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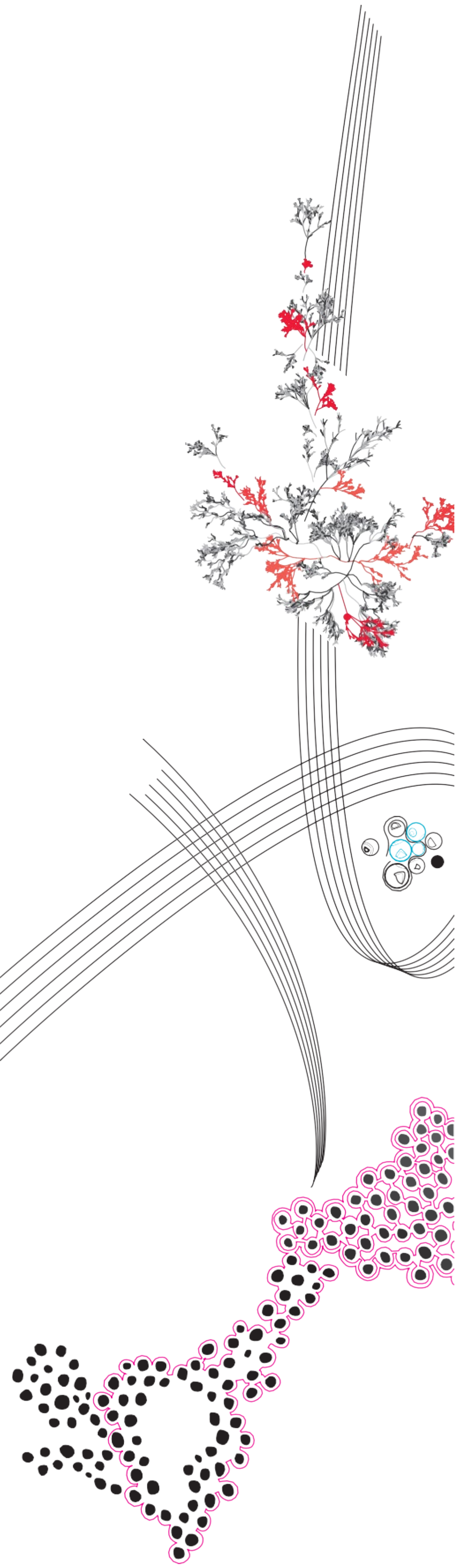

Thesis Project Report

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Integrating a multi-layer safety approach in the Dutch city of Zwolle, Noorderkwartier area: Enhancing housing flood resilience in an old center

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Abstract

This thesis investigates the potential of the 2^{nd} layer of the multi-layer safety approach by designing an inventory of feasible and effective spatial measures aimed to enhance the housing flood resilience for redevelopment plans of the Noorderkwartier project in the municipality of Zwolle. Utilizing a combination of literature review, interviews, case study analysis, and spatial analysis, the proposed inventory will be assessed on feasibility and effectivity of the proposed measures.

The research showed that there are three different types of implementation barriers that could hinder the consideration of spatial measures as an alternative to conventional flood defense methods, the findings showed that the proposed measures will have to overcome physical-spatial limitations, being accepted by the public and stakeholders and overpass institutional-organizational conflicts to be considered feasible. On the other hand, the spatial measures need to be suitable for the area according to the redevelopment plans while being able to tackle flood scenarios that could happen in 2050.

It was proposed a methodology to aboard the different stakeholder's opinions, perspectives, and priorities in order to select spatial measures that are more likely to be accepted, becoming feasible measures in terms of social acceptance. Likewise, it was proposed the use of a planning resilient tool to assess the effectivity of the measures according to a key performance indicator.

The results of this study contribute to improving the reception of the 2nd layer of the MLS approach within urban planning and water management in the municipality of Zwolle so it can become a pilot study for future research on the implementation of integrative approaches.

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1. Introduction

1.1. Background

Climate change is a widely discussed topic nowadays, despite skepticism about its impacts or existence. However, scenarios of extreme weather events, heavier peak rainfalls, and more frequent heat waves indicate that the planet is undergoing evident environmental change. In fact, according to Seneviratne et al. (2012), these scenarios will occur ten times more frequently by the beginning of the 22nd century, with the thawing of glaciers causing a decrease in ice volume in the poles, leading to an increment in sea surface temperature as well as a rise in worldwide sea levels and heavier rain discharges.

In this context, a country like the Netherlands is in a precarious position due to its location below sea level, with 60% of its surface at risk of flooding, and within a major river delta area (Stead, 2014). The Dutch meteorological office (KNMI) predicts a rise in sea level of up to 1.3 m by 2100, a scenario that nowadays is unmanageable with the current Dutch water. This fact is much more concerning considering that sea storms can directly affect the flow of the Rhine branches, which could mean numerous flood events due to the influence of the sea over the rivers and heavy rain showers, as happened before. Moreover, factors such as densely urbanized low-lying areas or, limitations in soil surface and basin storage capacity, make the Netherlands extremely vulnerable to water-related problems caused by climate change (Stead, 2014).

Considering the risks at which the valuable land was, the Dutch government had to develop a flood protection policy that gradually maneuvered itself into the network of defensive systems (windmills, levees, polders, etc.) that protected the land from floods coming from the sea and rivers (Slomp, 2012). Nonetheless, this approach was soon challenged by the well-known major floods of 1993 and 1995 which revealed that the Netherlands was not ready for events of such magnitude (Wesselink, 2007). That is why, the government had to research and embrace a new risk approach, one that could not only assess new water defense systems, but also that fits the perspective of the European Union Flood Risk Directive about an Integrated Flood Risk Management (IFRM) plan that can reduce both, the probability of a flood and the consequences it may causes (De Moel et al., 2015).

Under these conditions, a Multi-Layer Safety (MLS) approach was presented in 2009 as part of the Dutch National Water Plan in order to integrate what would become the three layers of the FRM plan: flood prevention, resilient spatial planning, and disaster management (Postma, 2015). However, since its presentation, the attempt to integrate the MLS approach has been unsuccessful as there is a historical record that makes evident that the first layer (preventive structural measures), tends to be implemented separately because the government gives it greater importance (Jong & van den Brink, 2017). This proves the engineering-based paradigm in which Dutch flood management is locked-in and the reason why it seems that the FRM plan is building ever-growing dikes rather that investigating mitigation adaptations.

According to Scholten et al. (2019), one of the reasons for the deficit of the integrative approaches is that the integration of layers in a multi-layered system is complex as it is deeply entangled with physical, social, economic, and political subsystems. However, the authors recognize that the failure of these approaches is given due to the late combination of layers imposed to the existing structure of a system, which leads to layers replacing the functions of others instead of supporting each other. Thus, the combination of layers roughly reaches an integration status, usually leading to a fragmented risk-based approach with ambiguity and conflicts of interest.

Here is where the Dutch city of Zwolle, and specifically the Noorderkwartier area, appear as a great opportunity to study the implementation of a multi-layered safety approach within the urban redesign of an area that is still in an early redevelopment phase so that the IFRM plan can be applied to develop measures and adaptations to mitigate climate change effects. On one hand, the region of Zwolle is considered as great example of combination of land and water, from high-dry sandy soils, peat meadow areas, polders to river landscape. The inhabitants of Zwolle that have lived in this delta for centuries, learned to coexist with water and rather than representing an obstacle, water became a key factor in the development of the region which resulted in a pleasant living environment and prosperity (Praamstra et al., 2018). Thus, Zwolle is considered the Netherlands in miniature. Like the country, the region is located within a delta zone with various waterways crossing through urbanized areas coming from different sources: Zwarte Water from Ijsselmeer, Ijssel and Vecht rivers, Sallandse waterways, groundwater from Veluwe, and rain showers (Praamstra et al., 2018), see Figure 1.

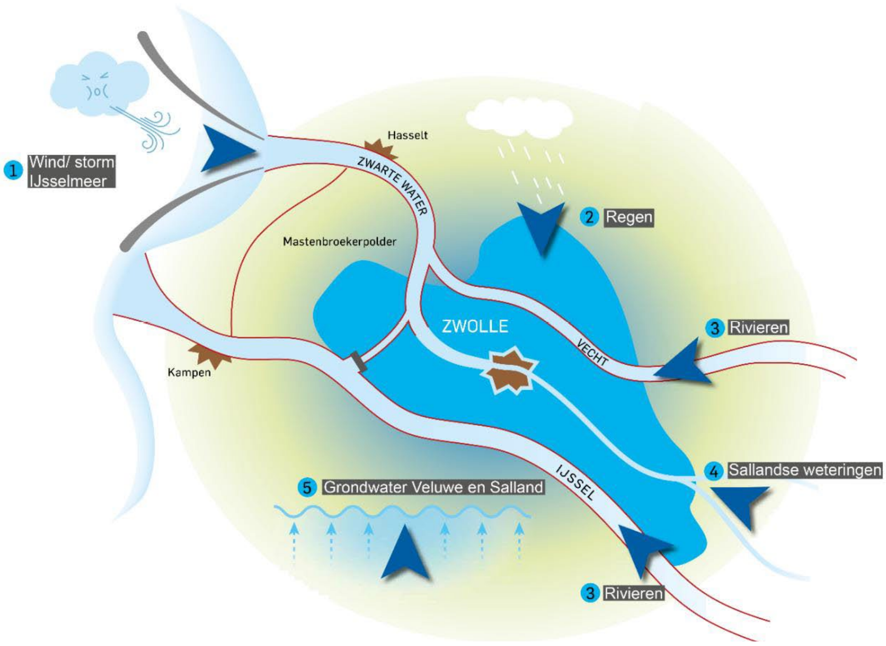


Figure 1, Water sources in the Zwolle region (Klimaatbestendige groeiregio Zwolle, 2018)

Due to the configuration of the city, Zwarte Water, IJssel and Vecht rivers have become characteristics of the Zwolle city center and key factors in terms of water management for the municipality (Deltastad Zwolle moet in 2050 een superspons zijn, 2019). In recent years, flood risk from the IJssel has been reduced through the "Room for the River" program and work will continue in the upcoming years on dike improvements along the Vecht and Zwarte Water. However, as a delta area, Zwolle is vulnerable to climate change due to colliding systems, for instance, water-related problems could be triggered by persistent north-west sea storm that would lead to a rise in the Ijsselmeer water level, that although can be controlled by the Ramspol defense, prolonged rains might influence the discharge from the Zwarte Meer that could directly raise the water level in the city canals, see Figure 2, (Klimaatverandering, 2019).

Figure 2, Effect of extreme discharge from Zwarte Meer on Zwolle (Waterrobuust Zwolle, 2019)

In this context, the redevelopment of the Noorderkwartier area, located on the north side of the city center, could mean an opportunity to study the MLS approach and implementing spatial measures and adaptations to mitigate possible fluvial flood scenarios since the inner-city would be the area with most considerable impact as this is located outside the dikes' protection (Omgevingsvisie 2030 "Mijn Zwolle van Morgen", verslag documentant, 2021). The report on climate-proof growth in Zwolle (Praamstra et al., 2018) states that in the last decade, the region has become a popular place to live for both city dwellers and peace seekers, thus, the city has experienced a growth in population that has led to an increasing the demand in housing which is mainly concentrated in the inner city. The report suggests that by 2040, at least 10,000 new households will have to be built to cover the demand, but rather than considering this as a problem, it could represent an excellent opportunity for linking the housing demand challenges to tasks in the city such as climate adaptation. For instance, the construction of new houses and structures around them could adopt spatial measures and techniques to enhance their flood resilience. In such case, measures from the 2nd layer of the MLS approach could be focused on developing adaptations that can be applied to existing and future housing constructions so these can be flood resilient, achieving one of the main goals of the municipality's environmental vision for the following decades.

1.2. Research Dimensions

1.2.1. Problem Statement

Considering that effects of climate change are already triggering a rise in the sea level and more frequent heavy rainfall events, it is not arguable that the Netherlands is at a constant flood risk. However, although the existing water management system and policies have provided a strong defense against water-related risks, this system is often isolated and oriented to prioritize reacting systems (dams, dikes, etc.) rather than investing in the development of anticipating and mitigating plans (spatial planning solutions). Therefore, since the presentation of the Multi-Layer Safety approach in 2009, there has been little success in its implementation into the current Dutch water management system and its potential is still unknown (Molenveld & Van Buuren (2019) and Oukes et al. (2022)).

Nevertheless, the Noorderkwartier area within the city of Zwolle is presented as a suitable case study because it is in an early redevelopment phase which allows the exploration of the MLS approach potential embodying its first two layers to develop spatial planning solutions that can be applied to housing structures within urban areas that lack of space and preventive systems to protect them against floods. In such a way, the layers within the MLS approach would support each other in creating a schematized bottom-up plan while contributing to materialize the municipality goal for housing flood resilience structures in the area. This study could also help to position Zwolle as a pilot study in implementing the MLS integrative approach since there is no previous investigation on the best spatial planning practices and solutions that can be applied in housing constructions to adapt flood scenarios and enhance resilience in the area.

1.2.2. Objective and Scope

As this is a design-oriented investigation, the objective of this research is to develop an inventory of spatial planning practices and solutions to enhance the housing flood resilience for the redevelopment plan of the Noorderkwartier area, in Zwolle. Such practices and solutions will be based on the second layer of the Multi-layer safety approach and assessed in terms of effectiveness (measured by probable flood impact in this area) and feasibility (considering implementation barriers on social, physical, and political levels).

It is important to set certain limitations for this study due to the duration of the project. For the sake of this investigation, the focus will mainly rest on the second layer of the MLS approach (resilient spatial planning solutions). It was already stated that the developing area to be analyzed is located out of the protection of flood-preventive measures (layer 1), therefore it will be only assessed their influence on the solutions within the second layer. Likewise, the third layer (disaster management), although will be defined, it is considered beyond the scope of this research due to limitations in time. Thus, the multi-layer safety approach will be implemented through suggested practices that can be classified within the MLS second layer and that also consider issues with measures from the first layer.
Furthermore, the research will be looking for solutions to tackle principally spatial issues to enhance flood resilience in housing structures but with a special focus on their effectiveness (e.g., spatial flood risk) and feasibility (e.g., overcoming implementation barriers), therefore, the spatial solutions to be researched will be principally aimed for external structure of housing buildings and spatial configuration in their surroundings, leaving internal infrastructure and connections of buildings relegated to second plane. Finally, although there exists a large set of practices of the MLS approach inside and outside of the Netherlands, this study will mainly take into consideration those case studies with relatable characteristics to the city of Zwolle (river delta area), as well as those case studies with

innovative practices that are aimed to enhance water robustness of housing structures with a base on the MLS approach.

1.2.3. Research Questions

The main research questions are based on the beforehand described objective, therefore these 3 questions formulated below concern the development of effective and feasible spatial planning solutions to enhance housing flood resilience in the Noorderkwartier, such solutions are based on the second layer of the MLS approach. Likewise, these main research questions are supported by several sub-questions that will be answered during the thesis assignment.

- **What are the best practices and solutions for the second layer MLS approach to enhance housing flood resilience and what are their implementation barriers?**

  Even though the MLS approach is a relatively new concept, it has had certain development in cities with water-related problems in and out of the Netherlands, nonetheless, reviewing all these cases would be out of the scope of this investigation, therefore:

  - Which comparable area development projects have implemented the second layer of the MLS approach inside and outside the Netherlands?
  - What are the characteristics of best practices of spatial planning solutions?
  - What kind of barriers could challenge the implementation spatial adaptations and solutions in the Noorderkwartier area in terms of feasibility?

Besides the observed solutions in comparable area development projects, it is important to evaluate the effectiveness of these solutions if they are applied to the spatial configuration of the Noorderkwartier, thus they need to be evaluated in terms of spatial impact:

- **Which areas and structures in the Noorderkwartier are found the most flood sensitive?**

  - What are the different flood scenarios that the Noorderkwartier could experience, and how do they vary in terms of severity?

In order to assess the relevance of the potential practices, it will be necessary to select those that contribute to mitigating the flood consequences in the Noorderkwartier area in terms of spatial impact and feasibility, therefore:

- **Which practices and solutions for the second layer of the MLS approach are considered effective and feasible to enhance the flood resilience of housing structures in the Noorderkwartier area?**

  - What practices and solutions from the preliminary inventory are considered feasible to be implemented in the Noorderkwartier redevelopment plan?
  - What practices and adaptations are considered effective to be applied to reduce the flood sensitivity of existing and new housing structures in the Noorderkwartier?
  - What physical characteristics of the Noorderkwartier area might restrict and/or facilitate to the implementation of the proposed spatial solutions?

1.2.4. Research Relevance

This study pretends to address the application of an integrative approach with different layers (MLS) to manage flood risks as an alternative to the traditional direct flood protection system (dike reinforcement) used in the Netherlands. The second layer of the MLS approach will be used to study and advise climate-adaptive spatial solutions to enhance housing flood resilience in the urban neighborhood Noorderkwartier, so it becomes future-proof.

As specified by the municipality's Environmental Vision for 2050 (Zwolle, 2021), because of climate change, pluvial flooding incidents in urban areas are more frequently affecting public spaces and private property, without mentioning the expected increased fluvial flood risk in the city center. Ergo, traditional infrastructure defenses around the city will become obsolete against water effects, existing dikes will not be able to withstand the rising water levels and sewerage systems and canals will lack the capacity to cope with the increase of stormwater (Oukes et al., 2022).

Despite the faltered progression in the implementation of the MLS approach into the Dutch water management, the most recent Delta Programme concluded that there is room for improvement of the MLS especially regarding its second layer: resilient spatial planning (Oukes et al., 2022). Therefore, the Noorderkwartier appears as a great opportunity to study strategies, adaptive measures, and spatial solutions within the 2nd layer of the MLS for the urban redesign of an area that is still in an early redevelopment phase.

By developing an inventory of resilient spatial solutions applicable in this area, it is expected to provide an advising instrument for the next phase of the Noorderkwartier redevelopment in which the Spatial Plan could consider the implementation of these solutions to build blue-green infrastructure, resilient housing structures, and to improve the current water management system in the area. Furthermore, the methodology to be used in this research is expected to provide guidance in overcoming implementation barriers that usually hinder the development of these measures.

The final inventory is expected to provide feasible and effective spatial solutions applicable to the Noorderkwartier project so if considered in the final design, this project could become a pilot study for the Delta Programme which intends to implement the MLS approach in other cities with similar characteristics and issues (Bosoni et al., 2021), so that resilient spatial planning solutions gain more momentum in Dutch water management and give more attention to climate-proof construction and water robust redevelopment.

2. Literature Review

This chapter examines key theoretical concepts from the literature that are pertinent to this research. In essence, the spatial measures that are being investigated are based on the second layer of the multi-layer safety approach applied in the water management of the Netherlands, thus it is important to define these terms as well as explaining where the best practices of the MLS application can be found.

The literature review is divided into 4 sub-chapters in order to provide a comprehensive analysis of the key concepts associated with spatial measures to enhance housing resilience in the Netherlands. The first part will provide an overview of the conceptual foundations and theoretical framework of the MLS approach, its background, and its components. The part will also explain what the characteristics of the second layer of the MLS approach are. The second sub-chapter will provide a systematic literature review of the multi-layer safety approach, with a focus on its application in the Netherlands. The third sub-chapter will examine case studies from international contexts, highlighting best practices and lessons learned from the application of the MLS methodology. Finally, the implementation barriers of these measures will be described in the fourth sub-chapter.

2.1. Multi-layer safety approach in the Netherlands

After dealing with the consequences of devastating river floods during 1993 and 1995, it was evident that the traditional flood management practices in the Netherlands, which mainly relied on preventive-defensive structures, resulted insufficient to counteract the effects of inundations in the country. This was particularly noticed when the first line of defense (reinforced dikes after 1993 storm) along Nederrijn and Waal branches resulted intact during the 1995 river flood events, but the rise in the water height in the rivers ultimately overtopped the barriers and in consequence, the cities of Nijmegen and Arnhem resulted inundated (Slomp, 2012).

In response to these events, the Dutch Delta Committee was required to update the flood risk management policy to shift from flood protection and toward an integrated approach where flood risk is actively controlled to also reduce flood impacts of future inundations (Van Herk et al., 2013). In 2008, the European Union Flood Risk Directive redevelop its policies in order to endorse a new integrative approach that addresses five phases of the flood risk management cycle:

- Protection: measures to reduce the probability of floods.
- Prevention: employ spatial planning techniques to lessen flood damage.
- Preparedness: strengthening organizational flood plans, emergency procedures, risk assessments, flood insurance, etc.
- Emergency relief: evacuation of affected zones and construction of temporary flood defenses.
- Recovery: reducing the negative social and economic effects in the impacted areas.

On the other hand, in 2009 the Dutch government decided to present a three-layered approach in its National Water Plan, such approach provided a new interpretation of risk management whose essence is that a flood can never be completely avoided and there will be inevitable floods in the Netherlands, thus, there must be a mitigation system and plans to act efficiently against the consequences (Postma, 2015). The main change that this approach brought was a technical-engineering-based paradigm shift attempt to a new focus on sustainable spatial planning considering that existing flood defenses would be unable to manage future and imminent flood events due to climate change. This introduced strategy is the so-called Multi-Layer Safety (MLS) approach, which explores ways to lessen the negative effects of floods and how to operationalize these ways instead of simply focusing and relying on constructing flood prevention systems (Van Herk et al., 2013). Overall, the MLS strategy is based on the risk approach whose essence is that a flood can never be completely neglected.

According to Leskens et al. (2013), the MLS approach is based on the flood risk management cycle but with a principal focus on strategies that are affordable by the government. The MLS approach introduced by the Dutch risk management plan contains three layers that englobe water protection systems, spatial planning, and crisis management, respectively. Specifically, the three different layers are described as follows:

- Layer 1: Flood prevention measures in the form of combined flood defenses (dikes, dunes, dams, and storm surge barriers) to prevent floodings and protect vulnerable areas.

- Layer 2: Flood adaptation measures in vulnerable areas in the form of physical resilient spatial planning solutions that are aimed to reduce flood impact.
- Layer 3: Flood disaster management measures in the form of evacuation plans and crisis management procedures in case of a flooding event.

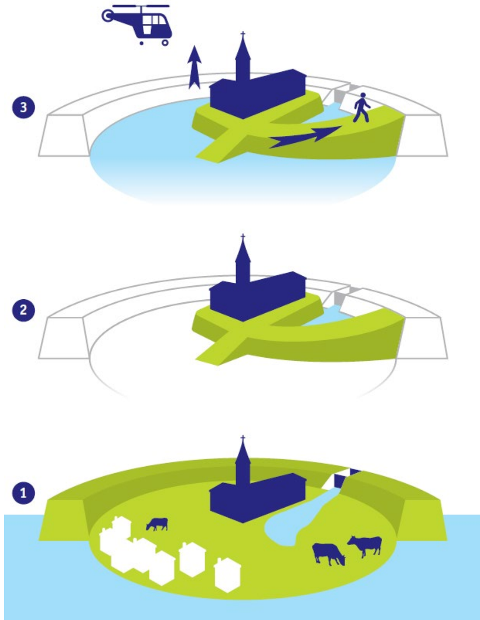


Figure 3, Schematization of the layers of the MLS approach Multi-layer safety: 1)Prevention, 2)Resilient spatial planning, and 3)Disaster management (Pötz et al., 2014)

2.1.1. Second layer of the MLS approach

According to Stead (2014), the spatial configuration of cities and towns, as well as how land is used and developed, have a substantial impact on both adaptation and mitigation of climate change. Besides, the redevelopment of flood-prone areas offers opportunities to sustainably improve flood risk management by exploring innovative ideas that include multifunctional spatial solutions, e.g., nature zones with recreational opportunities.
The policy memorandum report on flood risk management in the Netherlands (Postma, 2015), explains that it is urgent to conduct study on the second layer's potential for climate change adaptation in order to maintain long-term affordability and dependability of water management. In general, the report suggests that appropriate research on sustainable spatial planning measures for an area should include:

- **Flood risk zoning:** To transform flood hazards into perspectives for spatial development, the national government mandates that municipalities provide protection zones with a specific role within a structured vision. The Spatial Planning Act would serve as a basis for detailed mapping of sensitive areas that are localized. The risk zones are determined based on two main parameters, water depth and flooding arrival time.
    - Water depth is a key factor in estimating the likelihood of economic loss, ecological harm, and casualties. This parameter has a greater impact in infrastructures that are designed to adapt climate change effects.
    - Flooding arrival time parameter provides a more comprehensive perspective on the amount of time that is available to evacuate people of the affected zone and also provides information on how to set up protective mechanisms in the area for future disasters.

- **Attention to vital functions and vulnerable objects:** In a flood event, it is important to consider those significant functions and infrastructures that need to remain operating to reduce the effects of the inundation as well as to facilitate evacuation plans. Among the vital functions one could find energy supply, telecommunications, food and water supply, transportation. On the other hand, some vulnerable objects are healthcare facilities, bus/train stations, roads, industrial complexes, and cultural/ecological objects. The proper allocation of this vulnerable system needs to be considered in risk zones mapping so the vital functions and vulnerable objects have certain priority in construction (location, integration, and design) and protection (physical and organizational disaster management measures)

- **Compartmentation of dike rings:** Although this could be considered as a preventive measure (part of the first layer), the report suggests that the vulnerability of certain areas can be reduced by dividing the dike ring into smaller compartments with intermediate dikes. Nonetheless, this would require major maintenance costs and it does not ensure that these obstacles can withstand extreme events. Furthermore, this measure is only applicable to certain zones that are found within a dike ring.
- **Responsible use of space outside the dikes:** For all the areas that cannot be protected by preventive-structural systems, the spatial configuration needs to ensure that these fulfill a drainage and storage functions in order to reduce damage. The chance of casualties in these areas is usually minimal as these are not as deep as polders, however, the economic damage is much larger as areas outside the dikes are also attractive locations for nature, agriculture, living, recreation and have cultural-historical value. The report also suggests that current water management policy in areas outside dikes is inconsistent as the relation between infrastructure and land-use leads to delays in initiatives for new development projects.
- **Emergency flow areas:** This relates to the regions that were previously planned and constructed to prevent flooding. When the dikes failed, these locations were meant to manage the flooding as the last resource. However, because most of these places were never again utilized, they have been neglected for decades. According to the report (Postma, 2015), the Interim Decree (2005) dropped the reservation of emergency overflow places because the majority of them were left as empty spaces with only one use.

2.2. Housing Flood Resilience

Along with the MLS approach concept, this new paradigm in the Dutch water management started to evolve based on prevention and anticipation rather than reaction (Oukes et al., 2022). This new paradigm is usually referred as a "new water culture" and characterized by resilience over resistance strategies, a theory much discussed in climate adaptation and planning research nowadays. In line with the research done by Oukes (2019), the concept of resilience from the Dutch national policy departs from a so-called risk-based approach which instead of solely focusing on minimizing hazard probability (resistance strategy), it aims to reduce flood probability and consequences. However, the author also reflects on how this term can be ambiguous in different fields, for instance, engineering resilience takes resilience as the ability of a system to bounce back from a hazard event while the ecological perspective takes resilience as the ability of a system to change and still persist the hazard.

In this study, a similar concept is used to understand the resilience for livable structures in urban environment. Bertilsson, et al. (2019) have defined the resilience in urban areas as all the strategies and measures that not only keep water away from sensitive structures but also to adapt land-use and the structures themselves to minimize the damage potential, thus resilience and resistance are not opposites, but resistance is an important aspect of resilience. Nonetheless, Restemeyer et al. (2015) and Oukes (2019) acknowledge that building water robust is not sufficient within the concept of urban resilience, and that housing structures should be able to withstand, recover from, and reorganize in response to a flood event. Therefore, both authors agree that urban resilience should couple other two attributes besides water robustness construction, namely, adaptability and transformability.

In this context and based on the research done by Restemeyer et al. (2015), for this research, water robustness construction is described as those technical and spatial measures that will reduce the chance of floodwater reaching housing structures even after floodwater has overtopped the first line of protection surrounding the built-up zone (dikes). Adaptability will imply those adjustments of the physical environment, and sometimes of social spheres, to develop measures that prepare housing constructions considering that flood might be allowed but controlled in specific areas. Finally, transformability is taken as the capacity of structures to shift from "fighting the water" to "living with the water" where the water that has reached the public domain and private property does not represent a problem necessarily, but an opportunity to use this water for other purposes tackling different tasks in the municipality's agenda, for instance water shortage, heat waves, etc. (see Figure 4)

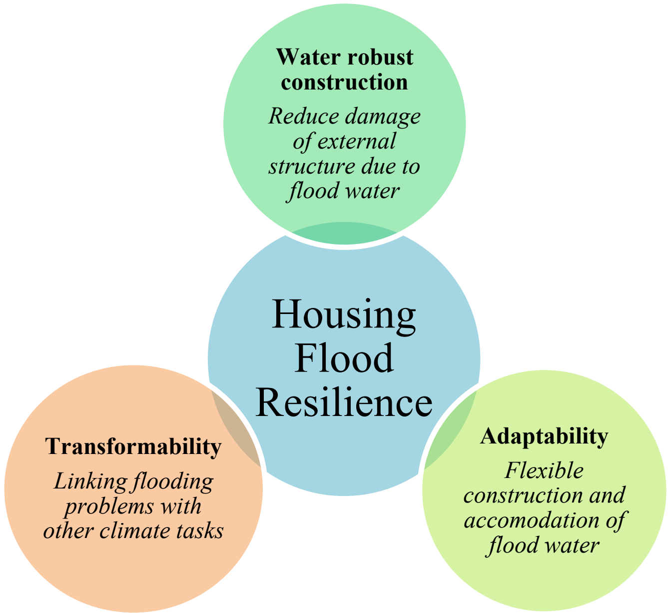


Figure 4, Adapted figure of the housing flood resilience components (Oukes et al., 2022)

2.3. Best practices within the MLS approach second layer in the Netherlands

2.3.1. Dordrecht

Due to their vicinity to water bodies and their susceptibility to flooding, the Dutch cities of Zwolle and Dordrecht share similar physical characteristics, both cities are located in a zone that serves as a transition between the tidal reach and the river regime reach. This zone is characterized by drastic water stages caused by a combination of heavy river runoff and storm surges from the sea (Van Herk et al. (2013). Furthermore, both cities have unembanked zones that comprise part of the historical city center and residential areas, thus, these municipalities have a long history of overcoming challenges associated with dealing with water in the urban area. Besides the fact that several redevelopment projects in Dordrecht are comparable cases to the Noorderkwartier in Zwolle, this case study is principally considered as a pilot study to be followed since this city adopted an IFRM plan based on measures from the MLS approach with relative success within the Dutch Delta Program (Gersonius et al., 2011), by combining conventional prevent systems with spatial measures (Hoss et al., 2013). As a result, government bodies in Dordrecht have devised comprehensive water policies that prioritize water safety, sustainable urban planning, and adaptation to climate change (Van Herk et al., 2013).

In recent years, the city of Dordrecht has included a variety of adaptive measures in its redevelopment plans in order to increase the flood resistance of its housing stock. Several research papers, books and reports explore some of the measures, strategies and adaptations that were implemented in different projects and some others that have the potential to enhance building's resilience in delta areas. In general, Van Herk et al. (2013) present an evaluation framework for the contribution of the MLS approach to the IFRM plan, where the second layer is addressed by a planning, design and engineering phase that explores possible flood-measures suggested by Van de Ven et al. (2009). The book published by Pötz et al. (2014) explores how 2nd layer measures have been recently applied in the island of Dordrecht by linking them to nature management, recreation, and housing infrastructure. In their book, the authors mention solutions for housing structures by adapting the buildings' architecture, temporary flood defense systems around the buildings, or new methods to construct water-resistant structures classified in different levels (e.g., buildings, blocks, and neighborhood levels). Similarly, the report presented by Oukes (2019) about pathways to resilient spatial planning in FRM in Dordrecht and Ijssel-Vecht delta, explains adaptability strategies to enhance housing resilience by adapting blue-green measures into the urban infrastructure and surroundings so there exist solutions to avoid water entering the building but also solutions to reduce damage and casualties. Gathering the different measures in a simple classification, these can be described for different spatial scales, namely, single buildings, buildings blocks and neighborhoods.

- ***Measures at building level***
  - *Sealable buildings:* prevent water from entering the building by equipping structures with mechanisms that allow for their closure, such as bulkheads or hatches. Not only should this involve shutting large openings like windows and doors, but it should also involve closing smaller apertures like open butt joints, ventilation grilles, casing pipes, letterboxes, and similar openings. Buildings with functions that require few openings, such as car parks, are easier to make lockable.
  - *Water-resistant construction:* It is possible to design structures so that inundation does not cause structural damage. This should involve the use of water-resistant materials, such as concrete, closed-cell insulation, masonry, wall and floor tiles, aluminum and steel frames, glass, etc. After a flood, only cleaning, painting, and possible replacement of damaged domestic items should be needed. Building structures should be able to withstand any water pressure.
  - *Elevated buildings*: buildings can be elevated on piles so that housing functions are on higher floors while less vulnerable or transient functions, such as parking or storage are at ground level, it is important to consider water-resistant construction measures. Pötz et al, (2014) remark that if the structures are constructed on an elevation (such as a mound or dike), the elevation may function as part of the flood defense, however in the Netherlands, building on a flood defense is not practiced.
  - *Controlled flood within a building:* there is a high probability that water will find its way into the structure. Because of this, it is essential to utilize materials that are resistant to water. Van Herk et al, (2013) suggest wet-proofing adaptations such as tiled floors or covering for foundations to preserve the infrastructure.
  - *Buildings with high floors and skylights:* considerable high buildings could be used as shelters for people during a flood event so they can be evacuated from the highest floors (vertical evacuation), when roads become impassable and dangerous (difficult horizontal evacuation).

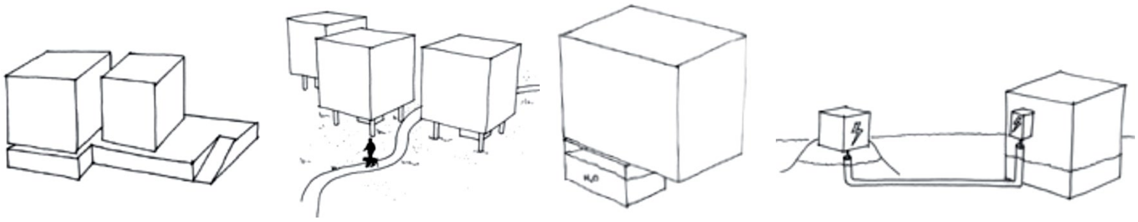


Figure 5, Measures applied at building level (GROENBLAUW atelier, Pötz et al. (2014))

- ***Measures at building block level***
  - *Artificial barriers outside the building:* a more effective and manageable security solution because a flood defense system surrounding a number of buildings requires less work than a separate temporary flood defense system for each building, this will most likely also be a more cost-effective alternative. The challenge would be adapting the barriers to urban structures, so they do not obstacle the traffic flow.
  - *Temporary flood defenses:* movable panels, partitions, and inflatable tubes can be used to protect an entire neighborhood at once. As management, maintenance, and operation are in public hands, this measure is controlled by residents, but the costs are relatively high. Several neighborhoods in Dordrecht have adapted baffles to restrain water flow.
  - *Elevated areas:* It is possible to raise considerably an area to a certain elevation so it becomes a mound in which buildings can be erected, however, this is only feasible if the area has no

previous constructions, or if such can be raised too. Pötz et al, (2014) suggest that mounds are suitable for vulnerable functions such as utilities, emergency services, and improvised shelters.

- *Differentiation in heights*: The connection between the water level and the elevated living and working areas can be constructed in phases within the same neighborhood. Stepped construction allows for the creation of additional height that influences the resident's awareness of low grounds and safe zones.
- *Streaming*: If an area is found to be subject to frequent flooding, buildings should be placed in such a way that these do not impede the flow of water. This reduces the risk of building collapsing due to water pressure.

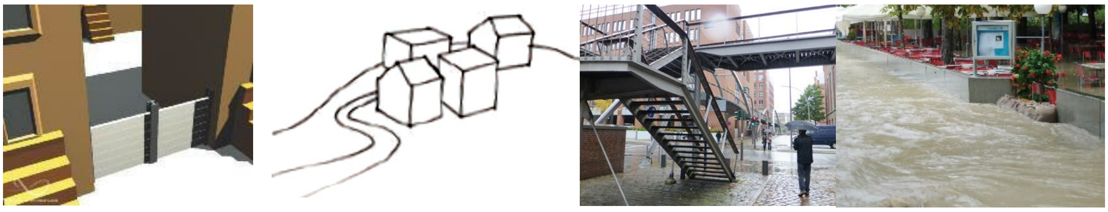


Figure 6, Measures applied at building blocks level (Van de Ven et al. (2009) & Pötz et al. (2014))

- ***Measures at neighborhood level***
  - *Reintroducing raised pavement*: Sidewalks keep water on the street and dwellings dry during severe rainstorms, a raised sidewalk could help to prevent building flooding at a limited water depth. Many cities and districts have removed sidewalks to make them wheelchair-accessible, reduce traffic, or for landscape reasons.
  - *Guidance of rainwater over the road*: Restructuring and housing redevelopments can arrange road decay to send rainfall to areas where it can be stored o limited. The concave design of roads increases the storage and drainage capacity of the road. Combined with a sidewalk and a slightly raised floor level and/or threshold in the houses, this can prevent flooding in the houses.
  - *Additional water storage*: the authors explore the opportunity of creating water storages in public spaces, for instance, parks, sports fields, and vacant lots.
  - *Water-resistant bulkheads*: consist of vertical H-profile aluminum girders that are attached to the waterline of canals. Although this measure is suitable for protecting existing areas with erected structures, the barriers would impact the added aesthetic value of the area.

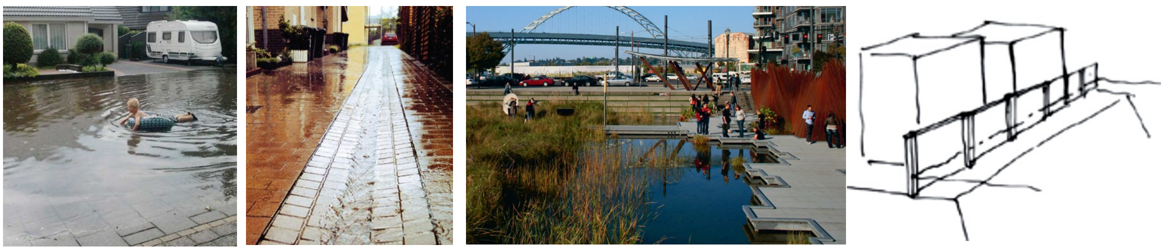


Figure 7, Measures applied at neighborhood level (Pötz et al. 2014))

2.3.2. Rotterdam

Although the city of Rotterdam could be considered a distant case study due to its location and size in comparison to the city of Zwolle, it is possible to identify areas with a similar spatial configuration, for instance, unembanked areas that are outside the primary flood defenses. Like Zwolle and its city center, some areas in Rotterdam lack structural flood defenses and thus are vulnerable to climate change effects. De Moel et al. (2014) present a research that evaluates spatial measures in the second layer of the MLS approach to be applied in unembanked areas with a high probability of flooding. Nonetheless, beyond the geographical similarities with Zwolle, Rotterdam is being considered as a relevant case study to identify best practices for the MLS 2nd layer because of the paper presented by Moel et al. (2014), which has a special focus on resilience of housing structures and which actually proves that damage-reducing measures within the MLS 2nd layer can significantly lower the flood risks in unembanked areas. In general, the authors classify the spatial measures in two: structural and non-structural. In their paper, the authors present both type of measures to reduce the possible consequences of a flood that are slightly based on adaptations applied in the city of NewYork that in turn are based on urban waterfront architecture and planning projects in Tokyo and Hamburg (Aerts & Botzen, 2011). It is worthy to mention that the authors limited the reaseach to calculating the effect of structural measures in singlular buildings in a risk assessment model, which is why the measures presented can be considered adaptive measures for single buildings. In terms of structural adaptive measures, the auhtors mention:

- *Elevating buildings*: is described as a straightforward measure as it decreases the inundation depth of an entire area and thus, reduces the flood damage considerably. Elevated areas will require higher and unlikely inundation depths before the areas get flooded.
- *Dry proofing measures*: propose adaptations such as waterproofing outside facades or measures like sealing the infrastructure and checking the swerage system so no water enters the dwelling.
- *Wet proofing measures*: allow certain areas to get flooded but in a controlled way so that damage effects are less as possible. It also proposes moving vulnetrable functions and installations of dwellings to higher floors, this includes chaning electric and gas connections.

For non-structural adaptive measures, the authors mention:

- *Adequate warning and effective communication:* with those residing in risk locations. Despite the fact that these precautions are included in the MLS 3rd layer, good communication may allow the occupants to develop safety measures themselves or evacuate valuables to safe elevations.
- *Zoning regulations:* include the relocation of vital functions within flood-prone land, this reduces both direct and indirect damages due to floodings. However, since zoning plans are usually developed every 10 years, rezoning in existing build-up areas is difficult.

Likewise, practices within the MLS 2nd layer can be found in the risk assessment research of a case study on Heijplaat by Wolthuis (2011) and the redevelopment study of the Rijnmond area by Van Vliet & Aerts (2015), both studies in the proximities to ports in Rotterdam. In the first case, the author constructs a framework to recommend spatial adaptations for the planned urban dwelling project in an unembanked area. In the second case, the auhtors develop a toolbox of adaptive measures that not only assess adaptations in buildings but also in building blocks and entire neighborhoods. Both studies mention strategies to have flood adapted buildings to reduce impact of flooding, such strategies are given another type of classification: individual flood proofing of buildings and adapting the building activities to risk. On one hand, individual measures against flooding involve dry proofing, wet proofing, elevated configuration of zones, as mentioned previously by De Moel et al. (2014). On the other hand, adapting building activities to risk explicitly considers the design and infrastructure of the building so it can manage water overflow or retain it. Wolthuis (2011) agrees about how certain physical construction interventions have been proved effective to reduce the immediate impact of floods, however, he contradicts De Moel et al. (2014) and says that compared it to regular dwellings, the investment costs to adapt the buildings is expected to be higher than the original construction costs.
For the case studies of Heijplaat and Rijnmond, the authors give more concise solutions for each category, for individual flood proofing measures they recommend the following constructional adaptations:

- *Constructional dry proof measures:* dry proof outside walls, sprayed cement, flood resistant external doors, non-return valves in waste pipes and outlets, airbrick covers, pump and sump, drainage lines around the perimeter of the house.
- *Constructional wet proofing measures*: wet-proofed gardens, solid concrete slabs, plastic flooring, closed cell insulation, composite internal walls, flood resilient kitchen, flood resilient doors, windows and frames.
- *Constructional measures for elevated dwelling*: concrete walls, concrete staircases, redesign of building functions such as electricity and gas, and elevated foundations to keep the main structure above floodwater level.

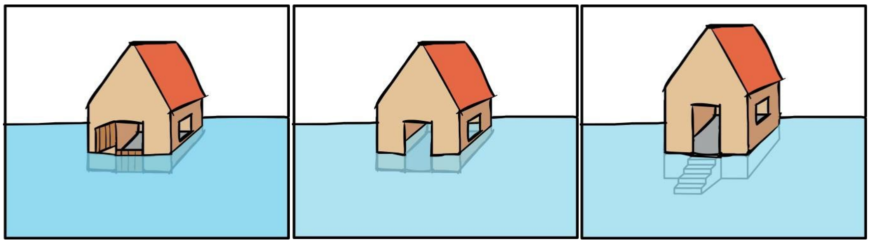


Figure 8, Constructional adaptations: Dry proof, Wet proof, and Elevated dwellings (Wolthuis, 2011)

For adapting the *building activities to risk*, the authors reflect on how adapted buildings can contribute to the social and spatial context of the project, for instance, an elevated building will give room to inhabitable spaces below it which can be used as both, a parking lot and water storage to manage fluvial floods. Similarly, it is also feasible to permit water to enter the structure while yet limiting the damage, for instance, households with basement windows could incorporate flood bulkheads to control access of water. Inside the household, a tiled floor can be put in place of a wooden floor, and the fuse box and plugs can be raised (Van Vliet, et al., 2012). In addition, the infrastructure of the building can incorporate features to manage pluvial floods, for instance, rain gardens, green roofs, and permeable floors that could absorb and delay water flow so traditional drainage systems can manage the runoff effectively.
In the case of non-structural adaptations, Van Vliet and Aerts (2015) suggest building codes and land-use zoning plans as regulations for buildings and neighborhoods respectively. The authors acknowledge that the current regulatory framework is limited and although building codes present standards for the water resistance and absoption of facades, these are not aimed to extreme flood situations. Thus, wet and dry proofing can be enforced within building codes, so contractors take this regulations as strict policies, instead of being considered voluntary agreements between the government and bulding companies. On the other hand, land-use zoning can serve as a guide for the positioning and layout of crucial infrastructure including green areas, multifunctional buildings, and drainage systems. Infrastructure can be deliberately positioned in locations less prone to flooding or built to withstand flood occurrences by taking flood risks into account during the planning stage. This lessens the possibility of harm and increases the built environment's resilience.

Overall, the practices previously mentioned by De Moel et al. (2014), Wolthuis (2011) and, Van Vliet et al. (2012) are related to housing resilience and considered some of the best practices for this matter since they were assessed in terms of effectiveness through risk assessment models and in terms of affordability. The model used by De Moel et al. (2014) uses a damage curve for building content and simulates a flood raising from 0.6 to 3m, which is the standard height of the first floor of a dwelling. The risk assessment showed that slight structural adaptations can reduce the probabilty of flooding greatly. For instance, in the event of a river discharge increment of 21%, elevating a building 50cm would reduce the flood risk in 61% while elevating it 100cm would virtually eliminate the damage at all, although this will ultimately depends on the topography of the studied area and the building content. Likewise, the model showed that wet proofing and dry proofing adaptations would reduce the flood risk by 40% and 89% respectively. Furthermore, Wolthuis (2011) emphasizes on how dry proofing adaptations are effective for a flood depth until 0.9m while wet proofing is usually designed for flood levels until 1.2m. In terms of affordability, the authors agree that costs of building adaptations are well manageable. According to De Moel et al. (2014), flood adaptations would represent a share from 0.75% to 9% of the original building costs, besides, several studies revelead that when areas and buildings are to be elevated, the adaptation would require transportation and mining costs, but these would not surpass the 9 euros per cubic meter in the Netherlands (Van Vliet & Aerts, 2015). Nonetheless, the authors indicate that solutions could be cost-effective only for the development of new buildings since this would not require extra costs for adaptations to exisitng structures.

2.3.3. Enschede

In the last decade, Enschede has become a relevant municipality within the Twente region regarding water management to control and adapt waterlogging due to heavy rainfall (Projecten Klimaat en Energie Enschede, 2023). In fact, according to the research done by Van den Berg and Coenen (2012), climate change projects adapted to the local policies of Enschede have derived into urban resilience efforts to mitigate floods.

Comparing Zwolle and Enschede, it is true that Zwolle is located within a delta zone and thus there is an increased flood risk due to the Ijssel River. On the other hand, Enschede is situated "high and dry" on the slopes of a lateral moraine along the Dutch-German border (Van den Berg & Coenen, 2012). However, despite the different geographical characteristics of these municipalities, both have similarities in their policies to mitigate and adapt climate change effects, such as setting similar goals to reach a climate-proof city by 2050 through water-robust construction and green-blue infrastructure integration (Enschede, 2021).

Currently, Enschede is notable for developing innovative programs to mitigate climate change effects as a response to experienced inundations due to rainstorms, being the 2010's extreme precipitation the most recent and heavy one (Van den Berg & Coenen, 2012). Due to the remarkable progress of the municipality of Enschede in developing climate-adaptation projects, the "GroenBlauw Twekkelerveld" project is considered one of the best practices for the implementation of the MLS 2nd layer in an urban area due to its recent development and because both municipalities will have to experience extreme weather events due to climate change in the future and this will add pluvial flood to the risk equation.

The "GroenBlauw Twekkelerveld" is an ongoing project that started in 2022 as response of continuous flooding and waterlogging due to heavy rainfall in a residential neighborhood in Enschede (GreenBlue Twekkelerveld, 2021). As principal activities, this project is tackling the flooding in the streets by using structural measures in the surroundings of the households; among the most relevant:

- Design and construction of a new *separate sewer system* for the drainage of clean water below the most affected streets. In the process, asphalt from the street is replaced with cobblestones for a better filtration.
- Implementation of more efficient *gutters with grid*s to drain rainwater in such a way that it does not affect the existing design of the bicycle street.
- Redesign of the bicycle streets so the *surface is slightly convex* to the sides, increasing its water capture and drainage capacity.
- The most important measure is the construction of a "*blue vein*" which will be a sort of *60-meter-deep trench* that would be able to collect and rain rainwater from the paved ground. According to the website "GreenBlue Twekkelerveld" (2021), when it rains heavily, the trench will become a stream that drains water from the entire neighborhood towards the Twente canal. Although part of the water will sink into the ground, in an extreme scenario, the canal would not be able to manage this discharge, that is why low green areas are created in the surroundings so water can be temporarily stored up to 24 hours.

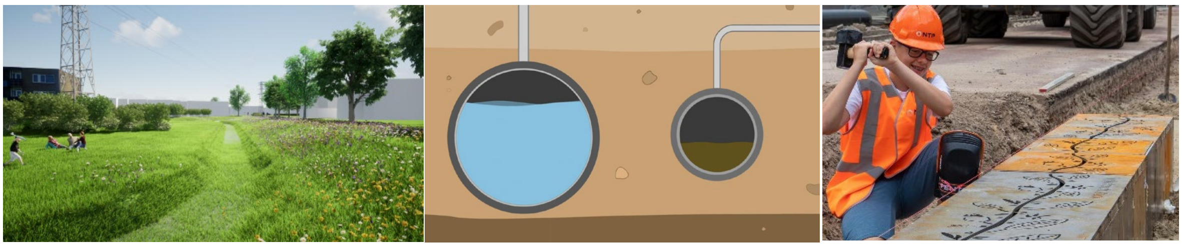


Figure 9, Structural measures designed for Twekkelerveld, (GreenBlue Twekkelerveld, 2021)

One of the main cores of the green development in Twekkelerveld and in Enschede generally, is the design of Dutch wadis in the green areas. According to Boogaard et al. (2007), the wadis are originally a type of drainage system that is designed to only carry water after rain showers, nonetheless, the authors explain that wadis in the Netherlands have another purpose: collect, retain, and infiltrate rainwater into the soil, becoming a rainwater harvesting system. The authors specify that below the Dutch wadi system there exist a special layer of sand that directs water to a container filled with soil aggregates, this box also contains a drainage pipe which is connected to a drainage pipe from a bioswale whose inlets (gulps) are in the surface of the wadi (see Figure 10).

Furthermore, the municipality of Zwolle actively participates in increasing general population awareness of flood risks by providing a website with recommended measures and their estimated cost, implementation difficulty, and maintenance, so residents are advised what type of green and climate-proof measures are recommended in their gardens. Among the relevant measures found in *GroenBlauwEnschede* (2022)related to housing resilience, it is possible to find:

- Disconnecting the downspout: detaching the downspout from the sewer system so rainwater accumulated in the roofs is redirected to a place in the garden, to a barrel to be used later, or to a nearby wadi. From 2022, the municipality offers a subsidy for the applying this measure.
- Make height differences: it is recommended to have high parts in the garden such as an elevated terrace that remains dry after a heavy rain shower as the water flows in lower parts of the garden. It also recommended to take tiles and impermeable surfaces out so water can easily infiltrate the soil.
- Greening roofs and walls: capable of absorbing and retaining precipitation, thereby reducing the volume and intensity of stormwater discharge. In these green systems, the plants and soil function as natural sponges, slowing water flow and allowing for gradual absorption. This reduces the risk of urban inundation and helps relieve pressure on stormwater infrastructure.

Figure 10, Structural measures applied in projects in Enschede, GroenBlauwEnschede *(2022)*

It is important to notice that the precise implementation of the second layer of the MLS approach in Enschede varies based on local conditions, ongoing projects, and the understanding of flood risk management in this municipality (mainly pluvial flooding). Nevertheless, all the previously mentioned measures were proved effective in several climate-adaptive projects for housing resilience in terms of rain resistance (Maatregelen Voor Een Groene En Klimaatbestendige Tuin, 2022). Therefore, the before mentioned practices make Enschede and the Twekkelerveld one of the best practices of the MLS approach to adapt flood coming from heavy rainfall and is worth to be considered since these measures are primarily focused on detached and semi-detached households. Likewise, beside structural measures, the municipality of Enschede continues to assess non-structural measures to improve awareness and interest of residents in climate-adaptation projects in their neighborhoods (GreenBlue Twekkelerveld, 2021).

2.4. Best practices within the MLS approach second layer outside the Netherlands

2.4.1. Hafencity, Hamburg

Since the inner city of Hamburg began to be redeveloped in 2008, it has served as a pilot model for the construction of urban waterside projects in Germany. Hafencity represents a large reclamation of the city center from the water in order to develop housing and leisure activities while re-establishing the link between water and the urban areas (De Hoog, 2012). In fact, the spatial development project was intended to be the most significant and expansive inner-city renovation in Europe, according to the development firm HafencityHamburg-GmbH. According to Clermont

(2016), similar to the spatial configuration of Zwolle, Hafencity is not only excluded from the protection of dikes and structural defenses but is also spanned by rivers and canals whose water levels could be influenced by storm surges coming from the north sea, fact that poses a flood risk to the city residents and built-up infrastructure. However, despite the risk of occasional flooding, the redevelopment plans never contemplated the disconnection of the urban area and water by surrounding it with dikes. Due to the long tradition of Hamburg with flood risk management, Hafencity is thus considered as a great referent of urban area development and comparable to the redevelopment of the Noorderkwartier in Zwolle for not only combining workplace, residential uses, culture, and leisure in mixed-urban structures, but for the intensive interaction between land and water (About HafenCity, n.d.).

Among all the functions that are part of the redevelopment project of HafenCity, this research considers those that characterize measures within the 2nd layer of the MLS approach. For instance, De Hoog (2012) mentions that as part of the redevelopment, Hafencity needed a new urban topography against tidal water levels, emergency flooding and occasional storms, however, as a large part of the area's appeal stems from the coexistence of urbanization and water, enclosing the area with dikes would be counterproductive because it would deprive the view. The author remarks the combination of waterline zones and flood barriers as structural adaptations that can be applied in these types of redevelopments, for instance they show how public areas and greenery could be placed along the river so that flood defenses can be adapted to the topography and landscape (see Figure 11).

Figure 11, Urban topography at riverfront areas (De Hoog, 2012)

From an urban standpoint, it was known that the shoreline topography alone would not be able to withstand heavy floods, leaving roads and housing structures unprotected. As a result, the ground level would need to be raised by 4 to 8 meters above sea level because the water level rises and falls around 3m daily (De Hoog, 2012). This structural adaptation is the main flood protection in the area and gave buildings enough space in the lowest floors to adapt other functions such as parking, in such a way that stationary traffic can be accommodated out of sight. In fact, according to Roumen (2012), the master plan for Hafencity contemplated using the first line of buildings as a secondary protection line against floods, for instance, using the underground garages as retention areas would leave the higher level of public flood protection to connected open spaces, parks and squares so this can serve as a buffer of floods at different altitudes (Luchterhandt et al., 2011). Nonetheless, by including plinths and water-tight hatches into the building design, these spaces can also house other activities; in Hafencity, plinths took the form of public spaces, promenades, and parks along the waterline (Luchterhandt et al., 2011). Similarly, roadways and pedestrian bridges were accommodated at a 7.5m distance to ensure people's safe passage during storms and create at least two flood-protected access routes available all the time for emergencies (HafenCity, 2006). Following this concept, open spaces were built to be experienced on two to three levels by using stairs, walks, and ramps, these would not only impact the mobility of pedestrians in the area but also functions as emergency conducts in case of floods (De Hoog, 2012) & (Clermont, 2016).

Considering a pluvial flood due to persistent rain showers and looking at the masterplan of the redevelopment (HafenCity, 2006), it is possible to notice that the sewer system was redesigned as a dual system to drain sewage and rainwater separately. The redesign for this area proposed that the rainwater run-off should be retained as long as possible in green roofs and land surfaces such as parks so it can be discharged directly into the Elbe and the harbor basins after the storm. On the other hand, run-off water from streets, underground garages and other lands will be discharged to the Elbe first but it must be treated before it can be drained through the sewer. The advantage of having the dual sewer system is avoiding the pluvial flooding due to excess of water in the streets.

All in all, Hafencity is considered a paradigmatic instance of the application of measures within the MLS 2nd layer in the redevelopment of an area prone to get flooded. The research shows that this redevelopment project proposed innovative and sustainable urban planning solutions so that multi-functional structures can be adapted to flood and therefore can mitigate the risk of flooding. However, the authors did not reflect on specific solutions within housing structures, they limit the study to the principal flood defenses implemented in Hafencity, which was found to be elevating the entire area and redesigning buildings would virtually eliminate the flood risk in the area, or at least, it would reduce the impact of an unusual storm surge as the authors agreed upon.

Gathering the relevant measures and adaptations that were implemented in the redevelopment of the city center for housing resilience, these are considered as the best practices because of the way the redevelopment achieved constructing appropriate mixed urban areas, adapting public spaces to artificial water defenses, and enhancing interaction of urban structures and water. In the first case, old buildings within Hafencity were adapted and others were built in such a way that they share residential and office use domains on upper floors while the ground floors were adapted to public use, this creates mixed zones between public use of the open spaces and semi-public use of ground zones that could work as a buffer or artificial barrier during flood events (HafenCity, 2006).

Besides, Hafencity is considered a pilot study because, despite the limited space available, the new area has a high proportion of publicly accessible zones that are multi-functional. The networking of parks, streets, squares, and mainly, the redesigned docks into boulevards, in combination with the closeness to the water, results in potential spaces to block and/or retain water. Nevertheless, the developers were aware that water defense areas should not only have a visual effect but also be usable as urban spaces. This characterizes a green-blue approach that uses greenery elements to be part of the mitigation system implemented in the mixed structures. Likewise, the masterplan also specifies that the redevelopment of public zones was based on a strong connection between public spaces and the residents, for instance, cultural functions such as museums could be in a favorable location on the waterfront, while the surroundings can withstand a larger range of daily activities (HafenCity, 2006).

From a policy perspective, Hafencity and Hamburg in general are considered as best practices because redevelopments that have taken place here have usually set on the application of an MLS approach within their FRM plans. Considering that the principal flood defense in Hafencity relies on constructing buildings on elevated surfaces, such constructions already satisfy the building codes imposed by that same city instead of dealing with different legal frameworks. This results in flood defenses of Hafencity operating within a flood risk of 1:7200 while the German FRM plan states one of 1:200 (Clermont, 2016). Therefore, it was concluded that several innovative solutions for flood protection control can be developed through different strategies and well-planned urban structures that are supported by a legal framework within the city or region (De Hoog, 2012).

2.4.2. New York and Boston

The cases of New York and Boston are worth to be studied and considered as ones of the best practices in applying the 2nd layer of the MLS approach within their own national flood management system with success. In short, the application of spatial measures to flood-resilient developments plans was achieved through the combination of flood policies such as bridging flood insurance, building codes and flood zoning (Aerts & Botzen (2011) and Auton (2015)). Although the American cities do not share substantial physical characteristics with Zwolle, these cases are relevant in order to understand how design guidelines, regulations and governmental policies are powerful tools in the implementation and the success of the MLS approach in development projects.

Among the measures established by the New York municipality, there is particular attention to setting risk-based incentives to house owners. This measure is based on what is the potential flood-risk of a building or an entire area, in such case, the municipality can provide an incentive to house owners so they can consider wet- and dry-proofing measures for their buildings. The paper related to flood-resilient waterfront development in NY city explains that this incentive system is distributed according to another measure: classification of risk zones using detailed flood hazard maps. That is why, the paper also explains that insurance costs from private companies are set to reflect the actual risk of flooding of certain area and according to the risk of individual properties, in this way, houseowners in high-risk areas pay higher insurance costs than those in low-risk areas, accepting the incentive system from the municipality and ultimately implementing risk reduction measures to make neighborhoods more resilient. (Aerts & Botzen, 2011)

In the water management governance in the U.S., local municipalities are allowed to impose zoning regulations and building codes in addition to the minimum standards established by national plans (Aerts & Botzen, 2011), similar to the case of Hafencity in Germany. The additional flood building code regulation for New York includes:

- Stricter foundation standards for all the structures in areas historically and potentially prone to get flooded. This measure depends heavily on new zoning regulations that explicitly classifies zones in risk categories. Likewise, the use of flood-resistant materials is a mandatory requirement for buildings near water, pressure-treated wood, concrete and other materials are considered for being resistant to long exposure, moisture, and decay.
- Elevation standards considering flood-risk mapping and water depth levels so important functions of buildings are located above expected and extreme floodwater levels (residential function). Elevation is also considered within buildings, where research suggests floodproofing utility services (electric, gas, water, internet, and other connections) or allocating them above the potential flood water depth.
- Ground elevation is strictly recommended in project areas prior construction, elevating a zone would eliminate the need for an enormous technical and economic operation as water levels would hardly reach the elevated zone, for instance Hafencity.

In flood-prone areas, zoning regulations play a crucial role in fostering the flood-resilience of residential buildings. From lessons learned from the past, Aerts and Botzen (2011) emphasize the following zoning regulations:

- Setback requirements to determine the minimum distance between residential buildings and water bodies. These setbacks establish buffer zones that provide a protective space between the water source and the structures.
- Open space requirements are derived from the first regulation as the local government in New York measures the total ground floor area available around a building and its adaptability to serve as flood storages. This also includes the design of parks, green areas, promenades, and parts of squares so these allow flooding once or twice a year for few hours.
- Environmental legislation encourages the conservation of natural features that provide flood protection; however, it also accounts for the implementation of flood defenses in green areas without disturbing the existing environment nor the landscape.

In the case of Boston, Auton (2015) takes the governmental provisions that were established for a flood-risk neighborhood in Boston and translate them into area design guidelines for flood high-risk zones. The author distinguishes 2 different areas, the access to a building through streets and venues, and the public realm that involves public spaces and greenery attached to the structure:

- For accessibility, the author suggests that street design should facilitate the movement of pedestrians while accommodating water, this can be done by an appropriate sewerage or infiltration system. Likewise, the street design should have a slope to connect it with the waterfront. For a better sense of connectivity, the author suggests three main structures with different functionalities, an open square to store water, a boulevard that infiltrates and redirects water, and an elevated place as a meeting zone in case structures are inaccessible.
- For public realm, the author suggests that building blocks should not create a continuous wall or limiting the mobility of people through the buildings. Besides, ground-level elements such as gardens should avoid creating blank walls limiting the pedestrian space, although these areas should comprehend around of 25% of the building total accessible area. Finally, the geometry and topography of the area formed by buildings and public space, should retain and infiltrate as much water as possible before redirecting runoff towards the closest water

bodies.

As shown above, the different measures applied in the American cities are presented as regulations, or requirements that are established by the local governments to control the design and construction of structures in flood-risk areas. A closer management to the construction of buildings in these areas allows the municipality to implement stricter rules to private companies and house owners. A final remark from the authors states that several regulations, insurance measures and building codes explained beforehand are dependent on what is the actual risk and what is the future scenario. In such case, authors agree that further research is needed to examinee climate change projections to develop policies based on the potential risk. Aerts and Botzen (2011) recognize that the first issue that local governments find is the lack of detailed maps showing the potential flood risk in determined areas. In fact, for a proper water management, it might be needed to study the expected flood risk until 2050, in such way, mapping risks and finding sensitive spots are also considered as non-structural measures.

2.5. Implementation barriers of spatial measures

In order to manage urban growth while considering the proper management of water, among other societal and environmental concerns, spatial planning solutions are essential. But putting these solutions into practice can be a difficult process with many obstacles that can prevent success (Wüstenhagen et al., 2007). Some of the extant implementation barriers stem from the large disparity between theory and practice of the MLS approach (Oukes et al., 2022). In their paper, the authors state that the Dutch Delta Program concluded that there is room for improvement regarding the second layer of the MLS approach; however, previous research on their implementation also revealed that spatial planning measures are described as non-committal, open-ended, and obligation-free, resulting in a poor application of the second layer and a slow paradigm shift from traditional command-and-control measures to prevention and anticipation planning labeled as a "new water culture" (Oukes et al., 2022). This new paradigm embraces approaches centered on living with and making space for water, for instance, Casiano et al. (2023) describe implementation of blue-green infrastructure (BGI) to take the 2nd layer and the MLS approach concept one step further and applying it so that cities like Zwolle can leapfrog to a water sensitive state. The BGI concept refers to using blue elements (rivers, canals, ponds, etc.) and green element (trees, gardens, and parks) in urban and land-use planning; implementing BGI means shifting from hard/grey mono-functional infrastructure to a nature-based multifunctional infrastructure using a systematic approach with collaborative efforts across multiple policy sectors and scales (Casiano et al., 2023). However, the authors acknowledge that the BGI is currently hampered by barriers that impede uptake and innovation. Assessing the implementation of BGI in the city of Zwolle, the research found that there exists a lack of common practice, difficulty in combining different projects among governmental actors, and regulations related to aesthetics and architectural value, for instance.

Considering the case study of Zwolle in applying sustainable urban water measures (Casiano et al. (2023), Oukes (2019), and Oukes et al. (2022)) and other common implementation barriers to flood resilient spatial planning (O' Donell et al. (2017), Wüstenhagen (2007), and White et al. (2016)), it is possible to identify and describe 3 main implementation barriers with different sub-issues for resilient spatial measures within the 2nd layer of the MLS in the Netherlands: social acceptance, physical-spatial limitations and institutional-organizational barriers.

2.5.1. Social Acceptance

According to the research done by Wüstenhagen et al. (2007), many of the barriers for achieving successful projects at integration level can be considered as a manifestation of lack of social acceptance. In their paper, the authors introduced 2 dimensions of social acceptance: socio-political acceptance and community acceptance. White et al. (2016) describes the socio-political actors as the ones with a professional background and with the highest level in decision making while community stakeholders are the people affected directly by the decisions.

Socio-political acceptance is defined as the approval of technologies and policies by local governments, key stakeholders, and policymakers. From this perspective, O'Donnell et al. (2017)

recognize that land legislation, building regulations, and governance systems could formulate a regulatory complex environment that can hinder implementation of spatial measures and make private companies, investors, and contractors hesitate about being involved in area development projects. Besides, Brown et al. (2006) argue on how obtaining permits, adhering to zoning laws, and traversing bureaucratic procedures can be time-consuming and cumbersome. In the case of the Netherlands, inconsistent or overlapping regulations at various government levels can also cause confusion and impede progress. For instance, Dai et al. (2014) mention that spatial measures on national level are usually developed within the Dutch Spatial Planning Act and oblige municipalities to determine strategic development plans with legal binding characteristics, however in practice, there exists ambiguity for who takes responsibility when the control of land by private owners and companies has made difficult to create legally binding rules. Examples of climate adaptations initiatives in Amsterdam and Rotterdam have shown that although municipalities are required to manage regional rainwater, responsibility for the collection of water on private ground still lies with landowners (Dai et al., 2014).

Similarly, the diverse objectives and interests of different government bodies could jeopardize the sociopolitical acceptability of climate adaptation projects (Roth et al., 2017). In terms of the urgency and prioritization of adaptation measures, Oukes (2019) explains that contradictions can arise between different levels of governance, for instance, regional and local authorities may face pressure to resolve more immediate concerns or to prioritize short-term economic development, whereas national policies may emphasize long-term climate resilience. Thus, the authors reflect on how difficult is translating national policy objectives into locally accepted policies.

On the other hand, community acceptance concerns to acceptance in siting decisions by local stakeholders such as residents and local groups, the most common social barrier to the implementation of spatial measures denoted by O'Donnell et al. (2017) is the lack of knowledge/awareness of the public and the overestimation of risks by key actors. In the Netherlands, this issue is rooted in the success of traditional Dutch water management; ironically, enhancing the primary flood systems has resulted in a high safety perception but also in a low awareness of flood risks among stakeholders and citizens (Oukes et al., 2022). This problem is also encouraged by ineffective communication from governmental bodies, so people are neither aware nor prepared to face a flood event (O'Donnell et al., 2017). Besides, the high safety perception has led citizens and stakeholders to have larger reliability towards first-layer protection systems (dikes, dams, and storm surge barriers), therefore a paradigm transition could seem not viable for the general population as it does not bring relevant benefits; this way of thinking also has repercussions in the stakeholder's perspective.

2.5.2. Physical-spatial limitations

According to the research done by Oukes et al. (2022), the most important physical barrier in the implementation of spatial measures is the maximum flood depth of an area. The authors explain that 2nd layer measures of the MLS are most -if not only- effective for a relatively shallow maximum flood depth (depending on the topography of the area). Thus, when this threshold is reached, spatial measures would be useless as water levels would exceed the system capacity to mitigate or adapt the flood. This limitation usually leads stakeholders and policymakers to give more attention to defenses against extreme fluvial floods or to evacuation plans, the 1st and 3rd layers of the MLS respectively.

The rigidity of the existing built environment is a second physical-spatial barrier that reduces the potential to radically alter urban environments and implement blue-green infrastructure (Leichenko et al., 2015). This also implies the lack of space in urban centers and how populated these are in the Netherlands. As indicated by Oukes et al. (2022), the available surface to implement spatial measures is limited and makes it difficult to implement large-scale spatial measures, such as the construction of flood retention areas or the creation of natural spaces. Similarly, there are cultural and historical factors to consider, as the Netherlands possesses a rich historical heritage with numerous buildings and areas of historical significance. Preserving these cultural assets and preserving the character of cultural landscapes can restrict the implementation of certain spatial measures that may necessitate alterations to the constructed environment (Oukes C. , 2019).

This last statement is also related to the architectural and aesthetic value that certain adaptations should accomplish to be accepted within a development plan. Thorne et al. (2015) indicate that certain spatial adaptations will be part of the cultural identity of an area and therefore their design should be compatible with the existing environment. Finding a good balance between flood resilience function and maintaining the architectural value of an area can be hard and needs careful thought, as this will not only affect how people see and accept the measures but also in the economic implications for property values and real estate market of the surroundings.

2.5.3. Institutional-organizational barriers

One of the principal barriers at organization level is the lack of cooperation between important stakeholders in flood risk management (Oukes et al., 2022). In the Netherlands, there exist different authorities involved in water management and urban planning, for instance the water boards and municipalities, however, these seem to be working separately when it comes to study spatial measures. As stated by Oukes et al. (2022), the water authorities aim to guarantee water safety by relying on primary flood defense mechanisms, but on the other hand, municipalities are responsible for land use planning, urban development, and infrastructure. These different mandates and priorities can create divergent interests and objectives leading to a lack of alignment and cooperation between two of the most influential and powerful stakeholders in urban development projects. Casiano et al. (2023) discuss examples of the challenges in cooperation between municipalities and water boards in the Netherlands where land use decisions to implement blue-green infrastructure by municipalities may conflict with the flood risk reduction strategies proposed by water boards. Similarly, Molenveld and Van Buuren (2019) agrees that water safety organizations believe that spatial strategies are undesirable and inadequate since they are largely static, challenging to adjust, and unresponsive to changing conditions if the actual defense system is successful. A simple reorganization of the decision-making progress could seem the solution, but a full cross-sectoral integration could lead to endless negotiations, planning and other processes (Roth et al., 2017).

Another important barrier is described as the finance behind spatial measures. According to Oukes et al. (2022), flood-resilient spatial planning is simply expensive, and its acquaintance frequently depends on social acceptance and the key actors' priority. In the first case, authors found that low awareness of risk level in the general population and stakeholders may not allow the investment in long-term measures if these have a low probability of happening, Oakes (2019) explains that the benefits of flood-proofing every single structure in an area do not outweigh the costs. Contradictorily, economic resources for 2nd layer measures are also considered unnecessary in the event of severe flood events, the author stated that if water depth surpassed 20cm, then stakeholders would have a larger interest in reinforcing primary defenses and allocating resources in evacuation plans. Furthermore, research done by Dai et al. (2014) explains that there exists a national Dutch Fund for the construction and maintenance of primary flood defenses, but for the 2nd and 3rd layer the accountability remains fuzzy, this is because flood resilient spatial planning are still considered as an additional measure to the first and not its replacement. For both research done by Oakes (2019) and Dai et al. (2014), financial aspects are the key institutional-organizational barrier.

3. Noorderkwartier Case Study

3.1. Historical Background

The so-called Noorderkwartier is a historical area that was formed between 1615 and 1790, when the city of Zwolle intended to expand northwards, linking what is now the Binnenstad and Diezerpoort boroughs. However, the construction of the star-shaped moat and a fortress belt around it supposed a remarked separation between the center and the northern part of the city by the Achtergracht, a separation that remains strong nowadays. In the period of 1800-1920, the area witnessed the abolishment of the fortress belt and the construction of a gas factory and an iron foundry which shaped the area's structure and landscape, transforming the Noorderkwartier into an industrial area with null residential options. In 1940, after the bombardments during WWII that destroyed part of the Diezerpoort district and the dismantlement of the gas factory, several urban expansion plans were proposed but due to the industrial fabric history of the area, residential areas were built further and further from the city center. After 1970, the gas factory and iron foundry were dismantled, thus it was proposed to combine residential and office areas in a campus model, but the idea was partly abandoned, and more separated objects were added to the site. (Biewenga, 2023)

Nowadays, the northern part (Dieze) is a working-class neighborhood with an active club life and a relative balance between city and village feel, the Bollebieste and Schildersbuurt neighborhoods are part of the Noorderkwartier area and allocate iconic constructions such as the Diezerpoort shopping center, concert hall Poppodium Hedon, the state archives building and the Belastingdienst and GAK office buildings. Nonetheless, the neighborhood has the appearance of a closed area and is still hidden among the buildings blocks. On the other side of the Achtergracht, the south of the Noorderkwartier is formed by the Nijkerkenbolwork sub-area within the Noordereiland, an area widely known by residents and tourists for having relevant buildings such as the Theater De Spiegel and the five-star restaurant-hotel De Librije. Such landmark buildings have contributed to encouraging activity from the inner city through the north. Besides, this area is compound by a green quay located on the shoreline of the Achtergracht, but the beauty of the greenery is usually overshadowed by large pavement structures (Biewenga, 2023).

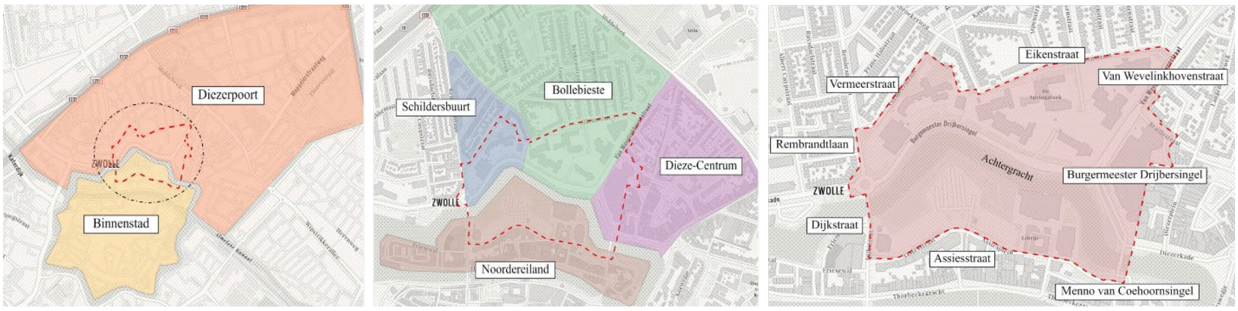


Figure 12, The Noorderkwartier within Zwolle (ArcGIS)

3.2. Geographical scope

The Noorderkwartier is the denomination given to the continuous connection area between the city center and Diezerpoort borough, such area is composed by two well limited parts. The northern part is formed by buildings blocks among the Bollebieste, Schildersbuurt, and Dieze-Centrum neighborhoods within the Diezerpoort. The southern part is denominated Nijkerkenbolwork, and it is the northernmost part of the Noordereiland, within the Binnenstad (see Figure 12). This area is enclosed by the streets Rembrandtlaan, Eikenstraat, Van Wevelinkhovenstraat, Menno van Coehoornsingel, Assiestraat, and Dijkstraat, and separated in two by the Achtergracht canal (Biewenga, 2023). The total surface comprehends about 14.4 hectares and its topography indicates that is a generally flat area, with a street average elevation of 2 meters above the NAP and having as lowest point an average of 0.4 meters above NAP in the shorelines of the Achtergracht canal (Oosterom, 2019), see Figure 35 in Annex A.1. In terms of natural characteristics, the area is separated by singular water body (Achtergracht), besides there exists greenery in the surroundings, although is limited and much less extensive compared to the paved surface, for instance the park Hondenlosloop in the Noordereiland is dwarfed by an existing parking lot that spans over most of the Nijkerkenbolwork surface (Figure 13).

The neighborhood typology indicates that the Noorderkwartier is composed by part of the historic city center, renovated buildings, and working-class areas (HvA/TAUW, 2021). In terms of demographic factors, there is not an exact number of residents in the Noorderkwartier enclosed area as the residential structures are scarce, however there are approximately 400 households which are principally located in the Dieze part. The land use pattern is divided in a range of activities including living, shopping, culture, social, leisure, and industrial/office. However, by far industrial/office is the most extensive land use, with 6 office buildings built for this purpose (Kadaster/BAG, 2023)**.** In total, the area has 15 buildings for the different functions, and these are distributed as shown in Figure 13.

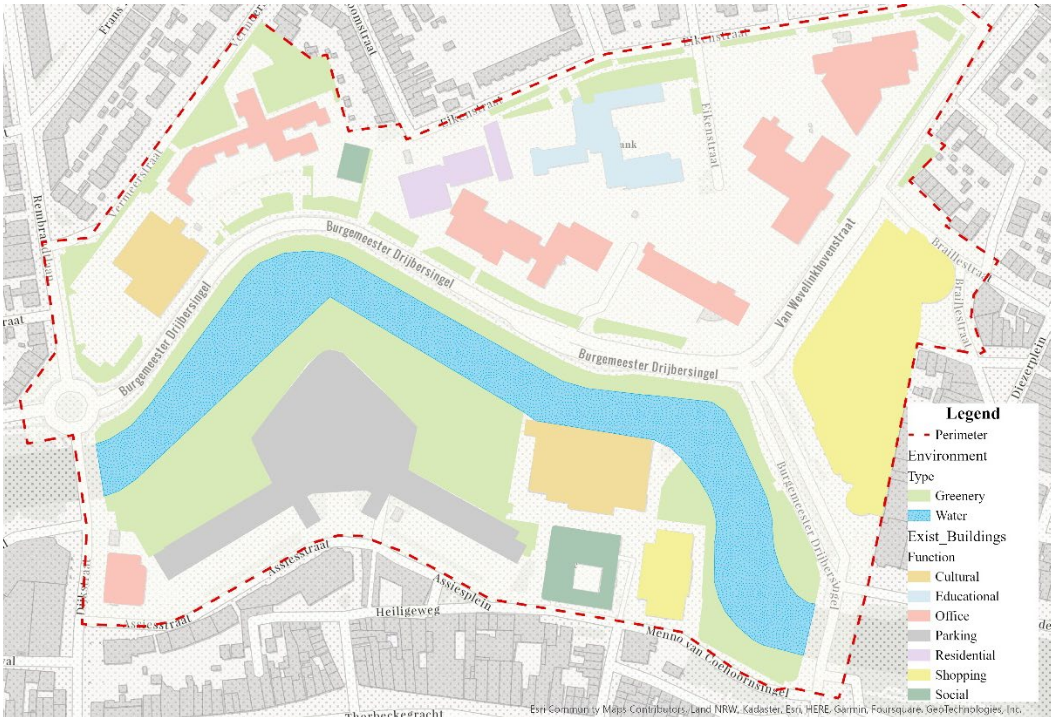


Figure 13, Buildings and natural features of the Noorderkwartier

Similarly, according to the neighborhood typology (HvA/TAUW, 2021), the Noorderkwartier has a relatively high mixedness of land-use which is characterized by extensive pavement areas, little municipal greenery, and high pedestrian densities which is an indicator of vulnerability to waterlogging (Figure 34, see Annex A.1). Furthermore, as specified in the Environmental Vision for Zwolle 2030 (Zwolle, 2021), the city center is one of several built-up areas located outside the defense dikes. Considering that a significant part of the Noorderkwartier is part of the city center and some of the existing buildings were built prior 1900, the area can be considered in significant and potential flood risk due to climate change. Finally, among the relevant infrastructure of the area, this study concerns the existing sewerage system which can be retrieved from PDOK (Kadaster/PDOK, 2023), in general, the area is surrounded by a mixed pipeline system (collecting wastewater and rainwater in the same pipeline) and several drainage points allocated in the streets, nonetheless, some structures in the Nijkerkenbolwork also count with especial infiltration systems and rainwater sewer around them, and there exists an especial overflow pipe that acts as an emergency inlet to discharge rainwater from the Noordereiland neighborhood into the canal, see Figure 14. Furthermore, a rainwater sewer spans along the Van Wevelinkhovenstraat avenue until reaching an outlet point at the Achtergracht.

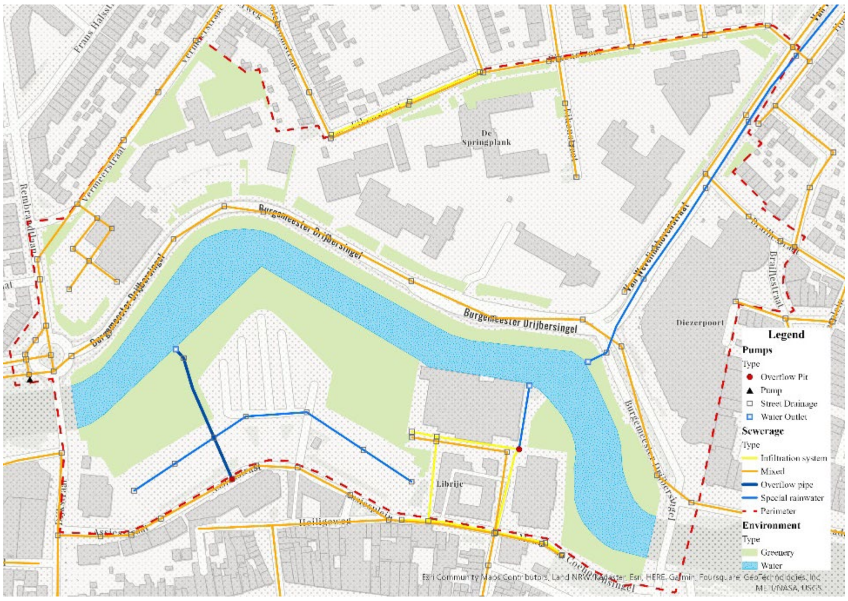


Figure 14, Sewerage system in the Noorderkwartier

3.3. Redevelopment plan and Area Vision

The Noorderkwartier area has long marked a dichotomy in the city, for many years the Noordereiland was the center of industrial activity in Zwolle, while on the other side of the canal, the Diezerpoort was a growing neighborhood that was heavily damaged by bombings and the affected areas were filled in partial plans focused on social/office opportunities. Although several projects raised to transform the area into a green campus-like area setting, the idea never became true and although today one could find emblematic buildings, they are built in such way that they seem self-contained and randomly dispersed in the neighborhood. Besides, the area was designed for cars accessibility, with prominent streets, several parking lots and limited greenery. Therefore, the municipality has proposed a new redevelopment plan which will remove the buffer between the Diezerpoort neighborhood and the historic city center by means of reconnecting and expanding the inner-city northwards. New functions and buildings will be added to contribute to the attractiveness and culture of the neighborhood, however, one of the cornerstones of the redevelopment project is transforming the new Noorderkwartier into a residential area, with a large number of new households (approx. 700) and small-scale business combined in a mix urban center environment next to the canal (Biewenga, 2023).

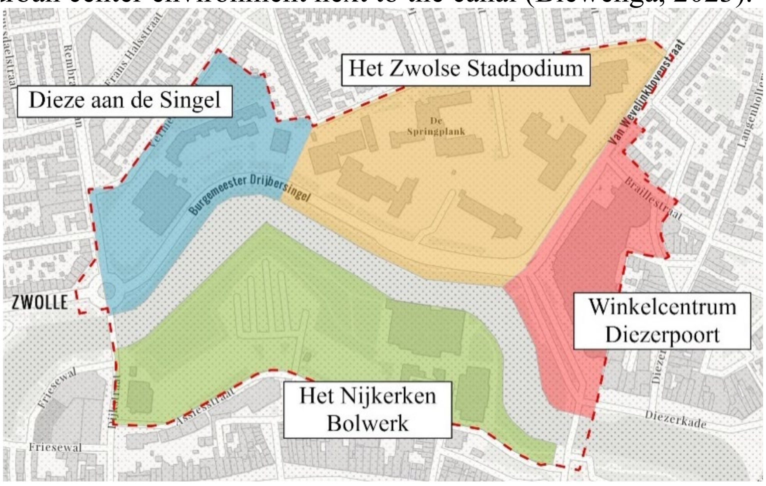


Figure 15, Sub-areas of the redevelopment

Following the Gebiedsvisie document of the project (Biewenga, 2023), the redevelopment of the Noorderkwartier is part of the redevelopment of Zwolle as a whole. The Environmental Vision and the Development Program “Stadshart” are documents redacted by the municipality that give direction to the Noorderkwartier redevelopment plan. In the case of the Environmental Vision for 2030 “*Ons Zwolle van morgen*”, municipality wants to transform Zwolle into a future-proof city by setting tasks such as building more homes and make them greener, reusing valuable buildings as much as possible, and create a car-free inner city (Zwolle, 2021). The Development Program "*Ons Stadshart van morgen*" set the focus on the inner-city growth and how to allocate living, working and recreation in the same spot. The area vision is based on these requirements and presents a sustainable approach which focuses on greening, bluening, reusing and making energy neutral the four sub-areas within the Noorderkwartier: Het Nijkerken Bolwerk, Dieze aan de Singel, Het Zwolse Stadspodium, and Winkelcentrum Diezerpoort (see Figure 15). Thus, the area vision is built on 5 main principles derived from the environmental and development programs:

1) Fordable and accessible inner-city: car-free
2) Healthy, Green, and Water-robust Noorderkwartier
3) Sustainable and circular city
4) City with human touch: mixed activities for everyone
5) Enterprising and creative city

In order to fulfill these principles, the area vision document (Biewenga, 2023), proposes the redevelopment measures, structural adaptations and spatial reconfiguration as specified in Table 1:

Table 1, Area vision proposals for Noorderkwartier sub-areas

Het Nijkerken Bolwerk	Dieze aan de Singel	Het Zwolse Stadspodium	Winkelcentrum Diezerpoort
Building the Singelpark on both sides of the canal, it is meant to be the green-blue heart of the Noorderkwartier.	Extend Singelpark until this area, limited by Rembrandtlaan and a new residential block.	Build a new music venue between the existing Belastingdienst and Diezerveste buildings.	Reuse the existing building but remove the roof to add public space.
"Dynamic center" a mix of facilities and new residences in combination of water, greenery, and historical qualities.	Reuse the existing concert hall building to arise a mixed city block within the Singelpark extension. A parking garage for residents is considered.	Relocate activities of Poppedium Hedon into the new music venue to reuse the building for residential purposes.	Existing parking garage within the building will be upgraded to a mobility hub for the city center.
The two-storey existing public garage will be adapted to a one-floor neighborhood hub.	New buildings will have multiple storeys and might give room to shops, offices, or small companies in the ground floors.	Reuse and transform the Bestalingdienst into a residential building or a hotel. Use the first two storeys of the as Hedon's lobby.	The existing parking garage on Van Wevelinkhovestraat will be readapted to become a new open public space.
Apartment buildings with heights of 3-6 storeys can be built above the new hub and give room to offices/shops in the ground floors.	Repurpose the Dr. Itardschool as an educational building again, with its own courtyard around (not part of Singelpark but still connected).	Create a green cultural square enclosed by the existing government school buildings: "Cultuurplein".	Shopping function is strengthened by a smart use of existing parking garage above shopping center (mobility hub).
Adjustment of slope within the Singelpark to create more space for water storages.	Maintain surrounding houses and the existing church untouched. However, they are connected to Singelpark now.	Reuse and transform De OBS Springplank primary school into a Culture Center in front of the Cultuurplein.	Build a green-blue connection all along the Var Wevelinkhovenstraat.
Implement flood defense structures and measures as integral parts of the Singelpark landscape.		Reuse but redesign Diezervest building as a workspace with apartments on top of the building.	
Set up an outdoor theater facility in the Singelpark, next to De Spiegel.		Reuse GAK old building as a residential space, however the newest part could become a place for meeting or catering.	
Make this area care-free and redesign streets, alleys, and squares as residential areas with lots of greenery and direct connection to the Singelpark.		The existing building for State archives is difficult to transform, thus, a new building block is planned, including a hub for residents only.	

Bluening measure · Greening measure · Building/adapting · Reusing

3.4. Main stakeholders

The municipality of Zwolle is the most interested party in the redevelopment of this area as it is part of the Environmental vision and Development program "Stadshart van morgen". However, according to the official websites of the redevelopment program (Jouw stukje Zwolle) and the Area vision document (Biewenga, 2023), four other parties with various land and real estate properties within the Noorderkwartier are also interested in the opportunities of the district, namely the Rijksvastgoedbedrijf (Ministry of the Interior), Lenferink Groep (real estate partner), DLH-VolkerWessels (building company), and VanWonen (area and property developer). Together these five parties form the so-called 'Eigenarencoalitie' (Owners' Coalition) and have collaborated with the residents of the area in developing a Letter of Intent to work together integrally instead of separating the area in sub-plans and having restrictions from current ownership relationships (Biewenga, 2023).
Likewise, it is known that the placemaking for the Area Vision was developed in coordination with residents from the Noorderkwartier and the surroundings of Dieze, and with local entrepreneurs, these actors were involved through several meetings and workshops since 2021 so they could give their input in the area vision document development (Biewenga, 2023). Such collaboration between the Owners' Coalition and the residents is expected to continue for the following steps of the redevelopment process, meaning that residents will become regular and relevant actors, although not as influential as the Owners' Coalition. The next step in the planning process is the Spatial Development Plan, which is needed to explore spatial measures and technical solutions to adapt to climate change effects in the forms of potential floods within this area.

3.5. Linking flood resilience to housing demand

As one of the fastest growing economies in the region, Zwolle has become a trade hub and a connecting link between western, eastern, and northern Netherlands. According to the Environmental vision document for 2030 (Zwolle, 2021), more a more people is feeling attracted to live in Zwolle due to its inherent lifestyle, a combination of work, private life, nature, and recreation. Likewise, the number of students residing in the city has been doubled in the last decade. It is estimated that around of 1000 new households are planned to be built yearly until 2030 in order to accommodate migration from the Randstad and the southern municipalities. However, the document also details the need for accessible housing in order to tackle the existent accommodation shortage that has affected students, entrepreneurs, and the elderly in the last years.

Although the goal of adding new housing facilities to the urban area is driven by the clear shortage of households, the municipality acknowledges that changing climate will have an impact on the physical living environment, thus measures must be taken to be able to live, do business and recreate in Zwolle safely. A flood event could have far-reaching consequences and a disruptive effect in the city center because its location outside the dike protection (Zwolle, 2021). Even though, the water level has remained within the set limits so far, there is no doubt that due to climate change, more downpours and higher water levels are expected to increase by 2050. This would have disastrous consequences for the areas outside the dike rings (Deltastad Zwolle moet in 2050 een superspons zijn, 2019).

In order to mitigate the effects of climate change, the municipality has traditionally relied on the existing main flood defenses (dikes) for regional management, however, the municipality has recently studied the opportunity to connect water and space through suitable solutions (Zwolle, 2021). This would improve the current water management system and include an integrative approach by upgrading the existing green-blue structure of the city with a sponge action as a physical underlay connection among all the neighborhoods. As part of this green-blue system, the municipality seeks innovative solutions and measures such as using multifunctional land use where spatial measures might allow water-robust constructions (housing and recreation), (Zwolle, 2021). Enhancing housing flood resilience could increase the sponge effect on the city by retaining water until there is room to discharge it back to rivers and waterways and keep residents' feet dry.

The environmental vision report for 2030 mentions that measures to address the potential excess of water have been already approached by the Drents Overijssel Delta board, suggesting temporary storages, wadi designs, and a new drainage network. Nonetheless, the municipality also aims for housing resilience and water-robust structures so households and commercial buildings can withstand transient flooding (Zwolle, 2021). For instance, one could refer to a recent construction close to the Noorderkwartier area, namely 'de Steeling' building, where the floor level has been raised from 2.4 to 2.8 meters so the residents can keep dry feet in case rising water levels (see Figure 16).

Figure 16, De Stelling building, a water robust construction (De Stelling, Zwolle, 2016)

That is why, the new area development needs to embrace an integrative approach, considering spatial planning solutions that enhance housing resilience against flooding. The approach should be based on the idea of coexisting with water, accepting that there will be areas in which occasional flooding might occur, but preventing as much damage as possible. In such a way, the redevelopment of the Noorderkwartier would follow a blue-green vision where the designed solutions will match the climate adaptation measures that the municipality desires to implement. All this in favor of making Zwolle climate-proof and adaptable by 2050 (Zwolle, 2021).

3.6. Perspective from the field

As part of this research, a field trip was conducted to the area to be redeveloped. The idea behind the trip was gaining insight on what is the current situation of the area, why the redevelopment is needed and what are the opportunities that the area offers to implement spatial measures in housing constructions. The entire tour can be visualized in Figure 17, where it is illustrated the places that were visited as well as pictures taken in these areas.

The starting point was De Librije restaurant-hotel, walking from this point towards the canal shoreline, one could appreciate some bits of greenery on both sides of the canal, although these zones are quite difficult to access. Following the Assiestraat, the prominent parking garage is found in the northernmost corner of the inner city, overshadowing the existing park next to the canal. The parking lot is in a precarious condition with concrete as the principal construction material, providing a poor landscape to the surrounding houses, however, the area is quite extensive, and a large residential area can be built here. It is important to notice that the parking lot has two storeys, and the ground floor might keep its functionality as it gives room for water retention measures due to its closeness to the canal. Following the Dijkstraat, one can appreciate the canal and the side of the canal, the area is careless and even seem abandoned, but it is possible to see that the topography of this area provides a sort of double dike, one to protect the park and other to protect the parking lot and the historic center, thus there is room for improvement using the existing slopes.

Walking to the other side of the Achtergracht, one could find the Hedon music hall, the area is heavily paved, and although there are views to the canal, access to the shoreline is impossible. As the Hedon building and its parking lot are closed to residential structures, these might serve as a buffer area, so water does not represent an issue to neighbors after a storm event. Accessing behind the Hedon and following the Vermeestraat, the long street delimiting the Noorderkwartier is quite flat, having greenery such as bushes and trees on the sidewalk, however, there is room to enhance water retention and sponge action with spatial adaptations of these zones. Reaching the Eikenstraat, one can see the only residential building in the area, the existing structure is elevated and has a parking garage on the ground floor so its dry-proofed, however, it is known that this zone is still out of the redevelopment scope. The rest of the street provides more green space on the sidewalks, but it can be used in a better way, considering that a school is located here.

Almost at the end of the street, one could gaze at the back side of the different government buildings, all of them have their own parking lots and these are interestingly below surface level. This means that they might serve as water storages during heavy rain showers, nonetheless, there was no sign of

drainage points or gutters to drain the accumulated water. Following the Van Wevelinkhovenstraat avenue and accessing behind the Diezerpoort shopping center, one can see that the area is enclosed and does not provide a proper landscape to the neighborhood, however the main problem is the lack of greenery and the extensive pavement around it which was built to facilitate the car accessibility. Thus, there might be an opportunity to close the street, redesign it and apply a green infrastructure along it to enhance the flood resilience of the apartment buildings and attached households.
Arriving at the Burgemeester Drijbersingel Street, one will find the Belastingdienst building in front of the canal, the building has a certain elevation above the ground level which gives the opportunity to use this floor for other purposes and move residential functions to higher storeys. Likewise, the parking lot next to the building has a certain depth which accumulates rainwater during peak rainfalls.

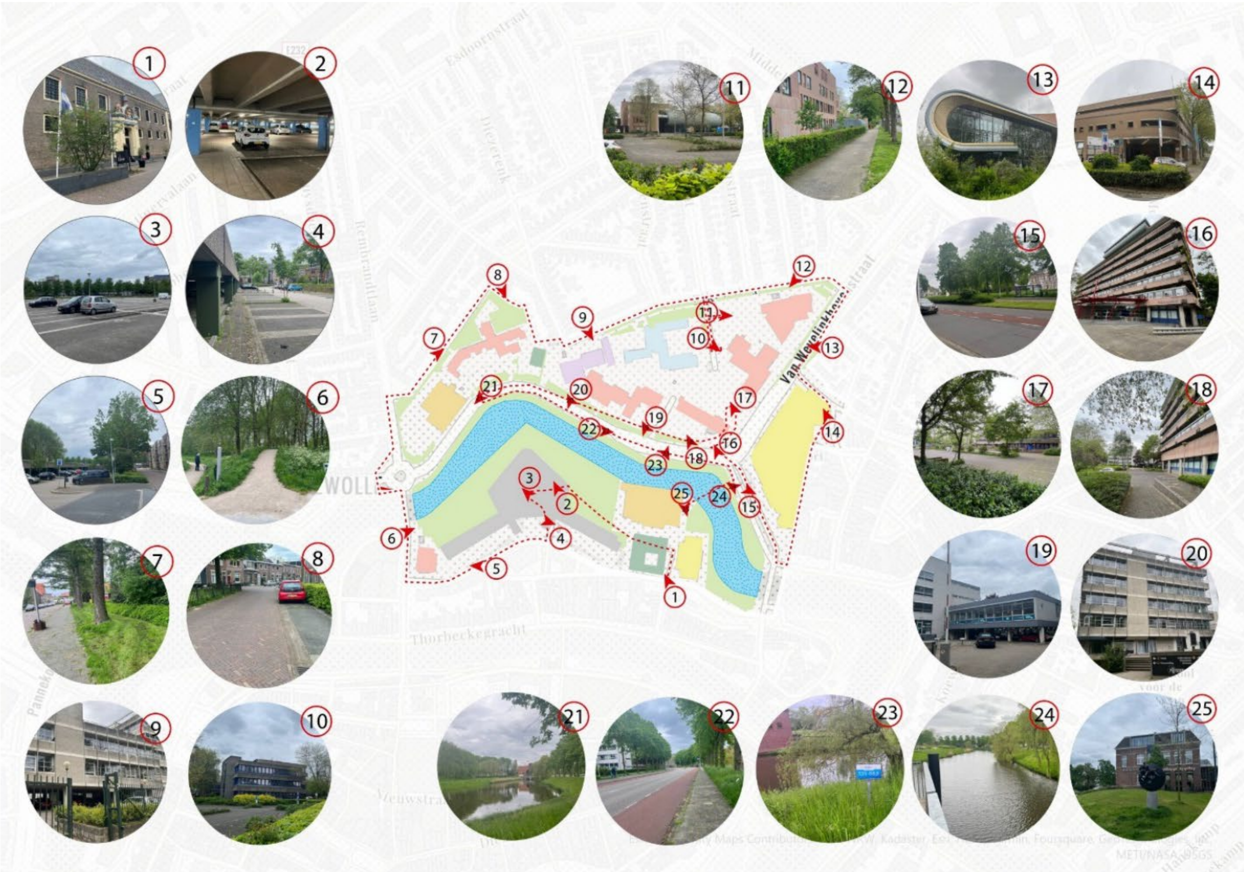


Figure 17, Tour around the Noorderkwartier area

4. Methodology

This chapter will provide insight into the research approach, research strategy, and data collection process used in this investigation in order to progressively answer what are the best practices and solutions that enhance housing resilience, which areas are flood-sensitive in the Noorderkwartier and how to assess effectiveness and feasibility of suggested practices and solutions in order to develop a final inventory as the main objective of this assignment.

4.1. Research approach

Since this is a design-oriented investigation whose objective is to design and develop an inventory of resilient spatial measures as an advising instrument for an ongoing redevelopment project, this research uses two different methods to approach the problem, a case study within the city of Zwolle and a qualitative and quantitative (mixed) analysis. This methodology is used to evaluate the feasibility and effectiveness of resilient spatial measures to be applied in a real-life project context. The case study of the Noorderkwartier area was conducted in collaboration with the municipality of Zwolle to gain insight on what is the current situation of the redevelopment, the area vision, and climate adaptation goals in the long-term as well as to retrieve information about physical characteristics and opportunities shown in the area vision that could be relevant for the posterior analysis of the area. Furthermore, a field trip was undertaken as an empirical method to observe the physical state of the area and potential barriers that could not be mentioned in literature.

A qualitative approach is used to develop a preliminary inventory of spatial measures and evaluate their feasibility by understanding how to overcome common implementation barriers in these types of projects. This approach employs two different data collection methods: a literature review on best practices of the 2nd layer of the MLS approach and interviews with key stakeholders involved in the redevelopment project and with experts in urban development and water management. On the other hand, the quantitative approach is used to find flood-sensitive areas within the Noorderkwartier and evaluate the effectiveness of the spatial measures in these hotspots. The needed data is collected by means of desk research to understand the current and future flood risk in the area and the current water management situation. Nonetheless, quantitative research will be also partly fed by responses during the interview process to understand physical and spatial barriers particularly applicable in this area.

4.2. Research strategy

The research strategy is designed to respond the three main research questions by sequentially answering the different sub-questions developed for this research. Therefore, there will be three relevant parts to reach the objective of this investigation.

4.2.1. Finding the best practices for the 2nd layer MLS approach to enhance housing flood resilience and their implementation barriers

This initial part applies qualitative research to develop a Preliminary Inventory that englobes the best practices, measures, and spatial solutions to particularly enhance housing flood resilience. The solutions are retrieved from reviewing a set of case studies and redevelopment projects where the MLS approach, and specifically its 2nd layer: resilient spatial planning, were implemented with general success inside and outside the Netherlands. The set of cases considered in the literature review is not only comparable to the physical characteristics of Zwolle but also presents innovative solutions to adapt floodwater in urban areas. In order to define these cases as the "best practices" in implementing the 2nd layer of the MLS, it will be analyzed what characteristics and attributes made possible their application and what are the implementation barriers that were overcome. This latter step requires the research of the principal implementation barriers in the application of the 2nd layer of the MLS approach which forms part of the literature review.

4.2.2. Finding the flood-sensitive areas and structures within the Noorderkwartier

This phase is described as quantitative research which will use a Spatial Analysis to find flood-sensitive hotspots within the Noorderkwartier area. The spatial analysis is undertaken by GIS tools and makes use of maps with elevation, land-use, and topology, building functions, and sewerage system information. Likewise, the flood risk in this area is assessed for the current situation and the expected scenario in 2050, according to the climate goals of the municipality. Furthermore, the flood risk research makes use of maps with datasets about the expected flood depth levels due to pluvial and fluvial flooding in this area. Combining the different information and data from these maps, a GIS desktop tool (ArcGIS software) will be used to perform a suitability analysis to suggest which areas within the Noorderkwartier are susceptible to flooding and therefore which are suitable for housing structures and where spatial solutions can be applied. This phase also uses the insight gained during the interview process in the first phase and the information retrieved from the redevelopment Area Vision document where it describes the different opportunities for bluening, greening, and redesign structures in this area.

4.2.3. Evaluating the feasibility and effectiveness of spatial solutions in enhancing housing flood resilience

The last phase will consist of analyzing the results from the previous steps to develop a Final Inventory with feasible and effective spatial measures with a potential to be applied in the Spatial Plan as the next step in the redevelopment project. The feasibility evaluation of the suggested measures will be undertaken in base of the responses from the different interviews, it will be considered the perspective from the different respondents on which solutions seem more relevant and practical as well as what are the implementation barriers that they consider in this specific project. The final inventory will present solutions that are classified as feasible according to a general agreement between stakeholders' opinion and that are also capable of overcoming the different implementation barriers.

On the other hand, the effectiveness evaluation will be performed according to the characteristics of the 2nd layer of the MLS approach: flood risk zoning, attention to vulnerable objects (housing buildings) and responsible and effective use of space (spatial solutions). The suggested solutions retrieved from the final inventory will be assessed by means of using a planning support tool for climate adaptation in urban environments, this is an interactive software called Climate Resilient City Toolbox used by stakeholders to analyze the performance of spatial measures (described later in the report). This tool will use the set of spatial solutions previously assessed as feasible and applied in the Noorderkwartier area to analyze how effective these would be according to one key performance indicator: water storage capacity increment after the implementation of the spatial solutions. A final inventory with all the relevant spatial solutions will be presented as an advisory instrument for the next redevelopment phase.

For a better understanding of the research strategy used un this investigation, Figure 18 below shows how the methodology is structured in a graphic way.

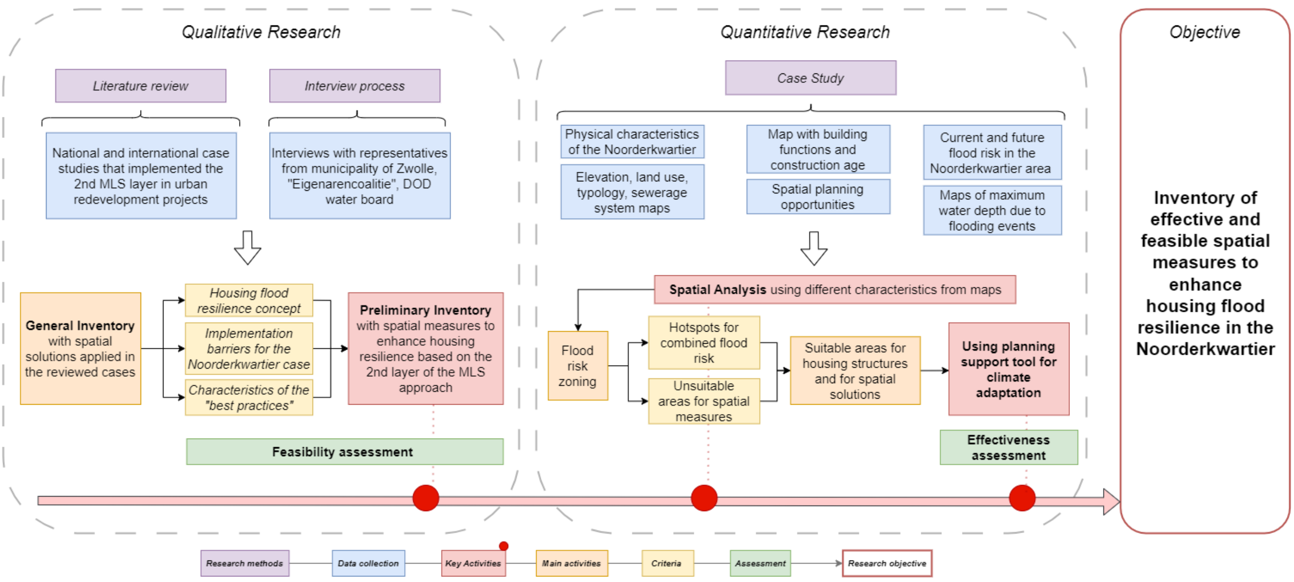


Figure 18, Research strategy model

4.3. Data Collection and Analysis

4.3.1. Literature review

This phase is principally described as a desk-research process in which the first part was focused on defining key concepts for this investigation. Academic literature such as papers, books, and reports was reviewed in order to find the definition of "multi-layer safety approach", "resilient spatial planning" as the 2nd layer of the MLS, and "housing flood resilience" (See sub-chapters 2.1 and 2.2 in Chapter 2). Then, the next part aimed to review academic sources related to spatial measures, strategies, and solutions applied in redevelopment projects according to their relevance and success in the application of the MLS approach. The case studies considered for this investigation are found not only in national projects but also in examples outside the Netherlands, likewise, these were selected not only for being physically comparable to the Noorderkwartier characteristics or to the Zwolle region (as a delta zone), but also for the innovative ideas and practical solutions that can be used to enhance housing resilience.

The academic literature to be obtained will be reviewed thoroughly to find what are the spatial measures applied in different development projects, this also involves examining how different authors classify the measures and what is the description, advantages, and disadvantages that they consider for each measure. This process will be helpful in preparing a general inventory of the 'best' practices for applying the MLS approach through spatial measures. The last part of this phase used different research papers that discuss the failure of integrative approaches such as the MLS in the Netherlands to discover and understand the principal implementation barriers that could hinder the application of spatial measures and solutions in redevelopment projects. It is expected to find most of this information in journal papers that assess the concept of MLS in the Netherlands and why it has not had repercussion in urban planning and water management; the information collected in this phase will be used later for an interview process.

4.3.2. Interviews with relevant stakeholders

In order to gather information from firsthand sources, this phase is composed of a set of interviews with people involved in the redevelopment of the Noorderkwartier as well as with experts in water management and urban planning who have worked in redevelopment projects in the Zwolle region. The goal of the interviews is to find opportunities to implement spatial measures in the Noorderkwartier area and to understand how to overcome the principal barriers that could appear, so the final inventory can be considered feasible, according to what was found as implementation barriers in the literature review.
The questions for the interviews are designed to elicit relevant information and opinions, thus, the questions will be open-ended. The interviews are structured in three parts. First, a general inventory with a collection of spatial measures from different projects is presented so the interviewees can give their opinion about how feasible it is to implement these measures in the Noorderkwartier. Then, a set of questions about implementation barriers of spatial measures within the 2nd layer of the MLS approach are asked, These questions are designed based on what was found as an implementation barrier in the literature review phase. This section is aimed at determining the conflicts that might not allow the implementation of spatial measures on this specific area and thus the integration of the MLS approach. The last section of the interview aims to understand how the implementation barriers discussed before can be overcome or traded off to develop a final inventory with spatial measures that can be considered feasible for this redevelopment project.
The interviews are conducted with 6 stakeholders with different roles and responsibilities in the Noorderkwartier project, three of them are representatives from the Owners' Coalition, which are the main stakeholders of the project, while the other three are experts with different backgrounds but with knowledge on water management, urban planning, and physical aspects of Zwolle and the Noorderkwartier area.

Table 2, Interview participants and roles

Participants	Participant 1	Participant 2	Participant 3	Participant 4	Participant 5	Participant 6
Role	Noorderkwartier	Hydrology	Urban Planner	Development	Project	Project manager

	Area Vision Supervisor	Advisor		manager and Project developer	Strategic Advisor	
Company/ Organization	*Gemeente Zwolle*	*Waterschap Drents Overijsselse Delta*	*Gemeente Zwolle*	*Van Wonen*	*Gemeente Zwolle*	*Noorderkwartier Project*

Within the interview protocol, the participants are properly informed about the purpose of the study and ensures confidentiality of the information provided. The interviews are planned to be physical meetings but there is no inconvenient in doing it online, besides the interviews are audio-recorded with the permission of the participants and later transcribed verbatim and stored in a secure location for validity and reliability. The identity of the participants will remain confidential to be mentioned in the report.

4.3.3. Geospatial data collection

The last research method is a combination of desk-research, interviews results and information retrieved from a case study analysis of the Noorderkwartier to obtain GIS data and maps. Geospatial data is needed for a spatial analysis of which would evaluate the flood risk in the area as well as the suitability for the location of the suggested spatial measures within the Noorderkwartier. The required information is expected to be found in different sources, for instance, official documents, redevelopment masterplans, and area vision maps would provide insights about existing buildings and functions, demographics, and opportunities in the future plans. Desk-research on the area would provide maps with physical characteristics of the neighborhood such as elevation, land typology and sewer systems. Finally, an interview with a hydrology expert from the water board that englobes the Zwolle region would provide the necessary information to assess the flood risk, in this case, spatial information of the current and future flood risk of the area and maximum water depth expected due to different flooding events. The following geospatial is requires

- Actueel Hoogtebestand Nederland (AHN) 3 data: provides a digital height map for the whole of the Netherlands. It contains detailed and precise height data with multiple height measurements per square meter. The used version has information from 2012 until 2019 (TUDelft, n.d.)
- Maps with maximum flood depth due to dike breach: retrieved from National Database of Flood Information (LIWO, n.d.) in which provinces, water boards and Rijkswaterstaat have made information available for national use (Rijkswaterstaat, 2023). This map provides flood scenarios for protected and unprotected areas located along the primary and regional water system.
- Maps with current and future annual flood probability according to failure of flood defenses around the Zwolle region (LIWO, n.d.)
- Maps with maximum flood depth associated with severe and prolonged rainfall for urban areas with an average duration of 2 hours and with different return periods (Klimaateffectatlas, n.d.).
- Flooding base map showing the result of a stress test of flooding locations in municipalities of Overijssel after an extreme shower including water flow in sewers for the built-up areas developed by Drents Overijsselse Delta Water Board (DOD, n.d.).

The retrieved information will be used to perform 3 different spatial analysis, the first one will assess what is the actual and potential flood risk in the Noorderkwartier area by combining the elevation data (AHN) and the expected flood depths due to fluvial and pluvial risks (LIWO and Klimaateffectatlas). The seconds analysis will consist in finding the flood sensitive areas due to combined flood risk in order to examine hotspots that require the implementation of spatial measures with higher priority (DODelta map will be used to see water flow behavior with elevation map AHN). The last analysis will be aimed to find suitable locations to apply spatial measures, for this purpose, information about the physical characteristics of the area will be retrieved from the case study analysis in order to examine which areas would represent a physical limitation for the implementation of spatial measures.

5. Preliminary Inventory

5.1. General Inventory

After reviewing the pertinent Literature Review in Chapter 2 in search of the set of case studies and redevelopment projects inside and outside the Netherlands which applied resilient spatial measures as part an integrative approach (MLS), it is possible to develop a general inventory which contains all the spatial measures considered as the “best practices” for adapting flood risk in urban areas to enhance housing flood resilience. In the literature review phase, the cities of Dordrecht, Rotterdam, Enschede, Hamburg, New York and Boston were considered as the “best practices” in applying resilient spatial measures.

- Spatial measures applied in Dordrecht were considered because this city is comparable to Zwolle in terms of physical characteristics (delta cities influenced by sea storm surges). But Dordrecht is also considered as one of the “best practices” because its application is considered by several authors as the first relative success in combining conventional prevent system (dikes) with sustainable urban planning and spatial measures. Since 2011, Dordrecht urban planning has prioritized climate change projection to develop resilient solutions at different spatial levels: singular buildings and houses, neighborhoods, and city.
- Despite the evident discrepancies between Zwolle and Rotterdam positions against flood risks, this last one is considered in this research as one of the “best practices” because the MLS concept was approached in a comprehensive way to combine structural and non-structural measures to manage flood risks. In this case, the best practice attribute is derived from the innovative and modern solutions that have been applied in urban areas: water squares, elevated plazas, riverfront promenades and dry- and wet-proofing for singular buildings.
- The case of Enschede is particularly interesting because it presents a recent redevelopment project that tries to solve the persistent waterlogging issue due to short-term rainstorms in a residential neighborhood. Enschede is described as one of the “best practices” in applying spatial solutions because it tackles extreme events consequences due to climate change by engaging residents’ participation and proposing innovative solutions that include blue-green infrastructure and redesigning street profiles to actively participate in redirecting rainwater.
- Hafencity in Hamburg is considered as a reference point for being a successful redevelopment project that built a multi-functional urban area (living, working and leisure activities) while considering and intensive interaction between water and land. This case study is considered as one of the “best practices” because of how the implementation of tough spatial measures is well integrated with the “water culture” paradigm that demands a better connection with water bodies as part of the livable environment.
- Regarding New York and Boston, these cases can be attributed the label of “best practices” because of their comprehensive and innovative flood risk management strategies, principally in terms of applying soft non-structural measures by means of collaborative governance. Research showed that redevelopments projects in these cities were generally successful because of a combination of flood policies, building codes and zoning plans which are results of proper management and agreements among different levels of governance.

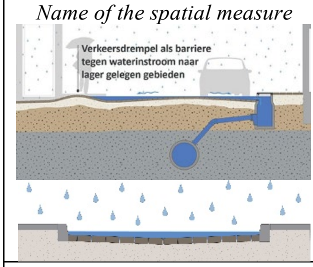
It is also worth mentioning that for the elaboration of the general inventory table, some definitions and illustrations of the selected spatial measures were taken from literature and online tools such as climate adaptation apps used by municipalities of Amsterdam, Enschede, and by water board authorities to increase awareness of residents in flood risk. Van de Ven et al. (2009) present an overview of spatial measures that can be implemented to make an area water robust, The authors classify these measures in two, soft measures mainly focused on planning and behavioral and tough measures targeted on the physical environment and often installed permanently. The “Climate Adaptation app” developed by Deltares, Sweco, KNMI, Witteveen+Bos, and Bosch Slabbers was also used and offers insight into feasible spatial measures for projects with specific climate adaptation goals. This toolbox presents measures for different land uses, surface levels, and spatial scales (Deltares, 2023). Finally, the website “Amsterdam Rainproof.nl” was used to obtain detailed information about spatial measures applied in houses in Amsterdam since this online platform also offers examples of how different measures can be combined or designed in urban residential areas (Amsterdam, 2023).

All in all, the spatial measures collected are listed in the General Inventory which can be found in Annex A, Table 15 shows the name, identification number, and graphical applications while Table 16 details their definition, advantages, and disadvantages of their application. Regarding the classification type, three different criteria were used to classify the spatial measures in both tables:

- The measures displayed in both tables are classified according to the definition of housing flood resilience stated in sub-chapter 2.2, thus, displayed measures are aimed to have water robust construction (*dry-proofing*), adaptable structures (*wet-proofing*) and transformability capacity (*retain water*).
- Literature review revealed that spatial measures have multiple classifications according to its construction nature, for instance, if the use of greenery is primordial or if it requires structural design and artificial adaptations. In this investigation, all the measures that describe physical interventions (using green features or not) are labeled as *structural interventions*. On the other hand, all those described as soft measures involving regulations, policies, building codes, and participation plans are labeled as *non-structural recommendations.*
- Literature review also suggests that spatial measures are usually classified according to the spatial level at which these are applied. For this investigation, there will be 3 different spatial levels at which measures can be applied: *street level* (or ground level), *households and singular building level*, and *neighborhood level*.
- Finally, the measures are also classified according to the type of flood risk these measures try to mitigate or adapt, in this research the main two flood risks at which the Noorderkwartier is susceptible are considered: *pluvial and fluvial flooding*.

For a better understanding of the general inventory, see Table 3 below to see how the measures are classified in the Table 15 in Annex A.4.

Table 3, Classification used in general inventory

<table>
<tr><td rowspan="6">Name of the spatial measure
</td><td>Pluvial flood risk</td></tr>
<tr><td>Fluvial flood risk</td></tr>
<tr><td>Street level</td></tr>
<tr><td>Household level</td></tr>
<tr><td>Singular building level</td></tr>
<tr><td>Neighborhood level</td></tr>
<tr><td colspan="2">In Annex A.4, Table 15 shows illustrations of the spatial solutions while Table 16 shows a description with their advantages and disadvantages.</td></tr>
</table>

The "General Inventory" counts with 49 spatial measures aimed to enhance housing flood resilience. There are 32 structural interventions that are classified considering three main characteristics: dry-proofing the surrounding area of residential structures so water does not reach them, wet-proofing the residential structures so these become water-resistant to a flood event and transforming the water issue into an opportunity to reuse retained water. There are 17 non-structural recommendations classified in land and design regulations, building codes, citizen participation and recommendations for institutional organization. Table 4 below gives an overview of the 49 spatial measures, however, for a complete description of the structural interventions refer to Annex A.4.

Table 4, Overview of structural interventions listed in the general inventory

#	Structural Interventions
1.	**Threshold or increased floor** is suggested to drain water before it could reach an estimated elevation and affect underground constructions like basements. This measure is used in unembanked and urban areas in Dordrecht.
2.	**Redesign of the street** proposes the adaptation of the street profile to have a mild slope to redirect water towards the sides or in the center of the street and drain it through a sewer system. Rotterdam and Enschede have decided to transform street profiles to be more inclusive but eliminating sidewalks as barriers.
3.	**Increasing the sewer capacity** aims for the redesign of pipelines to have a larger diameter and thus, these can process more extreme rain showers. The first redevelopment plans in Rotterdam use this measure to handle excess of water in hard-access urban areas.
4.	**Semi-open gutters** are part of a drain system that can be integrated to the existing environment without major structural interventions. It has been applied in recent projects in Enschede
5.	**Water-permeable pavements** is a measure used in Hafencity for those walkable areas destinated to pedestrians and cyclists only. This measure can replace heavy concrete areas for a new and green cover.

6.	**Urban infiltration strips** are becoming very common in Rotterdam and Hafencity, this measure use greenery as a natural buffer to retain water, however, the design can be improved to infiltrate water and to store it for longer periods.
7.	**IT sewer pipes** is a new development for sewer systems that was applied in projects in Rotterdam. This measure presents new pipelines with permeable walls to collect water and transport it to a new area.
8.	**Parking above green areas** is a relatively new approach which pretends to replace concrete in parking lots with low traffic to have green strips that can manage the extra weight and can allow infiltration of water. Some parking lots with this feature have been installed in Rotterdam already.
9.	**Reintroducing the sidewalks** is a recent measure that have raised in response to waterlogging problems where the sidewalks have been lowered to ground level allowing a larger surface to accumulate rainwater. The measure has been adapted in Dordrecht where urban neighborhoods asked for the use of sidewalks even if this hinders the accessibility for all the users.
10.	**Non-return valves** can be adapted to the existing sewer system in order to avoid the collapse of pipeline for a combination of fluvial and pluvial floods. This measure ensures that water does not go in the wrong direction since it is common to have pipe outlets in canals.
11.	**Separated sewer system** proposes the redesign of an entire sewer system to manage rainwater and wastewater separately. This has been applied in several projects in Rotterdam, Amsterdam, Dordrecht and Enschede. In fact, it has become a standard for new urban redevelopment.
12.	**Installing temporary defenses** (for significant facilities and areas) is a measure designed to have emergency barriers that can be installed before an extreme flood event hits an historical area, for instance. Sandbags, water bags, demountable bulkheads and other measures have been used in the unembanked areas of Dordrecht to protect important facilities like hospitals.
13.	This measure proposes **elevated buildings built on piles** as can be found in the area of Hafencity to keep residential functions always dry. Buildings can also be elevated if these are built on an elevated ground floor level as some areas in Dordrecht and Rotterdam.
14.	**Wadis** are structural measures redesigned in the Netherlands to not only collect rainwater but also to infiltrate it when there is an excess of water coming from built-up areas. It has been largely applied in Dutch cities like Enschede where the availability of land for spatial measures is limited.
15.	**Activating urban rooftops** is an innovative idea which implies adapting rooftops of buildings to create new public and open spaces in order to have different layers in an urban area. Urban rooftops have been applied in Hafencity to function as emergency meeting points in case of extreme events.
16.	**Height differences in ground level** is a measure implemented in areas with waterlogging issues in order to create new ways to redirect excess of rainwater and avoid its accumulation close to residential areas. If this is applied in green areas, the soil can also get saturated as much as possible before allowing runoff. This has been applied in green parks surrounded by neighborhoods in Rotterdam and in main plazas designed to stay dry in Hafencity.
17.	**Disconnecting the rain pipe** of the households and buildings would relief the sewer system since this water would not reach the maximum capacity of the ground pipes. This measure has become a standard in redevelopment plans in Rotterdam and Amsterdam since it allows residents to reuse rainwater in their gardens
18.	**Sealing buildings** is considered a tough measure since it ensures that all the possible gaps of a building are properly closed to resist a flood event, this includes windows, doors, ventilation, and even underground garages. Structures prone to get flooded in Rotterdam have applied this although it has reduced their aesthetic value.
19.	**Use of water-resistant materials** ensures that a construction is no damaged by the constant interaction with water from rainfalls, groundwater and even floods. The use of these materials became a local regulation in Hafencity to ensure that structures can stand floods without present structural damage.
20.	**Raising land** is considered as the most effective and cheap measure since it ensures that new constructions are built above water depth design levels so these always stay dry. This measure has been applied in the entire surface of Hafencity, however this is only feasible if there are no built-up structures.
21.	**Elevated functions** and utilities recommend the allocation of all residential spaces in the higher floors of buildings so these are not affected by a fluvial flood. Likewise, all the pertinent connections such as electricity, gas or even internet should be built above certain threshold or with water-resistant materials. This measure has become and standard for the construction within Hafencity.
22.	**Rainwater storages** is a complementing measure that can be part of the disconnection of the rain pipes from the sewer system. Water storages can be built for singular structures or for large areas to take advantage of the accumulation of rainwater to use it for watering or for recreational purposes. This measure is widely used in several cities in the Netherlands to have water during drought periods.
23.	**Rainproofing rooftops** is a measure with an adaptation designed to protect the buildings of households from heavy and often rainfalls, this measure is principally aimed to avoid structural damage and redirect water towards gardens or artificial ponds.
24.	**Flood defenses adapted to topography** are a relatively new development that involves the construction of artificial waterfront defenses with other functions such as meeting spots or open areas close to the water. This measure is used in several parts of Hafencity to restate the connection between recreation and water while protecting the urban environment.
25.	**Green roofs** act as a natural stormwater management system by absorbing and retaining rainwater instead of leaving it flow to the ground floor. By keeping the water in higher layers, the sewer system would not get overpowered by the excess of water.
26.	**Green facades** are a very common measure which involve the participation of house owners to transform the outside structure into vertical gardens to redirect the rainwater flow through the walls to nearby pond or garden. This measure is widely applied in heavily built-up environments.
27.	**Water roofs** make use of the usually unoccupied space in the rooftops of households and buildings to store water temporarily during rainstorms, this would also require the rooftop to be built with water-resistant materials and to have been designed to support extra load. There are numerous examples of water roofs in introvert office buildings in Hafencity.
28.	**Water squares** are innovative solutions that pretend to be artificial storage for the excess rainwater in heavily paved areas. This multifunctional measure is designed to be a deepened recreational area that collects rainwater in extreme scenarios of rainfalls. Rotterdam has built a characteristic water square in the center of a mixed neighborhood so the waterlogging issue is can be eased.
29.	**Urban watercourses** are innovative and practical solutions to make use of excess rainwater and keep it flowing. This measure proposes the creation of a water streamline that collects water from different spots and discharge it safe spaces. Enschede has applied this measure in two different projects where one is similar to a natural trench towards the local canal, while the other is an artificial water pond with recreational purposes.
30.	**Water elements** such fountains or recreational plazas with splashes from the ground can make use of stored rainwater and keep the heat effect low. This measure is considered a great aesthetic feature in Rotterdam, Utrecht and Enschede.
31.	**Infiltration crates** are innovative objects that are designed to be implemented below permeable streets or with gutters, since these crates have a sponge effect that drains excess of water in streets. This measure has already been implemented in Rotterdam and in some areas in Zwolle.
32.	**Emergency underground water storages** are built to capture and store rainwater underground, this reduces pressure on surface drainage systems and prevents urban inundation during combined flood events. This measure usually considers bike storages as the most optimal to be adapted to water storage, since this would not represent a large economical damage. This measure has been already implemented in Rotterdam, Amsterdam, Hafencity and Zwolle.
#	**Non-structural recommendations**
	Land and design regulations
33.	New regulations proposed from local governance to prioritize open green spaces and natural buffer zones within built-up urban areas.
34.	Focus on controlling waterlogging spots in urban areas and neighborhoods, this also comprehends an analysis into the existing sewer system and the installation of pumps and inlet guts.
35.	Promoting the incorporation of blue-green infrastructure in urban development as much as possible, this includes green roofs and facades.
36.	New open space requirements that encourage the multipurpose use of public space so they can adapt for different events such as meeting places, buffering areas or water storage. This also includes green areas and parts of public squares, so these allow flooding every once or twice a year for few hours.
37.	Conservation of natural features that provide flood protection; however, it also accounts for the implementation of flood defenses in green areas without disturbing the existing environment nor the landscape
38.	Street design should disconnect rainwater discharge from main sewer system where possible, so it is not overwhelmed, measures like infiltration or permeable surfaces need to be implemented.
39.	For a better sense of connectivity, three main structures should be present in waterlogging-prone areas, an open square to store water, a promenade that infiltrates and redirects water, and an elevated place as a meeting zone.
40.	Building blocks should not create a continuous wall or limiting the mobility of people through the buildings.
41.	The geometry and topography of the area formed by buildings and public space, should retain and infiltrate water before redirecting the runoff towards the closest water body.
	Building codes
42.	Strict building codes risk-based on design flood water levels so living functions and relevant connections (electricity, gas, internet, water) are built

	above the specified design level so these areas remain functional in a flood event.
43.	Set standards on water-resistant materials for construction from infrastructure till maintenance and structural adaptations.
44.	Establishing a ground elevation standard for every project presented prior construction so the elevated zones do not require enormous technical and costly operations.
Citizen participation:	
45.	Comprehensive communication with people living in flood-prone areas by using flood hazard mapping to remark the potential damage and potential solutions.
46.	Encourage the purchase of flood insurance (higher costs for constructions in high-risk areas) or offer financial incentives to homeowners so they can make investments in flood-resistant renovations and retrofitting.
47.	Encourage a higher compromise of residents to participate in the protection of historical areas by deploying temporary flood defenses.
Recommendations for Institutional organization	
48.	Local municipality should be allowed to impose land regulations and spatial strategies in addition to minimum standards established by national plans or higher governance levels according to the level of risk experienced in the area.
49.	Workshop meetings to discuss and agree on priorities of a project having as goal flood resilience for structures in risk zones. For this purpose, a proper study of possible future scenarios and climate impact consequences is needed to base the measures on design flood water levels from water depth maps.

5.2. Measures applicable to the Noorderkwartier

Once the "General Inventory" has been designed, it is necessary to know how many of these measures are actually relevant for the Noorderkwartier by assessing the existing opportunities that this area offers. To understand these opportunities, this subchapter will discuss which interventions are recommended or needed according to the stakeholders' opinion. The interview process during the data collection phase is used to know the opinions of the participants about the spatial measures presented in the general inventory plus what measures (not listed in the inventory), they think could enhance housing flood resilience.

5.2.1. Interview results: Opportunities for spatial measures

According to the results of the interview, the six participants have a relatively positive opinion about the implementation of spatial measures to enhance housing flood resilience in this area, however, participants with relevant roles within the project agreed that spatial measures have not been explored nor assess yet. The principal remark from the participants was the application of different spatial measures in the Noordereiland and in the Dieze part as both experience a different level of flood risk. According to what was found in the case study, the inner city is located outside the dike protection, thus the risk of fluvial flooding is high although not alarming at the moment; conversely, the Dieze part is well protected by the regional dike ring, but since this area is heavily paved, there has been a persistent waterlogging problem due to rainfalls which represents a nuisance to people working in this area. In a sudden and extreme scenario, water-related problems could be triggered by a persistent north-west sea storm that would lead to a rise in the Ijsselmeer water level, that although can be controlled by the Ramspol defense, prolonged rains might influence the discharge from the Zwarte Meer that could directly raise the water level in the city canals. In consequence, there would a pluvial flooding due to the limited capacity of the sewer system at the Dieze part, while the Noordereiland could experience a fluvial flood due to the water-raising levels of the Achtergracht canal. Therefore, different spatial measures need to be considered for both parts.

Gathering all the responses from the different participants, there are suggestions and opinions about some spatial measures, these can be listed as shown in Table 5 below:

Table 5, Opinion and recommendations about spatial measures

	Participant 1	Participant 2	Participant 3	Participant 4	Participant 5	Participant 6
Opinions and important recommendations	• Any type of measure that make people feel the area less gray, part of the "Stadshart" program is to have a green venue in this zone. • There have been talks about possible designs with inspiration in the Kraanbolwerk project. • A flood event is rare to happen, maybe in 1/100 years, so spatial adaptations should be discretely adapted to the area. • The available surface for spatial measures is limited (around 20-25%), so measures should be practical and occupy as less space as possible. • Accessibility was an important matter when the draft of the Area Vision started, this area is expected to be inclusive for students, workers, elderly, cyclists, and even occasional cars.	• Elevating the area would be the most viable solutions since is effective and relatively cheap although this would require a non-built-up surface. • According to the historical data on rainfalls, an extreme situation would not represent a serious problem in the Dieze part, a major upgrade to the sewer system should be enough to avoid accumulation in lower parts. • Spatial measures on the Noordereiland should be mainly focused on fluvial flood adaptations. This also involves considering a design water depth level that could be reached in an extreme event. • Relocating vital functions within buildings would involve electric, gas and internet connections above a threshold level.	• Waterfront parks, boulevards and green squares are important to encourage people to transit here and could serve as storages, but the design should not be gray. • Water elements added to plazas and parks are opportunities to use collected rainwater. • For the historical area in the Noordereiland, measures should be temporary and demountable, so it does not affect the landscape. • Infiltration crates have been proved effective as temporary rainwater storages to be used for greenery. • Green infrastructure is strongly recommended, walls and facades have perks in water management and heat effect. • Dieze shopping center is a difficult building, spatial measures should be applied on the sides or surroundings to ease waterlogging.	• Most of the measures for flood resilience should be aimed to apartment buildings since these will represent the 90% share of housing facilities. The other 10% is for singular Dutch style households. • The first masterplan for the area vision already presents a sort of water trench that redirects rainwater along the Van Wevelinkhovenstra at. • Spatial measures could bring opportunities to store rainwater and reuse it for greenery in the area (disconnect gutters from sewer pipes). • The Noordereiland surface needs to be raised following the Kraanbolwerk example, however the historical side of the island cannot be due to the valuable buildings. • Water squares are great ideas, but these should be part of a water collection system, and not leave this are as an isolated storage. • Accessibility is a cornerstone for the redevelopment plan since all the areas should be remain accessible for all type of users.	• The interviewee agrees about elevating the area as the most effective, economical, and practical measure. • The Noordereiland could only allow spatial measures that do not require digging the soil or using underground spaces. • If building rooftops are required for greenery, then there is a chance to research about solar panels in the sides of buildings. Although the number of suitable buildings is unknown. • Water elements added to the area should ensure water flowing to keep a quality standard. • Spatial measures should have multiple functions such as an infiltration function and a meeting spot for people.	• Having playgrounds in the area is a requirement as the residents of nearby neighborhoods asked for this during the workshops, thus there are opportunities to apply spatial measures here. • A waterfront area could be placed in the Noordereiland to have new open space and storing water in emergency situations. • Certain buildings and areas are not included in the area vison because the owners of these were not interested in the redevelopment plan. • Most of the waterlogging issues are concentrated in the Singel area. • The Cultuurplein is expected to be a meeting spot surrounded by restaurants and cafes, a water square is a good idea but maybe it can be located in other areas. • Adjusting the street profile to be flattered is important to have a better connection between this area and the other neighborhoods, if there are areas with serious waterlogging then new measures need to be explored.

An important resolution inferred from the interview results is that the current sewer system in this area certainly lacks capacity to manage extreme runoff due to downpours, however, the area vision and the redevelopment plans already contemplate upgrading the sewer system to have different pipelines to manage rainwater and wastewater separately, although this might take several years to be completed. Furthermore, the majority of participants mentioned the Kraanbolwerk redevelopment project as a great inspiration for this plan, principally for the area denominated as Het Nijkerken Bolwerk.

5.2.2. Lessons learned from Kraanbolwerk project

The Kraanbolwerk project is considered in this investigation as result of multiple responses that suggest a high relevance of this redevelopment in influencing the redevelopment of the Nijkerken Bolwerk (Noordereiland). As a matter of fact, the building "De Stelling", previously mentioned in the sub-chapter 3.5, is located within the Kraanbolwerk neighborhood and therefore, it presents some water robust features. During the interview process, participant 4 provided a Sustainability Manifesto which details examples of redevelopment projects that were VanWonen has worked before (VanWonen, 2021). In this booklet, the Kraanbolwerk is described as an area redesigned in such way to ensure that the structures are protected against extremes weather conditions, thus the neighborhood was designed on a higher water level than the rest of the city center. Within the residential structures, living functions and electricity facilities are built above 3.20m + NAP level so residents keep their feet always dry. In fact, entrances of the buildings are built in such a way that these are still accessible when water is extremely high. Furthermore, the surrounding of the apartment buildings is composed of ramp and stairs varying from 1.80 to 2.6m + NAP. The booklet also describes the construction of a semi-sunken underground garage that is sealable and serves as a buffer between water and houses, for this purpose, additional tension piles are placed to ensure that upward force of groundwater is resisted. Finally, the rainwater is visibly drained through waterways that surround this peninsula on three sides towards the canal.

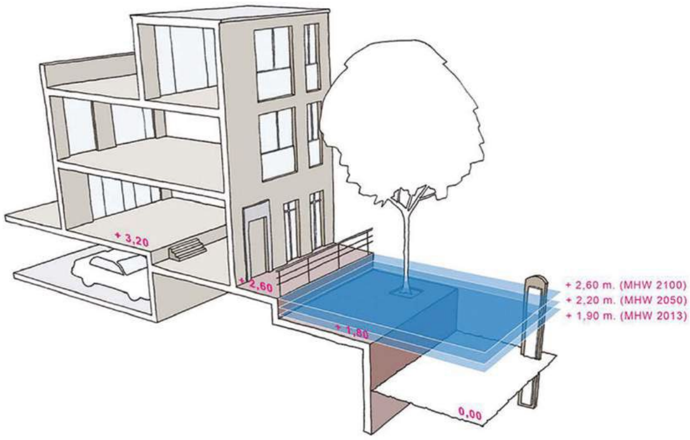


Figure 19, Height difference in the Kraanbolwerk design (Peilstok, 2021)

5.3. Feasibility Assessment

The next step in developing the "Preliminary Inventory" is the evaluation of the existing implementation barriers for the recommended spatial measures that were listed in the General Inventory and considered by the interviewed participants. This step will assess which measures are conflictive with different factors: social acceptance, physical-spatial limitations, and institutional-organizational barriers. First, it will be reviewed what are the perceived implementation barriers according to the responses from the interviews which are based on findings in the literature review of sub-chapter 2.5. Before suggesting the Preliminary Inventory, the implementation barriers found the interview process will be evaluated to know if there are opportunities to overcome these constraints or if it needs to be accepted that some spatial measures cannot be applied in the Noorderkwartier.

5.3.1. Interview results: implementation barriers in the Noorderkwartier

By using the findings from sub-chapter 2.5, it is known that in the Netherlands, there are three main implementation barriers for resilient spatial measures within the 2nd layer of the MLS: social acceptance, physical-spatial limitations, and institutional-organizational barriers. These findings were used to develop a set of questions aimed to know the opinion of the interviewed participants about what they perceived as implementation barriers for the Noorderkwartier area.

All the relevant responses retrieved from the different participants are listed in Table 6 below. From a quick overview of the responses, it was noted that participants have similar thoughts about some physical limitations that could allow the implementation of few spatial measures in specific areas, however, it is also evident that there are some conflicts about what the participants consider tasks of higher priority for the redevelopment plans: e.g., energy-neutral task and housing flood resilience task. The table below will be used to contrast the recommended measures provided in Table 5 to find conflicts with recommended measures and between the opinion of stakeholders.

Table 6, Perceived implementation barriers

	Participant 1	Participant 2	Participant 3	Participant 4	Participant 5	Participant 6
Opinions about potential implementation barriers	• Some measures are only applicable in the Dieze part since spatial measures in the Noordereiland would be useless during a fluvial flood event • Water boards regulations have a larger stake in choosing spatial measures, dike protection might seem to be enough for them. (water board regulations above the municipality's) • Neighbors might not like spatial adaptations if they are not aware of the risks • Not much surface can be considered for spatial measures, according to land-use plans, just the sides of the canal are apt to water management measures. • Housing resilience task might not get as much attention as solar energy.	• People are not aware of the flood risk, and neither are some authorities not related to water management, the dikes have been effective in the last decades so there is no need for a change. • Urban areas are too dense and tight that it is difficult to find space for such measures. Sometimes increasing the capacity of underground systems seems to be the most effective solution • Spatial measures in rural areas around the city like the restauration of floodplains and wetlands to have controlled floods draw more attention. • Areas with a flood depth higher than 50cm do not need spatial measures because the consequences would overpass their adaptive capacity.	• Soil in the Noordereiland is polluted because of an old gas fabric placed here, therefore spatial measures that require excavating or underground solutions are impossible • Measures like increasing the capacity of the sewer system can only be applied if the entire system needs maintenance because the streets need to be open and it is very expensive, it needs to be done in phases. • At the moment building codes follow national policies so, the municipality does not have a say in this matter. • There were some regulations about having living function in high floors years ago, nowadays living functions are at street level. Besides, shop owners do not like thresholds	• Green roofs or any other type of structure would not be allowed as the goal is to have all the rooftops full of solar panels. • Green walls or facades are considered not that effective in absorbing water, so it is better to implement greenery at the street level only. Besides the maintenance is very expensive. • One of the principal requirements is making this area accessible for everyone, thus the must be ramps, stairs where possible but also eliminate height differences in ground levels. • Responsibility is ambiguous as the development of spatial measures does not rely on a specific party.	• The Noordereiland would be the main problem since most of the measures cannot involve underground construction, no pipelines, or drain system, even wadis are difficult, but some temporary barriers could happen • Any measure applied in existing buildings is expensive since this implies many technicalities, like structural analysis for extra weight. • Water board is a political institution, so people there have different agendas, taking care of keep water out is more important than water accumulating in the streets occasionally.	• The Dieze shopping center is too introverted, and it is almost impossible to have sustainable measures here, the entire area will be used as a mobility hub. • A water square might be difficult to implement since the area vision contemplates horeca facilities in the area around the Cultuurplein • Probably some stakeholders would not be happy in applying green upgrades in their buildings, some of them are old-school developers. The main problem would be how costly would this be for them and if there is no strict law to do it, they will not apply them.

5.3.2. Suggested spatial measures against implementation barriers

This sub-chapter will find potential conflicts based on the relevant implementation barriers found for the Noorderkwartier area, it will be explored how these barriers can hinder the application of spatial measures from the General Inventory. This step will show the conflicts between the opinion of different stakeholders about the implementation of spatial measures based on their experience and roles.

Table 7 below shows the classification used for the implementation barriers as was found in sub-chapter 2.5. Physical and spatial limitations describe those scenarios where spatial measures cannot happen at different spatial levels due to the physical characteristics of the Noorderkwartier, structures already built there, and redevelopment plans presented in the Area Vision. Social acceptance refers to those possible barriers imposed by the general public which will be the people affected or benefited by the spatial measures. Institutional-organizational barriers describe those relationship issues among the principal stakeholders that go from ambiguity in responsibilities to difficulties in adopting regulations from higher-level actors. Table 7 below indicates how implementation barriers listed in Table 6 conflict with the other participants' opinion as can be found in Table 5.

Table 7, Conflicts between implementation barriers and participant's opinions

Implementation barriers		Conflicts with participants' opinions
Physical-spatial limitations	Soil in the Noordereiland is heavily polluted, therefore spatial measures that require excavating or underground solutions are not feasible nor recommended. It is considered to simply elevate the entire surface up to 40cm.	In general, all the participants agree that raising the land level is the most economic and effective measure to be applied in this area, however, there are different opinions about if this is enough to control waterlogging issues too. Besides, participants 3 and 4 acknowledge that the historical part of the Noordereiland cannot be raised, so other measures are needed.
	It is difficult to find space for spatial measures in built-up areas, only around of 10% of the area is aimed to haver spatial measures for water management and this is just the space close to the canal, not between buildings.	Participant 1 explains that there is limited space to have large spatial adaptations like water squares, measures should be more discrete and integrated to the landscape. Participant 2 suggests that a major upgrade on the sewer system is enough to manage the excess of water.
	Green walls or facades are considered not that effective in absorbing water, so it is better to implement greenery in horizontal surfaces.	Participants 1 and 3 strongly recommend green features to be applied in the new buildings for this area, principally to redirect water and ease the heat effect.
	Applying measures in rooftops of existing buildings are	Participant 5 doubts about the use of green roofs in this area since the existing

	difficult because these would need to support extra loads of greenery and water layers.	buildings might not be designed to support extra loads for greenery and water layers. Furthermore, the new buildings should include extra structural analysis to encourage these measures.
	The Dieze shopping center is planned to be used as a mobility hub, most of the space is required for parking functions so spatial measures are not recommended.	Participants 3 and 6 agree on the Dieze shopping mall building being difficult due to its closed and gray design, there are chance for improvements with green facades, but it is mainly recommended to have measures around the building that do not interfere with the mobility hub function.
	A water square might be difficult to implement in the Cultuurplein zone since this type of measures generally take a significant amount of surface to have a as much storage capacity as possible.	Participant 3 considers water squares as rough structures that just add a gray look to the environment. Participant 4 differs from this and argues that water squares are good examples of water catchment systems in urban areas. However, the participant also recognizes that this area should be part of a large collection system and not be left as isolated storage. It could include greenery details.
	Stakeholders want this area to be accessible for all users and cyclists.	Participant 1 acknowledges that there are plans to flatten the streets and make them car-free for accessibility, Participant 6 recognizes that this would eliminate the retention areas created by the sidewalks, other measures like gutters need to be explored.
	Considering the elevation of the ground level by raising land is only possible in non-built-up areas to avoid extra demolition costs.	There are no conflicts about this spatial limitation, all the participants agree that raising land level is the most effective measure for the Noordereiland. In fact, Participant 4 mentioned that this has already been planned for the Spatial Plan document.
	The area vision proposes open buildings that are accessible for all users. That is why spatial measures hindering this characteristic are not allowed.	Various participants suggest the Kraanbolwerk as an example of sealing structures that are not conflictive to the requirements of the project, buildings cannot be sealed completely but other functions like garages can.
	Accumulation of water after a rainfall requires that it keeps flowing so water can maintain a standard quality.	Participants 3 and 5 consider water elements as a great feature for paved surfaces like plazas, but if the used water comes from rain, then this should have a quality standard before being delivered to the environment again.
Social Acceptance	Residents from nearby neighborhoods might not be convinced of the need for spatial measures due to a low-risk awareness, principally at Diezerpoort.	Participants 1 and 2 mention that an extreme flood event is unlikely to happen, even in the inner city, and since people have not experienced a flood in decades, thus they are not willing to accept extra costs for measures.
	Future residents might not be willing to accept a wet-proof measures for a controlled flood in public spaces or in underground garages since they are not aware of the flood risks.	Participants 4 and 5 agree on the fact that nobody wants to see their property flooded. Wet-measures should be implemented; however, the focus should lie on dry-proofing so people can feel more protected and willing to accept adaptations and to participate.
	The redevelopment project is expected to be completed in 10-12 years and some measures would need to be implemented in phases if the construction processes take too long there might be some discomfort from the residents.	Participant 6 mentioned that spatial measures are not yet assessed but these would be implemented in phases, starting with the Diezerpoort center and then with the Noordereiland, spatial measures should also be prioritized to tackle water problems as soon as possible.
Institutional-organizational barriers	Water board is a political institution with strict regulations and standards that prioritize large-scale flood defenses over small-scale measures, regulations from water authorities are above municipality control.	It was mentioned that spatial measures would have a better reception if these were developed in floodplains outside the urban area, however this approach is out of the scope of this investigation.
	The water board does not consider spatial measures as a priority since a fluvial flood event would overpass the capacity of spatial measures to manage water.	Participant 2 has a more technical perspective, it is mentioned that reinforcement of dikes is still more important and although there is room for 2nd layer MLS improvement, this is still far from obtaining the same results as the conventional defenses. Participants 5 and 6 recognize the position of the water board as institutional limitation.
	Stakeholders do not consider spatial measures because there are different opinions on which task is more important: housing flood resilience and energy-neutral structures.	Several participants encourage the use of green infrastructure and features as much as possible but there is no preference on which task has a higher priority. It was also mentioned that several meetings and future workshops will define the importance of the different tasks.
	Spatial measures that involve regulations of building codes are difficult since these follow national policies that do not meet local flood risk requirements.	Participant 2 recommends the elevation of utilities within buildings since this would keep people communicated and using basic services during an extreme flood event, however according to Participant 3, this has passed from a strict building regulation to a soft recommendation for contractors.
	Responsibility is still ambiguous as the development of spatial measures does not rely on a specific actor but in a general agreement. However, priorities are not set yet.	Participants from the municipality mentioned that implementation costs and logistics for spatial measures would depend on the land and house owners. Participant 4 acknowledges that although selecting spatial measures would be done in a general agreement, there is still some ambiguity on who will be responsible for them since the municipality owns the public area, but several buildings belong to different parts.

After reviewing the results from Table 7, it is noticeable that most of the barriers mentioned by the interview participants have conflicts with spatial measures related with physical-spatial limitations, this already suggests that some of the measures provided in the General Inventory and suggested by the participants might not be used in the Preliminary Inventory. A critical implementation barrier that was not listed in Table 6 or Table 7 is the economic considerations, this barrier is described as an institutional problem and it was addressed during the interviews, however, it was found that the Area Vision document was just developed and it needs to be accepted before the Spatial Plan can be developed and suggest spatial measures in this phase. A budget will be prepared to guide which measures can be considered, thus there are no economic considerations yet, in fact, several participants agreed that this investigation would be a first step in reviewing the opportunities for spatial measures in this area.

5.4. Overcoming implementation barriers and conflicts

This sub-chapter will explore what are possibilities to overcome the implementation barriers and conflicts previously mentioned. It is expected to provide a list of spatial measures that could meet the requirements and opinions of the interviewed stakeholders so these can be considered feasible in terms of general acceptance. The first part will look into the priorities that each stakeholder has according to their role and experience in these types of projects. It will be analyzed the perspective that the participants took when they gave their opinion about which spatial measures, they considered feasible or not according to their preferences.

5.4.1. Participants' perspective about spatial measures

Analyzing the interviews results, one could notice that participants have different perspectives about what characteristics of the spatial measures (e.g., more green, nicer designs, practical solutions, land used, etc.) they consider more relevant. This can be explained on the perspective of the participants due to not only their background, roles, and experiences but also on what they consider more urgent issues to attend, therefore, this can provide an idea of what kind of measures are more likely to be selected for the next phase of the project.

The spatial measures' attributes to be considered can be interpreted as:

- **Practical Design**: *how important is that spatial measures have a practical technical design and that are easy implementation process?*
- **Wet-proof function:** *would you prefer spatial measures that adapt floods effectively once these have reached housing structures?*
- **Dry-proof function:** *would you prefer spatial measures that keep water out of reach of residential structures and public spaces?*
- **Multipurpose function:** *how important is that spatial measures retain water in specific areas to tackle other climate tasks?*
- **Appearance:** *how important is that spatial measures offer an aesthetic added value or that do not alter the existing landscape greatly?*
- **Land use:** *how important is that spatial measures do not occupy much land?*
- **Greenery**: *how important is that spatial measures use green features as much as possible within the designs or as the principal system to infiltrate, drain or retain water?*

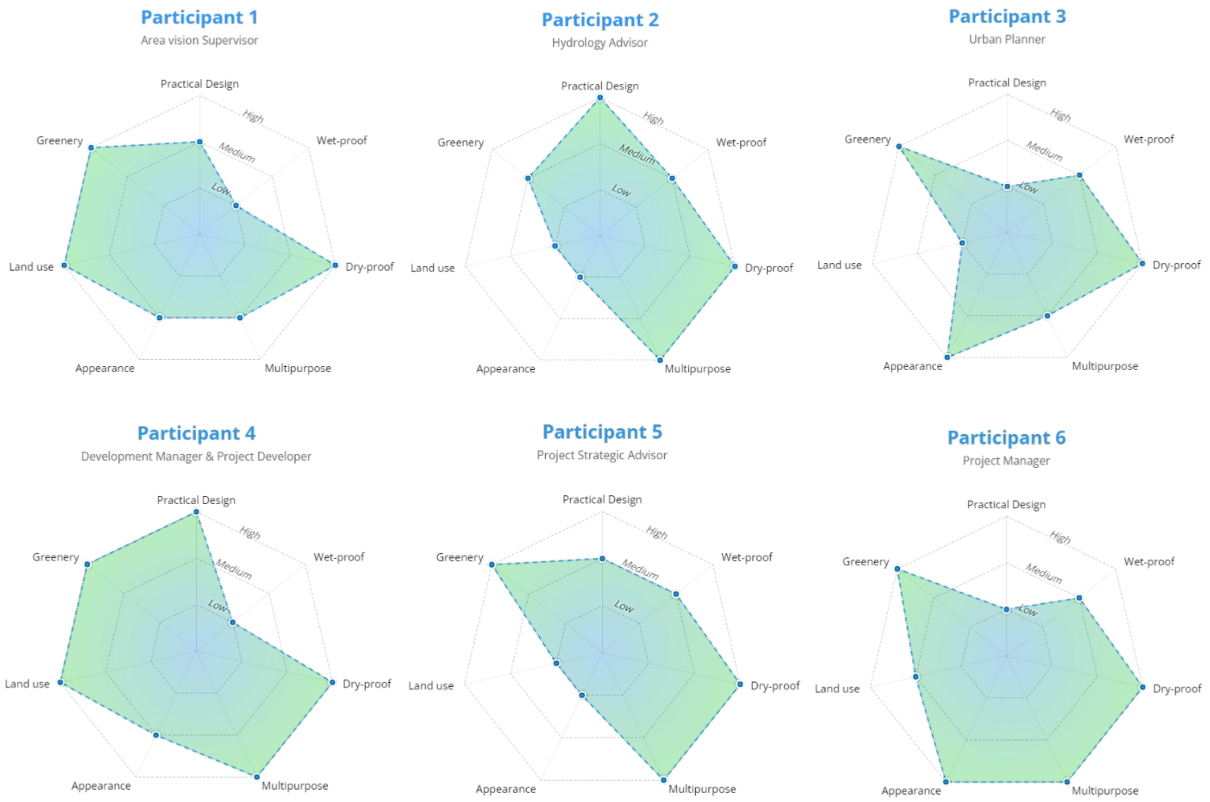


Figure 20, Perspectives of the interviewed participants about attributes of spatial measures

The results of the analysis are shown graphically in radar charts (Figure 20) that define the priority level that the participants showed towards each spatial measures' attribute. It can be appreciated two visible patterns which indicate that participants would prefer spatial measures with dry-proof functions and greenery features to keep water out of reaching housing structures while creating a sponge function that infiltrates, drain and store water. However, to define what other characteristics are important for participants when selecting spatial measures, it is necessary to have average of all the figures to evaluate the priority level of the rest of attributes.

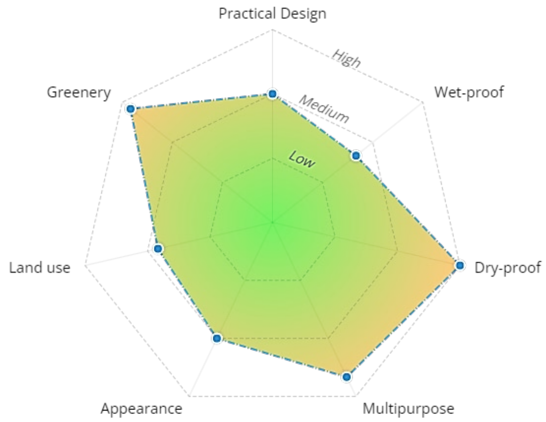


Figure 21, Average of attributes considered by all participants

Looking at Figure 21, it is possible to distinguish that participants also consider spatial measures that have other functions besides retaining water. Participants are interested in using retained water to tackle other climate tasks such as heat effect in urban areas or watering during drought periods. Nonetheless, multipurpose function also comprehends spatial measures that are not isolated solutions but are also part of the environment proving recreational purposes for instance. In the medium priority ring, the attributes appearance and practical design are displayed, this means that participants are moderately interested in how difficult the implementation and construction of these measures is as well as how these can contribute to the existing landscape. To a lesser extent, participants would prefer that measures do not occupy too much surface for the implementation, probably because they prioritize the construction of mixed building blocks. Finally, participants consider wet-proof function as a low priority since in the interview results showed that spatial measures should keep water as far as possible from housing buildings and open spaces. Figure 21 will be used in the next session to prioritize what kind of measures are suitable according to the different implementation barriers.

5.4.2. Assessment of spatial measures conflicting with implementation barriers

The last step of the feasible assessment consists of overcoming the found implementation barriers (Table 6) by selecting the structural interventions from the General Inventory that are not considered feasible to overcome physical-spatial limitations but also meet the attributes that the participants consider of high priority (dry-proof function, multipurpose function, and green features); identification number of spatial measures (#) is displayed according to numeration in Table 4.

Table 8, Suggested measures to overcome physical limitations

Physical-spatial limitations	Conflict	Suggested measures	Attributes considered
Polluted soil in the Noordereiland does not allow excavating or underground solutions.	All the measures that involve digging the soil to implement certain mechanisms are not possible in this area, this includes: (24) flood defenses adapted to the topography, (11) major upgrades in the sewer system.	• (20) Raising the land will ensure that all structures in the Noordereiland will keep dry during a flood event. • (16) Adjusting the slope to have difference in heights would manage rainwater runoff while having a park with different heights.	• Dry-proof function • Land-use • Greenery • Multipurpose function
Space destinated for spatial measures development is limited, upgrading sewer system is considered the only option.	Upgrading the sewer system in (3) capacity or (11) effectivity is only possible during maintenance processes because of costs and time.	• (33) New regulations should guarantee that green areas are destinated as natural buffer zones within built-up areas. • Improving the sewer system is already contemplated for the redevelopment plan so it can incorporate (7) IT sewer pipes in unpaved zones.	• Dry-proof function • Land-use • Practical design • Wet-proof function
Green walls or facades are considered not that effective.	The Area Vision contemplates green features like (26) façade gardens installed in buildings and houses.	• (26) Façade gardens are considered to be applied in detached houses only to ease heat effects and redirect water to a nearby (22) storage.	• Greenery • Appearance • Multipurpose • Wet-proof function

Applying gardens in rooftops is difficult because buildings would need to support extra loads of greenery and water layers.	(25) Green roofs and (27) water roofs are principally designed to be implemented in large buildings where the retention of water can be significant, but according to the area vison, most of the buildings will be reused, leaving few options for this measure.	• (25) Green roofs can be implemented only in new buildings considering that there is a structural analysis that allows it. • (17) water accumulated in roofs can flow through rain pipes disconnected from the sewer system to a water storage. • (23) detached houses need to install rain-proof rooftops to redirect water to the soil and avoid structural damage.	• Greenery • Land use • Appearance • Multipurpose
The Dieze shopping center is planned to be used as a mobility hub, most of the space is required for parking functions so spatial measures are not recommended.	The Winkelcentrum Diezerpoort is an important structure since it connects the Noorderkwartier with the east Dieze part, thus this structure should allow measures to avoid waterlogging.	• There are not recommendations for this building since the mobility task is higher than the resilience task in this structure. • (6) urban infiltration strips, (31) infiltration crates, and (5) water-permeable pavements can be used in the space next to the building	• Dry-proof function • Greenery • Appearance • Multipurpose
A water square might take a significant amount of surface to have a as much storage capacity as possible.	The area vision contemplates numerous horeca facilities in the Cultuurplein area which would require large surface.	• (28) water square would be useful to collect rainwater that could be retained in the Cultuurplein and surrounding of shops, but a new location needs to be explored.	• Dry-proof function • Multipurpose • Appearance • Wet-proof function
Stakeholders want the Dieze area to be accessible for all users and cyclists.	The accessibility of this area would require the removal of sidewalks and height differences at ground level which would leave surrounding areas without artificial barriers from water.	• (16) the available surface can have differences in height by following the example of Kraanbolwerk and using ramps and stairs so there is space for rainwater runoff.	• Multipurpose • Dry-proof function • Practical design
Measures that hinder or alter the aesthetic value of buildings and the general landscape are not allowed.	(18) Sealable structures would have a negative impact in the appearance of the area.	• There are no recommended measures since Noordereiland is the only part with a high fluvial flood risk but rising the land would be enough.	
Accumulation of water after a rainfall requires that it keeps flowing to maintain a standard quality.	Measures like (27) water roofs and (30) ponds as water elements would storage water for long periods which could incentive the development of mosquitos, mainly in warm season.	• If the collection of water is needed for recreational purposes, a (29) water course can be added to the area to store water and keep it flowing as an ornamental addition.	• Multipurpose • Practical design • Appearance
Historical side of the Noordereiland cannot be raised since there exists iconic constructions.	Since this is the historical side of the city, temporary measures that alter the landscape and aesthetic value of buildings are not allowed.	• (12) temporary flood defenses like sandbags or demountable bulkheads can be installed if there exists a proper warning system	• Dry-proof function • Land use
Spatial measures would get obsolete with a flood depth level higher than 50cm	Most of the structural interventions are designed to manage extreme downpours events in the Diezerpoort, however, for sudden fluvial flood events, these systems would collapse.	• A (24) waterfront area can be implemented as a flood defense adapted to the topography of the canal shores. There are examples of this measure in Kraanbolwerk	• Dry-proof function • Practical design • Multipurpose
Existing sewer system is designed to drain all the water towards the canal.	In an extreme event of combined flood (storm surge with prolonged rains and rising water levels), the sewer system would collapse.	• (10) non-return valves need to be installed in all the sewer pipe outlets in the canal to avoid water entering to the urban areas.	• Dry-proof function • Practical design
Area vision requires a smooth connection between the Noorderkwartier and residential neighborhoods	Area vision contemplates flattening the streets so this can be accessible for all type of users and cyclists.	• (2) Redesigning the street could eliminate the need of sidewalks if the design redirects the flow of water to the sides so it can be drained by (4) semi-open gutters. • Water can also get infiltrated through the street by implementing (30) infiltration crates below the (5) permeable pavement.	• Dry-proof function • Practical design • Multipurpose • Appearance

Finally, the spatial measures will be considered feasible in terms of institutional and social acceptance by recommending soft measures to address the conflicts with participants' opinions (see Table 7). For non-structural recommendations, identification number of measures (#) is displayed according to numeration in Table 4.

Table 9, Suggested soft measures for conflicts with stakeholders' opinion

	Conflicts with participants' opinions	Non-structural recommendations
Physical-spatial limitations	In general, all the participants agree that raising the land level is the most economic and effective measure to be applied in this area, however, participants 3 and 4 acknowledge that the historical part of the Noordereiland cannot be raised, so other measures are needed.	• Measure (47) discuss the creation of a neighborhood brigade which would participate in protecting historical areas by installing temporary flood defenses. • Participation of residents needs to be encouraged (45) by comprehensive communication and using flood risk maps to show potential damage.
	Participants 3 and 6 agree on the Dieze shopping mall building being difficult due to its closed and gray design, there are chance for improvements with green facades, but it is mainly recommended to have measures around the building that do not interfere with the mobility hub function.	• Land regulation (34) suggest that there should be a focus on waterlogging spots, since this building is not able to adapt spatial measures, maybe the surroundings can be used. • Furthermore, measure (41) explains that topography of an area formed by buildings and public space, should retain and infiltrate water before redirecting the runoff towards the closest water body.
	Participant 3 considers water squares as rough structures that just add a gray look to the environment. Participant 4 differs from this and argues that water squares are good examples of water catchment systems in urban areas. However, the participant also recognizes that this area should be part of a large collection system and not be left as isolated storage. It could include greenery details.	• Measure (39) suggests that for a better sense of connectivity, three main structures should be present in waterlogging-prone areas, an open square to store water, a pathway that infiltrates and redirects water, and an elevated place as a meeting zone. In this case a water square is advised to be built but not in the Cultuurplein area.
	Participant 1 acknowledges that there are plans to flatten the streets and make them car-free for accessibility, Participant 6 recognizes that this would eliminate the retention areas created by the sidewalks, other measures like gutters need to be explored.	• (38) For streets without sidewalks, there should drain and infiltrate solutions that do not overwhelm the drainage system.

Social Acceptance	Participants 1 and 2 mention that an extreme flood event is unlikely to happen, even in the inner city, and since people have not experienced a flood in decades, thus they are not willing to accept some measures.	• Measure (46) encourages the purchase of flood insurance (higher costs for constructions in high-risk areas) or offer financial incentives to homeowners so they can make investments in flood-resistant renovations and retrofitting.
	Participants 4 and 5 agree on the fact that nobody wants to see their property flooded. Wet-measures should be implemented; however, the focus should lie on dry-proofing so people can feel more protected and willing to accept adaptations and to participate.	• This concern was already addressed in Table 11 where most of the structural interventions were suggested considering the attributes that the participants consider as high priorities.
	Participant 6 mentioned that spatial measures are not yet assessed but these would be implemented in phases, starting with the Diezerpoort center and then with the Noordereiland, spatial measures should also be prioritized to tackle water problems as soon as possible.	• In order to know which areas, require urgent spatial measures to tackle flood risk, it is necessary to have a (45) flood-risk maps or perform stress-tests to know the potential economic damage.
Institutional-organizational barriers	Participant 2 has a more technical perspective, it is mentioned that reinforcement of dikes is still more important and although there is room for 2nd layer MLS improvement, this is still far from obtaining the same results as the conventional defenses. Participants 5 and 6 recognize the position of the water board as institutional limitation.	According to findings in soft measures applied in New York and Boston to manage urban flood risk, (48) Local municipalities should be allowed to impose land regulations and spatial strategies in addition to minimum standards established by higher governance levels according to the level of risk experienced in the area. In the case of the Noorderkwartier, it is expected to involve water authorities more in the project so they can understand the relevance of spatial measures in this type of projects.
	Several participants encourage the use of green infrastructure and features as much as possible but there is also a need for covering rooftops of buildings with solar panels, there is no preference on which task has a higher priority.	• At the moment, there is not information about which task would have more relevance in the project, from lessons learned of other projects it is suggested to (49) organize workshop meetings to discuss and agree on priorities, there might be opportunities to link both tasks.
	Participant 2 recommends the elevation of utilities within buildings since this would keep people communicated and using basic services during an extreme flood event, however according to Participant 3, this has passed from a strict building regulation to a soft recommendation for contractors.	• (42) this measure strongly suggests strict building codes risk-based on design flood water levels so living functions and relevant connections (electricity, gas, internet, water) are built above a designed threshold
	Participants from the municipality mentioned that implementation costs and logistics for spatial measures would depend on the land and house owners. Participant 4 acknowledges that although selecting spatial measures would be done in a general agreement, there is still some ambiguity on who will be responsible for them since the municipality owns the public area, but several buildings belong to different parts.	• This barrier can be overcome by using the information retrieved in sub-chapter 5.4.1 which would indicate what is the preferred characteristic that stakeholders look in a spatial measure. Then, there can be an agreement on which actor develop which spatial measures according to their own motivation, requirements, preferences. However, for this project it also important to collaborate as one coalition for the success of a sponge system in the entire area.

5.5. Preliminary Inventory Table

This last step results in a preliminary list of structural and soft measures that can be applicable to the Noorderkwartier area because these have the potential to both: overcome physical-spatial limitations, institutional-organizational barriers and to receive social acceptance from residents and important stakeholders. After reviewing the stakeholders' preferences, potential implementation barriers, and suggesting measures to solve existing conflicts between stakeholders, these acted as a fundamental criterion to select those spatial measures, from the General Inventory and lessons learned from Kraanbolwerk, applicable to the Noorderkwartier. Table 10 below show these measures classified according to what is their main function in enhancing housing flood resilience.

Table 10, Preliminary Inventory with feasible spatial measures

Dry proofing	Wet proofing
• (2) Redesigning the street to have a convex design • (4) Semi-open gutters • (5) Water-permeable pavements • (6) Urban infiltration strips • (7) IT sewer pipes • (10) Non-return valves • (12) Temporary flood defenses • (14) Wadis • (16) Slope adjustment to have difference in heights • (16) Differences in height (Kraanbolwerk), using ramps and stairs	• (17) Rain pipes disconnected from the sewer system • (20) Raising the land • (22) Rainwater storages • (23) Rain-proof rooftops in detached houses • (24) Waterfront areas (Kraanbolwerk)
Adaptive capacity to retain water	**Non-structural recommendations**
• (25) Green roofs • (26) Façade gardens • (28) Water squares • (29) Watercourse • (31) Infiltration crates	• (33) New regulations that guarantee green areas destinated as natural buffer zones • (39) A sponge system should count with three main structures: water storage, a pathway that infiltrates and redirects water, and an elevated place. • (41) Topography of an area formed by buildings and public space, should retain and infiltrate water before redirecting the runoff towards the closest water body. • (42) Strict building codes risk-based on design flood water levels so living functions and relevant connections (electricity, gas, internet, water) are built above a designed threshold • (45) Comprehensive communication using flood risk maps and stress tests • (46) Encourage the purchase of flood insurance (higher costs for constructions in high-risk areas) or offer financial incentives to homeowners • (47) Creation of a neighborhood brigade for temporary flood defenses • (48) Local municipalities should be allowed to impose land regulations and spatial strategies in addition to minimum standards established by higher governance levels. • (49) Workshop meetings to discuss and agree on priorities, and opportunities to link climate tasks.

6. Spatial Analysis of the Noorderkwartier

This chapter will address a quantitative assessment of geospatial information through a GIS software tool (ArcGIS) to acquire insights on the current and future situation (2050) of the Noorderkwartier area regarding flood risk scenarios due to pluvial and fluvial sources. This analysis will follow the structure proposed within the 2nd layer of the MLS approach (see sub-chapter 2.1.1), in general, for appropriate research for sustainable spatial planning, it is proposed to:

1) Perform a **flood risk zoning** that determines maximum expected water depth for two different flood types: fluvial and pluvial flooding.
2) Give **attention to vulnerable objects**, in this case residential buildings.
3) **Responsible use of space** and suggestions of spatial measures (to be addressed in next section)

Therefore, tis quantitative assessment has three objectives; first, it is intended to discover which zones have the higher flood risk in the Noorderkwartier area and interpret this information as a flood risk map with flood sensitive areas that indicate hotspots of waterlogging or potential fluvial floods. The second objective is to perform a suitability analysis to determine which areas are suitable to allocate spatial measures considering the existing structures. The last objective will be contrasting the available space apt for spatial measures with the opportunities for their implementation according to the Area Vision plan, this will be discussed in the next section.

6.1. Flood risk zoning

Reviewing the information form the sub-chapter 3.2, all the physical characteristics described there will be used to assess what is the current and future flood risk in this neighborhood. In the first place, the area to be analyzed has been determine delimited by the streets: Rembrandtlaan, Eikenstraat, Van Wevelinkhovenstraat, Menno van Coehoornsingel, Assiestraat, and Dijkstraat, and separated in two by the Achtergracht canal. All the pertinent environmental features such as existing green strips and water bodies are also consider, see Figure 13.

Sub-chapter 3.2 also states that the Noorderkwartier is separated in two areas well remarked, the Dieze and the Noordereiland which also belongs to the city center. Literature review states that the city center is one of several built-up areas located outside the defense dikes and considering that some of the existing buildings were built prior 1900, the area can be considered in significant and potential fluvial flood risk due to climate change. On the other side of the canal, the Dieze part is an industrial neighborhood characterized by heavily paved surfaces and the presence of multiple parking garages and office buildings, that is why the typology map (see Figure 34 in Annex A.1) indicates that this area is vulnerable to constant waterlogging. However, this area is well protected from raising levels of the canal since is surrounded by a regional dike.

In general, both areas have different issues due to different flood risks, bout due to the evident climate change effects, literature suggests that a combined flood risk could happen due to colliding systems such as a persistent storm surge that not only raises the water levels of the canal but also presents a prolonged rainfall that overpowers the capacity of the existing sewer system, this combined risk would lead to an extreme event where both areas would inevitably get flooded. In order to assess the flood sensitive areas, it is necessary to first find geospatial data that contains the information about consequences of intense rainfall events (pluvial flood risk) and raising water levels in the canal (fluvial flood risk).

6.1.1. Data Collection: Geospatial data

To obtain the required geospatial information and gain some insight on flood risk in this area, a hydrology expert from the Waterschap Drents Overijsselse Delta was interviewed during the interview process described in sub-chapter 4.3.2. During the interview, several online sources with the required maps and data about flood risk were provided by the participant while other geospatial data was retrieved from sources such as the Nederlands ESRI Community archives, Landelijk Informatiesysteem Water en Overstromingen (LIWO), Royal Netherlands Meteorological Institute (KNMI) files and others. The relevant data to be used in this analysis and their respective sources are detailed below:

- Actueel Hoogtebestand Nederland 3 data: provides a digital height map for the whole of the Netherlands. It contains detailed and precise height data with multiple height measurements per square meter. The used version has information from 2012 until 2019 (TUDelft, n.d.)

- Maps with maximum flood depth due to dike breach: retrieved from National Database of Flood Information (LIWO, n.d.) in which provinces, water boards and Rijkswaterstaat have made information available for national use (Rijkswaterstaat, 2023). This map provides flood scenarios for protected and unprotected areas located along the primary and regional water system.
- Maps with current and future annual flood probability according to failure of flood defenses around the Zwolle region (LIWO, n.d.)
- Maps with maximum flood depth associated with severe and prolonged rainfall for urban areas with an average duration of 2 hours and with different return periods (Klimaateffectatlas, n.d.).
- Flooding base map showing the result of a stress test of flooding locations in municipalities of Overijssel after an extreme shower including water flow in sewers for the built-up areas developed by Drents Overijsselse Delta Water Board (DOD, n.d.).

In order to find which areas are described as flood sensitives within the Noorderkwartier, it is important to understand what the current and future flood risk is. For this investigation, the reference for future flood risk will be taken as the extreme but medium-probable scenario that could happen in 2050 since most of the development projects and programs designed by the municipality are aimed to be climate-proof and future-proof by 2050.

6.1.2. Fluvial flood risk

The fluvial flood risk is evaluated according to an extreme scenario where the first flood defenses protecting the Zwolle region fail, therefore, there will be rising water levels in the canal due to a dike breach that would influence the water level in the Achtergracht. According to the literature, the levee system surrounding the Zwolle region is the Salland ring no.53 which has an annual probability of flooding 1/30, while the scenarios in 2050 expect an annual probability of 1/300 with a minimum flood depth level of 50cm (Vergouwe, 2019). Furthermore, the closest dike section to the city center has a failure probability per year of 1/1000, but assuming a pessimistic scenario for 2050, the failure probability considered is 1/250, see Figure 36 in Annex A.1 (LIWO, n.d.). Assuming these return periods for the inner city, the LIWO website provides a map with the flood scenario that could happen if the dike section Zwolse Ijssel fails with a probability of 1/250, Figure 22 shows that flood from the Zwarte Meer does not affect the inner city directly, but has an indirect effect on the water level of the canals. Then, after an arrival flood time longer than 24 hours (Figure 37 in Annex A.1), the maximum water depth in the areas surrounded by the canal would reach a water depth of around 2m to 5m (see Figure 23).

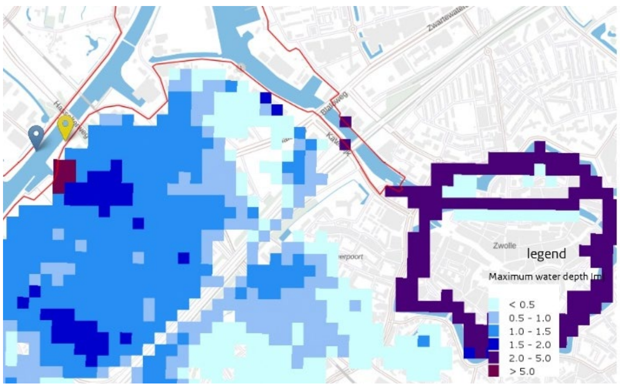


Figure 22, Dike breach flood scenario (LIWO, n.d.)

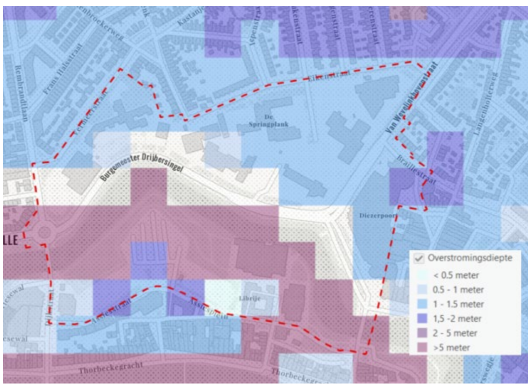


Figure 23, Maximum water depth due to dike breach (LIWO, n.d.)

6.1.3. Pluvial flood risk

For the evaluation of pluvial flood risk, it is considered the maximum flood depth that may occur at particular locations as a result of severe precipitations. Nowadays, the current risk due to rainwater

is medium-low where the maximum intensity recorded is set as 70mm with an average duration of 2 hours; this event is likely to happen 1/100 years (Klimaateffectatlas, n.d.). In the current climate, this situation does not represent a great risk to the Noorderkwartier since the number residential structures is null and the rest of structures are office buildings that rarely face issues with waterlogging. However, as a result of climate change these probabilities may increase by factor of 2 with more frequent and intense downpours, thus assuming an optimistic scenario, by 2050 the return period of extreme rainfalls would be 1/1000 with an intensity of 140-150mm and a duration of 2 hours.
Information and geospatial data from Klimaateffectatlas (n.d.) and Drents Overijsselse Delta Water Board (n.d.) are used to assess the severity of the waterlogging issue in the Noorderkwartier. Accroding to the Klimmateffectatlas tool, the waterlogging map shows how much water would be accumulated in the surface after 2-hour downpours and 4 dry hours in which water only runs off via land, is drained by the sewer, or infiltrates into the soil. The tool considers a sewer system with an estimated discharge capacity of 20mm/hr and an optimum connecction between built-up areas.

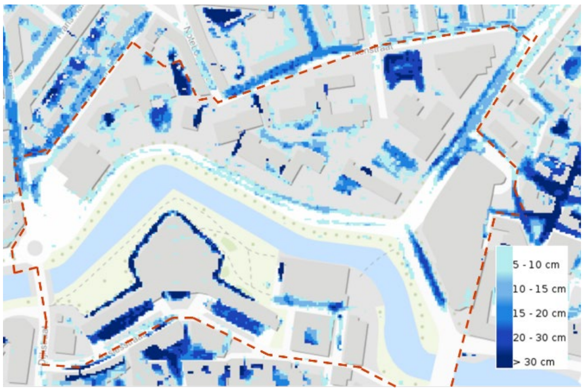


Figure 24, Waterlogging for 70mm/2hr (Klimaateffectatlas, n.d.)

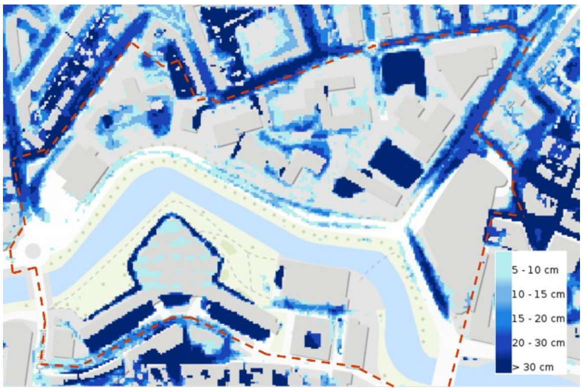


Figure 25, Waterlogging for 140mm/2hr (Klimaateffectatlas, n.d.)

6.2. Suitability Analysis

This sub-chapter will evaluate which areas within the Noorderkwartier are susceptible to get flooded in a greater extent due to water rising levels and accumulation of rainwater in the surface. The main objective of this evaluation is to know which areas are suitable for the implementation of spatial measures so these can effectively mitigate and adapt water in flood sensitive areas. For this purpose, it will be assumed a pessimistic scenario which relates to forecasted flood risk in 2050, thus, the suitable analysis will suggest suitable areas according to an extreme flood event combining both risks.

6.2.1. Flood sensitive areas

The first step will be assessing what are the areas within the Noorderkwartier that are affected to a greater extent due to the combination of flood risks. It is already known that the Noorderkwartier has two different areas separated by the Achtergracht Canal that could experience different flood events.
In the first place, the southern part of the Noorderkwartier is mainly affected by fluvial floods which could lead to most of the area being below water level, considering that the maximum water depth is 5m + NAP and the average depth level of the canal is 2.1m. To know how much surface could be flooded, the analysis requires geospatial elevation data of the entire area (see Figure 34 in Annex A.1), an elevation map provides valuable information about the highest and lowest points in the Noorderkwartier, then the ArcGIS tool can be used to assess how much surface could be flooded.
Secondly, the northern part of the Noorderkwartier, Dieze, is principally affected by waterlogging because of two factors: the limited presence of green features and the heavily paved surface that covers most of the area. To assess the accumulation extent of rainwater on the surface it is necessary to use geospatial information from waterlogging maps and elevation maps as well as water flow maps to see how water acts with the built-up environment (built-up structures or sunken garages)

Figure 26, Flood scenario due to rising water level

Figure 27, Pluvial flood hotspots

Using the ArcGIS tool, it is possible to assess the maximum flood depth in the area. As shown in Figure 26, the flood depth level in the Noordereiland could go from 0.5m to a maximum depth of around 3m which makes evident that the entire area would be practically get flooded, in fact, the flood would even reach the areas behind the existing parking lot (residential neighborhood), because water can access this area through the historical side which is in a slightly lower-ground than the rest of the area. Likewise, the water depth would reach ~3m in the shores of the Dieze part, but it is shown that rising levels hardly overtop the regional dikes and reach the streets. On the other hand, Figure 27 shows that waterlogging in the Dieze part becomes a critical problem when rainfall events are more intense, by using the ArcGIS tool and calculating the influence of the elevation and the water flow, it can be noticed that rainwater is not accumulated in the street next to the canal, however this is a severe issue in the other streets surrounding the Noorderkwartier, Van Wevelinkhovenstraat, Eikenstraat, and Vermeestraat, with approximately 0.3m of flood depth. Besides, it can be appreciated that water is accumulated in parking lots because these are low-ground areas. For the rest of the space, waterlogging does not represent an issue as it does not exceed 0.15m.

6.2.2. Suitable areas for spatial measures

To find the areas that are more apt to give room to spatial measures, first it is necessary to know which structures and areas would represent a physical constraint for the development of the measures. From now on, the area vision document will be used as a guide to see which new structures or areas could represent a barrier for the spatial measures. Likewise, it will be used the insights gained during the interview process (subchapter 5.3.1) and solving the conflicts between the implementation barriers and the stakeholders' opinion (subchapter 5.4.2). Therefore, it was found 5 characteristics that could not allow the development of spatial measures:

- New structures/areas part of the redevelopment plan like a the Cultuurplein area and the new Hedon music hall are not contemplated to have spatial measures.
- Historical area has constructions built prior 1900, thus the opportunities for drastic changes in the environment is limited or null.
- There are certain buildings that are not included in the development plan and therefore will not give room to any measure.
- There are buildings that are not suitable for having spatial measures because these are expected to be used for other tasks (solar panels for energy neutral or mobility hubs).
- Pollution in the soil would not allow any type of measures that involve excavation.

The second step will suggest which areas are needed to have spatial measures to mitigate and adapt the water issues that will appear in the upcoming years due to climate change, this would represent a problem in the future for the new residents of the Noorderkwartier. Looking back at the different flood scenarios that could happen in 2050, a new spatial analysis can be performed to obtain the areas with water issues due to combined flood risk, this can be observed in Figure 29 below altogether with the structures and areas that could represent a problem for the implementation of spatial measures and therefore considered unsuitable, see Figure 28.

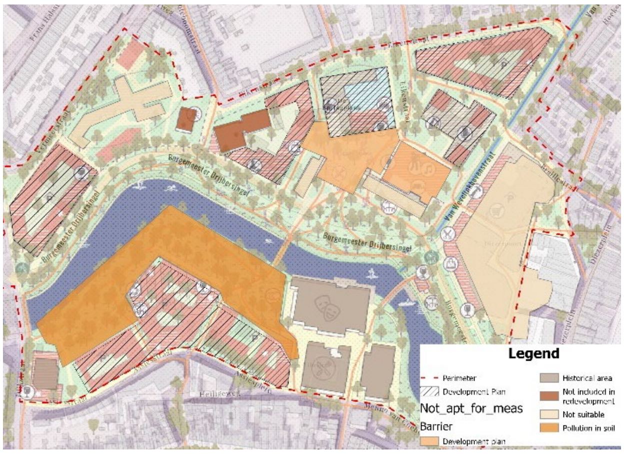


Figure 28, Unsuitable areas for spatial measures

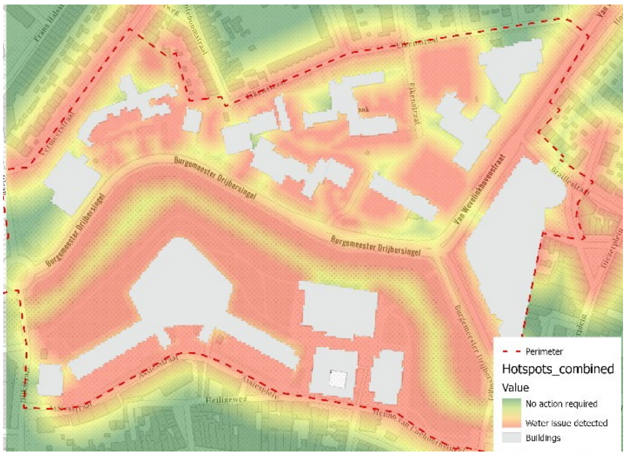


Figure 29, Combined flood risk

At last, the maps obtained previously can be used once more to perform spatial analysis and find those areas and structures that will be suitable for the application of spatial measures. The analysis will use the Area Vision plans and the Masterplan (Figure 38) and consider those development plans for new or improved buildings as suitable for spatial measures. The result from the spatial analysis can be found in Figure 30 below. An important remark for the resulting map is that in the Noordereiland part, the analysis shows that spatial measures are not convenient, however, it is known that the only applicable measure here is raising the land; besides, a new residential building is planned in this area, so it could allow other spatial measures.

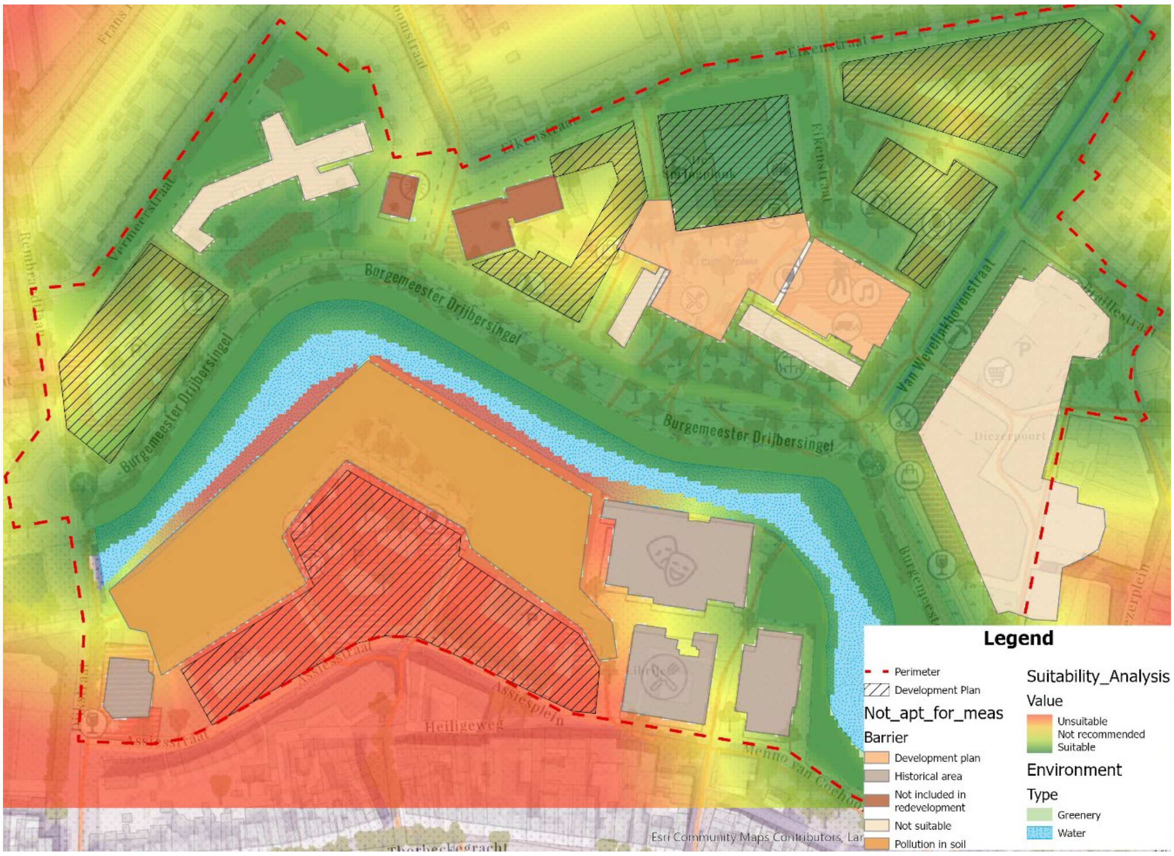


Figure 30, Suitable areas to implement spatial measures

7. Effectiveness assessment

The last part of this investigation comprehends the assessment of spatial measures once these have been applied in the Noorderkwartier. This assessment will explore how effective the measures from the Preliminary Inventory are in order to mitigating and adapting flood risk in this area. Now, that it is known which areas within the Noorderkwartier are suitable for the implementation of structural measures, it will be explored what are the physical opportunities according to the Area Vision plans, so structural interventions can tackle different water issues. Once these measures have been chosen, a planning support tool for climate adaptation will be used to assess the effectiveness of these measures. This tool is an online software used in sessions with stakeholders and experts from different backgrounds to assess potential spatial measures for redevelopment projects.
The opportunities for spatial measures will be found by reviewing the redevelopment proposals that the Area Vision proposes (subchapter 3.3) as well as using the information gained from observations during a field trip in the area (3.6).

7.1. Opportunities for spatial measures according to the Area Vision

By reviewing the information gained in the analysis of the case study (Chapter 3), the area vision document provided redevelopment proposals that could happen in the different areas of the Noorderkwartier. By using the Table 1 in sub-chapter 3.3, spatial measures from the Preliminary Inventory will be selected to fit within the different proposals' objectives that describe the masterplan of the area vison (see Figure 38in Annex A.2).

Table 11, Spatial measures apt for the redevelopment plans

Het Nijkerken Bolwerk	Dieze aan de Singel	Het Zwolse Stadspodium	Winkelcentrum Diezerpoort
Building the Singelpark on both sides of the canal: (5) Water-permeable pavements can be incorporated for walkable paths. (6) Urban infiltration strips can be placed closed to the existing buildings (8) Parking above grass can be used in areas with less intensive traffic (parking spots for emergency cars)	**Extend Singelpark until this area, limited by Rembrandtlaan and a new residential block:** Since the Singelpark ends here, the new residential area can be covered by greenery to function as a buffer for rainwater, there is also room for walkable pathways with (5) water-permeable pavement.	**Build a new music venue between the existing Belastingdienst and Diezerveste buildings:** (25) green roofs and (26) green facades can be implemented in a building that is trying to become an icon within this neighborhood. Spatial measures can be considered as the building is planned to be built from scratch.	**Van Wevelinkhovenstraat will remain open as a street for emergency vehicles:** Either a (14) wadi or a (29) water course can be implemented to manage all the excess of rainwater after a rainfall. Streets can be (2) redesigned to avoid waterlogging and drain it through gutters on the sides
"Dynamic center" a mix of facilities and new residences: (20) raising the existing land level to build apartment buildings (21) elevated living functions and pertinent connections (gas, electricity, and internet) above a threshold level	**Arise a mixed building block reusing the concert hall:** (17) disconnect the rain pipe of the buildings from the sewer system to store it in (22) storages closed the rain gutters so these can collect water during downpours. (31) installation of infiltration crates below streets where residents' cars are still accessible	**Reuse and transform the Bestalingdienst into a residential building or a hotel.** (21) Use the first two storeys of the as music hall's lobby. Fluvial flood risk in this area is low but the design could incorporate this measure.	**Redesigning open area between shopping center and residential neighborhood:** (28) A new water square or public space can be designed to store the excess of rainwater to protect the residential households in the neighborhood.
Apartment buildings can be built above the new garage: (19) Use of water-resistant materials for walls and floors in contact with groundwater. (18) Sealable structures such as the garage is recommended to protect residents' properties.	**Repurpose the Dr. Itardschool as an educational building again**: (28) playgrounds designed to storage water in extreme events can be built nearby the high school, so these become a recreational area for the new residential building.	**Create a green cultural square, "Cultuurplein" in the heart of this zone:** (13) and (16) there is an opportunity to have a meeting square which is slightly raised, creating a sort of elevation effect so rainwater can runoff towards the closest infiltration grounds.	
Creating a new and larger Singelpark (16) Adjustment of slope to create more space for water storages.	**Existing parking garages will be removed**: There are several garages built below the street level, if these are not removed, there is an opportunity to infiltrate water and (22) store it below the garages to be used for watering the Singelpark.	**Transform De Springplank into a Culture Center in front of the Cultuurplein**: Buildings hosting cultural activities can take advantage of greenery for an aesthetic added value, (25) green roofs and (26) facades can slow water flowing.	

Implement flood defense structures: (12) important parts of the Noordereiland such as the historic center cannot be elevated but can be protected by removable and temporary flood defenses in the eastern side of the Noordereiland	**Old office buildings will be transformed to residential areas:** (25) green roofs can be installed in the newer buildings to slow the water flow from buildings to the surface	**Reuse but redesign Diezervest building as a workspace with apartments on top of the building:** (17) disconnect the rain pipe of the buildings from the sewer system. (22) a storage needs to be placed closed to the rain gutters so it can collect water from rain pipes. (31) installation of infiltration crates below the attached street since emergency and cargo cars will remain using this avenue	
Outdoors theater facility next to De Spiegel: (24) Waterfront area adapted to be an open theater with water storage features.	**Space that is part of the Singelpark surface:** It can be adapted to have (16) different heights for a more interactive landscape and a better run off effect.	**Reuse GAK old building as a residential space:** (17) disconnect the rain pipe front e sewerage to (22) collect water for watering purposes. (6) replace the existing parking garages in the area with a green surface to slow the water infiltration.	
Make this area care-free and redesign streets (2) Streets can be redesigned with a convex design to send rainwater flow to the sidewalks limits and be drained by (4) semi-open gutters. In quays where the pedestrian transit is less intense, (5) water-permeable pavement can be installed to filtrate rainwater. (10) Non-return valves should be installed to avoid water from the canal entering the Noordereiland or to block the runoff.	**Public spaces designed as recreational areas:** These can incorporate (30) water elements such as fountains, water splashes or artificial ponds to reuse the stored water during downpours, if water keeps flowing, the quality of it would not be altered much.	**Redesigning existing streets, sidewalks, and bike paths:** (11) all the streets that already have an underground pipeline connection can upgrade them to have a separate sewer system. (7) IT pipes can be used to catch infiltrated water and discharge it somewhere else.	
		Areas designated to be parking spots for short-term: (8) parking cars can happen above green areas as long as this is not frequent, this would reduce the amount of concrete in the area.	

Greenery involved Structural interventions Fluvial flood Waterlogging

Table 11 above provides the type of structural interventions that could take place in the redevelopment plans of the sub-areas of the Noorderkwartier. Within the table, it is possible to observe what type of food risk is considered for the interventions and if these will consider greenery features.

7.2. Opportunities for spatial measures observed in the field trip

Thanks to the observations retrieved from a field trip around the area to be redeveloped, described in chapter 3.6, it is possible to suggest spatial measures and solutions according to the existing structures placed in this zone and to what is perceived as opportunities for greening and spatial development.

- In the Noordereiland, the shores of the canal are actually accessible but hard to do it. Surface of this area is planned to be elevated, there could be space for adjusting the slopes so people can have an easy access to the canal while this adjustment integrates an artificial flood defense or a waterfront area.
- The surroundings of the parking garage in the Noordereiland are lower than the street level and since these areas heavily paved, these could represent a nuisance in draining the accumulated water from rainfalls. The new redesign should consider permeable pavement, green urban infiltration strips or a water storage to use this accumulated water.
- Passing the bridge that connects both parts of the Noorderkwartier, the Hedon music hall is in a strategic position to become a sponge for the excess of water that could be runoff from the Dieze Aan De Singel area principally in collecting water from the paved surfaces.
- Along the Vermeestraat and Eikenstraat, there are urban green strips, however, there is no difference in heights or apparent sponge functions. Due to the number of facilities in this zone (schools, storages, and office buildings) and the possible new residential blocks, the green areas should be redesigned to have a sponge action which retains water, infiltrates the flow until the soil gets saturated, and discharge the excess to the sewer system.

  The rest of the potential spatial measures for other observations were already addressed at the review of opportunities found in the Area Vision.

7.3. Climate Resilient City Toolbox

The Climate Resilient City Toolbox (CRCT) is a planning support tool designed to explore effectiveness of spatial measures that enhance the resilience of neighborhoods, sites, and streets against flooding. This subchapter delves into the applications of the CRCT for the spatial measures suggested in the Preliminary Inventory.

This tool is considered for this study because is an interactive tool based on the established qualities and performance of spatial measures customized to the Dutch climate setting, in fact, it was developed for urban planning and flood resilience so that recommendations from an inventory of spatial measures can help in the decision-making process to apply the measures in real-world climate resilience projects. Furthermore, the tool was developed by a group of important companies and organizations that maintain a strong and close relationship with the water management of the Netherlands, the developers of this tool are Deltares, Wageningen University, GroenBlauw atelier, TNO, Bosch Slabbers, Tauw, and the Hogeschool van Amsterdam, (Brolsma, 2023).

Figure 31, Screenshot of the CRCTool (Brolsma, 2023)

7.3.1. Assessment

The CRCT offers an extensive range of spatial measures that can be applied in an area to be redeveloped. In this case, not all the spatial measures from the Preliminary Inventory are listed within the tool, however, this would not represent an issue when assessing the effectiveness of the Inventory in general. To assess the effectiveness of the Preliminary Inventory, a key performance indicator is used: the water storage capacity will be calculated for the current situation and compared against the new storage capacity after the spatial measures have been applied in the area.

The current water storage capacity will be calculated by suing the geospatial information retrieved during the Spatial Analysis phase. The calculation of the storage capacity in the Noorderkwartier will examine the maximum water that can get accumulated before it can be considered as a flood issue, therefore, the calculation will roughly take the total volume of the places within the Noorderkwartier that accumulates water up to 0.15m. For this calculation the existing greenery is considered, but since there is no information about the infiltration properties of the urban green strips, it will be assumed that these areas retain water up to a maximum height of 0.10m. The pertinent calculation was retrieved from the ArcGIS tool and can be found in Table 14 in Annex A.3. It was found that the current water storage capacity, considering just the waterlogging in the paved surfaces and limited green areas, is 5159 m^3.

Now, the CRCTool will add the suggested spatial measures to the Noorderkwartier area according to the opportunities found in the Area Vision and in the observations. The first step consists in adding the physical characteristics information to the tool; thus, some assumptions have been taken:

- Current Scenario: the current situation is assumed to be a *Closed urban building block* since there is a lack of living functions and recreational facilities.
- The land use is chosen as multi-functional but with a *low priority* since most of the

structures in the area are destinated for office functions.

- The scale level is chosen as *neighborhood*
- The current situation is chosen as *mainly grey with paved surfaces* due to the lack of greenery.
- The sub-surface availability is chosen as low, since the current sewer system is not separated, and it was assumed to have a discharge capacity of 20mm/hour
- The soil type is taken as *sandy* as most of the Zwolle region.
- The roof characteristics option is taken as *flat roofs*
- The area is describing as generally *flat area on low ground*

The redevelopment project is intended to convert this zone into a *high residential housing area* where house functions are principally found as apartment buildings, and the greenery covers most of the available surface. Once all the measures have been applied to the Noorderkwartier area according to the specifications detailed in Table 11 and section 7.2 but also considering the limitations that were found in the spatial analysis (Figure 30), the CRCTool displays the following results, see Figure 32.

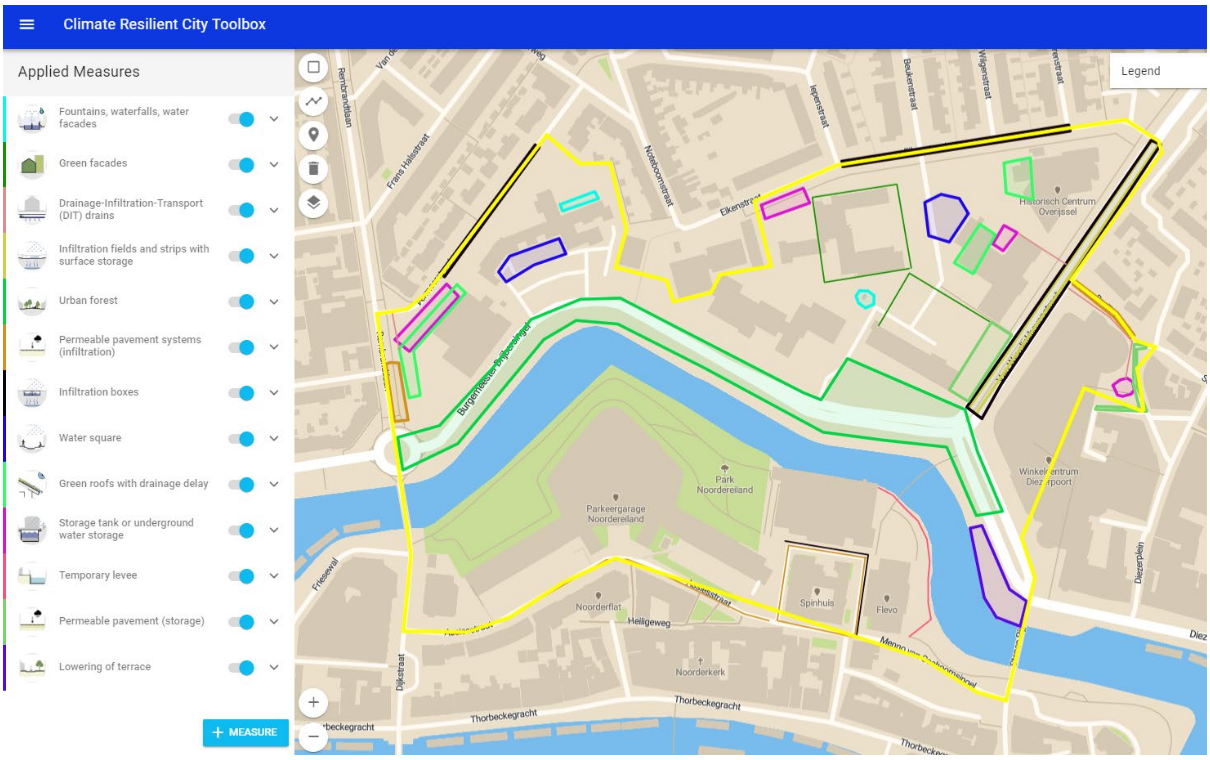


Figure 32, Spatial measures applied in the CRCToolbox software

Then, the tool proceeds to evaluate the measures applied in the area and provides a calculation of the relevant fields such as used surface by the measures, groundwater recharge, evapotranspiration, construction costs, and maintenance costs per year, however, this investigation is only focused on the potential storage capacity which resulted to be 6578 m3, see Table 12.

Table 12, Potential water storage capacity calculated with CRCTool

Results ✕

CLIMATE AND COSTS | CO BENEFITS

Measure	Surface (m^2)	Storage capacity (m^3)	Return Time Factor (-)	Groundwater recharge (mm/year)	Evapotranspira... (mm/year)	Heat reduction (°C)	Cool areas	Construction (€)	Maintenance (€/year)
Fountains, waterfalls, water facades	234,99	0	1	0	0	0	0	411.227	105.726
Green facades	168,95	6	1	0	0	0	0	506.840	50.684
Drainage-Infiltration-Transport (DIT) drains	145,44	15	1,12	1	0	0	0	25.452	1.033
Infiltration fields and strips with surface storage	1.244,12	373	4,57	9	0	0,03	0	74.647	620
Urban forest	10.447,58	2.090	13,25	6	5	0,22	1	10.448	522
Permeable pavement systems (infiltration)	2.476,22	258	1,81	1	2	0	0	247.622	1.040
Infiltration boxes	3.432,36	1.293	6.342,51	128	0	0	0	1.630.371	18.260
Water square	1.210,21	363	6,81	-1	0	0,03	0	1.996.849	2.197
Green roofs with drainage delay	1.614,82	161	1,47	3	2	0,03	0	129.186	7.751
Storage tank or underground water storage	1.223,68	1.584	2.823,56	-1	0	0	0	544.539	8.713
Temporary levee	0	0	1	0	0	0	0	0	0
Permeable pavement (storage)	1.046,6	209	1,28	2	0	0	0	183.156	1.557
Lowering of terrace	1.069,85	225	1,07	0	0	0	0	80.238	1.067
TOTAL		**6578**							

8. Results

Once all the pertinent analysis and assessments have been performed, it is possible to suggest a final Inventory of spatial measures that can be considered feasible and effective, this would motivate stakeholders and other important actors to apply these types of measures in redevelopment projects that involve enhancing housing flood resilience. This would also promote the implementation of the multi-layer safety approach as a cornerstone to achieve climate-proof and future-proof goals.

8.1. Results from feasibility assessment

A Preliminary Inventory is presented at the end of Chapter 5; this contains all the relevant spatial measures that are described as feasible because these have the capacity to overcome the different implementation barriers that could arise for this project: overpassing physical-spatial limitations, being accepted by the general public and the principal stakeholders, and suggesting measures to improve the institutional-organizational relationship of the actors and parties involved in the redevelopment project.

In the first place, spatial measures presented have the capacity to overcome physical-spatial limitations because these were chosen to solve the existing conflicts found in the physical characteristics of the Noorderkwartier that impede the development of spatial measures. This does not only include the existing characteristics of the area but also what will be the spatial limitations according to the Area Vision plan for the upcoming years. Secondly, the spatial measures presented can be accepted by the general public and stakeholders because these measures were chosen on the basis of what some of the most important stakeholders consider a priority, based on their perspective and experience. In general, it was found that stakeholders prefer to choose spatial measures that resist and adapt to the impact of flood events without letting water access residential structures or nearby areas. At the same time, these measures should have multi-purposes so these can be part of the landscape and offer other functions to the residents besides only protecting them from water, for instance, retaining and storing water to be used later, presenting a friendly design that attracts people for its aesthetic value, and contributing to the heat effect. Likewise, the measures should implement as many green features as possible as one of the goals for the area so this can become a significant space where blue and green infrastructure have proper development. Selecting measures in based of these priorities would not only facilitate their acceptance from the principal actors of the project but also would motivate general public to participate actively in the implementation of some measures e.g., installing temporary defenses managed by neighbors of the historical center. Thirdly, the spatial measures have the capacity to improve the institutional-organizational relationship of the principal actors in the project because these were selected and thought to present solutions to the potential conflicts of interest due to the different opinions of the interviewed stakeholders. Therefore, the spatial measures presented in the Inventory are feasible because of having a general socio-political acceptance and not representing a problem to the existing or future redevelopment plans.

8.2. Results from effectiveness assessment

In this report, a spatial analysis was also presented as the first part of an assessment that resulted in calculating the water storage capacity that the area would have after the implementation of the spatial measures suggested in the Preliminary Inventory. The objective of this assessment was to determine the effectiveness of the proposed Inventory so that measures can gain relevance and facilitate their consideration during decision-making processes so that stakeholders feel motivated to implement these solutions to solve water-related issues in urban areas as an alternative to conventional flood defenses such as dikes.

The first part of the assessment involved a spatial analysis phase that was aimed at obtaining a map with suitable areas for the implementation of spatial measures. For the obtention of such information, Chapter 6 followed a process that first required the analysis of geospatial data containing current and future flood scenarios due to dike breaches and severe rainstorms in the Zwolle region and specifically in the inner-city area. In this part, it was already presented a spatial analysis that showed what are the flood-sensitive areas that should be taken care of by spatial measures. Figure 26 displays information that suggests that in the event of a dike breach, the Noordereiland would result sunken below water level with a maximum flood depth of 3m. On the other of the canal, Figure 27 shows how severe is the waterlogging issue in this neighborhood, in fact, the map shows that there are areas where the accumulated rainwater would reach a maximum depth of 30cm which would create a nuisance to the existing workers, and if the problem is not addressed, to the future residents. Both scenarios are combined paying attention to which areas are more problematic so that spatial measures can be applied here (Figure 29), however, it was also necessary to know which areas represent a physical conflict for the implementation of spatial measures, for this end, information regarding the future development plans, sensitive historic buildings and other physical factors were considered as unsuitable spaces for the development of spatial measure and thus, a final spatial analysis was performed to show which areas could give room to structural interventions.

Looking at Figure 30, it shows the suitable areas for the implementation of spatial measures. It can be inferred from the map that most of the land in the Dieze part is available and suitable for structural interventions, the few areas that are not considered apt for hosting spatial measures are the existing buildings (due to their historic context or because these are planned to be redesigned), buildings with specific tasks that could not allow other interventions, and buildings whose owners have not signed to be part of the redevelopment project, at least not by the date of this investigation. An important remark for the resulting map is that in the Noordereiland part, the analysis shows that spatial measures are not convenient, however, it is known that the only applicable measure here is raising the land so the spatial measures that can be applied here should be limited to be surface constructions that do not occupy too much surface; but, a new residential building is planned in this area (where the current parking garage is located), so the new structure could allow other spatial measures to ease the waterlogging issues of the neighboring houses.

Finally, the last part of the assessment involves the performance evaluation of the spatial measures once this has been applied in the Noorderkwartier, considering the areas that are suitable or unsuitable for these. Subchapters 7.1and 7.2 explain that the feasible spatial measures suggested in the Preliminary Inventory are selected according to which water issues these could tackle while fitting in the Area Vision plan proposals for redevelopment and to solve issues that were observed during a field trip to the area (subchapter 3.6). By following this structure, spatial measures will not only be added to areas that need to ease flood impact for the future but also, spatial measures will be chosen to specific areas according to their inherent attributes that might improve the landscape, increase greenery, and serve for other purposes like storing rainwater for use in drought periods (according to the priorities of the interviewed stakeholders).
Finally, a planning support toll is used to evaluate the performance of the selected measures by using the change in the current and potential water storage capacity as key performance indicator. For the current state, spatial analysis previously performed can be used to obtain a rough estimation of the current storage capacity, after the calculations this resulted in 5159m^3. For the potential storage capacity in the new area, the CRCTool calculates this feature automatically but based on characteristics that are designed for each spatial measures (surface, depth, infiltration capacity, etc.). It is important to mention that not all the measures that were listed in the Preliminary Inventory could be implemented in the CRCTool because of different reasons: some measures have some technicalities that the software cannot process, some measures are not available in the software because this is based on Dutch-climate problems and the inventory is based partially on international case studies and because there are non-structural recommendations that cannot be assess quantitatively.
Table 12 displays the final calculation provided in the CRCTool, which clearly specifies that the new water capacity is 6578m3, this value already suggests that the implementation of spatial measures would improve the current storage capacity by 22%, however, the CRCTool only considers the potential storage capacity of the applied measures within the area, which neglects the storage capacity of the existing paved areas and greenery that would remain or that can be expanded in the neighborhood, therefore the final calculation would be much higher than the presented in Table 12, improving the water storage capacity of the area approximately 50% to 60%, if we consider that at least half of the existing paved surface will remain and the urban greenery will be expanded.

Furthermore, by using Table 12, it is also possible to know which spatial measures contribute the most to the water storage capacity in the area. According to Figure 33, urban forest (designed to be the Singelpark) has the greatest performance in relation to the surface used for this measure, this just supports the idea of larger parks within urban centers. Then storage tanks for rainwater (placed next to buildings that allow green roofs and permeable pavement in the surroundings) is presented as the second-best solution, The great benefit in this intervention is the possibility to reuse the collected water for fountains, watering gardens, etc. Equally important, infiltration crates resulted very effective in infiltrating and retaining water in the streets. This measure was principally applied in the streets that surround the Noorderkwartier since the waterlogging issue is more severe here. It is important to notice that this is an approximate calculation, and many more factors could be considered, nonetheless, it resulted as a great tool to exemplify how the spatial measures could be applied in the redevelopment project.

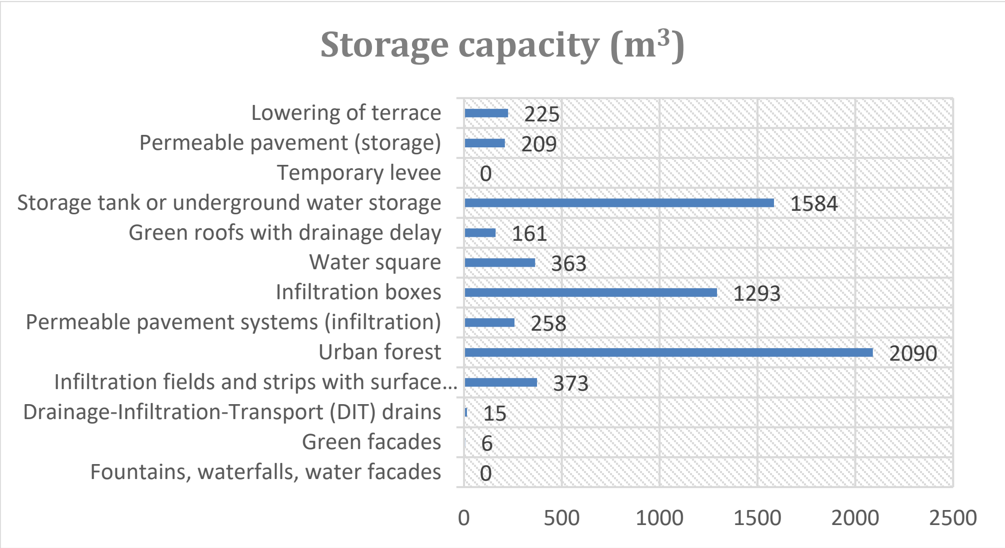


Figure 33, Storage capacity per spatial measure applied

By analyzing the results from Chapter 5 and Chapter 6, it can be said that the Preliminary Inventory proposed now can be presented as the Final Inventory with feasible and effective measures to enhance housing resilience flood in the area. In this new inventory, all the measures were proved feasible, but only those that are marked with (*) were proved as effective.

Table 13, Inventory with feasible and effective measures

Dry proofing	**Wet proofing**
• (2) Redesigning the street to have a convex design * • (4) Semi-open gutters (on the sides of the streets for better drainage) • (5) Water-permeable pavements • (6) Green urban infiltration strips and urban forests* • (7) IT sewer pipes (to be implemented when the entire sewer system is upgraded) * • (10) Non-return valves (for outlets in the Achtergracht canal) • (12) Temporary flood defenses (coordinated and installed by residents of historical area) • (14) Wadis (to control rainwater accumulation in the Singelpark) * • (16) Differences in height (Kraanbolwerk), using ramps and stairs to create a connection effect.	• (17) Rain pipes disconnected from the sewer system (a standard regulation for all the new buildings) • (20) Raising the land (applied in the Noordereiland to protect the residential area of rising water levels) • (21) Elevated functions and utilities (given a maximum flood depth of 3m in the Noordereiland all buildings should be elevated at least 30cm above this threshold to avoid water entering in the structures, also utilities like electricity needs to be elevated above 3.20m + NAP to avoid power outage) • (22) Rainwater storages (allocated underground next to existing and new buildings to collect water for other purposes) * • (23) Rain-proof rooftops in detached houses (to avoid structural damage and slow water flow to the streets) • (24) Waterfront areas such open spaces with stairs that approached the canal to increase connectivity between urban and water environments (Kraanbolwerk)
Adaptive capacity to retain water	**Non-structural recommendations**
• (25) Green roofs (only applicable to new buildings that include a structural analysis for the extra weight) • (26) Façade gardens (applicable to a limited number of structures and small houses) • (28) Water square (designed as playgrounds to have multipurpose function) * • (29) Watercourse (placed along the van Wevelinkhovenstraat to redirect rainwater flow and not discharge it in the canal) * • (31) Infiltration crates (placed in all the streets surrounding the Noorderkwartier) *	• (33) New regulations that guarantee green areas destinated as natural buffer zones • (39) A sponge system should count with three main structures: water storage, a pathway that infiltrates and redirects water, and an elevated place. • (41) Topography of an area formed by buildings and public space, should retain and infiltrate water before redirecting the runoff towards the closest water body. • (42) Strict building codes risk-based on design flood water levels so living functions and relevant connections (electricity, gas, internet, water) are built above a designed threshold • (45) Comprehensive communication using flood risk maps and stress tests • (46) Encourage the purchase of flood insurance (higher costs for constructions in high-risk areas) or offer financial incentives to homeowners • (47) Creation of a neighborhood brigade for temporary flood defenses • (48) Local municipalities should be allowed to impose land regulations and spatial strategies in addition to minimum standards established by higher governance levels. • (49) Workshop meetings to discuss and agree on priorities, and opportunities to link climate tasks.

9. Validity discussion

The goal of this investigation was developing an inventory of spatial measures that can be proved feasible and effective to enhance housing flood resilience in a redevelopment project. Nonetheless, it is possible to argue on some flaws that might be present in the assessment for feasibility and effectiveness of the spatial measures. For the feasibility assessment, an interview process was performed to consider the opinions, suggestions and perspectives from different stakeholders related to the Noorderkwartier project, nonetheless, it was not possible to have an opinion from all the stakeholders that conform the Owners' Coalition (the principal parties behind the project) since interviews were not able be scheduled. Therefore, there might be other conflicts that were not considered when selecting spatial measures, likewise, part of the assessment required the evaluation of the interviewed participants to know their perspective and priorities about characteristics of spatial measures, but obtaining more information from the actors that were not interviewed could change the findings. To have an impartial and transparent process, some of the interviewed participants have different roles and responsibilities within the Noorderkwartier project, and others are not completely related to the project but represent organizations that are interested in the application of spatial measures for the future, thus, the insights gained from this process are considered not that far from a situation where all the stakeholders would be involved in the process.

Similarly, the effectiveness assessment could be considered as not realistic since the spatial analysis takes pessimistic assumptions to model the worst-case scenarios for flooding events in this area. This might seem unrealistic since a flood event of such magnitude has not happened in Zwolle in at least a century, however the reason behind these assumptions is the undeniable consequences that the climate change is having on the Netherlands. Literature suggests that extreme scenarios with sudden storm surges and severe rainfalls could happen more often in the next decades which would lead to extreme flooding events. Furthermore, it was explained that a great part of the Noorderkwartier is located outside the dike ring protection, thus this area is susceptible for floods in the future. Another issue that might arise in regards of the spatial analysis is the validity of the data used for this assignment, most of the geospatial data used for the spatial analysis were retrieved from official websites of the Dutch government such as flood risk maps developed by the local water board, the validity topic was addressed during the interview process with a hydrology expert from the DODelta water board. During the meeting, it was stated that these maps are continuously updated by the water board and have reliable data based on previous floods experience in the zone and mathematic models that prognostic how much the water level could rise in consequence of climate change. Therefore, the geospatial data used can be considered validated by an expert.

10. Conclusions and Recommendations

In conclusion, it can be said that the 2nd layer of the MLS approach can be used in this project in order to structure a pathway to develop an Inventory of feasible and effective spatial measures to enhance housing flood resilience, the measures considered in the inventory can be implemented in an early phase of a redevelopment project so this can become an alternative solution that instead of mainly focusing on first line defenses (such as dikes), addresses and integrative approach that is not only focused on resisting and avoiding floods but also considers the possibility to adapt the flood to the physical opportunities of the area so water does not become an issue for the public.

The final proposed Inventory was reached by selecting feasible measures that are applicable to the Noorderkwartier project, these measures were taken from a general inventory that was designed to collect the "best practices" in applying the 2nd layer of the MLS to enhance flood resilience. For this general inventory, several case studies and projects nationally and internationally were considered, however those that are mentioned in this report were selected for also being comparable to the area. Dordrecht was considered for being physically comparable to the Zwolle region since both are delta cities influenced by sea storm surges, but the best-practice attribute is given for being the first city in the Netherlands with relative success in applying the MLS to the urban planning projects. Rotterdam was considered for having development projects in unembanked areas comparable to the city center of Zwolle, but the best-practice attribute is given for the innovative and modern solutions that have been applied in urban areas. Enschede was considered for having rainfall events and waterlogging issues comparable to the situation in the Dieze part of the Noorderkwartier, but the best-practice attribute is given for applying spatial solutions that engage residents' participation and include blue-green infrastructure. Hafencity was considered for having a comparable development plan which intends to build multipurpose buildings in an inner city surrounded by water, but the best-practice attribute is given for implementing tough spatial measures that promotes the paradigm shift from conventional defense systems to a "new water culture". New York and Boston were considered because these cities took inspiration in the Dutch water management to improve their flood defenses, but the best-practice attribute is given for implementing the MLS approach in their own water management by applying soft measures with relative success.

For the measures in the general inventory to be feasible it was necessary to overcome the potential implementation barriers that could arise for this project, in general it was found that this area have physical-spatial limitations, socio-political acceptance issues and institutional-organizational barriers that could hinder the application of spatial measures.

The proposed preliminary inventory needed be assessed to evaluate the effectiveness of the spatial measures that were proved feasible for this area, for this assessment a spatial analysis required to know what areas and structures are the most flood sensitive. In the first place it was found that the Noorderkwartier is susceptible to both, flooding due to water rising levels in the canal and for severe storm events that could accumulate more water than the sewer system can handle at the moment. By performing a spatial analysis using geospatial data on the possible flood scenarios it was found that the Noordereiland is the most flood sensitive area for being outside the dike protection and also for the physical characteristics of the area that do not allow the implementation of spatial measures. In a lesser extent, it was found waterlogging hotspots in the Dieze part which are principally located next to the existing office buildings.

After assessing the effectiveness of the proposed measures, a final inventory is shown which provides spatial measures divided into structural interventions and non-structural recommendations. The first classification comprehends all those measures that are aimed to infiltrate and drain the water on the surface, adapt the structures so water does not create an issue, and transform the environment to give another purpose to the flood water. On the other hand, non-structural recommendations are aimed to resolve institutional-organizational conflicts as well as to promote risk awareness in future residents, for this purpose several measures are proposed in terms of building codes, land regulations, and participation plans. The spatial measures presented in the final inventory were proved feasible because they were designed to be accepted by solving potential conflicts regarding the stakeholder opinions and priorities. The spatial measures were proved effective because the assessment showed that implementing them would increase the water storage capacity in the area from 22% to a 60%.

The final Inventory with feasible and effective measures was the main objective of this investigation, this inventory can be used as an advisory instrument to be used at decision-making processes to evaluate what are the spatial measures that can be applied in the Noorderkwartier project considering other factors such as construction costs, heat reduction, maintenance, etc. Besides, this investigation also proposed a methodology to aboard the different stakeholder's opinions, perspectives, and priorities in order to select spatial measures that are more likely to be accepted, becoming feasible measures in terms of social acceptance which would improve the reception of the 2nd layer of the MLS approach within urban planning and water management projects.

As final recommendations, there are several spatial measures that require more attention in order to improve the residents' participation in the project, for instance, several municipalities promote interactive online tools to motivate residents to apply spatial measures by themselves. Likewise, it is important to have reliable flood risk maps that show people what is the flood risk in the area where they are living, so there can be proper warning systems to inform the public about potential floods that could happen. Finally, the inventory proposed in this investigation can be used for the next step of the MLS approach, evacuation plans, to improve and implement measures that do not only adapt water but can relieve certain areas to be emergency exits or to provide areas for vertical evacuation for instance. In general, it is recommended to follow the research on the MLS approach and explore all the possibilities in this area.

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A. Annex

A.1. Maps with relevant geospatial information

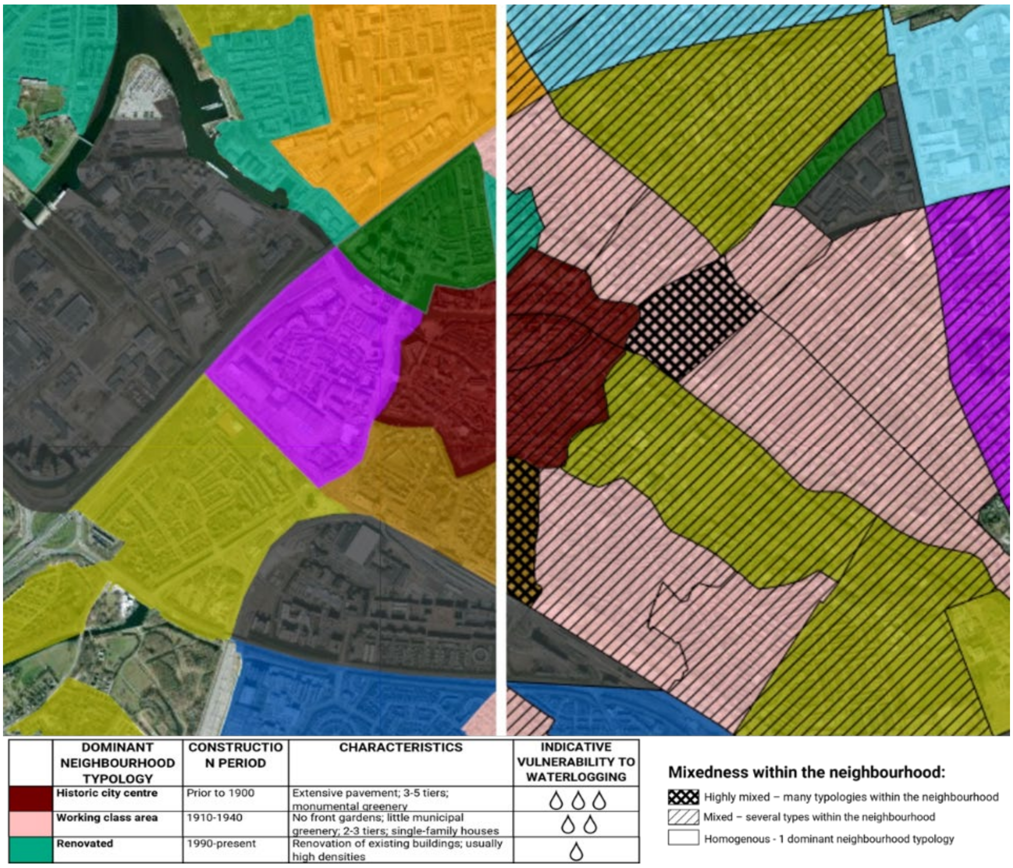


Figure 34, Typology map of the Noorderkwartier (Klimaateffectatlas, n.d.)

Figure 35, Elevation map of the Noorderkwartier (TUDelft, n.d.)

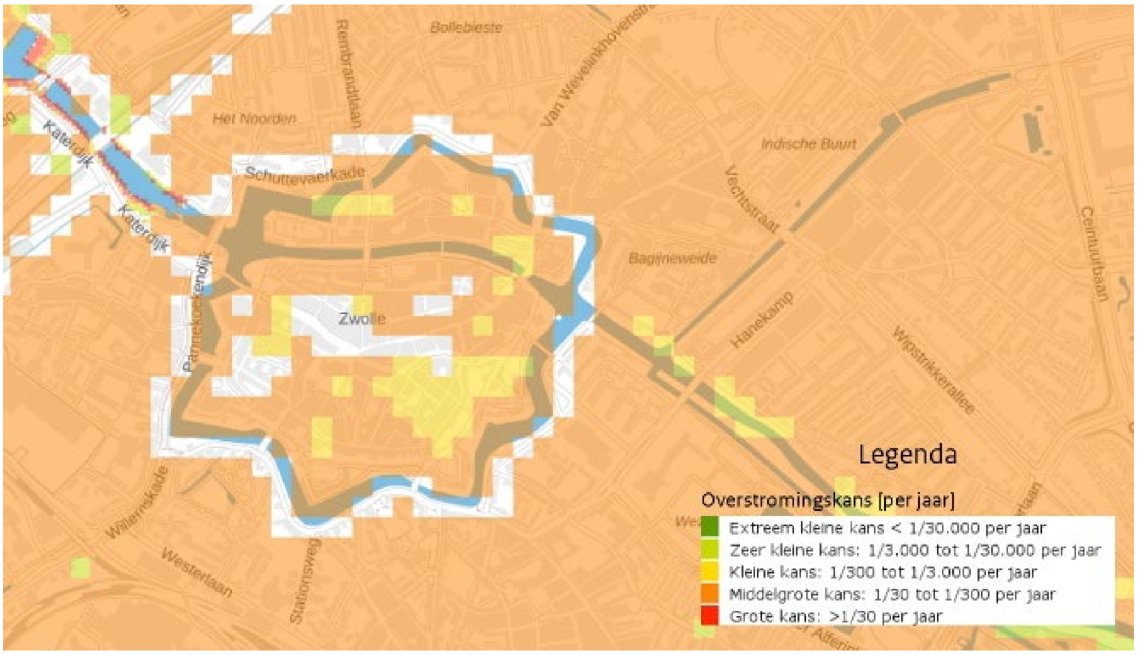


Figure 36, Flood probability in the Zwolle region for 2050 (LIWO, n.d.)

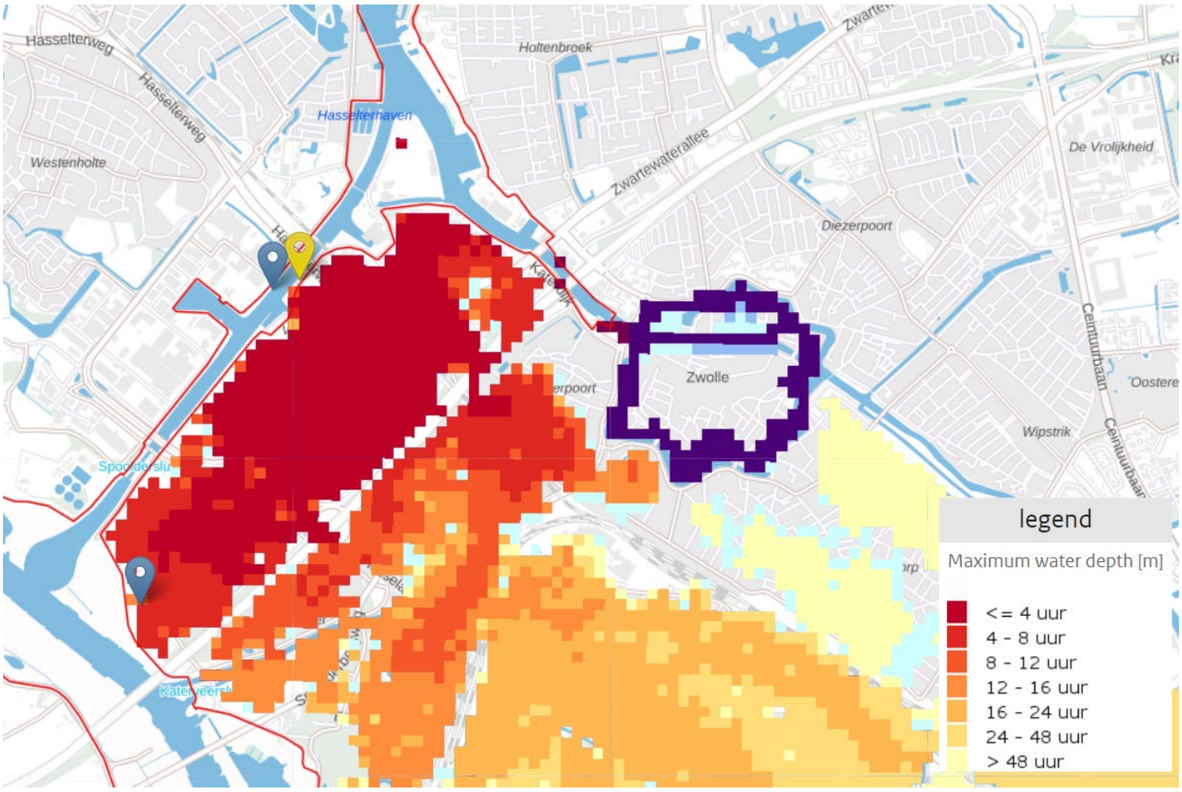


Figure 37, Arrival time of a flood due to dike breach in Zwolle (LIWO, n.d.)

A.2. Masterplan for the Noorderkwartier redevelopment

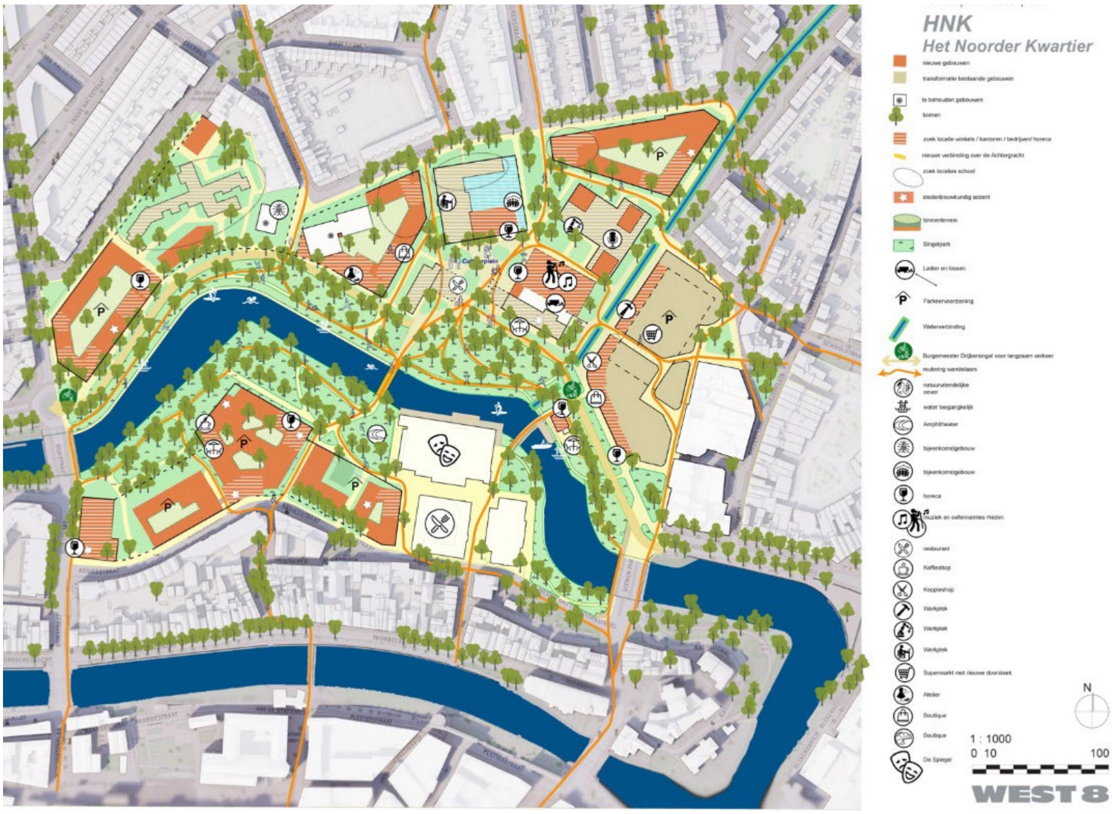


Figure 38, Masterplan of the Noorderkwartier Area Vision (Biewenga, 2023)

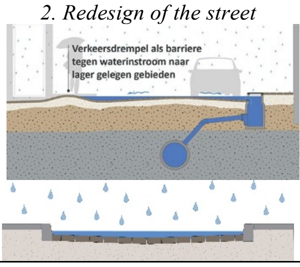
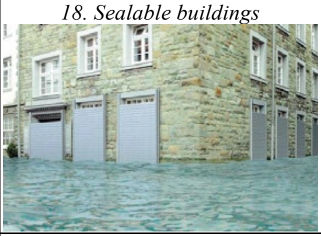
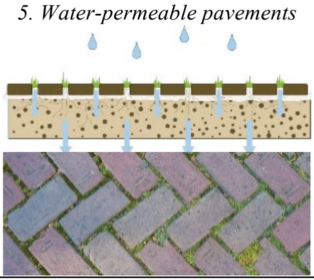
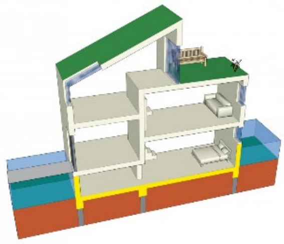
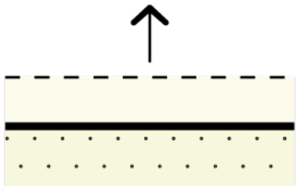
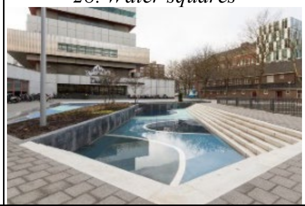
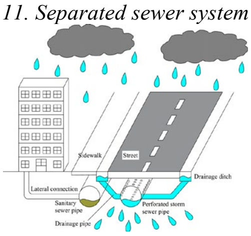
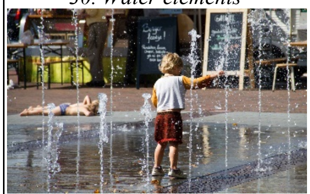
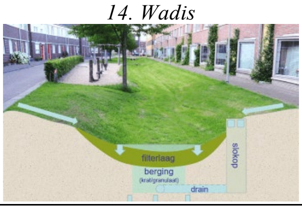
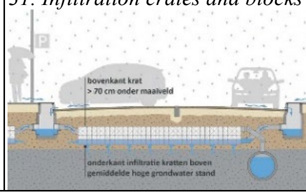
A.3. Water storage capacity from the current situation

Table 14, Total Storage Capacity of the current area

OBJECTID	SHAPE *	Shape_Le	Shape_Area	Depth_avg	Storage_capac
1	Polygon Z	184.3551	1573.640523	0.3	472.09
2	Polygon Z	161.6435	1604.469772	0.27	433.21
3	Polygon Z	90.64845	464.041178	0.4	185.62
4	Polygon Z	150.4548	523.202687	0.3	156.96
5	Polygon Z	137.1066	382.284804	0.15	57.34
6	Polygon Z	170.0023	398.153529	0.35	139.35
7	Polygon Z	49.59742	67.720044	0.15	10.16
8	Polygon Z	22.68438	17.493395	0.1	1.75
9	Polygon Z	47.80252	78.749282	0.3	23.62
10	Polygon Z	60.27292	101.70736	0.33	33.56
11	Polygon Z	26.01171	35.277492	0.3	10.58
12	Polygon Z	86.89202	239.18855	0.28	66.97
13	Polygon Z	204.0252	652.636499	0.2	130.53
14	Polygon Z	192.49	973.091892	0.43	418.43
15	Polygon Z	26.73682	43.932999	0.1	4.39
17	Polygon Z	53.88861	172.940593	0.33	57.07
18	Polygon Z	110.437	351.25818	0.41	144.02
19	Polygon Z	190.9098	351.553487	0.23	80.86
20	Polygon Z	414.5759	2269.943064	0.17	385.89
21	Polygon Z	335.1408	1160.535342	0.42	487.42
22	Polygon Z	178.5978	393.34552	0.23	90.47
23	Polygon Z	195.2117	311.721999	0.2	62.34
24	Polygon Z	238.0231	824.122218	0.38	313.17
25	Polygon Z	77.16117	205.071873	0.25	51.27
26	Polygon Z	161.6371	1117.675571	0.05	55.88
27	Polygon Z	89.15901	338.713965	0.15	50.81
28	Polygon Z	192.1282	1266.4934	0.15	189.97
29	Polygon Z	723.1553	3721.22884	0.04	148.85
30	Polygon Z	534.9049	3170.699721	0.15	475.60
31	Polygon Z	222.6655	2988.325006	0.12	358.60
32	Polygon Z	118.4892	249.742761	0.25	62.44
	TOTAL STORAGE CAPACITY				**5159.235**

A.4. General Inventory

Table 15, General Inventory of spatial measures

Structural interventions			
Dry proofing (infiltrate and drain water)		**Wet proofing (build water robust)**	**Transformability capacity (retain water)**
1. Threshold or increased floor 	*2. Redesign of the street* 	*17. Disconnect the rain pipe* 	*25. Green roofs* 
3. Increase sewer pipes diameter 	*4. Semi-open gutters* 	*18. Sealable buildings* 	*26. Façade garden* 
5. Water-permeable pavements 	*6. Urban infiltration strips* 	*19. Use water-resistant materials* 	*27. Water roofs* 
7. IT sewer pipe 	*8. Parking above green areas* 	*20. Raising land* 	*28. Water squares* 
9. Reintroducing the sidewalks 	*10. Non-return valves* 	*21. Elevated functions and utilities* 	*29. Urban watercourses* 
11. Separated sewer system 	*12. Protecting relevant structures* 	*22. Rainwater storage* 	*30. Water elements* 
13. Elevated buildings and ground floor level 	*14. Wadis* 	*23.Rain-proof rooftops* 	*31. Infiltration crates and blocks* 

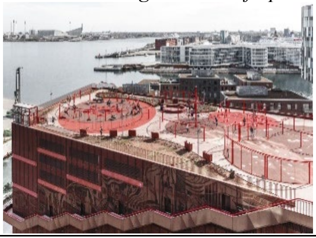
15. Activating urban rooftops	16. Height differences in surface	24. Flood defenses adapted to the topography:	32. Emergency underground water storage
			

Table 16, Description of listed measures in the General Inventory

Structural interventions			
Dry proofing (infiltrate and drain water)		**Wet proofing (build water robust)**	**Adaptative capacity (retain water)**
1. Threshold or increased floor: provide protection against flooding of several centimeters. (+) stairs to basements, basement windows, and garages can be protected with an increased threshold (-) elevated surfaces would mean less accessible houses, limitation to inclusive access for residents	***2. Redesign of the street:*** involves adapting the surface of a street to redirect water (concave or convex streets) and adding a threshold to steer rainwater in the desired direction (speed bumps) (+) slope and decay are often less of an obstacle in hollow roads to drain the water over longer distances (+) the rainwater can be led to a green zone, where it is temporarily held and can slowly sink into the soil. (-) during extreme rain, traffic still uses these roads, which can lead to splashing water (-) if the street is convex, it should count with elevated sidewalks to drain water	***17. Disconnect the rain pipe:*** to relief the sewer system from rainwater. (+) collect rainwater for a local pond or rain barrel, it can be used later for watering the garden (+) redirecting water to the ground so it sinks and replenish groundwater, limiting drought (-) not all locations might allow infiltration of water (-) if water is not diverted properly there could be moisture problems	***25. Green roofs:*** have a deeper layer of substrate with varied planting, (for water retention slope should go from 1 to 7). (+) less rainwater flow from the roof and cleaner (+) considerable water retention and less space required (+) polder roofs could have an extra layer under the green layer to retain water (-) constant maintenance depending on the choice of plants (-) these roofs are heavier and more expensive in construction (-) With prolonged rains, retention function is obsolete
3. Increase sewer pipes diameter: If space allows, it is possible to enlarge sewer pipes so that they can process more extreme rain showers. This reduces flooding risks. (+) increasing pipe size immediately increases discharge capacity moving water faster to storage areas (-) expensive measure that is only justified financially if the sewerage is planned to be replaced (-) space in the subsurface in the city is very limited due to other connections	***4. Semi-open gutters:*** gutter is covered with a grid and thus it does not obstruct traffic and can be used in the garden as well as on streets and squares. (+) gutters can drain more water due to their depth and are less dependent on polluting (+) if applied in the street profile, street gullies might not be needed (+) gutters do not hinder the use of the road, cyclists and pedestrians can safely pass these (-) deserve extra attention in maintenance since they cannot be cleaned with a regular brush trolley but must be rinsed regularly and sucked out if necessary.	***18. Sealable buildings:*** *exterior of buildings can be made waterproof to prevent flood water* entering through gaps and holes below design flood water level like open butt joints, ventilation grilles, casing pipes, letterboxes, etc. (+) barriers can be removable which does not affect the aesthetic value (-) measures are usually responsibility of house owners	***26. Façade garden:*** removing tiles and bricks in the streets to install a garden next to the households. (+) rainwater flowing from the façade can infiltrate the soil (-) plants in the façade garden should be able to withstand drought periods
5. Water-permeable pavements: designed for water-passing hardening, this allows rainwater to be partially drained from hard surfaces to the soil. (+) flooding on street and garden can be reduced greatly without disturbing the environment (+) the pattern design includes several materials: porous bricks, open-joint bricks, grass-concrete pavement, aggregate cover, etc. (-) not suitable for heavily used roads (-) high polluting risk requires extra maintenance (-) open and porous paving materials eventually become clogged with sediment. At that point, even with good maintenance, it is impossible to achieve the initial performance level, and the water infiltration capacity is lost	***6. Urban infiltration strips:*** are gently sloping, vegetated strips of land that provide opportunities for slow conveyance and infiltration. (+) easy to construct and low construction cost (+) water runoff on surface is reduced through trees and shrubs (+) planted surfaces improve the infiltration capacity of the soil (-) no significant attenuation or reduction of extreme event flows	***19. Use water-resistant materials:*** buildings should be designed in such a way to avoid exterior structural damage. Thus, materials for: -Facades: concrete, insulation cover, impermeable bricks, doorframes, aluminum, steel windows -Floors: tiles, closed cell insulation. Using these materials make it possible for buildings to be functional indoors (-) construction elements must be able to withstand water pressure or currents and water must be able to run off or be pumped away easily	***27. Water roofs:*** a dynamic water roof is equipped with a control system to temporarily retain rainwater and discharge it slowly through a drain. (+) Since there is no greenery, construction and maintenance costs are low (-) a higher load due to water needs to be considered when constructing the roof (-) in the Netherlands, roofs should have a maximum water height of 10cm
7. IT sewer pipe: Infiltration and Transport sewer infiltrates the rainwater underground through a geotextile-wrapped perforated horizontal tube into the soil. (+) used in unpaved surfaces where the permeability of the soil is low (+) during heavy showers the IT sewer can result in an emergency transfer facility on surface water (-) only clean rainwater may be infiltrated (-) IT sewer must always be above	***8. Parking above green areas:*** parking areas with a less intensive use can be paved with materials open to vegetation. (+) green parking lots can serve as cool islands in industrial areas where the hottest spots are. (+) with a shading design implementing trees, cars can also stay cool (-) extra maintenance to keep a green layer	***20. Raising land:*** by raising the land level, the living spaces and critical infrastructure of houses are kept above the floodwaters, reducing the potential for damage exponentially. (+) practical and cost-effective solution already proved in other redevelopment projects. (+) long-term resilience against recurring flood events and future scenarios (-) only feasible if the area is non-built-up or if it is planned to redesign from	***28. Water squares:*** are deepened, multifunctional areas where rainwater can flow from the area during an extreme rain shower. The water is then temporarily collected there. (+) a multifunctional solution is created when rainwater is collected in a visible place in the public space (+) investments for water storage are simultaneously used to create an attractive outdoor space and incur less additional costs

groundwater		scratch certain area (-) environmental Impact: such as alteration of natural drainage patterns, or groundwater levels	(-) in densely built-up urban areas it is difficult to find space between the structures (-) regular maintenance needed to ensure proper functionality
9. Reintroducing the sidewalks: During heavy rain showers, curbs can stop the water and together with the street form a temporary shelter for water. This keeps the sidewalks passable and the facades and houses dry. (+) water can be temporarily collected on the street between the curbs, so an elevated sidewalk can prevent flooding in homes (+) ramps can be constructed in strategic locations for prams, wheelchair, and walker users to ensure accessibility (-) Sidewalks have disappeared in neighborhoods due to accessibility for wheelchair and traffic-laundering	***10. Non-return valves:*** can be installed in pipes that are vulnerable to backflow in flood events. (+) valve will prevent water flow in the wrong direction (-) installation might require a major procedure since pipelines are underground	***21. Elevated functions and utilities:*** buildings in flood-prone areas should allocate vulnerable functions in higher floors. (+) ground floors would serve as temporary functions (parking or water storages) or for commercial activities (shops, offices, horeca, etc.). (+) buildings could be used as a flood defense if ground floor levels are designed with strict guidelines for constructions (-) in case of flood, vertical evacuation (-) ground floor and foundations should be built with high standards against water. All type of electrical, gas, telephone connections should be wetproofed or elevated above design flood water level	***29. Urban watercourses:*** form a temporary rainwater storage and drain the water. This simple yet beautiful solution can be used in new-build neighborhoods, or in redesign if there is space. The Enschede case study promotes the idea of a blue vein collecting rainwater from paved ground in the neighborhood until the stream reaches a water body. (+) open gutters and ditches, can drain on an open urban watercourse (-) a visible watercourse must be designed to remain attractive at both high and low water levels
11. Separated sewer system: *t*wo separate sewer systems are established: one for rainwater (often called a stormwater system) and another for domestic or industrial wastewater. (+) clean rainwater is not mixed with wastewater so it can be discharged directly to a waterbody (+) sewer system can handle extreme run offs properly during pluvial flooding (-) significant capital investment for the construction of two different networks (-) finding sufficient space for the installation of pipelines in densely built urban areas is challenging	***12. Protection of significant facilities:*** Significant goods such as historical structures should be well defended against climate extremes. (+) measures are usually temporarily and only visible in a flood event, i.e., sandbags or demountable bulkheads (+) economic damage to property is reduced greatly (+) measure can be adapted to buildings so buildings facades and temporal bulkheads form a defense to protect a neighborhood behind these. (-) quick action is needed to implement temporary defenses (-) require a combination of sufficient forecast accuracy and support from locals	***22. Rainwater storage:*** large tanks underneath or next to buildings and households to store rainwater captured in rooftops or along the sides of buildings. (+) provisional water for drought periods (+) cost-saving solution that will proportion water for residents and reducing the municipal demand (+) runoff towards sewer system is relieved (-) limited storage capacity due to space requirements	***30. Water elements:*** such as fountains decorate the garden and public space. They can be fed with rainwater from the area for much of the year. This relieves the sewer system. Many forms of water elements, such as ponds, water flows, fountains, and landscaped waterfalls. (+) water elements have a cooling effect on the immediate vicinity due to the greater evaporation (-) water elements related to recreational facilities require good attention to the water quality (-) water quality of artificial ponds is less easy to control which could lead to the appearance of mosquitos.
13. Elevated buildings and ground floor level: can be done in different ways to locate the ground level above flood water design levels, • Constructions on piles so water flow underneath the building (+) very effective for fluvial flooding (+) gives more space to public area (+) can be situated partly in the water (-) soil should be stable and strong • Ground floor level can be slightly elevated and accessed using stairs (+) relatively low cost (+) water buffer is created in the street and public spaces (+) aesthetic added value is not altered (-) accessibility to the structure is limited	***14. Wadis:*** in the Netherlands have another purpose: collect, retain, and infiltrate rainwater into the soil, becoming a rainwater harvesting system. (+) improved water quality since wadis are natural filtration systems that allow sediment and pollutants to settle and be retained within the basin (+) promote groundwater recharge by allowing stormwater to infiltrate into the soil (+) wadi design do not interrupt the landscape and can be easily integrated in green areas (-) regular maintenance is required as littering and leaves could accumulate within the wadi (-) performance will vary according to soil conditions, rainfall patterns and other factors	***23.Rain-proof rooftops***: are proper covered with waterproofing materials such as bitumen-base liquid for membranes covers, painting, joint sealants, and mastics. (+) non-sloping roofs can work as temporary water roofs to store a limited amount of rainwater for greenery use. (+) waterproofing materials for roofs are quite economical and easy to be applied (-) an extra weight needs to be calculated in the design of the rooftops	***31. Infiltration crates and blocks:*** form an underground storage space for rainwater. From these crates, the stored rainwater sinks into the soil in a delayed manner, towards the groundwater. (+) no extra space needed above ground (+) larger storage capacity than above-ground rainwater storage (+) crates can be used under gardens, roads, sport fields and parking squares (-) crates can only be used in areas where the groundwater us low, otherwise crates are saturated. (-) infiltration effect could be slower than expected (-) maintaining and spraying the crates is a difficult job
15. Activating urban rooftops: represent around of 25% of cities' land area and most of them have a wasted potential. (+) new layer of public space is created for recreation, leisure, and evacuation (+) green infrastructure can be implemented to adapt stormwater (-) not all rooftops are structurally suitable for public use (-) accessibility to rooftops can be challenging for people with mobility limitations (-) cost considerations like structural assessment, installation of amenities, and design.	***16. Height differences in surface:*** to manage runoff during an extreme scenario, low green areas are recommended to be created in green areas so water can be retained in the soil as much as possible, to slow the infiltration effect and to redirect water to a close water pond or storage. (+) economical solution that does not need to build prominent structures (+) it does not interfere with the existing landscape (-) it might require frequent maintenance in the lower areas to facilitate infiltration.	***24. Flood defenses adapted to the topography:*** Hafencity designed flood defenses integrated discretely in public spaces so the connection between the residents with water, living and working remains. New public spaces act as a sort of dike with different levels that hold rising water levels (+) new public spaces such as waterfront parks or meeting promenades can be created (+) contours of canal can be used to form natural depressions so water bodies are accessible for public (+) height difference could form a sort of dike and elements in this area could serve as a buffer to restrain water access (-) solution relies on topography characteristics and its inherent limitations (-) ongoing maintenance and monitoring	***32. Emergency underground water storage:*** would be an artificial and temporary reservoir to save water during extreme circumstances. (+) underground garages (cars and bicycles) could be adapted to collect water (+) discrete measure that could reduce flood impact greatly (-) costly measure that could never be used. (-) only feasible to build if there are no built-up areas above it

Non-structural recommendations
Land and design regulations: 33. New regulations proposed from local governance to prioritize open green spaces and natural buffer zones within built-up urban areas. 34. Focus on controlling waterlogging spots in urban areas and neighborhoods, this also comprehends an analysis into the existing sewer system and the installation of pumps and inlet guts. 35. Promoting the incorporation of blue-green infrastructure in urban development as much as possible, this includes green roofs and facades. 36. New open space requirements that encourage the multipurpose use of public space so they can adapt for different events such as meeting places, buffering areas or water storage. This also includes green areas and parts of public squares, so these allow flooding every once or twice a year for few hours. 37. Conservation of natural features that provide flood protection; however, it also accounts for the implementation of flood defenses in green areas without disturbing the existing environment nor the landscape 38. Street design should drain the water is the most effective way avoiding the accumulation of water. For streets without sidewalks, there should drain and infiltrate solutions that do not overwhelm the drainage system 39. For a better sense of connectivity, three main structures should be present in waterlogging-prone areas, an open square to store water, a promenade that infiltrates and redirects water, and an elevated place as a meeting zone. 40. Building blocks should not create a continuous wall or limiting the mobility of people through the buildings. 41. The geometry and topography of the area formed by buildings and public space, should retain and infiltrate water before redirecting the runoff towards the closest water body. ***Building codes:*** 42. Strict building codes risk-based on design flood water levels so living functions and relevant connections (electricity, gas, internet, water) are built above the specified design level so these areas remain functional in a flood event. 43. Set standards on water-resistant materials for construction from infrastructure till maintenance and structural adaptations. 44. Establishing a ground elevation standard for every project presented prior construction so the elevated zones do not require enormous technical and costly operations. ***Citizen participation:*** 45. Comprehensive communication with people living in flood-prone areas by using flood hazard mapping to remark the potential damage and potential solutions. 46. Encourage the purchase of flood insurance (higher costs for constructions in high-risk areas) or offer financial incentives to homeowners so they can make investments in flood-resistant renovations and retrofitting 47. Encourage a higher compromise of residents to participate in the protection of historical areas by deploying temporary flood defenses. ***Institutional organization:*** 48. Local municipality should be allowed to impose land regulations and spatial strategies in addition to minimum standards established by national plans or higher governance levels according to the level of risk experienced in the area. 49. Workshop meetings to discuss and agree on priorities of a project having as goal flood resilience for structures in risk zones. For this purpose, a proper study of possible future scenarios and climate impact consequences is needed to base the measures on design flood water levels from water depth maps.