2018).

In addition, there is a fourth type of uncertainty that is identified but cannot always be accounted for; it relates to events that are not known to happen and cannot be known. This is known as fundamental uncertainty, "deep uncertainty", or "unknown unknowns"(Chiffi & Chiodo, 2020; Kandlikar et al., 2005; Logan, 2009). This fourth type of uncertainty differs from ontological uncertainty as it does not necessarily relate to random behaviours but rather scenarios that cannot be predicted or considered. Some theories that rely on imagining hypothetical future scenarios to develop policies can help deal with fundamental uncertainty, especially in decision-making. However, this uncertainty is generally not addressed until it occurs, such as in the case of a global pandemic (Chiffi & Pietarinen, 2017).

When decision-makers face uncertain scenarios, conflicts often arise from assuming that these scenarios are isolated and not considering the surrounding factors. This is highlighted, for example, in large-scale projects where multiple points of view from technical, social, and cultural standpoints can provide different inputs and outputs regarding the project at hand (Böhle et al., 2016). These conflicts typically emerge because uncertainty is most of the times related to technological factors, which decision-makers often prioritise, but uncertainty also involves social aspects, which are frequently overlooked until conflicts arise (Böhle et al., 2016).

However, Van den Hoek et al., (2014) proposed an approach to supporting decision-makers when facing uncertainty, especially when considering social variables. The approach (Figure 1) distinguishes between three systems: the natural system, which relates to random behaviours such as the climate or nature; the technical system, which involves the limitation to gathering information from the artefacts or tools used; and the social system, which involves different points of view from economic, cultural, political, and organisational aspects. In addition, the approach highlights the relationships that exist between these systems. It is suggested that identifying critical uncertainties and their relationships with each other can lead to flexible and adaptive approaches for implementing successful policies or infrastructure when facing future uncertainties (van den Hoek et al., 2014; Warmink et al., 2017).

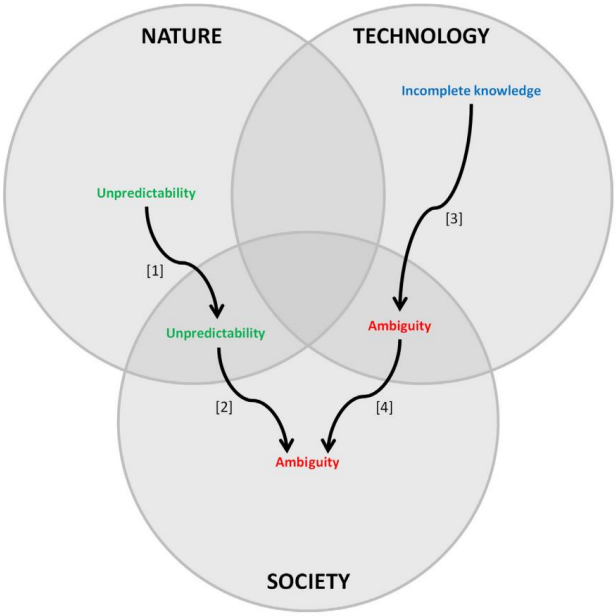

Figure 1, Schematization of systems and its uncertainties according to van de Hoek et al. (2014)

For this research, uncertainty is defined as the lack of knowledge about a situation or possible future events and the different interpretations of knowledge from the same situation. In this definition, three categories (i.e., incomplete knowledge, unpredictability and ambiguity) are used to identify the uncertainties directly involved in the decision-making process of quay walls (see Figure 1). "Deep uncertainties" are considered to be factors that indirectly affect the project, e.g. COVID-19. (Böhle et al., 2016; Chiffi & Chiodo, 2020; Chiffi & Pietarinen, 2017; van den Hoek et al., 2014; Warmink et al., 2017).

2.2. Combining Technical Assessment and Risk Communication in Risk Management

Uncertain knowledge about future events that cannot be fully known in any decision-making process impacts how decision-makers assess and manage risks associated with such future events (Ericson, 2006). Assessing and managing risks is known as risk management. This process often involves identifying risks and taking steps to reduce or avoid them as much as possible (Olsson, 2007). However, it is also crucial to communicate these risks to the people affected to avoid possible conflicts (Frewer, 2004; Hampel, 2006).

Risk can be understood as the likelihood of an uncertain event occurring and the magnitude of its consequences (Sjöberg et al., 2004). Therefore, the focus of risk management is on reducing possible risks related to a specific event (Olsson, 2007). Two primary objectives regarding risk management within decision-making processes are (1) to study and treat the risks of an event through a technical assessment. This assessment examines the environment surrounding the event to quantify the probability of certain risks occurring in order to develop methods to reduce these risks (Aven, 2016); And (2) to achieve a common understanding of risks between those affected by the risk and the experts determining its probability. If this common understanding is not achieved, conflicts may arise, potentially undermining the methods used to reduce the risks (Hampel, 2006).

An approach proposed by Frewer (2004) focused on approaching and interacting with people affected by the risk rather than assuming their reactions to risk information to reduce social issues within the risk management process. However, this approach is often neglected, with risk management typically driven by technical assessments, while interactions with the people affected by the risk are frequently overlooked (Frewer, 2004). Furthermore, one of the main problems in the interactions with people affected by the risk is the assumption that "expert knowledge" is always correct and that "local knowledge", e.g., knowledge from citizens, might be considered "wrong" or insufficiently informed (Hampel, 2006).

This research considers risk as the possibility of an event occurring, e.g., quay wall collapse, and its consequences, e.g., injury, death, and damage to infrastructure. Moreover, it focuses on the success of reducing this risk through a risk management approach that considers the technical assessment of the event, how the risks are communicated, and how people perceive these risks (Aven, 2016; Hampel, 2006; Sjöberg et al., 2004; Olsson, 2007).

2.2.1. On Risk Communication and Risk Perception

Risk communication seeks to align public perception with the expert assessment of a particular hazard; this alignment depends on how information is interpreted and reacted to within the social environment surrounding the hazard (Frewer, 2004). How risks are being communicated often depends on the audience's characteristics, the message's source, and the content. Additionally, factors such as trust in the information source, the provision of unbiased and transparent information, and straightforward interpretation must be considered when determining methods to communicate risks (Breakwell, 2000).

Risk perception refers to the varying ways individuals perceive the probability and consequences of a hazard; this is influenced by individual characteristics, the duration of the hazard, and communication routines (Siegrist & Árvai, 2020). Hampel, (2006) further explains that risk perception is shaped by an individual's cognition and motivation, which are influenced by the social, political, and cultural environment. Furthermore, perceived risks of hazards are formed depending on the assessment of the risk and the knowledge of those exposed to it (Breakwell, 2000).

In this sense, risk perception depends on how information about risks is communicated, while risk communication relies on how people perceive those risks. Thus, risk perception and risk communication are interdependent, both essential for achieving a successful common understanding of risks between the experts assessing them and the people affected by them (Sjöberg et al., 2004).

2.3. Stakeholder Participation as a Tool for Decision-makers within Urban Projects

In a decision-making process related to projects that can impact an urban environment, a stakeholder is anyone whose interests are affected by the project's outcomes; these interests often lead to a level of influence on the project's objectives and results (Buertey, 2016).

Therefore, stakeholder participation in urbanisation projects seeks to incorporate local perspectives and knowledge through interactions with the stakeholders (Reed, 2008).

Stakeholder participation has become a primary focus and a valuable tool for decision-makers to gather input (Glicken, 2000; Newig et al., 2023). This is particularly important for urbanisation projects, which often depend on meeting stakeholder expectations throughout the project lifecycle. Failures or conflicts often arise when these concerns are not addressed (Atkin & Skitmore, 2008). Various forms of stakeholder participation include public consultations, workshops, focus groups, surveys, interviews, public hearings, advisory committees, participatory mapping, online feedback platforms, and collaborative decision-making processes (Buertey, 2016; Luyet et al., 2012; Reed, 2008a; Reed et al., 2018b).

However, in reality, significant limitations affect stakeholder participation, particularly the concerns from stakeholders feeling that their input has little impact on the project, resulting from a sense of powerlessness to contribute to technical discussions (Reed, 2008). Other challenges come from the stakeholders having the time to participate and the support and commitment from decision-makers to ensure an efficient participation process (Vazquez et al., 2024). In addition to the limitations and challenges previously discussed, there is no one-size-fits-all approach to stakeholder participation, as the participation procedure varies depending on the project's context, the surrounding environment, and the level of stakeholder interest:

For example, Buertey (2016) highlights the importance of involving stakeholders early, recognising their input, providing technical support and information, and tailoring communication approaches. Luyet et al. (2012) suggest identifying stakeholders based on their concerns, characterising them by their interests, implementing suitable participation techniques, and evaluating these techniques. Reed (2008) recommends empowering participants through early involvement, establishing clear objectives, maintaining a positive dynamic, and combining scientific and local knowledge. Moreover, Newig et al. (2023) discuss aspects of stakeholder representation, communication procedures, and power delegation dimensions.

Finally, Butt et al. (2016) link effective stakeholder participation to communication routines, which include push communication (sending information), pull communication (stakeholders retrieving information), and interactive communication (multidirectional information exchange). Vazquez et al. (2024) expand on this by noting that communication methods often depend on the number of stakeholders involved and how organisations can adjust their communication strategies based on the stakeholders and the context of the project or decision.

All the authors previously mentioned address various aspects of a “stakeholder participation” process. However, their studies do not provide a step-by-step approach, making it challenging for decision-makers to manage participation in specific projects effectively.

Therefore, this research focuses on stakeholder participation as a process for directly (meetings and face-to-face) interacting with and gathering input from the asset users of the quay walls, which are the stakeholders of the PBK. The input gathered from the stakeholder participation should reflect the stakeholders' general concerns regarding implementing

interventions for quay walls. Additionally, efficient stakeholder participation will be taken as a process that follows the elements explained by Buertey, (2016), Luyet et al. (2012), Newig et al. (2023), and Reed (2008). These elements are interacting with stakeholders in the early stages, identifying their needs and concerns, tailoring communication channels according to their needs and evaluating participation.

As explained by Vazquez et al. (2024) and Butt et al. (2016), communication routines such as sending printed mail or emails can be utilised as participation tools, including the "risk communication" concept, as discussed in section 2.2. However, in this study, the distinction between "risk communication" and "stakeholder participation" will be defined by their objectives: risk communication will focus only on communicating risk information between asset owners and stakeholders. In contrast, stakeholder participation will aim to gather significant "local knowledge" from stakeholders for the project's success.

2.4 Conceptual Model

To illustrate how the previously mentioned concepts could affect the decision-making process of implementing interventions for quay walls, a conceptual model has been developed (Figure 3).

The decision-making process within the scope of this research is described using three phases (Figure 2). The phases are outlined to aid the understanding of the conceptual model within the decision-making process for quay wall interventions. The three phases in the context of the UBQs are described as:

- **The monitoring phase**: The asset owner sub-contracts a service provider to collect and analyse data on the quay walls to assess their condition.
- **The decision-making phase**: The asset owner interprets and manipulates the data provided to decide to intervene and implement a quay wall intervention. If there is a decision not to intervene, there is a loop back to the monitoring phase.
- **The implementation phase**: Once there is a decision to intervene, the asset owner (if necessary) sub-contracts another service provider to start implementing the quay wall intervention according to the decision made in the previous phase.

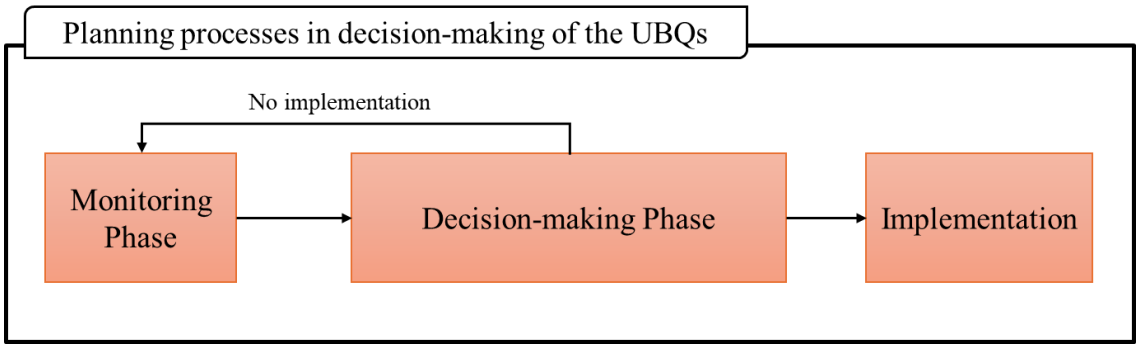

Figure 2, Decision-making process diagram used for this research

When considering the concepts of uncertainty, risk management, and stakeholder participation, it becomes clear that the decision to implement (or not) interventions (Figure 3) can be influenced by various factors. The conceptual model is further described below.

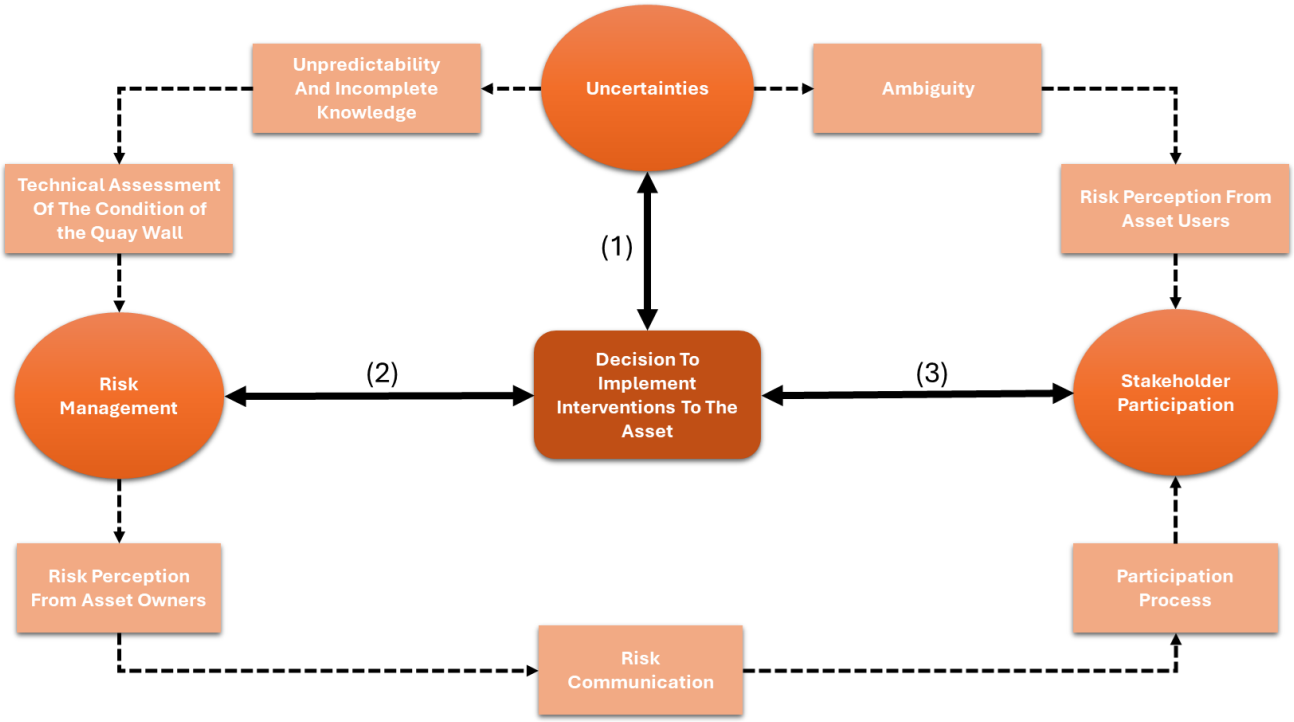

Figure 3, Conceptual Model on how uncertainties, risk management and stakeholder participation affect the decision-making of implementing interventions

The structural condition of quay walls can change over time, which means the decision-making process must be done each time an assessment for a quay wall is needed. According to Gemeente Amsterdam (2023b), a quay wall assessment changes every time new data is gathered. This means that the decision to implement interventions is an iterative process that happens until an intervention is implemented or renovation of the quay wall is achieved.

The first influence (1) on the decision-making process comes from the uncertainties surrounding the technical assessment of quay walls. These uncertainties vary depending on the methods, tools, or information used (Gemeente Amsterdam, 2023b). Due to the complexity of quay wall structures, technical assessments carry a level of "incomplete knowledge" from the lack of information from the quay walls and "unpredictability" from the deformation behaviour of the quay walls (van den Hoek et al., 2014; Warmink et al., 2017).

The second influence (2) is related to risk management, specifically regarding the potential collapse of a quay wall (Gemeente Amsterdam, 2023b). Risk management influences the decision-making process due to the technical assessment of the quay wall's condition and the asset owner's risk perception. This means that the asset owner will respond to their perception of risk and the technical assessment through the decision of implementing the interventions to reduce the risk of a quay wall collapse (Breakwell, 2000; Frewer, 2004; Gemeente Amsterdam, 2023b).

The third influence (3) comes from stakeholder participation, which starts through the interactions between the asset owner and the asset users through risk communication channels such as printed mail, emails, websites, and stakeholder participation procedures like meetings and face-to-face interactions (Butt et al., 2016; Frewer, 2004; Hampel, 2006; Reed, 2008). Stakeholders, as asset users of the quay walls, express concerns about how interventions might affect them, and these concerns can impact the decision-making process (Reed, 2008). In addition, stakeholders will form their risk perceptions regarding the quay wall collapse (Siegrist & Árvai, 2020). The risk perceptions from the asset users might differ from the perception of the asset owners, leading to "ambiguity", another type of uncertainty that can influence the decision-making process (van den Hoek et al., 2014).

3 Method

Since the research questions focus on "how" certain aspects of decision-making processes occur, and the study's objective is to provide recommendations to the municipality of Amsterdam regarding PBK's activities, studying a scenario from a previously resolved conflict is the best approach to achieve the objectives of this research. Analysing a specific scenario will help explore uncertainties decision-makers faced in determining quay wall interventions and their impact on stakeholders. Therefore, a case study approach as described by Yin (2023), will be adopted for this research.

Studying the interpretations and interactions that occur in the case study between users of the quay walls and the municipality of Amsterdam can highlight potential gaps in communication and help understand the impacts the PBK's activities have on the users of the quay walls, e.g., determining quay wall interventions (Butt et al., 2016; Sjöberg et al., 2004; van den Hoek et al., 2014; Warmink et al., 2017).

Furthermore, understanding the origins and outcomes of the decision-making process of determining quay wall interventions can contribute to better management of quay walls that resemble the characteristics described in the case study, especially in the interaction with users of the quay walls (Frewer, 2004). Additionally, this study's data collection and analysis allow for deeper insights into the decision-making processes regarding quay walls in poor structural conditions, specifically when determining interventions. The following section describes the selected case study and the data collection and analysis used for this research.

3.1 Case study: The Waalseilandsgracht

It was suggested by the municipality of Amsterdam to use the *Waalseilandsgracht* as a case study due to the intense conflicts between the municipality and the asset users residing along the quay walls. These conflicts caused a significant delay in the implementation of quay wall interventions for almost six months. Additionally, the municipality faced various uncertainties when assessing the condition of the quay walls at different points in time. The outcome of this case study is significant because it effectively addressed the concerns of the stakeholders, resulting in a conflict that turned into a positive outcome for both the municipality and the users of the quay walls. Furthermore, the case study took place within the PBK's scope and near the

city centre of Amsterdam, making it an interesting case for understanding potential future problems in similar environments for the municipality.

The history of the case is as follows. In December 2020, the municipality of Amsterdam determined that the "*Oude Waal*" and "*Binnenkant*" quay walls from the *Waalseilandsgracht* (see Figure 4) were in poor structural conditions (Gemeente Amsterdam, 2024b). Due to the condition of the quay walls, monitoring methods were increased, and interventions, i.e., safety measures, were implemented to ensure the safety of the users of the quay wall. Initially, load restrictions were enforced by removing car access and parking spaces. However, when the deformation of the quay wall continued, the municipality introduced another safety measure known as "sheet piles", i.e., sheet steel driven into the ground to support and stop the deformation of the quay walls (Gemeente Amsterdam, 2024b).

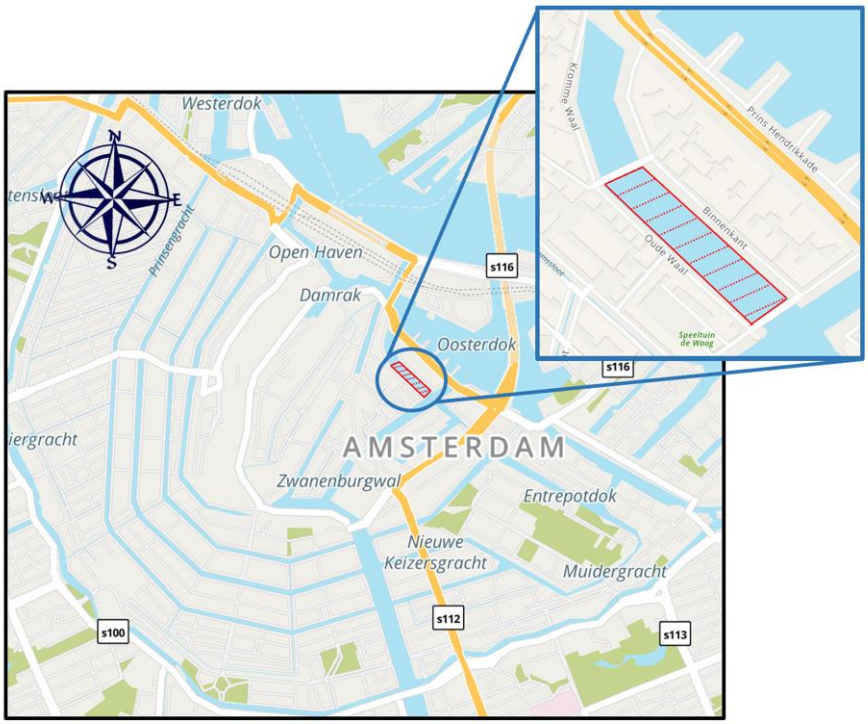

Figure 4, Location of the Waalseilandsgracht Canal (MapQuest, 2024)

Since the complete renovation of the *Waalseilandgracht* quay walls is planned for 2027 and 2029, the safety measures will remain in place until then (Gemeente Amsterdam, 2024b). For this matter, the users of the quay walls who were living along the *Waalseilandsgracht* expressed concerns about the effects of the sheet piles on accessibility and quality of life (Antonisse, 2021; Miltenburg, 2021).

At first, the users felt the municipality did not take their concerns seriously. Consequently, they saw the need to organise into groups like "*De Goede Wal*" and "*Waalseilandsgracht Groep*" to address specific concerns and seek alternatives that would be more visually appealing and less intrusive while ensuring adequate safety (Antonisse, 2021; Miltenburg, 2021).

The conflict escalated into a legal dispute, with users urging the municipality to consider other alternatives or agreements that could minimise the impact on their lifestyle. Although the court ruled in favour of the municipality of Amsterdam, the concerns from the users of the quay walls delayed the installation of sheet piles by almost six months (Antonisse, 2021; Miltenburg, 2021).

Recognising its responsibility for the impact of the sheet piles on users living nearby or in front of the canal, the municipality worked with the users to find a mutually satisfactory solution. This involved allocating funds for activities not initially considered in the original plan to address users' needs. The conflict ended when the users living in the *Waalselainsgracht* and the municipality agreed to the terms surrounding the installation of the sheet piles, resolving the situation until further renovation activities take place (Gemeente Amsterdam, 2024b).

3.2. Data Collection

Data were collected from sources provided by the municipality of Amsterdam at the start of this research and by interviewing asset owners, asset users, and service providers involved in the case study. Following the document analysis described by Sankofa (2023), a total of 58 documents were found in these sources. The documents comprised meeting reports, printed mail, news articles, and emails exchanged during the case study period. Additionally, interviews followed the method described by Bearman (2019), a total of 18 interviews were done. Of the 18 interviews, 9 were done with asset owners, 6 with service providers, and 3 with asset users. The interviews were conducted to explore specific aspects of the case study relevant to the key concepts of this research, such as events that occur, causes and consequences of such events, procedures for decisions or actions, etc. The instruments for data collection, including the document analysis and the guide used for the interviews, can be found in Appendix A.

The quantity and type of documents found in this research can be seen in Table 1. The sources provided by the Municipality of Amsterdam are the following:

- *Waalseilandsgracht* website: A site where asset users of the *Waalseilandsgracht* shared concerns and information about *Waalseilandsgracht*.
- *Gemeente Amsterdam* website: The official municipal website that publishes information on news, projects, and other activities in Amsterdam.
- *BouwApp*: An app for communicating specific details to citizens during the preparation and implementation of a construction project.
- *Het Parool*: An influential Dutch daily newspaper in Amsterdam.

Source	Type of source/interview	Amount of documents/interviews found or done
Waalseilandgracht website	Discussion Meeting Reports	22
	Printed Mail/Email	16
	Newsletters	4
	Social Media Posts	4
BouwApp	Digital Tool Posts	6
Gemeente Amsterdam	Websites	1
Het Parool	News Articles	5
Interviews	Asset Owners	9
	Asset Users	3
	Service Providers	6

Table 1, Data collection material

3.3. Data Analysis

To analyse the collected data, this research follows the procedures described in Appendix A by Bearman (2019), Buchbinder (2011), Mezmir (2020), and Sankofa (2023). The data analysis involved three steps: organising the data chronologically, categorising and reducing the data using codes and "Atlas.ti" (a software to analyse qualitative data), and validating the information through interviews with asset owners and users. The detailed description of the steps is as follows.

The first step involved chronologically organising all the collected data and identifying where key decision-making points occurred during the case study. This process helped in building a timeline for the case study. The key events found were the basis for identifying the three phases within the decision-making process explained in Section 2 (Figure 2) of this report. The timeline also displayed these phases to give more sense of their presence in reality. Furthermore, the "decision-making phase" was divided into two sections: the first section is called the "conflict period", and the second section is called the "resolution period". The "conflict period" highlights the events that created conflicts between asset owners and users, while the "resolution period" highlights the events that occur to resolve the conflict.

The second step of the data analysis involved coding the collected data. These codes were developed based on the concepts explained in Section 2. The breakdown and relationships between the codes and the concepts can be found in Figure 14, Figure 15, and Figure 16 from Appendix A of this report. The codes used for Atlas.ti can be seen in Table 2.

Using Atlas.ti, the codes were applied to the 58 documents found; each relevant section was coded according to its link to the key concepts. Once all the documents were coded, the researcher accessed the specific codes to determine the findings regarding the key concepts of this research.

Key Concepts of this research	Codes used in Atlas.ti
Uncertainty	Incomplete knowledge
	Ambiguity
	Unpredictability
	Methods to enhance information
	Possible effects
	Technological variables
	Technological system
	Communication
	Negotiation
	Social system
	Future Events
	Adaptable measures
	Natural system
Risk Management	Risk communication
	Risk perception
	Social Concerns
	Likelihood of consequences
	Engaging citizens
	Expert knowledge
	Lay knowledge
	Trust information
	Magnitude of consequences
	Social environment
	Personal experiences
Stakeholder Participation	Identify stakeholders
	Group stakeholders
	Participatory techniques
	Push communication
	Pull communication
	Interactive communication
	Evaluation of participation

Table 2, Codes used to analyse the data

Finally, in the third step, interviews from the data collection phase were used to validate the research findings. These interviews involved the same asset owners, service providers, and asset users who participated in the initial data collection. A storytelling approach was employed, utilising the timeline developed from document analysis to confirm the events identified during data collection. Since these interviews were conducted at various times, the validation process was ongoing throughout the data collection and analysis, culminating in the final interview.

All information about the interviewees had to be anonymised for this research following the consent form they signed before participating. The consent form can be found in Appendix C. However, Table 3 shows the type of interviewees, their status in the PBK, the type of actor they are and the objectives of the interviews done to them.

Type of Interviewees	Description	Asset Users	Asset Owners	Service Provider	Objective of Interviews
Municipal Employee #1	Currently involved in the PBK		X		Data collection and validation
Municipal Employee #2	Retired but involved in the PBK during the case study		X		Data collection and validation
Municipal Employee #3	Currently involved in the PBK		X		Data collection and validation
Municipal Employee #4	Currently involved in the PBK		X		Only data collection
Municipal Employee #5	Currently involved in the PBK		X		Only data collection
Municipal Employee #6	Currently involved in the PBK		X		Only data collection
Independent Consultant #1	Involved in the PBK during the case study			X	Data collection and validation
Independent Consultant #2	Involved in the PBK during the case study			X	Data collection and validation
Sub-Contractor	Currently involved in the technical assessment of the PBK			X	Data collection
Citizen #1	Houseboat resident in the *Waalseilandsgracht*	X			Data collection
Citizen #2	Houseboat resident in the *Waalseilandsgracht*	X			Data collection
Citizen #3	Houseboat resident in the *Waalseilandsgracht*	X			Data collection

Table 3 Interviews done with asset owners and users

4 Results

The results in the following section address the main concepts related to this study's research objectives and questions within the specific case of the *Waalseilandsgracht*. The results are presented by describing the three phases (monitoring, decision-making and implementation) in the timeline of the case study. All the references from the interviews and documents used for the results can be found in Appendix B.

4.1. Waalseilandsgracht Timeline

The following timeline (Figure 5) represents the events that occurred during the case study of the *Waalseilandsgracht.* In the context of the case study, the phases previously developed are described as:

In the monitoring phase (from June 2019 to December 2020), the asset owner hired a service provider to conduct a technical assessment of the quay walls by collecting and analysing data (specifically deformations) to evaluate their condition. During the technical assessment of the quay wall, no significant interaction was observed between the parties. The phase ends with the technical assessment indicating that the quay wall was posing a risk of collapse and the municipality deciding if there is a need to implement interventions, such as installing sheet piles or imposing load restrictions.

In the decision-making phase (from December 2020 to September 2021), the asset owner had to decide how and when to implement interventions for the quay wall; the decision is based on the technical assessment indicating a potential risk of collapse. This decision is the origin of the interaction between asset owners and users, centring on communicating the risk of collapse and the interventions planned to reduce the risk. Within this phase, two sub-periods are identified: the "conflict period," where disagreements arise between asset users and owners regarding the proposed interventions, and the "resolution period," where parties work towards finding a solution to implement the necessary interventions. This phase concludes when agreements are reached, and construction work begins.

In the implementation phase (from September 2021 to August 2024), the asset owner and users agree on an outcome that benefits both parties regarding quay wall intervention. Following these agreements, the asset owner starts the construction work while communicating with the asset users to address any additional concerns related to the quay walls.

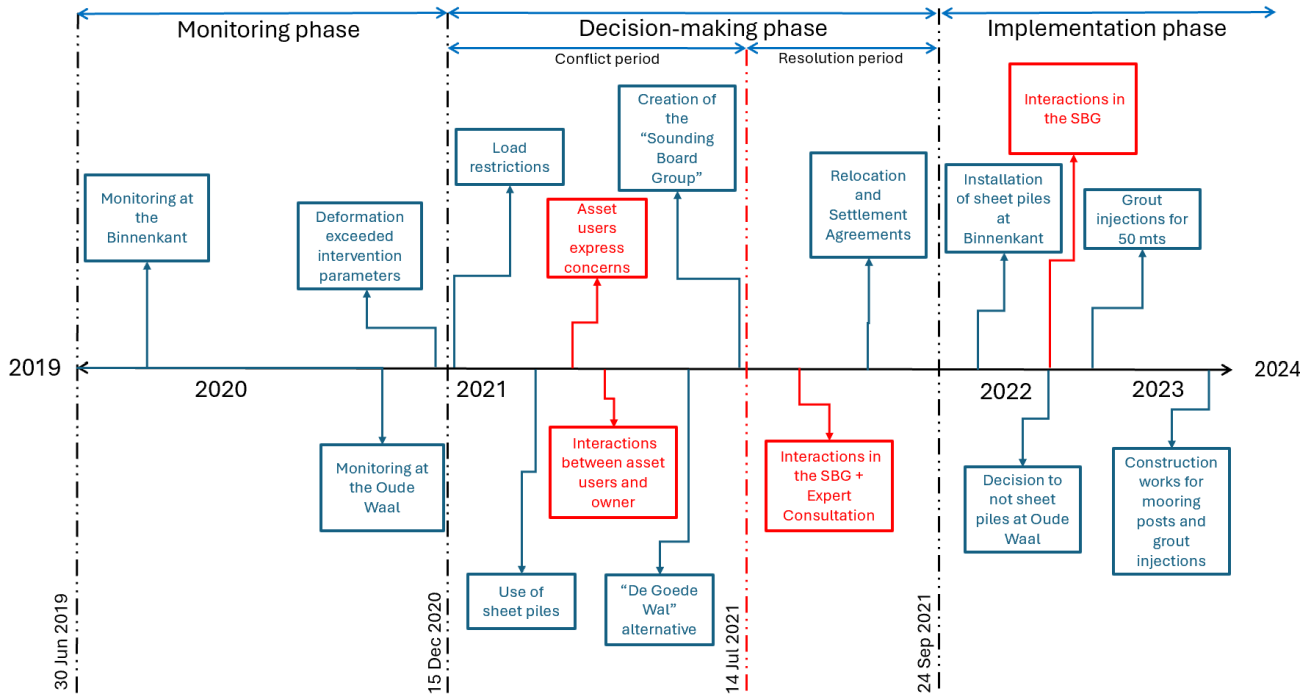

Figure 5, Key Events of the Waalseilandsgracht Timeline

The timeline shows that the monitoring phase had no interactions between the asset owner and user compared to the decision-making and implementation phase. Additionally, monitoring the *Oude Waal* quay wall and the decision to implement load restrictions occurred suddenly. During the decision-making phase, interactions between the asset owners and users began, particularly after the decision to implement sheet piles. Conflicts arose when the asset owner introduced the idea of sheet piles, but these conflicts were reduced when the "Sounding Board Group" was established and agreements were reached. In the implementation phase, construction started, but some interventions changed to other alternatives. This decision-making process took nearly eight months, including five months of conflict and a three-month resolution period. The planning and construction of quay wall interventions continued until the

summer of 2024, with interventions on the *Waalseilandsgracht* quay walls spanning from September 2021 to July 2024.

The following sections provide a more detailed explanation of each phase. References in these sections are abbreviated according to the type of document or interview done, such as “PM” for printed mail and “NA” for news articles; this is described in Appendix B.

4.2. The Monitoring Phase

The monitoring of the *Waalseilandsgracht* started with monitoring at the *Binnenkant* quay wall, which began almost one year before the monitoring at the *Oude Waal* [PM12]. This was initiated because, at the start of the PBK in 2019, 80 quay walls out of the total 200 km within the scope of the PBK were considered critical due to their physical condition and deformations [I-NG6.2]. However, the municipality of Amsterdam was uncertain about the total number of critical quay walls that required prioritisation [I-NG6.2, I-G1]. Consequently, monitoring at the *Binnenkant* started due to physical damage, which was used as the first sign of quay walls that needed prioritisation.

Initially, the *Binnenkant* quay wall was not considered at immediate risk of collapse, although it showed signs of deformation [I-G2]. However, the risk of collapse was the primary concern due to a “lack of knowledge” about the quay wall's structural condition prior to monitoring and the "unpredictability" of its deformation behaviour [I-G4.5]. Additionally, to manage the risk of a quay wall collapse, the municipality had established specific criteria within the technical assessment carried out by the service providers; if these criteria were met, interventions would be implemented to reduce the likelihood of collapse [I-NG6.3]. Consequently, the municipality increased the monitoring frequency to improve the accuracy of the technical assessments and determine if the *Binnenkant* quay wall needed interventions. This is one reason why monitoring began at the *Oude Waal* [I-G2, PM12].

Even though the risk of a collapse was uncertain and monitoring had increased for a more accurate assessment, there was little evidence that there was an interaction between the asset owners and the asset users living along the canal or that the municipality was carrying some form of interactive participation [I-G3.1]. However, some users had already expressed concerns regarding the state of the quay wall to the municipality due to the physical damage [I-G4.1]. Furthermore, news articles reported that the PBK’s method for restoring quay walls was flawed and that maintenance had been neglected for years [NA1, NA2]. The collapse of one quay wall in front of the University of Amsterdam also caught significant public attention [NA3].

While there is no concrete evidence that these news articles influenced how the municipality or the users reacted to the case of the *Waalseilandsgracht*, they suggested a negative image of how the municipality implemented specific quay wall interventions and their management of the quay walls. This negative image could have influenced how people perceived certain implementations, such as the sheet piles that would be later implemented in this case [I-NG5, I-NG6, I-G5, I-G6].

A decision-tree diagram (Figure 6), following the example from (Bert Enserink et al., 2022, p. 31) is used to represent the decisions made by the asset owner, i.e., the municipality of Amsterdam, regarding the quay walls in the monitoring phase. The description of the figure is as follows.

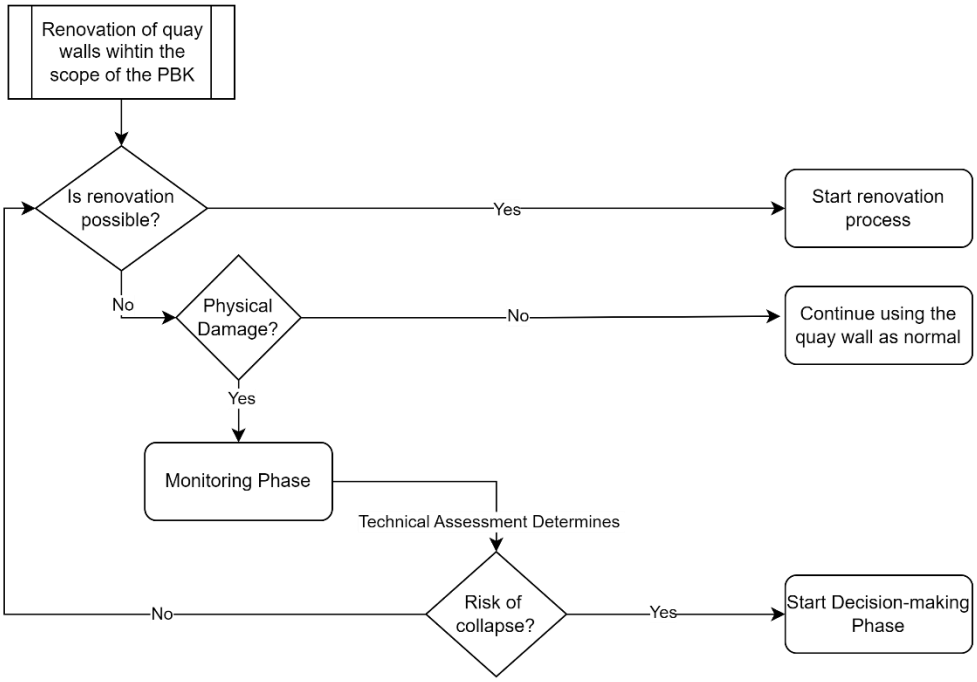

Figure 6, Decision tree representing the decisions made by the asset owner in the monitoring phase

The municipality of Amsterdam determined that renovating the quay walls in the *Waalseilandsgracht* was not possible. This led to a technical assessment of the *Binnenkant* and *Oude Waal* quay walls. These assessments were challenged by incomplete knowledge and unpredictability, making it difficult to accurately evaluate the risk of collapse [PM2].

After monitoring the quay walls, there was insufficient evidence to determine a risk of collapse, which only led the municipality to increase their monitoring methods to reduce uncertainties in their technical assessment [I-G2, PM12]. The technical assessment relied heavily on the frequency of monitoring [I-G2]. However, it was still affected by the lack of knowledge and unpredictability due to limited information and extended intervals between monitoring data, leaving the deformation behaviour between monitoring periods unknown [I-NG4]. This is one of the reasons why the load restrictions took effect in the decision-making phase.

As shown in Figure 6, the case study suggests that when a technical assessment indicates no risk of collapse, the decision-making process enters a loop of continued monitoring until a potential risk is identified or renovation is achieved. Without the risk of collapse, quay wall interventions are unnecessary, resulting in no interaction with asset users during the monitoring phase. In the case of the *Waalseilandsgracht*, this monitoring loop persisted from June 2019 to December 2020.

4.3. The Decision-Making Phase

Conflict Period

Once the technical assessment indicated that deformations exceeded the criteria for establishing a risk of collapse, the municipality decided to implement the first interventions. However, the assessment revealed that these critical deformations were only present in certain sections of the quay wall rather than along its entire length [PM3.2]. The municipality perceived this as a risk that could lead to deformation along the entire quay wall if interventions were not applied to the entire length. This perception was driven by the asset owner's commitment to prioritising the safety of the asset users [I-G2.3, I-G4.4].

The first quay wall intervention was load restrictions which did not pose a conflict between the asset owner and users [PM3.2]. However, conflicts arose when deformations persisted despite the load restrictions, leading the municipality to decide to implement sheet piles. At this point, uncertainties originating from incomplete knowledge and unpredictability still challenged the technical assessment as deformations kept increasing [PM3.2]. This risk perception led the municipality to decide to implement sheet piles as quickly as possible [I-G4.4, I-G2.3].

Installing sheet piles in a quay wall involved moving all the houseboats away from the quay wall (temporarily), installing the sheet pile, moving the houseboats back to their place and waiting until the final renovation of the quay wall (which, according to some reports, would be until 2027) [R2].

While the municipality viewed the installation of sheet piles as an urgent and necessary measure to reduce the risk of collapse, the asset users living along the canal perceived this intervention as sudden, unannounced, and unnecessary. To them, it was not a way to reduce the risk of a quay wall collapse but rather an intervention that would risk their view of the canal, quality of life, accessibility, and property values for the following years [DM18, I-NG1, E1-E4, I-G6.1, I-G5.1, I-G6.2].

At this point, the municipality of Amsterdam lacked experience in handling scenarios involving relocating houseboats and postponed the installation of the sheet piles for four months to address residents' concerns [I-NG2, PM4]. However, the interaction between the asset owner and the asset users was mishandled, as individual meetings with users created unfulfilled expectations [I-G2]. Additionally, small mistakes in the proposed design drawings made by the municipality made the asset users feel they were not being taken seriously [DM3, I-G2]. Delays in sharing documents or addressing users' concerns further affected the trust in the municipality's decisions [I-NG3, E5]. This was confirmed by interviewed asset users [I-G5.2].

Furthermore, the municipality was challenged by a new uncertainty (in March 2021) involving not knowing what intervention to use in the last 50 meters of the *Binnenkant* (see Figure 7). Installing sheet piles in this section would increase the risk of boat collisions near the bridge; it was unknown what safety measures were the best suited for this section [PM4]. This challenge made it difficult for the municipality to justify the urgency of installing the sheet piles while

also taking the time to find a suitable measure for the final 50 meters [PM7, E3]. These issues caused a further two-month delay in the installation of the sheet piles. [PM6].

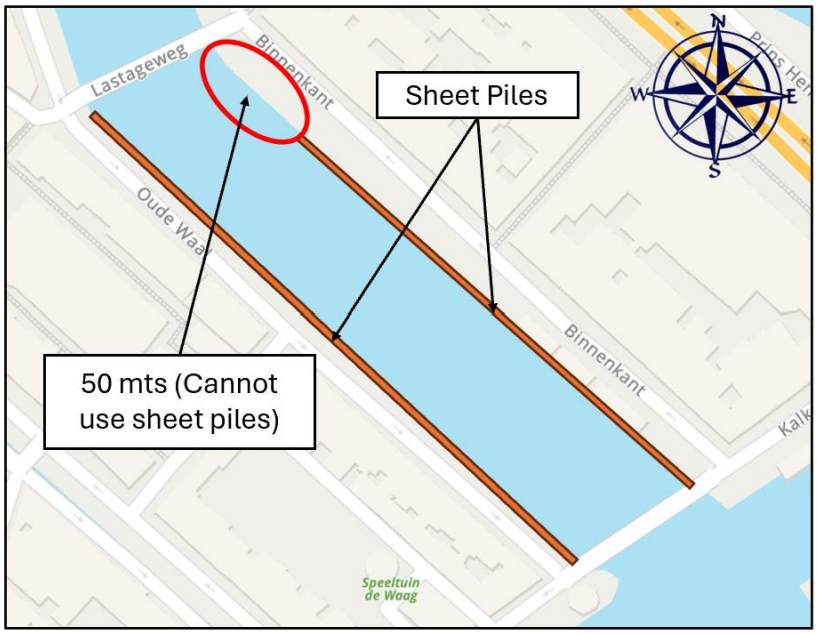

Figure 7, Sketch of the proposed implementation of sheet piles except for the 50 Mts in March 2021

The asset users started to organise communication procedures and group themselves to raise their voices and have more influence after feeling that the asset owner was not taking their concerns seriously [I-G5.3, I-G6.3]. For example, in searching for less intrusive alternatives, the users with a technical background formed a group called "*De Goede Wal*" to propose a new alternative that would satisfy their demands [E2]. Additionally, the users living in houseboats formed the "*Waalseilandsgracht Groep*" to advocate for communication, planning, and settlement agreements to ensure confidence in relocating their houseboats [E5, I-G1].

Public involvement in specific details regarding safety measures of the quay walls was unprecedented for the PBK before the *Waalseilandsgracht* [I-G4.2, I-NG3]. As the municipality realised the situation's complexity, they began organising meetings to address users' concerns [R3]. However, these meetings were ineffective in reducing conflicts due to a lack of trust of the asset users towards the asset owner and the slow responses from the municipality to specific concerns; this was confirmed by interviewed municipal employees and service providers involved in the case study [I-NG2.1]. The conflict escalated to a legal dispute, with asset users urging for better alternatives and better management of their concerns while the municipality was urging the users to agree to terms to avoid an "evacuation scenario", where users living in the houseboats would be legally obliged to move if the municipality deemed the situation unsafe [I-NG5.2, I-NG2.2]. The "evacuation scenario" risked losing the asset users' support, jeopardising the PBK's activities. Thus, the municipality wanted to avoid this scenario [I-G2.1].

Expanding on the decision tree used in the monitoring phase, the decisions made in the conflict period can be seen in Figure 8. The description of the figure is as follows.

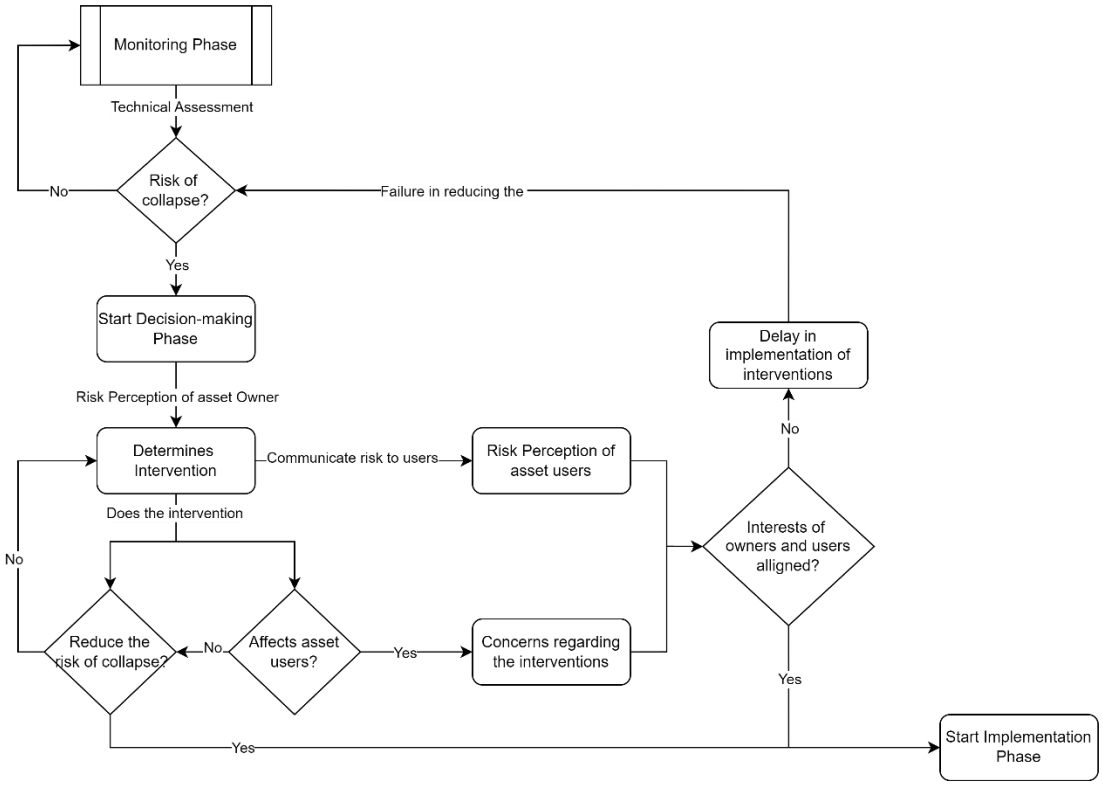

Figure 8, Decision tree representing the decisions made by the asset owner in the decision-making phase

The municipality quickly determined and communicated the necessary interventions based on the technical assessment of the quay walls. Initially, they implemented load restrictions to reduce the risk, which did not impact the asset users' lives [PM3.2]. However, as deformations continued to increase, the municipality determined the need to install sheet piles, a more effective intervention for reducing the risk of collapse [PM3.2].

Although sheet piles effectively reduced the risk of a collapse, this measure raised concerns among asset users about how the intervention would affect their daily lives [I-NG2.1, E2, I-G1]. Additionally, the concerns and risk perception from the users, the mistakes made by the asset owner in addressing such concerns, and the limited communication led to a misalignment of interests between the two parties [I-G5.3, I-G6.3]. This misalignment of interest caused a delay in implementing the sheet piles [PM6]; by not implementing sheet piles, the risk of a collapse is not reduced, leading to a loop in the decision-making phase that does not end until the interests are aligned.

Resolution Period

Realising the conflict was escalating instead of decreasing; the municipality had to reevaluate its risk perception and assessment to determine if the urgency of the quay wall interventions could be postponed sufficiently to address the users' concerns properly [I-G1.4]. The reevaluation of the risk was possible due to the increase of information (due to the monitoring) on the quay walls.

Additionally, the municipality of Amsterdam offered the asset users to participate and communicate their concerns in a “Sounding Board Group (SBG)”, a group of representatives of the asset users and representatives of the municipality handled by a public mediator. The initiation of the SBG aimed to understand the perceptions of the asset owners and users, address each other's concerns, and offer solutions to such concerns by understanding the surrounding environment of the quay wall interventions [PM10, I-NG2.1]. It is suggested that the municipality could not do this before due to COVID-19 measures [DM3.1, I-G1.2, PM10].

Communication and participation routines between the asset owner and the asset users were constantly followed in an unbiased environment within the SBG led by a public mediator[1] in order to gain the trust of the asset users [I-NG3.1]. During the meetings, residents could express their concerns regarding the relocation agreements directly and express discontent about the municipality's lack of answers and the unrealistic planning and implementation of the sheet piles [DM3].

The participation of the asset users in the SBG was more structured and followed a procedure that worked for both parties in comparison to the individual meetings and sudden communication done in the previous phases, which created mistrust and stress [DM3-DM20]. Additionally, the municipality made use of expert consultation by inviting several experts from universities and private companies who could answer and analyse the questions from asset users regarding the alternatives proposed by *De Goede Wal* and other technical concerns the asset users could have, therefore reducing the ambiguity of the situation and aligning the interest of both parties [DM4, DM11, I-G1.3]. The municipality of Amsterdam also hired a lawyer to support the asset users who lived in houseboats in addressing the legal concerns regarding the relocation agreements [I-NG2.3].

The outcome of the SBG meetings led to relocation and settlement agreements (September 2021). Additionally, social concerns were addressed, leading to a design proposal where the asset users and the asset owner collaborated, which led to the final installation of the sheet piles [I-G5.4, I-G6.4]. The agreements and the design proposal ensured that investments would be made to make the sheet piles more aesthetically appealing and less intrusive to the users. Additionally, the agreements ensured that the municipality would cover any damages (during the implementation of the sheet piles) that would affect the houseboats [R2, R1]. Despite some users not approving the installation of the sheet piles, there seemed to be a mutual understanding of perceptions and the complexity of the situation at hand from the asset users and the asset owner, making the conflict less intense and more collaborative [R1, R2, I-G3.2]. The agreements led to the construction of the sheet piles.

According to Figure 8, when the interests of both parties align, quay wall interventions are no longer seen as a threat or a concern by the asset users and can be used by the asset owner to reduce the risk of a collapse. This alignment leads to the acceptance of the intervention, allowing the start of the implementation phase (construction of sheet piles).

[1] Public Mediation is a company that dedicates itself to solving social issues of complex situations (*Public Mediation*, 2024).

4.4. The Implementation Phase

Once agreements were made, the municipality began the construction of the sheet piles [DM9]. At this point, the asset users felt comfortable enough to accept the changes to their living environment for the next ten years [DT1]. Communication between parties continued during the SBG meetings, with the BouwApp also used to update asset users living along the canal on the construction progress [DM10, DT1-DT3].

Communication and participation routines continued through the SBG but were less frequent (once per month instead of weekly) due to the common ground achieved during the "decision-making phase". The SBG meetings in the "implementation phase" aimed to identify unforeseen issues, address concerns about the maintenance of the final design of the sheet piles, and discuss the future renovation of the quay walls in line with PBK objectives [DM12]. The SBG was later dissolved, but meetings with asset users continued to discuss construction progress and address concerns [DM18.1, DM19].

About 4 to 5 months after construction began on the *Binnenkant*, the municipality conducted a new assessment for the *Oude Waal* (January 2022). Deformations had stopped almost a year after implementing load restrictions (January 2021), indicating that the quay wall could remain stable without sheet piles and only with load restrictions [DM13]. Despite previously signed agreements, asset users living along the *Oude Waal* preferred not to install sheet piles if the municipality deemed the quay walls safe [DM13.1].

The new assessment confirmed the safety of the quay wall without sheet piles, considering both technical evaluations and residents' requests. However, the technical assessment recommended installing mooring posts so that houseboats could be attached to them instead of the quay wall, thereby reducing horizontal loads on the structure. It was also agreed, through the SBG, that if deformations were to increase in the future, the houseboats would have to be quickly relocated following the agreements made during the "decision-making phase" [DM13, DM13.1].

While construction at the *Binnenkant* and the *Oude Waal* were ongoing, the last 50 meters of the *Binnenkant* were still being assessed to determine an effective method to secure the quay wall. Almost a year after agreements were signed, the decision was made (November 2022) to use grout injections, i.e., injecting cement under pressure to stabilise the soil to extend the life span of the quay wall [DM18.1, DM19.1]. The grout injections are planned to be completed in the summer of 2024, marking the end of the construction of quay wall interventions for the *Waalseilandsgracht* until the final renovation (presumably from 2027-2029) [DM11.1].

Thus, three different interventions (Figure 9) were used to ensure the stability of the quay walls and the asset users' satisfaction: (1) the *Binnenkant* was reinforced with sheet piles (lasting 10-20 years), except for the 50 meters, which used (2) grout injections as a method to extend the life span of the quay wall (+30 years), and the *Oude Waal* is currently being monitored with houseboats now secured to (3) mooring posts (it is expected that the quay wall can hold 2-5 years depending on deformations) [I-NG3.2, I-NG8]. The complexity of the different interventions and life extensions used on the different sections of the canal's quay walls and

other factors like rising prices and limitations in investment pose uncertainty in determining the exact period or method for the final renovation of the *Waalseilandsgracht* quay walls [DM19.2 DM19.2, I-NG3.2, I-NG8].

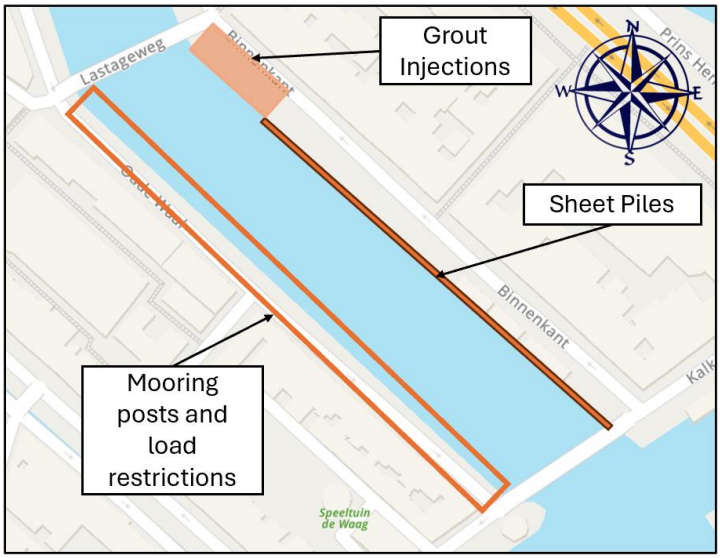

Figure 9, Sketch of the interventions used in the Waalseilandsgracht (July 2024)

Expanding on the decision tree used in the monitoring phase and the decision-making phase, the decisions made in the implementation phase can be seen in Figure 10. The description of the figure is as follows.

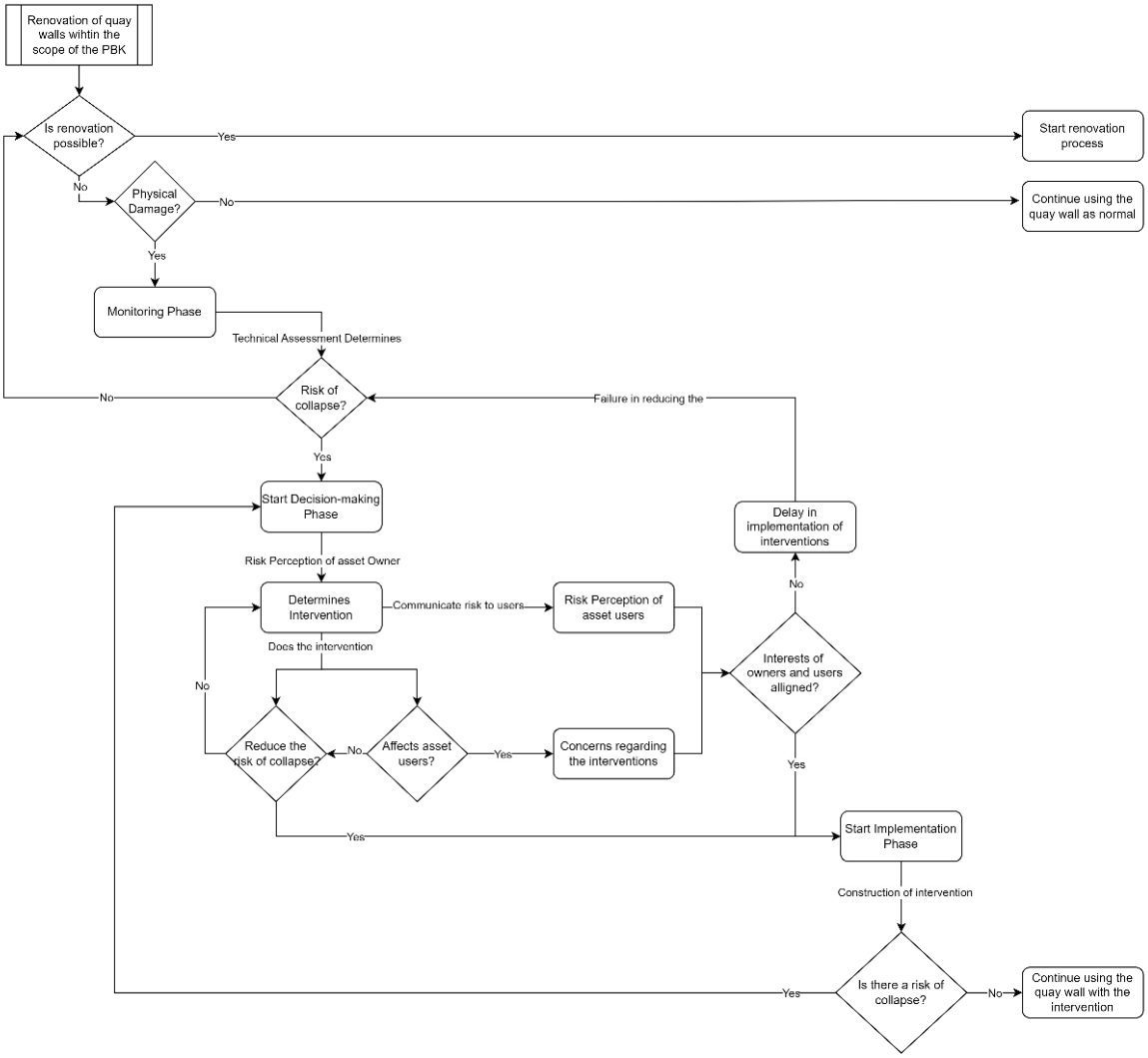

Figure 10, Decision tree representing the decisions made by the asset owner in the implementation phase

Once quay wall interventions are accepted and implemented, the process returns to the initial condition of assessing if there is a risk of collapse even with the intervention implemented; if there is no risk, the quay wall can be used with the intervention. For example, the municipality decided to reevaluate the intervention of the *Oude Waal*, which caused a loop back from the implementation phase to the decision-making phase when deciding if load restrictions were a sufficient intervention, which, in this case, it was. At the end of the *Waalseilandsgracht* case, the two quay walls are used with their respective interventions and waiting for renovations.

5 Analysis and Discussion

This section analyses and discusses the results to answer the main research questions and addresses the limitations of this research.

5.1. The presence of uncertainties in the Waalseilandsgracht case

The *Waalseilandsgracht* case study highlighted various uncertainties, especially in the technical assessment of the structural condition of the quay walls. When conducting a technical assessment of a quay wall, there is insufficient information from the quay walls before monitoring starts, which cannot be reduced quickly [I-G2]. According to van den Hoek et al. (2014), this is "incomplete knowledge". However, these knowledge gaps decreased by gathering more data through underwater research, foundation sampling, historical data analysis, and continuous monitoring [I-G2.3, I-G4.3, I-NG4], leading to greater accuracy in the technical assessments as time went on. This is further demonstrated by Kwadijk et al. (2010), who note that increasing the availability of information is an effective way to reduce incomplete knowledge.

This case study addressed the incomplete knowledge of the quay walls by intensifying monitoring efforts and collecting data over time [I-G2, PM12]. However, during the monitoring and decision-making phase, this uncertainty initially led to a perceived need for rapid quay wall interventions [I-G2.3, I-G4.4]. While in the implementation phase, the municipality had gathered sufficient information (from December 2020 to January 2022) from the *Oude Waal* to make a more accurate technical assessment and concluded that the quay wall could remain stable without the need for sheet piles [DM13.1].

Due to the incomplete knowledge of the quay walls at the start of the monitoring, the municipality based its technical assessments primarily on the deformation of the quay walls, which was considered the most reliable indicator of the risk of collapse [PM3]. However, De Gijt (2010) points out that quay wall structures are complex and influenced by soil conditions, water levels, loads, and lifespan. This complexity can cause the deformation behaviour of the quay walls to be random [I-NG4].Warmink et al. (2017) categories such chaotic or random behaviour as a form of uncertainty known as "unpredictability". In the case study, the municipality coped with this type of uncertainty by establishing criteria regarding the deformation, e.g., if deformation exceeded a specific value, load restrictions would be implemented, and if deformations continued, sheet piles would be implemented [I-G2.4].

Both types of uncertainties, incomplete knowledge and unpredictability, caused other forms of uncertainties in other systems. This is shown in Figure 11 by using the schematisation of uncertainties adapted from van den Hoek et al. (2014).

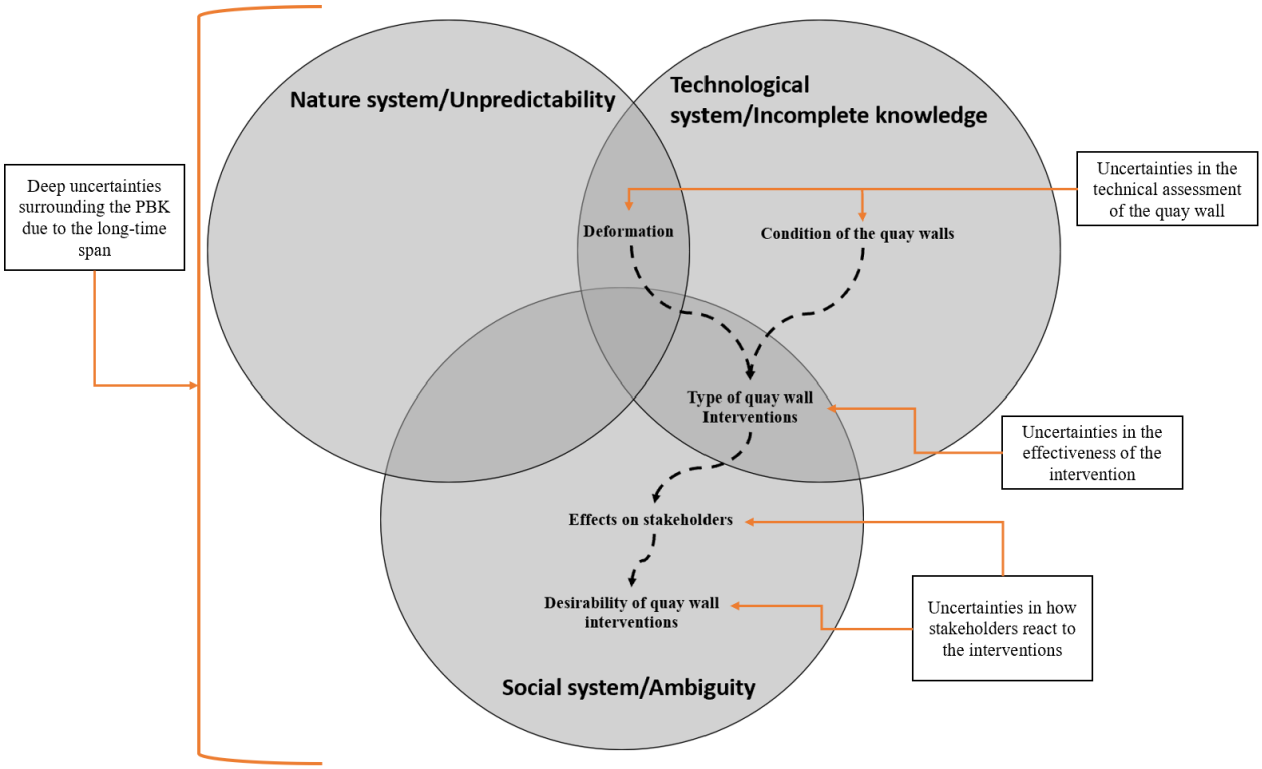

Figure 11, Schematisation of uncertainties present for the decision-making process for quay walls that cannot be renovated within the PBK, adapted from van de Hoek et al. (2014)

Other forms of uncertainty include quay walls not deforming along their entire length; deformation sometimes appears only in specific sections. This variability poses a challenge for technical assessments, as it complicates the effectiveness of the interventions for the affected areas of the quay wall [PM12.1]. For example, at the *Binnenkant*, only two locations in the whole length of the quay wall showed critical deformations, but their effects on the rest of the quay walls were uncertain [I-G3]. This uncertainty led to installing sheet piles along the entire length of the *Binnenkant* quay wall rather than only at the two critical locations [PM1].

Moreover, as seen in the *Waalseilandsgracht* case, there was uncertainty about how asset users (stakeholders) would react to the interventions and the effects of the interventions on them [NA4]. If the asset users' concerns are not considered, it can lead to conflicts due to "ambiguity" between the asset owner and the asset users on the desired quay wall intervention. Conflicts that relate to ambiguity are also mentioned by Böhle et al., (2016). Furthermore, as seen in the 50 meters of the *Binnenkant*, the installation of sheet piles was impractical due to the canal navigation of boats, leading to another uncertainty regarding which interventions can be implemented and which ones cannot depending on the physical location [PM4]. According to van den Hoek et al. (2014), the uncertainty in determining the type of intervention used in specific scenarios (e.g., the 50 mts of the *Binnenkant*) can be considered an interconnection of "incomplete knowledge" in a technological system and "ambiguity" in the social system (see Figure 11), further adding to the complexity of decision-making processes in the PBK.

Finally, given that the PBK's planning is thought to be over the next 20 years, there is a level of "deep uncertainty" about future scenarios that could impose restrictions or affect the planning of the renovation of the UBQs (Chiffi & Pietarinen, 2017). This uncertainty could impact how decisions are made in the future regarding selecting quay wall interventions. For instance, in the case of the *Waalseilandsgracht*, COVID-19 or the collapse of *Grimburgwal* might have had an influence in the municipality's decision to implement safety measures driven by a level of uncertainties in the technical assessment with limited communication with residents [NA3, PM10]. According to Bojórquez-Tapia et al. (2022), large infrastructures, e.g., dams, urban water systems or energy grids that occur in complex systems are usually affected by external factors such as globalisation, urbanisation, climate change, and socio-political aspects related to "deep uncertainty". External factors like pandemics are not typically considered within a project like the PBK. However, it is important to acknowledge uncertain future scenarios in Amsterdam, e.g. pandemics, international events (e.g., Olympic Games or wars), changes in political administrations, etc., that could arise in the next two decades [I-G1.5], that could potentially affect significant aspects like the budget or planning for renovations of the UBQs.

5.2. Management and Perception of Risks in the Waalseilandgracht case

This subsection discusses two elements of effective risk management (1) the technical assessment used to determine and reduce the risks of a particular scenario and (2) the method used to communicate those risks to the affected people.

Technical Assessment

The case study shows that the municipality of Amsterdam developed various methods to assess the structural condition of the quays more accurately (this also helped reduce the uncertainties previously mentioned) [I-G2.4, I-G1.3, I-NG4]. Consequently, the technical assessments done by the municipality went from assessing the condition of the quay walls due to physical damages to analysing the deformation behaviour of the quay wall to become more accurate (Gemeente Amsterdam, 2023b). However, uncertainties (which at some point are unavoidable) continued to influence the assessment of the quay wall's structural condition, particularly when interventions were required; this was seen in the *Oude Waal* when the assessment changed from an urgency to install sheet piles in the "Decision-making phase" to only apply load reduction in the "Implementation Phase". These uncertainties can impact the technical assessment, impacting the timing of communication and stakeholder interaction regarding the risk of collapse [I-G2.4].

Risk Communication

As Frewer (2004) explains that the communication of risks must consider the perception of those affected by the risks to reduce social concerns and conflicts that could occur in relation to the risk at hand. These conflicts affect the project's acceptability (e.g., quay wall interventions) and the methods used to reduce the risk.

In the case of the *Waalseilandsgracht*, during the "conflict period", asset users living along the canal acknowledged the risk of a potential quay wall collapse. However, they did not prioritise it to the same extent as the municipality. This was because they perceived the consequences of the quay wall interventions to have a higher impact on their life quality than the possibility of a quay wall collapse [E1-E5]. The concerns of the asset users included: indirect costs from moving houseboats, the aesthetic impact on the canal, the final location of their houseboats for the next ten years, accessibility issues, and water quality [R1, R2]. These concerns were more significant for the asset users than the perceived risk of a collapse, and vice-versa, the risk of a collapse was more significant to the municipality as the asset owner than the ones perceived by the asset user. As a result, even if the municipality tried to communicate through various channels or meetings all the data and methods used to assess the quays, the asset users would not accept the installation of sheet piles until their concerns were addressed [I-NG2, E4].

An excellent example of effective risk communication in the case study was in the "Resolution period" and the "Implementation phase", where the concerns and perceptions of the asset users were considered through the SBG. In the implementation phase, interventions changed due to better accuracy in the assessments; the change in interventions (on not implementing sheet piles or using grout injections) did not pose a conflict between the asset users and the municipality because communication was done effectively, leading to an understanding of perceptions from both parties. This corresponds with Sjöberg et al. (2004), where clear communication of risks and understanding different perceptions can significantly reduce conflicts between experts assessing the risks and those affected by them.

On the other hand, a bad example was demonstrated in the "conflict period", where the case study showed the conflicts that originated from individual meetings and failure to address individual concerns and differing perceptions of the impact of quay wall interventions, causing stress, mistrust, anger, and anxiety from the asset users towards the asset owner [DM18, I-NG1, E1-E4, I-G6.1, I-G5.1, I-G6.2]. The difference in perceptions between the municipality of Amsterdam and the asset users affected the communication about the risks associated with the quay walls due to the mistrust that had been created at the start of the conflict. Hampel (2006) and Breakwell (2000) expand on this idea by explaining that the social and political environment often influences risk communication. Moreover, factors such as trust in information sources, unbiased and transparent information, and how information is interpreted all play a significant role in shaping how risks are communicated and perceived.

5.3. Stakeholder Participation in the Waalselandsgracht case

The *Waalseilandsgracht* case study highlighted conflicts from underestimating stakeholders' (asset users) influence on quay wall interventions, particularly the users living in houseboats [I-NG3, I-G2]. Stakeholder participation began in the "decision-making phase" when the municipality sent information regarding load restrictions via printed mail, allowing the stakeholders to reach out if they had questions; this did not create an immediate conflict [PM1]. However, stakeholders began expressing their concerns when the municipality decided to proceed with more drastic quay wall interventions without improving communication. This led

to a more interactive but conflicting interaction between the stakeholders and the municipality [I-NG2.1].

The participation process in the *Waalseilandsgracht* was complex due to the diverse concerns of the stakeholders, which came from the type of homes they lived in and their locations—some lived in offshore houses, others in houseboats that could not sail, others in houseboats that could sail. Each group of stakeholders had varying degrees of concern regarding the quay wall interventions [I-G4.6]. These differing concerns became a challenge for the municipality, leading to individual meetings that created misunderstandings and confusion, further affecting the relationship between both parties. This contributed to the five-month "conflict period" [I-G2].

Eventually, stakeholder participation became more systematic and formalised, with the municipality tailoring its approach to address specific concerns in the "resolution period". In the *Waalseilandsgracht* case, the most effective approach was the "Sounding Board Group" [I-NG3.1], which was confirmed by the asset owner, service providers and the users involved in the case [I-G5.4]. [I-G5.4].

Using the correct participation technique to address stakeholders' concerns led to agreements that resolved issues for both parties and enabled the quay wall interventions to proceed. It also empowered stakeholders and resulted in outcomes that were generally more beneficial for the citizens [I-G3.2, DM3.2]. This solution aligns with the findings from Atkin & Skitmore (2008) and Reed (2008). Which revolves around tailoring stakeholder participation procedures to the project context and the stakeholders' interests.

5.4 Relation between uncertainties and interactions between stakeholders for quay wall interventions

Analysing the uncertainties surrounding the *Waalseilandsgracht* case study revealed that the municipality of Amsterdam faces significant challenges in interacting with asset users under uncertain conditions. The uncertainties identified as "incomplete knowledge" and "unpredictability", particularly in assessing the condition of the quay walls, affected how the municipality perceived the risk of a quay wall collapse, leading to challenges of "when" and "how" to interact with asset users. In the case study, the interactions played a role in how the asset user perceived the risk associated with the quay wall interventions and the possibility of a quay wall collapse that created a level of "ambiguity" between the parties involved [I-G2.5]. This ambiguity of the interventions led to conflicts between the asset owner and the asset users.

The literature suggests that to avoid this ambiguity and other social conflicts, interaction should start in the early stages of the project (Buertey, 2016; Luyet et al., 2012; Reed, 2008a). This was not the case for the *Waalseilandsgracht*, where stakeholder engagement started only when a decision on quay wall interventions had already been made.

Additionally, the three previously mentioned uncertainties (incomplete knowledge, unpredictability and ambiguity) were found to be significant in the case study when determining the type of intervention needed for each quay wall, the potential effects interventions have on

the asset users, and the desirability from the asset users to implement such interventions. This observation is supported by Chiffi & Chiodo (2020), who highlight that decision-makers frequently encounter various uncertainties and risks when managing projects within complex systems, such as urban environments.

Furthermore, the challenges for the decision-makers to interact with asset users in uncertain scenarios become increasingly complex when the project aims to renovate 200 km of quay walls in a complex system such as Amsterdam, where each quay wall has specific physical, social, and economic characteristics.

Therefore, predicting stakeholders' reactions and interacting with them is challenging. For instance, while some quay wall interventions may not present conflicts with specific asset users, others (as observed in the case study with the houseboat users) could involve conflicts with stakeholders that were initially overlooked, such as businesses, tourists, and emergency services, each with different concerns and perceptions [I-G3.3]. As demonstrated by Atkin & Skitmore (2008), failures or conflicts arise when these concerns are not addressed. Such conflicts can lead to legal disputes and delays in quay wall interventions, as with the *Waalseilandsgracht* case. Additionally, asset users who are unwilling to accept quay wall interventions due to perceived risks to their daily lives can force the municipality to spend additional time addressing these conflicts. This, in turn, delays the ability to mitigate the risks and uncertainties of a possible quay wall collapse for the asset owner until the conflicts are resolved [I-G1.4].

Therefore, efficient interactions between the municipality and asset users regarding quay walls that need intervention are crucial to ensure the smooth implementation of quay wall interventions and to avoid as much as possible conflicts that could delay such implementations, posing a significant obstacle to the PBK's planning.

5.5 Limitations of the study

The first limitation of the study is the specific case of the *Waalseilandsgracht*. The findings are based on the mistakes and knowledge gaps identified in this particular case. While literature was used to generalise the findings, other conflicts that could occur in other PBK locations might involve issues unrelated to the ones seen in the *Waalseilandsgracht*.

Additionally, the study relies on the technical assessments conducted by the municipality of Amsterdam to assess the risk of a quay wall collapse. Interviews revealed that the technical assessment involves multiple stakeholders, including subcontractors and private companies, who conduct their own assessments to support the municipality. Due to the complexity of analysing the complete technical assessment of the quay walls, this study did not delve into the assessment details. But rather generalised it into two outcomes: risk of collapse and no risk of collapse. Other factors that play a role in the technical assessment can be significant to the conclusions and recommendations from this study.

Furthermore, the data collected for this study was based on documents exchanged between the parties involved in the case study, meaning the findings are limited to the available

documents and the researcher's interpretation of them. The interviews were also restricted to the stakeholders willing to participate and reflect on their perceptions of events unfolding. Other significant stakeholders not addressed in this research might hold other insights that are not reflected in this study.

Finally, the municipality of Amsterdam has internal stakeholders and departments that may have other aspects and interactions with each other (e.g., the communication department with the safety department) regarding the PBK's activities, adding further complexity to the decision tree developed in this study. This research did not consider the internal interactions between the municipality's departments or other factors that influence the decision taken in the PBK. Furthermore, other municipalities dealing with UBQs were not considered for this study; only the municipality of Amsterdam and its process of implementing quay wall interventions were considered.

6 Conclusions and recommendations

This section will address the conclusions by presenting the main findings, recommendations and future research for this study.

6.1 Recommendations

The Waalseilandsgracht case study demonstrated the conflicts that can arise when the influence of stakeholders is underestimated in risky and uncertain scenarios, especially when implementing quay wall interventions [I-NG3, I-G2]. The municipality of Amsterdam already uses various methods of participation to gather input from the asset users. However, there is no one-size-fits-all approach to effectively engaging with the users, as the method and the approach depend on the context (Reed, 2008; Reed et al., 2018). This study demonstrates that each quay wall has its own unique environment, context, and stakeholders. Therefore, a stakeholder participation approach should be flexible enough to adapt to different scenarios while still maintaining a structured framework.

To provide a step-by-step process for improving interactions with users while considering the uncertainties surrounding the quay walls, this research proposes the following steps taken from the studies of Buertey (2016), Luyet et al. (2012), Newig et al. (2023), Reed (2008), and Reed et al. (2018):

1. **Identifying and Characterizing Stakeholders:** In the early stages of any project, stakeholders should be identified and categorised based on their concerns (Buertey, 2016; Luyet et al., 2012). For example, in the Waalseilandsgracht case study, it was crucial to distinguish between stakeholders, such as those living in offshore houses, non-navigable houseboats, and navigable houseboats. After identifying the stakeholders, the municipality should group them according to their concerns. In order to do this, a first approach to the stakeholder must be made. However, because the condition of the quay wall is mostly unknown and it might be impossible to map out all the stakeholders involved in the PBK at once, the recommendation is to propose a criterion within the technical assessment that can let the municipality know when is best to identify the stakeholders of a specific quay wall

before there is any risk of collapse and any implementation is done. For example, when the deformations exceed a specific value (a value less than that used by the municipality to determine quay wall interventions), the municipality must interact directly with stakeholders, allowing for proactive rather than reactive interaction.

2. **Selecting and Implementing Tailored Participatory Techniques:** The choice of participatory technique should be guided by stakeholder characterisation and project objectives (Reed, 2008; Reed et al., 2018). In the Waalseilandsgracht case, initial individual meetings during the "conflict period" led to mistrust and frustration, while the later implementation of the Sounding Board Group (SBG) during the "resolution period" proved more effective. The SBG was successful because it helped to align the stakeholders' concerns and the municipality's objectives. In addition, the participatory technique can make use of expert consultation in cases where the stakeholders need to understand technical information that might be outside of their expertise. The municipality's objectives should be clear from the start of the participation technique; for example, if the goal is to ensure the users' safety without compromising their quality of life, then the participatory technique should focus on addressing stakeholder concerns and the impact of quay wall interventions on their lives. Additionally, the technique should be tailored to the stakeholders' degree of concern, meaning there should be different ways of participating rather than just one. After the initial engagement, the level of stakeholder interest should determine whether a more interactive participation technique or simply providing information is most appropriate for the situation.

3. **Evaluating and Maintaining Engagement:** After making decisions regarding quay wall interventions, it is important to evaluate the effectiveness of the participatory techniques and continue interacting with stakeholders (Luyet et al., 2012). The evaluation will help improve future participating techniques for future scenarios because interactions with stakeholders would have to be done until the competition of the PBK (+20 years). In addition, the ongoing interaction ensures that stakeholders' concerns are addressed and helps prevent conflicts, especially if unexpected challenges arise during the implementation of the quay wall interventions. Once the quay wall interventions have been installed, the interaction and participation can be reduced until the final renovation of the quay wall is needed.

How these three steps work within the decision tree developed in this study is shown in Figure 12.

Following the proposed decision tree (Figure 12), the municipality can get insight into the stakeholders' concerns and perceptions of the risks regarding the quay wall interventions. By gaining insights into the perception of risk and concerns, the municipality can tailor specific risk communication channels or use the same participation process to ensure that the interests of the municipality and the stakeholders are aligned with each other.

Additionally, the municipality can use external experts to ensure information is perceived as unbiased, be transparent about the challenges the municipality faces, and respond to stakeholder

concerns promptly and concretely. As demonstrated by the SBG during the "resolution period," this approach builds trust, confidence, and cooperation among stakeholders, which is crucial when communicating risk (Breakwell, 2000; Hampel, 2006; Sjöberg et al., 2004). This can help reduce the ambiguity between parties and unforeseen conflicts with citizens, leading to quay wall interventions that benefit both parties if the risk of a collapse comes into play.

These recommendations were already effectively applied during the "resolution period" of the *Waalseilandsgracht* case study, leading to restored trust and a cooperative process for implementing safety structures [I-NG3.1].

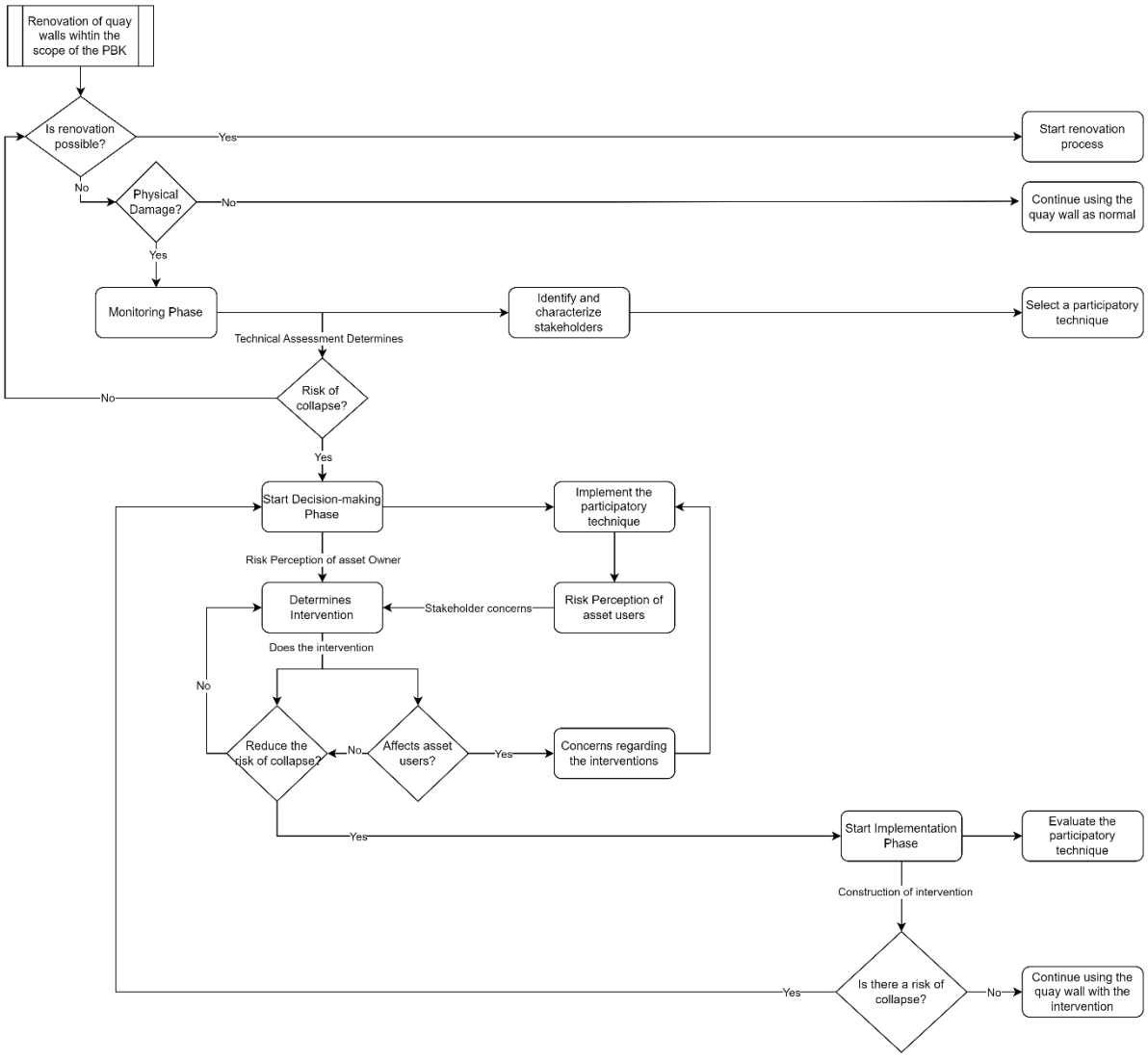

Figure 12, Proposed decision tree for interacting with stakeholders

6.2 Conclusion and Main Findings

This research examined the uncertainties surrounding the decision-making process for quay wall interventions within the PBK in Amsterdam, mainly focusing on how these uncertainties influenced the interactions between asset owners and users. By analysing the *Waalseilandsgracht* case study, the research identified critical uncertainties, such as the lack of information on the quay walls and the unpredictability of their deformation behaviour. These uncertainties played a significant role in shaping the municipality's decisions regarding the interventions used to reduce the risk of quay wall collapse and their interactions with users living along the quay walls.

The findings highlighted the pressure these uncertainties place on the municipality of Amsterdam. As decision-makers and asset owners, the municipality must determine and implement necessary interventions within a limited timeframe to protect specific quay walls until their complete renovation. However, the study also revealed that these interventions significantly impact the quay wall users, who are concerned about the quay wall structural condition and the consequences of the interventions used to keep them safe. For these users, the quay walls are a part of their daily environment, and long-term changes, such as the installation of sheet piles, can influence their perception of the PBK's actions.

Moreover, the study demonstrated how incomplete knowledge and unpredictability influence the perception of risks among experts assessing the situation and those affected by it, highlighting the importance of effective risk communication that considers the perception of both parties. This study also emphasised the need for decision-makers to involve stakeholders more closely in the early stages of assessing the condition of the quay walls to avoid conflicts and develop outcomes that benefit all the parties involved.

Although the municipality has made progress in reducing uncertainties regarding the structural condition of the quay walls, unpredictability still exists, especially when a quay wall is at risk of collapse. This ongoing unpredictability forces the municipality to act quickly, often prioritising the safest option, which can sometimes overlook the concerns of stakeholders, potentially leading to conflicts.

The case study further illustrated that the reaction from stakeholders can impact the PBK's objectives and delay the implementation of necessary interventions, particularly if they pose risks to the users' life quality. Given the 200 km of quay walls within the scope of the PBK, significant uncertainties remain regarding how stakeholders will react in each situation, complicating the planning of interventions and the timing of stakeholder participation. The PBK needs to create a flexible and adaptable approach to interacting with stakeholders and taking their concerns seriously and systematically when implementing quay wall interventions.

The research also found that a collaborative approach between asset owners and users leads to more favourable outcomes for both parties. The positive outcome of the *Waalseilandsgracht*

case, where asset users were satisfied with the changes to the sheet piles, provided the municipality with greater flexibility. Consequently, if renovation plans for the quay walls of the *Waalseilandsgracht* change or are delayed, the positive outcome from the situation allows for extended use of the current interventions if necessary. It is essential to combine expert knowledge with insights from stakeholders to develop interventions for quay walls that can provide structural safety and enhance the surrounding urban environment instead of decreasing it while renovation procedures are planned for the future.

In conclusion, the study emphasises avoiding ambiguity between asset owners and users during decision-making processes regarding quay wall interventions. It is important to address this ambiguity to avoid unforeseen conflicts when implementing such interventions. Thus, early and ongoing stakeholder participation is important, particularly in urban projects. Involving stakeholders from the beginning can prevent conflicts and ensure that their input contributes to the success of significant projects like the PBK, leading to better outcomes for the renovation efforts and the urban areas they impact.

6.3 Future Research

Future research from this study could focus on investigating whether an approach incorporating flexibility, such as "Adaptive Policymaking" and "Adaptive Pathways" (Haasnoot et al., 2013), might help build a systematic process in an uncertain scenario for determining how and when to engage stakeholders by using past experiences and hypotheses derived from potential future scenarios. Additionally, research on approaches from Elias (2017) and Locatelli et al. (2014) on "Stakeholder Management" combined with "Systems Engineering" can help address the requests of various stakeholders and improve communication channels. This method can further improve the approaches done by the municipality in determining quay wall interventions and potentially help in the final renovation of the quays.

Acknowledgements

This research is part of the Dutch Research Council (NWO) grant called LiveQuay; live insights for Bridges and Quay walls with number NWA.1431.20.002. This particular study is being conducted at the University of Twente through the ET Faculty and the Civil Engineering and Management (CEM) department.

Appendix A: More on Data collection and analysis

A.1 Instrument used for data collection and analysis

The instruments used for this research can be seen in Table 4 and Table 5. Data collected from the document analysis and the interviews was organised in textual form in an Excel spreadsheet. Within the spreadsheet, codes (see Appendix B) were created to highlight the essential topics relevant to this research, e.g. uncertainty, incomplete knowledge, ambiguity, stakeholder participation, risk communication, etc. Furthermore, with the help of "atlas.ti" software, data was analysed using the previously mentioned codes. The interviews were tape-recorded for later transcription. The recollection of this data was also analysed using the codes.

Table 4, Instruments for data collection

Method	Description	Source
Document Analysis	The municipality of Amsterdam will give access to electronic documents regarding the case study through the online portal. The data from these documents will be analysed, examined and interpreted to gain an understanding of the information presented. The documents analysed were personal documents (e.g. emails, incident reports, newspapers, etc.) and public records (e.g. mission statements and strategic plans).	(Sankofa, 2023)
Semi-structured Interviews	The municipality of Amsterdam will assist in arranging informal interviews with canal residents and municipal workers directly involved in the case study. These interviews will take place in casual settings such as lunch or coffee. The primary objective of these interviews is to gain insights into the various perspectives on the case study and the chronological sequence of events surrounding it.	(Bearman, 2019)
Observations	Data will be collected by physically visiting the location of the case study and observing the different elements employed to address the issues, such as preventive measures, aesthetic improvements, and relocation areas. These observations will be focused on understanding the actions taken by the municipality and their impact on the residents living along the canals	(Walshe et al., 2012)

Table 5, Instruments for data analysis

Method	Description	Source
Validation Interviews	Validation interviews will be conducted to verify the findings obtained from the data collection process. These interviews will involve presenting the results to the interviewees to elicit their reactions and feedback. This feedback will enable adjustments to any methods outlined in section 3.2 if the objectives were not achieved or any unforeseen factors were overlooked.	(Buchbinder, 2011)
Data Reduction	Qualitative data will be reduced and transformed to be more readily accessible and understandable and can be used to draw themes and patterns. Data reduction will aim to summarise, develop, and identify themes from the audio recordings and transcriptions.	(Mezmir, 2020)
Data Display/Timelines	Data display aims to present information in a structured manner to facilitate conclusions. These displays assist in identifying patterns within the data. In this case, timelines will be used to determine the sequence and significant events of the case study from the perspective of the Amsterdam municipality and the residents. The timeline's objective is to visually represent qualitative data and the chronological order in which it unfolds (this will be done in an Excel spreadsheet). This method facilitates linking events, identifying explanations, and drawing conclusions. Further analysis will be done using "atlas.ti" software.	(Mezmir, 2020)
Verification	Upon deriving initial conclusions from the patterns identified in the data analysis, verifying these conclusions to ensure their validity and objectivity becomes crucial. This verification process will involve reviewing the steps leading to the findings, conducting reliability checks involving another researcher, and ensuring the procedures are clearly articulated and thoroughly documented. This process will be done by explaining the findings to a government practitioner from the municipality of Amsterdam to verify if the data obtained is coherent.	(Howard Lune & Bruce L. Berg, 2017)

A.2 Interview Forms

Interviews were conducted to gather insights from municipal employees involved in the *Waalseilandsgracht* case and residents living along the canal. These interviews followed a specific guide outlined in Table 6, with topics designed to address the research objectives developed from the theory section of this study. The topics were structured for open-ended responses, providing an understanding of the perspectives of the municipal employees and the asset users.

Semi-structured Interview Forms	
Asset Owner	**Asset User**
Background information	
Position at the Gemeente Amsterdam	Age Range (young adults, middle age adults, old age adults)
Role within the Waalseilandsgracht works regarding the UBQ	Time living near quay walls
Period of involvement within the Waalseilandsgracht	Owner or Tenant
Professional Background	Professional Background (What do you do?)
Uncertainties	
Description of uncertainties in the timeline's different phases of the Waalseilandsgracht.	Level of knowledge of the UBQ program (Gemeente Amsterdam programma bruggen en kademuren, PBK)
Description of methods to deal with the previously mentioned uncertainties	Level of understanding of the reasoning behind the use of the safety measures used by the municipality of Amsterdam and its consequences
Elements that play a role in the origins of such uncertainties and their effect in determining safety measures	Information sources regarding information of the PBK and level of understanding of such information
Risk Management	
Factors that play a role in determining safety measures	Past positive or negative experiences with the municipality
Municipality's risk perception when assessing quay walls and determining safety measures.	Concerns regarding the state of the quay wall/Willing to risk a possible collapse (before and after safety measures)
Possible risks that were not considered but should be taken into account in the future	Influences regarding residents' perspectives (news, neighbourhood behaviour, etc./Negative or positive)
-	Possible risks that were not considered but should be paid attention to in the future
Stakeholder Participation	
Description of the participation process on the different phases of the Waalseilandsgracht timeline.	Involvement in the different phases of the project engaged or informed
Management/Significance of the input given by the stakeholders.	Overview of the process of receiving or sending information to the municipality (before and after)
Evaluation or validation of participation processes.	Sense of being heard by the municipality regarding the project and addressing social concerns

Table 6, Semi-structured Interviews Guide

A.3 Data Display

The data collected is displayed in a timeline to help the researcher understand this research's case study. Using the software "Timeline", the data was displayed in chronological order to give a sense of how events unfolded during the total time of the case study. This can be seen in Figure 13 and Table 7.

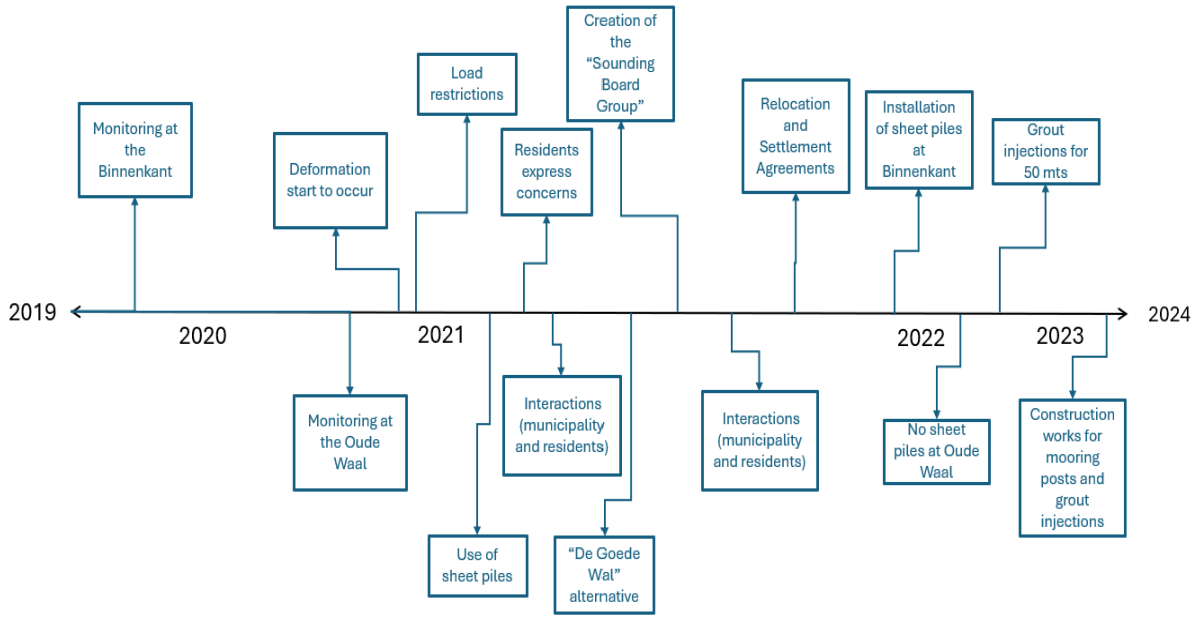

Figure 13, Waalseilandsgracth Timeline

Date	Event	Description
January 2019	Start of the UBQ program	The Municipality of Amsterdam starts a program with the main focus of renovating the city's Bridges and Quay Walls.
June 2019	Monitor at the Binnenkant	Monitoring methods started on one of the two Quay walls of the Waalseilandsgracht.
September 2020	Collapse of the Grimburgwal Quay wall	The Quay wall in front of the University of Amsterdam collapsed.
December 2020	Monitor at the Oude Wal	Monitoring methods started on the other Quay wall of the Waalseilandsgracht.
December 2020	Reduce Loads	Due to the condition of the quay walls, the Municipality decides to restrict loads by removing parking spaces and limiting the passage of heavy trucks.
February 2021	Implement Sheet Piles at the Binnenkant and Oude Wal	Given that the condition of the Quay Walls is worse than expected, the Municipality has decided to implement sheet piles to ensure the safety of the residents.
February 2021	Residents express their concerns to the Municipality of Amsterdam	The residents form a document called "Plan B" where they express their concerns as to the use of sheet piles as a safety measure.
March 2021	Uncertainty regarding 50 mts of the Binnenkant	The Municipality of Amsterdam cannot install a sheet pile on 50 mts of the Binnenkant because it will affect boat passage. However, what safety measures they can use for this section is uncertain.
March 2021 - July 2021	Interactions between Residents and Municipality	During this time, both parties (residents and municipality) communicated their concerns about the safety measures, possible

		outcomes, their attachment to the quality of life, and the different options for further development. In this process, few meetings were held, and the main forms of communication were mail, emails, reports, and individual interactive communication with residents. There is no evidence of consistent follow-ups on residents' concerns, objectives, negotiations, etc.
July 2021	The decision to form the "Sounding Board Group"	The Municipality of Amsterdam decided to organize a consistent meeting with an independent mediator to stop escalating the situation and recover the residents' trust in the municipality.
July 2021 – September 2021	Interactions between Residents and Municipality	During this time, there was constant communication between both parties, and there were structured meetings with follow-ups on the previous and future meetings. Objectives were set, and negotiation and communication were the main tools in this period.
September 2021	Residents sign agreements	Both parties reach agreements to start the works on the safety measures
September 2021	Construction process started	Initiation of preparatory works for the installation of sheet piles started
January 2022	New assessment on the Oude Wal	After a new assessment of the Oude Wal, the Municipality of Amsterdam decided not to install sheet piles on it; there is no more movement, and load restrictions are sufficient to ensure safety.
November 2022	The decision for safety measures on Oude Wal and the 50 Mts.	The Municipality of Amsterdam decided to install mooring posts on the Oude Wal so that houseboats do not pull from the quay wall, and grout injections will be used to reinforce the 50 mts of the Binnenkant where sheet piles could not be installed.

Table 7, Description of Events of the Timeline

A.3 Data Reduction

The software "Atlas.ti" was used to reduce the information from the documents recollected. The reduction was done by developing "codes" that can help pinpoint specific elements of the documents that address the three key concepts of this research, i.e. uncertainty, risk management, and stakeholder participation. The codes were developed based on the concepts explored in this research. The description of the development of the codes can be found below:

In Figure 14, uncertainty is divided into three categories. The first type, unpredictability, comes from chaotic behaviour that cannot be reduced, though there are strategies to manage it, such as forecasting future events and implementing adaptable measures. The second type, ambiguity, arises from the understanding of different perspectives influenced by the social system, i.e. economic, cultural, social, or political backgrounds. This type of uncertainty can be mitigated through communication and negotiation. Lastly, incomplete knowledge is primarily related to the technological variables or tools used to assess the quay walls and can be reduced by enhancing information or better estimating future events.

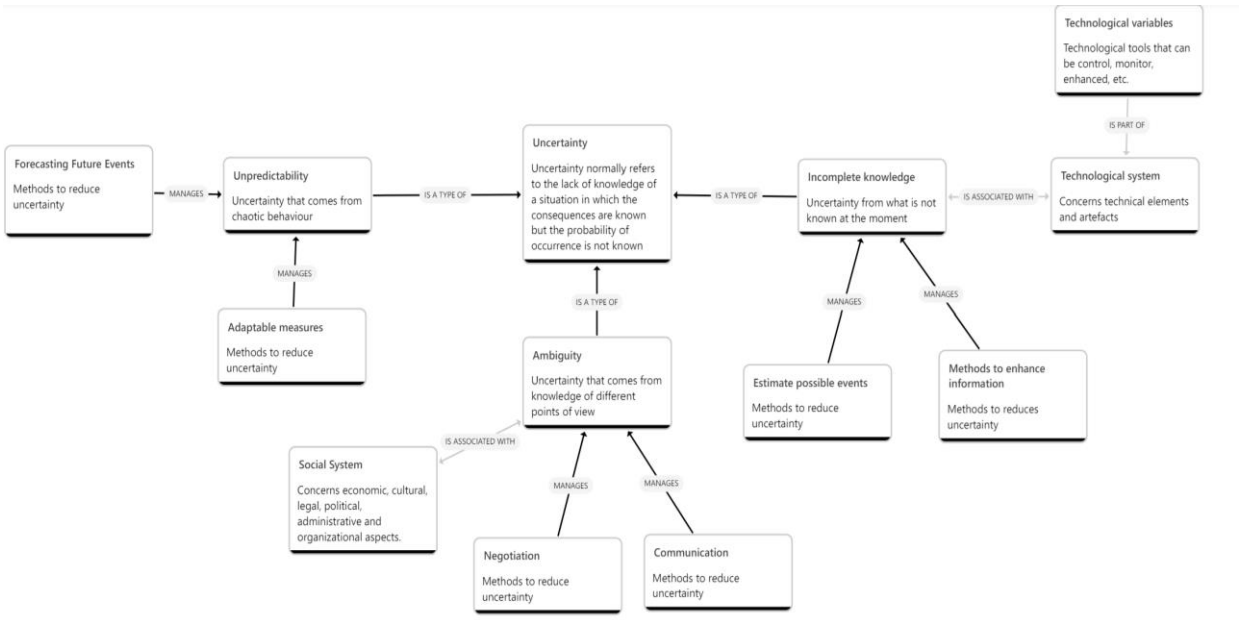

Figure 14, Code Breakdown Regarding Uncertainty

In Figure 15, effective risk management in the UBQ project requires addressing risk perception and communication to tackle social concerns and reduce risks. As defined in section 2.2.1, risk communication aims to combine expert knowledge and public understanding. This analysis included key factors for successful communication in the code breakdown, such as building trust in the information source and actively engaging with citizens. Additionally, as explained in section 2.2.1, risk perception involves understanding the communicated risks, which means that factors such as an individual's social environment and background must be considered in the coding for this analysis.

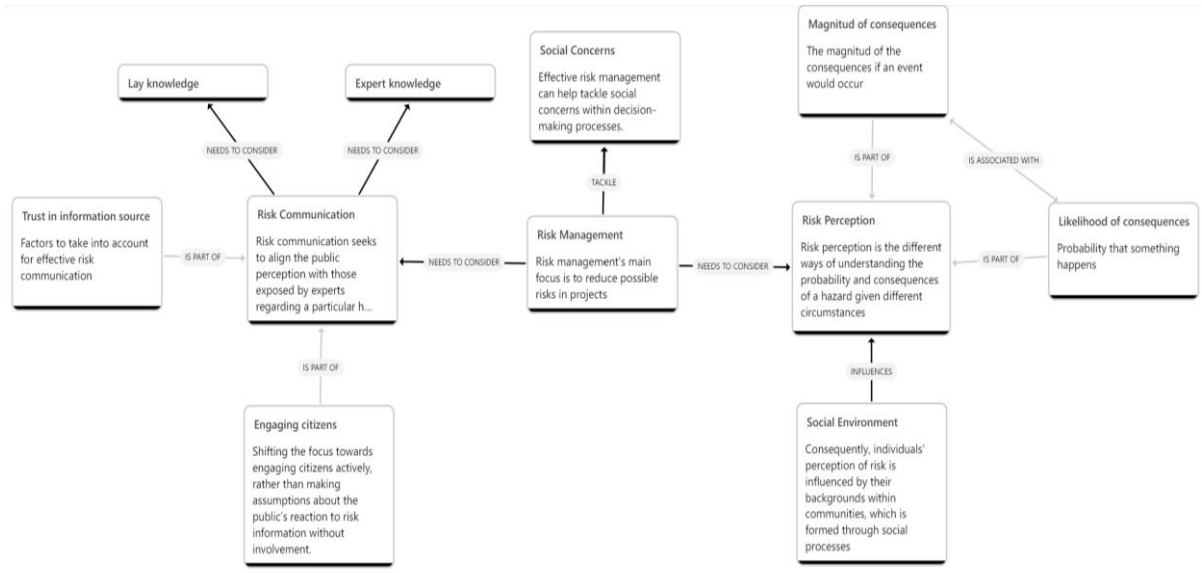

Figure 15, Code breakdown regarding Risk Management

In Figure 16, the various elements found from the literature review in section 2.3 for effective stakeholder management are illustrated. Key components derived from the literature review. These include identifying and grouping stakeholders, employing and evaluating participatory techniques, and implementing decisions. Additionally, following up on the implementation of decisions and ensuring effective communication, which combines interactive, push, and pull

communication methods, plays a significant role in stakeholder participation in public space projects.

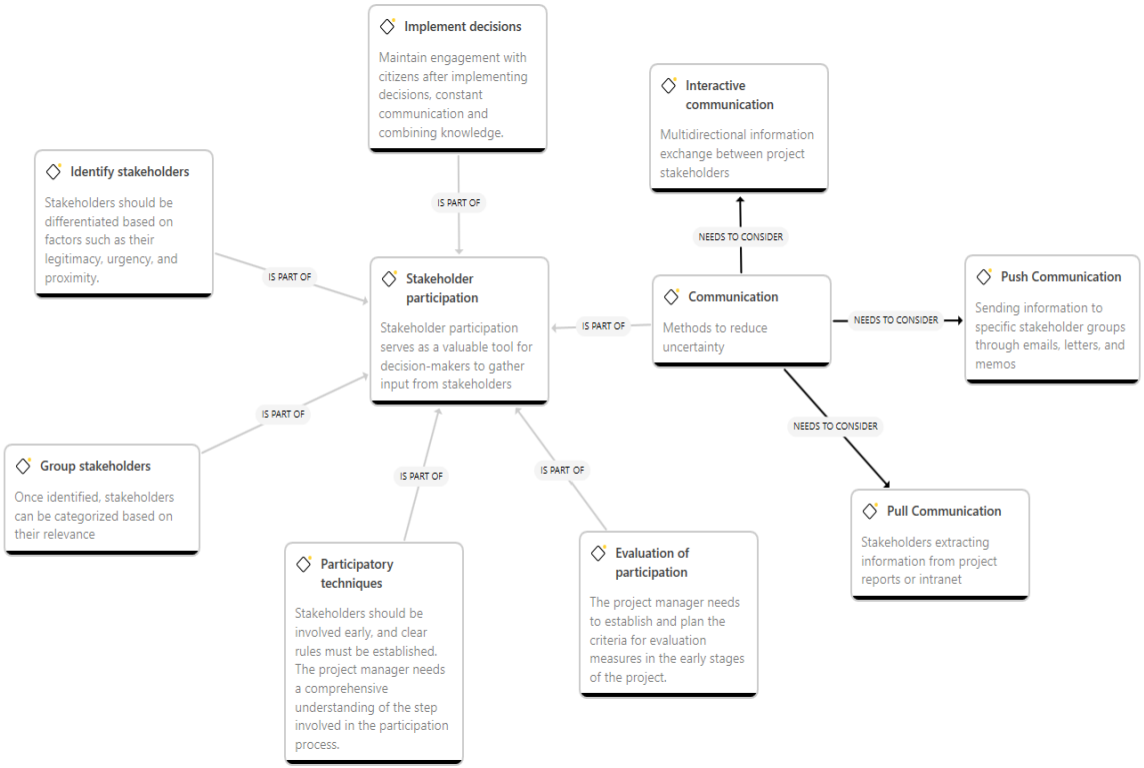

Figure 16, Code breakdown regarding Stakeholder Participation

Appendix B: References of interviews and documentation

In the following section, all the references used for the findings of the case study can be found in Table 8 and Table 9.

B.1 References from documents found

PM1	The quay walls in the Binnenkant are in poor condition	Printed Mail #1
PM2	We cannot renovate the quay walls in the short term. That is why we are taking temporary measures to keep the quays safe and extend their lifespan.	Printed Mail#2
PM3	The quay walls in the Binnenkant and Oude Waal are in poor condition.	Printed Mail#3
PM3.1	Safety construction will start at the beginning of March.	Printed Mail #3
PM3.2	To protect weak quay walls, we must limit the weight of the quays and strengthen them on both sides of the canal with sheet piling.	Printed Mail #3
PM4	We will be developing the finishing safety structures with ideas from the residents	Printed Mail #4
PM4	Stat moving houseboats in July at the earliest	Printed Mail #4
PM4	We decided not to implement a sheet pile on the quay wall at Binnenkant. We are investigating how we can strengthen that 50-meter quay differently.	Printed Mail #4
PM6	Strengthening of the quay walls will begin in August 2021	Printed Mail #6
PM7	An approach of doing the safety measures in one go is the best approach to limit inconvenience to residents in the coming years	Printed Mail #7
PM10	“We would prefer to have consulted all residents every week. This is not possible for practical reasons, such as COVID-19 measures. We propose a “Sounding Board Group” to better understand the situation's questions, concerns, progress, etc.. “	Printed Mail #10
PM12	Since the monitoring was carried out (Binnenkant from the end of June 2019 and Oude Waal from the beginning of December 2020).	Printed Mail #12

PM12.1	Structural collapse of the quay cannot be excluded, deformations are not linear	Printed Mail #12
NA1	Restauration experts proposed a more subtle approach compared to the municipality's current destructive method	News Articles
NA2	The maintenance of Amsterdam's quay walls has been neglected for years	News Articles
NA3	The recent collapse of the 10-meter section of the quay wall at Grimburgwal has underscored the neglect of Amsterdam's quay walls.	News Articles
NA3.1	Council members expressed their concerns that similar incidents could occur elsewhere.	News Articles
NA4	Residents, including Jochem Bakker and Marc Krone, have submitted a counterproposal to councillor Egbert de Vries, aiming for a more livable and aesthetically pleasing solution.	News Articles
DM3	Residents indicate that the proportions and dimensions in the current drawing are not correct.	Discussion Meeting #3
DM3.1	The municipality has not communicated sufficiently with residents; the SBG aims to unlock local knowledge and deal with uncertainties and doubts.	Discussion Meeting #3
DM3.2	Residents expressed their concerns to the SBG	Discussion Meetings #3
DM4	De Goede Wal alternative will be calculated to see if it can be used in the 50 mts of the Binnenkant	Discussion Meetings #4
DM9	The members of the SBG indicate that almost all residents are satisfied with the agreement	Discussion Meeting #9
DM10	Residents of the Waalseilandsgracht SBG met to discuss the work and temporary designs to secure the Waalseilandsgracht quay walls	Discussion Meeting #10
DM11	The Witteven+Bos report shows that the De Goede Wal solution is unlikely to be used.	Discussion Meetings #11
DM11.1	Final repair of the quays of Oude Waal and Binnenkant is planned for 2027-2029	Discussion Meetings #11
DM12	Discussions will be held regarding monitoring data, drawings, the progress of work, planters on decking, and water holes on sheet piles.	Discussion Meetings #12
DM13	The Municipality of Amsterdam has decided not to strengthen the Oude Waal quay. Monitoring shows that the quay is not moving. The integrated advice is based on knowledge that is now available but was not before when the initial decision was made. And the accessibility and livability of the residents who have expressed their requests not to implement sheet piles until necessary.	Discussion Meetings #13
DM13.1	The technical specialists of the municipality do not rule out reinforcement, but this is uncertain. If the movement exceeds the signal values, safety construction will start within 4 months to guarantee safety. In this case, all permits, plans, and agreements are already ready.	Discussion Meetings #13
DM18	Members of the Sounding Board Group indicated they were shocked by the letter at the end of 2020; this caused stress and unrest.	Discussion Meeting #18
DM18.1	Every few weeks, residents and the municipality of Amsterdam meet in the SBG to discuss the progress of the work	Discussion Meeting #18
DM18.2	50-Mts: All kinds of investigations have been started. Grout injections seem to be the most feasible option.	Discussion Meeting #18
DM19	Update the SBG (retired) about developments, agree to meet in the following months	Discussion Meeting #19
DM19.1	The signals are positive and the method with grout injections can be applied.	Discussion Meeting #19
DM19.2	"We are faced with rising prices and limited investment space. But we have gained a lot of knowledge and methods to improve. We rely on lifespan extension for partial renovation and replacements of the quay only if necessary."	Discussion Meeting #19
DM3-DM20	All meeting reports have a structure for addressing issues for past and future meetings	Discussion Meetings from #3 to #20
DT1	"Today, the preparatory work to strengthen the quay walls starts. The contractor first builds a temporary scaffolding in the canal. This is intended for the ships and barges that must be moved for the work in the coming months."	Digital Tools #1
DT2	"A new assessment has been made for the quay on the Oude Waal. The advice is: do not strengthen the quay now but continue to limit the load on the quay."	Digital Tools #2

DT3	"We are installing mooring posts for the quay of the Oude Waal. At the Inside, we place collision protection in the water."	Digital Tools #3
E1	"Our quays were judged unsafe based on personal interpretation of safety standards by municipal engineers"	Email #1
E2	"The ever-advancing sheet piling accumulates dirt and trash"	Email #2
E2	"Tubular piles are beautiful and multifunctional"	Email #2
E3	"After consultation with experts, there appears to be no acute threat according to the norm NEN 8700"	Email #3
E3	"One of the worst parts of the Binnenkant (50 mts) will remain without interventions. This is not being treated equally in the rest of the quay"	Email #3
E4	"An independent engineering team should do an assessment"	Email #4
E5	The delays and lack of information create concern among residents for less time for the promised participation	Email #5
E5	That is why the joint boar and ark residents have drawn a list of points themselves.	Email #5
R1	All agreements for ships and barges relating to movements up to and including return to the safety structure	Report #1
R2	Agreements for all boat residents from start of the work until the end (10+ years)	Report #2
R3	Carefully and in consultation with the residents we realize its impact on you. We will provide preparations for this.	Report #3

Table 8, References to findings from documents

B.2 References from the answers given in the interviews

I-NG2	"Residents felt like the municipality did not take them into account"	Interview without guide #2
I-NG2.1	"The municipality proposed to have meetings between stakeholders and the municipality, underestimated the resilience of the residents, didn't see value in their input... This is a technical project; look from the expertise, not the stakeholders' viewpoint. It escalated before the sounding boards; it was getting out of hand"	Interview without guide #2
I-NG2.2	"Boat residents have a permit, and the municipality can move them without asking them... looking for an agreement for the resident's lot of emotions, distrust, difficult in agreeing"	Interview without guide #2
I-NG2.3	Arrange to give a lawyer for negotiation (payed from the municipality)	Interview without guide #2
I-NG3	No experience handling boat residents, underestimating the impact that it would have on the residents (top-down approach).	Interview without guide #3
I-NG3.1	"Very strict meeting with the sounding board, public mediation is a company who arranges the meetings, one wanted to leave the canal, the negotiation was important to solve the problem, the key is in negotiation Do not underestimate the repair of the relationship"	Interview without guide #3
I-NG3.2	Important to understand the new assessment of the Oude Wal, 50 mts for 100 years binnenkant 10 yrs oude wal 2-5 years	Interview without Guide #3
I-NG3.3	"Very low level of trust In the end a lot level of trust."	Interview without guide #3
I-NG4	Multiple methods were employed to gather data, including: Checking deformations at multiple points. Taking numerous pictures and comparing them with previous images. Using satellite information through tree cover sometimes obstructed accurate data. Two data sets were used: the most certain data was validated with another set. Divers took wood samples to determine the foundation's	Interview without guide #4

	state, assessed the construction's age, and made necessary assumptions.	
I-NG5	The start was very weird, maybe influenced by Grimburgwal	Interview without guide #5
I-NG5	"While deciding on the construction, the 50 mts were identified, and boats could not pass under the bridge Grout injections were better but were more expensive. We did not have enough knowledge at that moment, but now it is known"	Interview without guide #5
I-NG5.2	There is a need for a private company to be neutral on the municipality. "We do not trust you", residents said to the municipality	Interview without guide #5
I-NG6	There is no connection to the collapse of the Grimburgwal.	Interview without guide #6
I-NG6.1	At the start of the PBK, there was no data; the only recollection of information was by asking maintenance workers for information and being reactive to the situation.	Interview without guide #6
I-NG6.2	From the 80 quay walls considered critical, it was not sure exactly where to start, so started with the most critical from the workers' perspectives.	Interview without guide #6
I-NG6.3	The dashboard includes safety measures based on the condition of the quay walls. Since the program's inception. As the program progressed, more critical elements were identified, leading to establishing criteria for interventions.	Interview without guide #6
I-NG8	Only 10 yr for temporary solutions but they can last 20 yr. 50 mts are calculated for 30 yr. Mooring poles are for 50 yr.	Interview without Guide #8
I-G1	"The municipality hasn't invested enough in its assets, such as bridges and quay walls, for 20 to 40 years. This underinvestment led to a lack of knowledge about the condition of these assets. Therefore, the program's first task in 2019 was to research and assess their stability"	Interview with Guide #1
I-G1	"Yeah, and when they started asking questions, the answers weren't precise or unclear. So, I was very critical of the responses we had given them up until April 20. I reviewed them and thought, 'This is not OK."	Interview with Guide #1
I-G1.2	"The main tool we relied on was the sounding board. They provided direct feedback on our behaviour and responses, including individuals we engaged with from the group, which was crucial. Of course, we also contacted residents outside the sounding board group, but they were secondary. I distinctly recall when they told us, "Your answers are inadequate." I meticulously reviewed all meeting transcripts, categorising questions and actions and compiling a comprehensive list. I presented this to my team, acknowledging our shortcomings and committing to improvement. We worked tirelessly for two weeks, day and night. I vividly remember the moment we presented the revised answers. They were pleasantly surprised by the thoroughness and responsiveness of our response."	Interview with Guide #1
I-G1.3	"We hired external experts, including professors from Delft University, to validate our data and judgments. This helped restore trust with the houseboat residents, who were sceptical of us. We held sessions where residents could participate with external experts, raising questions. This collaborative process improved our understanding and response to their concerns."	Interview with Guide #1
I-G1.4	"There were still uncertainties because the installation of the sheet piles kept getting postponed. This delay posed a risk of sudden collapse. We continuously assessed whether we could afford the time, acknowledging that it wasn't 100% certain. The risk was always present, which kept the problem active until we finally reached an agreement."	Interview with Guide #1
I-G1.5	This group included a representative from the Department of Justice and a manager responsible for assets in the eastern part of the country, among others. A senior official tasked them to evaluate the risks and needs concerning Amsterdam's assets. In January 2019, they released a report highlighting the severity of the problem. They warned that addressing it would require significant time	Interview with Guide #1

	and money, and it couldn't be fixed within a year. They emphasised the importance of taking the issue seriously, securing substantial funding, and gathering experts for a long-term solution. They also advised against changing plans in two years. Their report provided us with a strong mandate, which was accepted by the municipality and supported by politicians. This support allowed us to secure the necessary resources and build an organization to tackle the issue.	
I-G2	"I would say uncertainty begins right when we start monitoring. During inspections, we often spot issues like cracks in quay walls, displaced stones on roads, or other types of damage. Figuring out what causes these problems and their seriousness isn't immediately clear. That's why we monitor— to gather data and understand better."	Interview with Guide #2
I-G2.1	"However, managing Amsterdam's environment and infrastructure is a strategic issue. Losing the city's and the municipality's support for our actions would jeopardize the entire project."	Interview with Guide #2
I-G2	"So I think that the environment manager I was talking about just dismissed all the residents' worries and didn't give them any room to give input on the process. So there was no sending like, we're going to do this. This is the situation. We are going to move you. This is how your boat looks. This is what we're going to do, and the resident said hey, but the drawings of my boat don't match, and the situation is not correct"	Interview with Guide #2
I-G2.3	"We always prioritise the technical condition of the quay walls when deciding on actions because it's challenging to intervene preventively."	Interview with Guide #2
I-G2.4	"We focus on monitoring and inspections. Sometimes, we increase the number and frequency of inspections to improve certainty. For example, at da Costa where we urgently moved four houseboats in December, we inspected the quay wall twice a week, which is very frequent. This helps ensure safety and can be seen as a form of monitoring. Currently, our goal is to establish a consistent approach. We want a clear, step-by-step process instead of the current approach based more on expert opinions than a structured process. Here's how it typically unfolds: when we notice a concerning situation, we begin monitoring it. We might increase the frequency or scope of inspections. Next, we might restrict parking and traffic over certain weights, like 7.5 tonnes. Some areas of Amsterdam's city centre have exceptions for heavy traffic, but we could introduce stricter rules, reducing the limit to 3.5 tonnes. Ultimately, we may completely restrict traffic and parking to address the issue. If these steps don't solve the problem, we consider building a safety structure, renovating, replacing soil, or combining these measures."	Interview with Guide #2
I-G2.5	"Meanwhile, the department responsible for the measures might claim they lack the manpower or don't see the urgency. Another city department also says they can't enforce rules effectively due to staffing shortages. For instance, if we restrict traffic, we need enough staff to ensure compliance. Implementing such measures might not be a good idea if we can't monitor it properly. This leads to debates about what actions to take and when. In December, this situation reached a critical point. Even after receiving integrated advice from experts, decisions were made, but the discussions would start anew. People would say, "We can't implement this in two weeks," or "It'll take four weeks," all because of our discussed uncertainties. When you're dealing with a potentially serious issue and uncertain about when it might occur, these discussions become very intense and critical."	Interview with Guide #2
I-G3	"Yeah, in the first part of the monitoring phase, there was some uncertainty about how bad the situation was because there were three problematic areas at the Binnenkant, but between them, it wasn't so bad."	Interview with Guide #3

I-G3.1	"Here's what happened. We sent out the letter because we knew there was a problem, but we hadn't figured out what to do yet. Unfortunately, we didn't start coordinating with everyone until probably around April, which was too late"	Interview with Guide #3
I-G3.2	"Additionally, to formalise our agreements, we had to draft contracts with all the boat residents. Initially, they were sceptical about the terms, fearing we might relocate them arbitrarily after a few months. To address their concerns, we offered to cover the cost of a lawyer who could review the contracts independently. This assurance helped build trust because they felt secure knowing a lawyer had scrutinised the terms on their behalf, ensuring fairness. Ultimately, this approach reassured them that despite the project's requirements, we were committed to fair treatment and transparency."	Interview with Guide #3
I-G3.3	"Yeah, in Amsterdam, many people in similar positions as mine are cautious about engaging with residents. They tend to be reactive rather than proactive, only visiting when they have something specific to discuss. I encourage a different approach—I believe in building relationships first. I try to connect and listen even if I don't have all the answers or plans. Seeing others in government roles wait to figure everything out before engaging is frustrating. A year might pass by then, and people feel neglected and frustrated. I prefer to establish trust and communication early on, even if it means starting without all the details."	Interview with Guide #3
I-G4	It was concluded that the same measures would be taken on both quay walls of the Waalseilandsgracht	Interview with Guide #4
I-G4.1	Some houseboat residents, though not all, were worried about the stability of the canal wall.	Interview with Guide #4
I-G4.2	Many individuals who are not typically involved in these types of issues participated. This level of public involvement, especially concerning safety measures, was unprecedented for us, even though it may occur in other projects.	Interview with Guide #4
I-G4.3	Information was gathered through various methods, including monitoring, diving inspections, and conversations with houseboat residents and nearby citizens.	Interview with Guide #4
I-G4.4	Technical information has always been collected since the start of the program and the implementation of safety measures over the past years. This information has been crucial in assessing the likelihood of failure, a key aspect of ensuring safety.	Interview with Guide #4
I-G4.5	You never have full information. You start without information and gather more during the process, but you never have complete information. In 2019, we began gathering data; throughout this period, we continually received new information. Each time new data came in, we had to decide whether to act on it or do nothing. This ongoing information gathering included technical data like monitoring, diving inspections, and irregularities in the pavement, as well as input from citizens and houseboat residents. Each time we received new information, we had to react, make decisions based on what we had, and reconsider our previous decisions if necessary.	Interview with Guide #4
I-G4.6	There were varied reactions to the situation. Some individuals and groups remained concerned, while others initially expressed concern but later became reassured. Additionally, some were well-informed and actively engaged in discussing the decision-making process. The situation involved a mix of conflicting perspectives and genuine concerns among the various parties involved.	Interview with Guide #4
I-G5	"I didn't see anything initially. Then I saw it clearly on the other side. Yes, it was evident. Other locations in the city also collapsed, so it was possible that it could happen here, too."	Interview with Guide #5
I-G5.1	"There was a risk that we might have to leave the canal for two years. It's not a physical risk but a mental one, which is significant. Some people, particularly older individuals, were planning to sell their boats and retire, but they couldn't sell their houseboats in this uncertain situation. This added to the stress."	Interview with Guide #5

I-G5.2	"I requested drawings several times but didn't receive them. Now, we see where problems cannot be fixed, which is frustrating."	Interview with Guide #5
I-G5.3	"We had formed a club with the person I showed you, with black sailing boats and stars. We originally started this club to organise ourselves and to invite the municipality to explain things. That worked very well. Within a few months, we met with a high-ranking official, not the mayor, but someone else. We were well organised in gathering our information and expressing our opinions."	Interview with Guide #5
I-G5.4	"The municipality did a good job in the settlement agreement by funding a lawyer to help us with our concerns, which was a positive aspect."	Interview with Guide #5
I-G5.5	"Yeah, I don't have any problems now because I'm off the wall. I'm prepared, and if needed, I can just float away."	Interview with Guide #5
I-G6	"Then the Grimburgwal wall collapsed, which made the news. Following that, we received information indicating that they were monitoring these areas."	Interview with Guide #6
I-G6.1	"Yeah, I think there was a lot of uncertainty and stress at the start. We had many questions and were unsure about many things we didn't like. During this first phase, we started to communicate with each other, which was beneficial because it made us feel like we were part of a group, not just isolated individuals. This gave us more power and influence. They mentioned some measures, but there weren't many details—like how long it would take or if we would be relocated. Initially, they thought we would have to move out of the canal, but eventually, they decided we could stay. So there was a lot of uncertainty."	Interview with Guide #6
I-G6.2	"The implication was that the value of my houseboat, both financially and in terms of enjoyment, decreased significantly."	Interview with Guide #6
I-G6.3	"As houseboat owners, we also had our app to communicate. Due to our unique collective concerns, we had a separate app for the houseboats here."	Interview with Guide #6
I-G6.4	"Yeah, maybe it has improved a little bit already, but for me, the big difference was being part of this group. I felt much more control and influence and received much more information. We sent all the written reports of the meetings to all the stakeholders, which was probably appreciated by those who were not members of the group as well"	Interview with Guide #6
I-G6.5	"No, I knew there was a risk, but I thought, well, I will not die if the walls collapse. It wasn't very likely because it became clear quite soon that there were only a few places where the risk was highest, and it was not here. So, I slept well, unlike the woman over there. She was a bit scared after hearing about the weak spots in the walls."	Interview with Guide #6

Table 9, References for the interview responses

Appendix C: Consent form for interviews

Consent Form for Waalseilandsgracht case study

YOU WILL BE GIVEN A COPY OF THIS INFORMED CONSENT FORM

Please tick the appropriate boxes	Yes	No
Taking part in the study		
– I have read and understood the study information dated _____or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.	○	○
– I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.	○	○
– I understand that taking part in the study involves an audio-recorded interview and the elaboration of written notes of the interview. The purpose of the audio recording is to support the field notes observations, this will be transcribed as text, and later on the recording will be destroyed/deleted.	○	○
Use of the information in the study		
– I understand that information I provide will be used for academic reports, publications and online content, using the same terms as you used in the study information sheet.	○	○
– I understand that personal information collected about me that can identify me, such as [e.g. my name, address, geolocation], will not be shared beyond the study team.	○	○
– I agree that my information can be quoted in research outputs	○	○
– *I agree to be audio/video recorded. Yes/no*		
Future use and reuse of the information by others		
I give permission for the data collected that I provide to be archived and published in DANS repository so it can be used for future research and learning.	○	○
I understand that the anonymized information I will provide can be shared with, and potentially used by the partners of the Livequay project.	○	○
I give the researchers permission to keep my contact information and to contact me for future research projects.	○	○

Signatures

_____ _____ _____

Name of participant Signature Date

I have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting.

Daniel Alejandro Bejarano Macias _____ _____

Researcher Signature Date

References

Alvarado Vazquez, S., Madureira, A. M., Ostermann, F. O., & Pfeffer, K. (2024). Social participation in planning, design, and management of public spaces: the case of Mexico. *Planning Practice & Research*, *39*(4), 565–596. https://doi.org/10.1080/02697459.2024.2315391

Amsterdam Canal Cruise. (n.d.). *Explore Amsterdam Canals*. Retrieved July 4, 2024, from https://www.canal-cruise-amsterdam.com/canals-of-amsterdam/

Antonisse, R. (2021, September 24). *Canal residents are confronted by a judge in their fight against years of construction of sheet piling*. https://www.nhnieuws.nl/nieuws/292229/grachtbewoners-vangen-bot-bij-rechter-in-strijd-tegen-jarenlange-komst-damwanden

Atkin, B., & Skitmore, M. (2008). Editorial: stakeholder management in construction. *Construction Management and Economics*, *26*(6), 549–552. https://doi.org/10.1080/01446190802142405

Aven, T. (2016). Risk assessment and risk management: Review of recent advances on their foundation. *European Journal of Operational Research*, *253*(1), 1–13. https://doi.org/10.1016/j.ejor.2015.12.023

Bearman, M. (2019). Focus on Methodology: Eliciting rich data: A practical approach to writing semi-structured interview schedules. *Focus on Health Professional Education: A Multi-Professional Journal*, *20*(3), 1. https://doi.org/10.11157/fohpe.v20i3.387

Bert Enserink, Pieter Bots, Els van Daalen, Leon Hermans, Rens Kortmann, Joop Koppenjan, Jan Kwakkel, Tineke Ruijgh, Jill Slinger, & Wil Thissen. (2022). *Policy Analysis of Multi-Actor Systems* (Second). Eleven. https://doi.org/https://doi.org/10.5074/T.2022.004

Biswas, S. Kr., Sinha, N., Purkayastha, B., & Marbaniang, L. (2014). Weather prediction by recurrent neural network dynamics. *International Journal of Intelligent Engineering Informatics*, *2*(2/3), 166. https://doi.org/10.1504/IJIEI.2014.066208

Boelee, L., Lumbroso, D. M., Samuels, P. G., & Cloke, H. L. (2019). Estimation of uncertainty in flood forecasts—A comparison of methods. *Journal of Flood Risk Management*, *12*(S1). https://doi.org/10.1111/jfr3.12516

Böhle, F., Heidling, E., & Schoper, Y. (2016). A new orientation to deal with uncertainty in projects. *International Journal of Project Management*, *34*(7), 1384–1392. https://doi.org/10.1016/j.ijproman.2015.11.002

Bojórquez-Tapia, L. A., Eakin, H., Reed, P. M., Miquelajauregui, Y., Grave, I., Merino-Benítez, T., & Molina-Pérez, E. (2022). Unveiling uncertainties to enhance sustainability transformations in infrastructure decision-making. *Current Opinion in Environmental Sustainability*, *55*, 101172. https://doi.org/10.1016/j.cosust.2022.101172

Breakwell, G. M. (2000). Risk communication: fators affecting impact. *British Medical Bulletin*, *56*(1), 110–120. https://doi.org/10.1258/0007142001902824

Brugnach, M., Dewulf, A., Pahl-Wostl, C., & Taillieu, T. (2008). Toward a Relational Concept of Uncertainty: about Knowing Too Little, Knowing Too Differently, and Accepting Not to Know. *Ecology and Society*, *13*(2), art30. https://doi.org/10.5751/ES-02616-130230

Buchbinder, E. (2011). Beyond Checking. *Qualitative Social Work*, *10*(1), 106–122. https://doi.org/10.1177/1473325010370189

Butt, A., Naaranoja, M., & Savolainen, J. (2016). Project change stakeholder communication. *International Journal of Project Management*, *34*(8), 1579–1595. https://doi.org/10.1016/j.ijproman.2016.08.010

Chiffi, D., & Chiodo, S. (2020). *Risk and Uncertainty: Foundational Issues* (pp. 1–13). https://doi.org/10.1007/978-3-030-56067-6_1

Chiffi, D., & Pietarinen, A.-V. (2017). Fundamental Uncertainty and Values. *Philosophia*, *45*(3), 1027–1037. https://doi.org/10.1007/s11406-017-9865-5

Cousin, G. (2005). Case Study Research. *Journal of Geography in Higher Education*, *29*(3), 421–427. https://doi.org/10.1080/03098260500290967

Dewulf, A., & Biesbroek, R. (2018). Nine lives of uncertainty in decision-making: strategies for dealing with uncertainty in environmental governance. *Policy and Society*, *37*(4), 441–458. https://doi.org/10.1080/14494035.2018.1504484

Ericson, R. (2006). Ten Uncertainties of Risk-Management Approaches to Security. *Canadian Journal of Criminology and Criminal Justice*, *48*(3), 345–356. https://doi.org/10.3138/cjccj.48.3.345

Frewer, L. (2004). The public and effective risk communication. *Toxicology Letters*, *149*(1–3), 391–397. https://doi.org/10.1016/j.toxlet.2003.12.049

Gemeente Amsterdam. (2021, April). *Progress Reporting* .

Gemeente Amsterdam. (2023a). *Bridges and quay walls action plan 2023-2026*.

Gemeente Amsterdam. (2023b). *Bridges and quay walls action plan 2023-2026*. https://assets.amsterdam.nl/publish/pages/973509/actieplan_programma_bruggen_en_kademuren_2023-2026.pdf

Gemeente Amsterdam. (2023c). *Bridges and Quay Walls Program Plan*. https://assets.amsterdam.nl/publish/pages/973509/programmaplan_bruggen_en_kademuren_-_herstellen_en_verbinden_-.pdf

Gemeente Amsterdam. (2023d). *Bridges and Quay Walls Program Plan*.

Gemeente Amsterdam. (2024a). *Dashboard programma Bruggen en Kademuren*. https://experience.arcgis.com/experience/5f24774720454550ae8e2b93e909f564/page/page_7/

Gemeente Amsterdam. (2024b, February 27). *Waalseilandsgracht: measures due to poor quay walls*. https://www.amsterdam.nl/projecten/kademuren/maatregelen/waalseilandsgracht/

Glicken, J. (2000). Getting stakeholder participation 'right': a discussion of participatory processes and possible pitfalls. *Environmental Science & Policy*, *3*(6), 305–310. https://doi.org/10.1016/S1462-9011(00)00105-2

Haasnoot, M., Kwakkel, J. H., Walker, W. E., & ter Maat, J. (2013). Dynamic adaptive policy pathways: A method for crafting robust decisions for a deeply uncertain world. *Global Environmental Change*, *23*(2), 485–498. https://doi.org/10.1016/j.gloenvcha.2012.12.006

Hampel, J. (2006). Different concepts of risk – A challenge for risk communication. *International Journal of Medical Microbiology*, *296*, 5–10. https://doi.org/10.1016/j.ijmm.2005.12.002

Howard Lune, & Bruce L. Berg. (2017). *Qualitative research methods for the social sciences* (9th edition). Pearson.

Ignatius Teye Buertey, J. (2016). Stakeholder Management on Construction Projects: A Key Indicator for Project Success. *American Journal of Civil Engineering*, *4*(4), 117. https://doi.org/10.11648/j.ajce.20160404.11

J.G. De Gijt. (2010). A History of Quay Walls Techniques, types, costs and future. *ResearchGate*. https://www.researchgate.net/profile/Jg-De-Gijt/publication/46115658_A_History_of_Quay_Walls_Techniques_types_costs_and_future/links/5a720773458515512075da54/A-History-of-Quay-Walls-Techniques-types-costs-and-future.pdf

Kandlikar, M., Risbey, J., & Dessai, S. (2005). Representing and communicating deep uncertainty in climate-change assessments. *Comptes Rendus. Géoscience*, *337*(4), 443–455. https://doi.org/10.1016/j.crte.2004.10.010

Kavaratzis, M., & Ashworth, G. J. (2007). Partners in coffeeshops, canals and commerce: Marketing the city of Amsterdam. *Cities*, *24*(1), 16–25. https://doi.org/10.1016/j.cities.2006.08.007

Konter, L. (2023). *Management of (climate) uncertainties in urban development projects* [University of Twente]. https://purl.utwente.nl/essays/95165

Korff, M., Hemel, M.-J., & Peters, D. J. (2022). Collapse of the Grimburgwal, a historic quay in Amsterdam, the Netherlands. *Proceedings of the Institution of Civil Engineers - Forensic Engineering*, *175*(4), 96–105. https://doi.org/10.1680/jfoen.21.00018

Kwadijk, J. C. J., Haasnoot, M., Mulder, J. P. M., Hoogvliet, M. M. C., Jeuken, A. B. M., van der Krogt, R. A. A., van Oostrom, N. G. C., Schelfhout, H. A., van Velzen, E. H., van Waveren, H., & de Wit, M. J. M. (2010). Using adaptation tipping points to prepare for climate change and sea level rise: a case study in the Netherlands. *WIREs Climate Change*, *1*(5), 729–740. https://doi.org/10.1002/wcc.64

Lennart Sjöberg, Bjørg-Elin Moen, & Torbjørn Rundmo. (2004). *Explaining risk perception. An evaluation of the psychometric paradigm in risk perception research* (Torbjørn Rundmo, Ed.). Norwegian University of Science and Technology, Department of Psychology.

Logan, D. C. (2009). Known knowns, known unknowns, unknown unknowns and the propagation of scientific enquiry. *Journal of Experimental Botany*, *60*(3), 712–714. https://doi.org/10.1093/jxb/erp043

Luyet, V., Schlaepfer, R., Parlange, M. B., & Buttler, A. (2012). A framework to implement Stakeholder participation in environmental projects. *Journal of Environmental Management*, *111*, 213–219. https://doi.org/10.1016/j.jenvman.2012.06.026

Mezmir, E. A. (2020). Qualitative Data Analysis: An Overview of Data Reduction, Data Display and Interpretation. *Research on Humanities and Social Sciences*. https://doi.org/10.7176/RHSS/10-21-02

Miltenburg, J. (2021, August 31). *Canal residents fight against years of view of sheet piling: "Infringement on living enjoyment."* https://www.nhnieuws.nl/nieuws/290709/grachtbewoners-strijden-tegen-jarenlang-uitzicht-op-damwanden-inbreuk-op-woongenot

Mohamed Awad. (2023). *Development of a decision-making framework for assessing lifespan extension measures of quay walls* [University of Twente]. https://essay.utwente.nl/96393/1/Awad_MA_Engineering%20Technology.pdf

Newig, J., Jager, N. W., Challies, E., & Kochskämper, E. (2023). Does stakeholder participation improve environmental governance? Evidence from a meta-analysis of 305 case studies. *Global Environmental Change*, *82*, 102705. https://doi.org/10.1016/j.gloenvcha.2023.102705

Olsson, R. (2007). In search of opportunity management: Is the risk management process enough? *International Journal of Project Management*, *25*(8), 745–752. https://doi.org/10.1016/j.ijproman.2007.03.005

Pahl-Wostl, C. (2006). Transitions towards adaptive management of water facing climate and global change. *Water Resources Management*, *21*(1), 49–62. https://doi.org/10.1007/s11269-006-9040-4

Palmer, T. N. (2000). Predicting uncertainty in forecasts of weather and climate. *Reports on Progress in Physics*, *63*(2), 71–116. https://doi.org/10.1088/0034-4885/63/2/201

Public Mediation. (2024). https://public-mediation.nl/leidende-principes/

R. Voortman. (2021). *The historic quay walls of Amsterdam A study into the hidden structural capacity of masonry quay walls under the condition of a partly failing foundation* [TU Delft]. https://repository.tudelft.nl/record/uuid:a0fdfa81-9fbb-47cb-b5a0-4ca999ca8121

Reed, M. S. (2008). Stakeholder participation for environmental management: A literature review. *Biological Conservation*, *141*(10), 2417–2431. https://doi.org/10.1016/j.biocon.2008.07.014

Reed, M. S., Vella, S., Challies, E., de Vente, J., Frewer, L., Hohenwallner-Ries, D., Huber, T., Neumann, R. K., Oughton, E. A., Sidoli del Ceno, J., & van Delden, H. (2018). A theory of participation: what makes stakeholder and public engagement in environmental management work? *Restoration Ecology*, *26*(S1). https://doi.org/10.1111/rec.12541

Ruggeri, P., Fruzzetti, V. M. E., & Scarpelli, G. (2019). Renovation of quay walls to meet more demanding requirements: Italian experiences. *Coastal Engineering*, *147*, 25–33. https://doi.org/10.1016/j.coastaleng.2019.01.003

Sankofa, N. (2023). Critical method of document analysis. *International Journal of Social Research Methodology*, *26*(6), 745–757. https://doi.org/10.1080/13645579.2022.2113664

Sasidharan, M., Parlikad, A. K., & Schooling, J. (2022). Risk-informed asset management to tackle scouring on bridges across transport networks. *Structure and Infrastructure Engineering*, *18*(9), 1300–1316. https://doi.org/10.1080/15732479.2021.1899249

Siegrist, M., & Árvai, J. (2020). Risk Perception: Reflections on 40 Years of Research. *Risk Analysis*, *40*(S1), 2191–2206. https://doi.org/10.1111/risa.13599

van den Hoek, R. E., Brugnach, M., Mulder, J. P. M., & Hoekstra, A. Y. (2014). Analysing the cascades of uncertainty in flood defence projects: How "not knowing enough" is related to "knowing differently." *Global Environmental Change*, *24*, 373–388. https://doi.org/10.1016/j.gloenvcha.2013.11.008

van der Velde, J., Klatter, L., & Bakker, J. (2013). A holistic approach to asset management in the Netherlands. *Structure and Infrastructure Engineering*, *9*(4), 340–348. https://doi.org/10.1080/15732479.2012.657650

Walshe, C., Ewing, G., & Griffiths, J. (2012). Using observation as a data collection method to help understand patient and professional roles and actions in palliative care settings. *Palliative Medicine*, *26*(8), 1048–1054. https://doi.org/10.1177/0269216311432897

Ward, S., & Chapman, C. (2003). Transforming project risk management into project uncertainty management. *International Journal of Project Management*, *21*(2), 97–105. https://doi.org/10.1016/S0263-7863(01)00080-1

Warmink, J. J., Brugnach, M., Vinke-de Kruijf, J., Schielen, R. M. J., & Augustijn, D. C. M. (2017). Coping with Uncertainty in River Management: Challenges and Ways Forward. *Water Resources Management*, *31*(14), 4587–4600. https://doi.org/10.1007/s11269-017-1767-6