Designing for Health
Green Infrastructure's Role in Urban Resilience and Health

Bachelor Thesis: Spatial Planning and Design
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Abstract

Urban regions must quickly reduce their environmental impact as they contribute considerably to global CO_2 emissions. By 2030, it is projected that 60% of the global population will live in cities, making them more susceptible to the consequences of climate change, including the Urban Heat Island (UHI) phenomenon and changed precipitation patterns that increase the danger of flooding. With a focus on Groningen's Schildersbuurt, this study explores the possibility of incorporating green infrastructure (GI) with urban planning to improve public health and climate adaptation. This research investigates how GI can tackle urban environmental concerns and contribute to health through critical literature analysis and research-by-design. The Schildersbuurt's notable heat absorption and susceptibility to flooding are highlighted by the research's climate analysis. The proposed design attempts to improve air quality, mitigate the effects of UHIs, and retain rainwater by implementing a GI network that includes wall gardens, permeable pavements, raingardens, and a green roundabout with underground water storage. The results are consistent with GI projects that have been successfully implemented in other cities, indicating that a healthy urban environment can be created through the employment of GI. Despite obstacles like expenses and upkeep, the research highlights the capacity of GI in promoting healthy, climate adaptive urban environments. Further studies should continue to improve these approaches, guaranteeing their efficient adaptation and implementation in different urban environments.

Key words: *Research-by-design, Spatial planning, Green infrastructure, Healthy cities, Healthy urban planning, Climate adaptation, Urban heat island, Air quality, Pluvial flooding.*

Table of Contents

1. Introduction

Nowadays cities contribute significantly to CO_2 emissions worldwide, thus reducing their negative environmental effects will need to happen rapidly (Wang et al., 2021). According to the United Nations (2019), the proportion of people living in cities is expected to rise steadily, from 50% in 2010 to 60% by 2030. This makes urban regions especially vulnerable to impacts from climate change due to their core features, which include high population density, highly used infrastructure, and economic prosperity (Wang et al., 2021).

The Urban Heat Island (UHI) effect, which is defined by higher temperatures in urban areas than in surrounding rural areas, is one of the effects of climate change on cities. It presents serious risks to both environmental quality and human health. It is anticipated that climate change will significantly exacerbate this phenomenon (Basagaña, 2019; Sturiale and Scuderi, 2019). Furthermore, it is predicted that rising temperatures will change precipitation patterns, increasing the likelihood of frequent and heavy rainfall events and raising the risk of urban floods (Lo, 2013). Interventions in urban design have the potential to reduce the impact of the UHI and mitigate local pollution. Including green spaces in urban landscapes has been identified as a critical strategy to enhance cities' climate change resilience (Basagaña, 2019; Sturiale and Scuderi, 2019; Brown et al., 2015).
A structural method known as "green infrastructure" (GI) makes use of nature, natural processes, and mechanisms to construct infrastructure and plan cities, all the while fostering social and economic development. GI offers a multitude of advantages and can be characterised as multifunctional structures that generate numerous services. Thus, making use of GI can result in benefits that are obtained either directly or indirectly (Osei et al., 2022).

Experts in both urban planning and health have come to understand how closely urban design affects both public health and climate change. The growing difficulties encountered by climate change and its effects on health are the reason for this recognition (Wang et al., 2021). Urban planning measures have the dual effect of reducing climate change and improving public health. As stated by Wang et al. (2021), the distribution of land use, road networks, spatial form, and the availability of green spaces are critical variables that impact urban populations' health outcomes. Barton et al. (2009) state that enhancements of the built environment encourage social cohesion, physical exercise, and reduce the exposure to pollution. Urban planning, then, becomes a methodical approach to environmental management that has significant effects on the health and welfare of the public (Barton et al., 2009). Adopting the concepts of healthy city planning has the potential to improve public wellbeing outcomes and increase climate resilience, therefore contributing to being a healthy city (Wang et al., 2021; World Health Organization, 2015).

To determine whether GI can enhance citizens' health, this study investigates the relationship between urban planning and healthy cities. It is important to learn more about the potential outcomes of incorporating GI into a city as this indicates whether the strategy can be employed to both adapt to climate change and establish a healthy city.
Through critical literature analysis and research-by-design, to visualise possibilities for the future and finding answers to design issues (Hinterleitner, 2022), the impact of GI on the healthy city concept and a city's resilience have been researched to answer the question:
How can GI improve the healthy city concept while establishing resilient, climate adaptive urban neighbourhoods? With the following secondary questions:

- *How can the healthy city concept be achieved in the Schildersbuurt?*
- *What is GI and how can it be implemented in the Schildersbuurt?*
- *How can the UHI effect, air pollution, and pluvial floodings be reduced with GI?*

For this research, the Schildersbuurt in Groningen is chosen as a case study. The Schildersbuurt was constructed in the 1900s, when Groningen's spatial growth transitioned from "spontaneous" to "planned." Situated beyond the then-existing 17th-century fortification grounds, the area represents the city's first significant expansion (Gemeente Groningen, 2012). The neighbourhood was chosen based on the climatic factors that impact the area, such as UHI effect, the percentage of greenery, and the amount of flooding caused by heavy rainfall.

Firstly, this research describes how the concepts and theories used are defined and how they are related to each other. Then the methodology is described, and new design solutions for the chosen neighbourhood within the city of Groningen are proposed. The concluding part discusses how these designs will impact the healthy city and discusses the advantages and disadvantages of the designs, as well as comparing them to similar cases. Finally, it includes proposals for further research.

2. Theoretical Framework

2.1 Urban Heat Island Effect

As stated in the introduction, the UHI effect is a higher temperature in urban areas than in surrounding rural areas. When there is a calm wind combined with a warm summer day, the temperature difference is most noticeable. The UHI effect is induced by a variety of causes, for instance: fewer trees and plants to absorb solar radiation and facilitate evapotranspiration, more heat absorbing surfaces than rural areas and a lot of car traffic, producing heat from exhaust and engines. In the summer, health issues might arise from the heat created in the cities (Basagaña, 2019; Shmaefsky, 2006; Sturiale and Scuderi, 2019). The concerns around UHIs and their effects on public health are closely related to the goals of projects such as the European Healthy Cities programme of the World Health Organisation (WHO) (2015). These health issues range from an elevated risk of heat-related illnesses, an increased risk of underlying diseases, a higher chance of being admitted to the hospital or even dying (Heaviside et al. 2017). Urban planners are investigating strategies for expanding the amount of green space on rooftops and in the streets to absorb heat and minimise these issues (Basagaña, 2019; Shmaefsky, 2006; Sturiale and Scuderi, 2019). By tackling these issues, neighbourhoods can more effectively meet the WHO's criteria for healthy cities.

2.2 Urban Air Quality

When compared to rural residents, urban occupants typically experience higher levels of air pollution and temperature, along with less access to green spaces and wind (Wicht and Wicht, 2018). The increasing rate of urbanisation and excessive emissions have resulted in dangerously high levels of air pollution in various cities (Shiva Nagendra et al., 2020). As noted by Cichowicz and Bochenek (2024), these emissions are causing air pollution, which is one of the main challenges to contemporary society and has an impact on human health, life, and ecosystem function. They point out that the urban climate system is impacted by the continuous progress of urbanisation, with construction projects leading to alterations in land development, such as a rise in the amount of soil surface sealing. Consequently, Cichowicz and Bochenek (2024) note that physical process adjustments are understood to exacerbate the UHIs. The unique characteristics of the urban environment, such as rising outdoor temperatures, cause thermal inversion to form, which restricts the vertical mixing of air masses and could exacerbate smog (Cichowicz and Bochenek, 2024).

Shiva Nagendra et al. (2020) explain that air pollution is recognised as a worldwide public health concern since it increases the frequency and intensity of heat waves, which in turn increases mortality. Air pollution is caused by greenhouse gas pollution, specifically carbon dioxide. The effects of climate change on human health include increased exposure to ground-level ozone pollution, high temperatures, and the dispersion of airborne allergens, waterborne infections, along with other infectious diseases (Shiva Nagendra et al., 2020). Cities have created a variety of mitigation techniques to adjust to climate change, including raising surface albedo, reducing impermeable surfaces, and expanding urban green spaces (Wicht and Wicht, 2018).

2.3 Urban Pluvial Flooding

The severity and occurrence rate of weather-related disasters, such as flash floods, river and coastal flooding, and pluvial floods, are predicted to increase in a lot of regions due to changes in precipitation patterns caused by climate change (Asadieh and Krakauer, 2017; IPCC, 2021). Based on the IPCC (2021) report, extreme weather events linked to climate change will occur more frequently, have an impact on a variety of industries, and result in systemic failures throughout Europe. Especially, the frequency, extent, and geographic distribution of severe weather events are already being impacted by climate change. One of these occurrences is pluvial flooding, which happens when water flow surpasses drainage capacity along with the infiltration rate (Wheater, 2006). Heavy rains overload water treatment facilities, cause sewage to overflow or bypass into nearby waterways, or induce cross-contamination among drinking water and sewers. These scenarios can increase the spread of various waterborne pathogens (Cann et al. 2013; de Man et al. 2016). Stormwater containing the faecal contamination is responsible for pathogens that can infect humans and cause illnesses (Ahmed et al. 2019).

2.4 Healthy City

Since 1988, the WHO European Healthy Cities initiative has actively included local governments, raising health to the top of their political, social, economic, and environmental agendas, and making health a matter of concern for all (World Health Organization, 2015). Healthy cities, as defined by the World Health Organization (2022), are areas of prosperity for the community where methods that promote health, well-being, peace, and the common good are accountable, participatory, and inclusive. Healthy cities set an example both locally and worldwide by interacting with the environment as well as other actors to create social, cultural, and physical environments that encourage and promote everyone equally and help people realise their full potential as human beings (World Health Organization, 1998). In this research, the main focus of this broad definition is to change the physical environment with the main goals of a healthy city. These aims are outlined by the WHO to guide cities and urban planners in achieving a healthy city. Therefore, focussing on healthy urban planning to create environments that are healthy and support healthy lifestyles (World Health Organization, 2022).

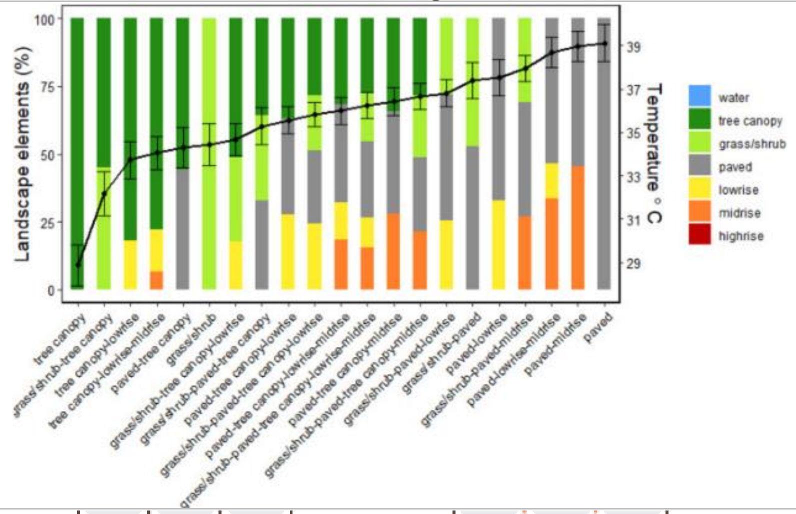
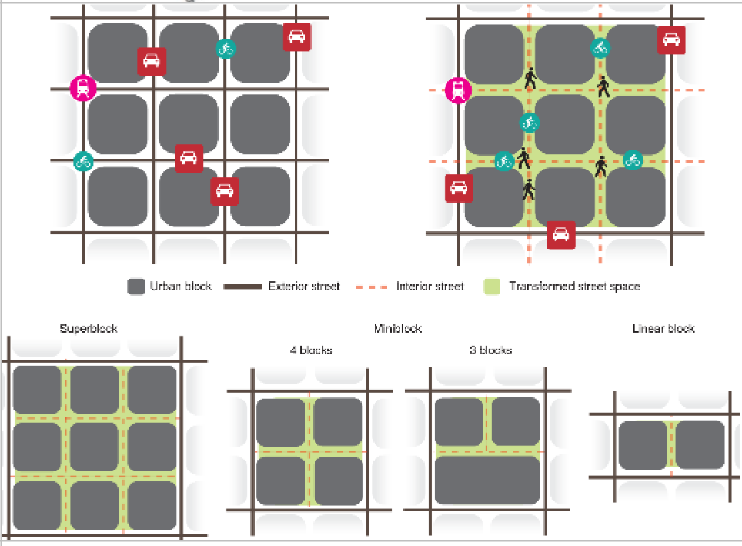
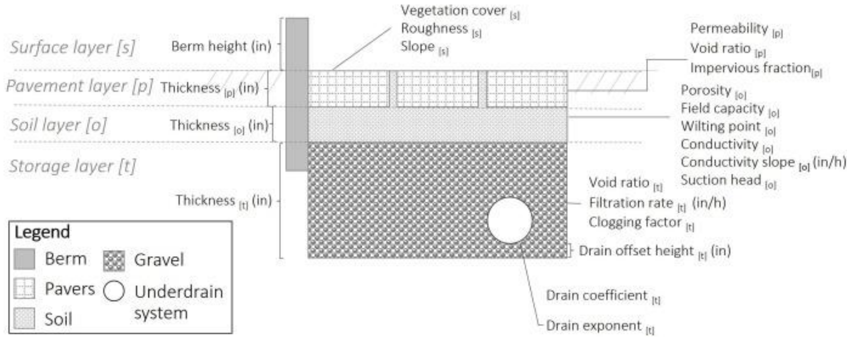
Human health depends on nature, as claimed by Maller (2018), who also argues that nature is vital to many facets of our life. Maller (2018) believes that a healthy city is one that is intended and acknowledged as a location or, more precisely, a habitat for species not limited to just humans. Thus, describing healthy urban environments as settings where non-human animals and plants are recognised, welcomed, and actively encouraged to thrive in addition to being locations where people and non-humans can coexist and profit from their shared presence (Maller, 2018).

2.5 Green Infrastructure

GI is a means that uses natural solutions to provide benefits to the environment, economy, and society. It helps prevent depending on costly infrastructure when often, nature has more affordable and robust solutions to offer. The foundation of GI is the idea that urban development and spatial planning should intentionally incorporate the preservation and enhancement of nature, natural processes, and the numerous advantages that nature provides to human society (European Commission, 2013; Osei et al., 2022). GI, which is a network of natural and built components, enables hydrological and ecological processes and services. These elements include stormwater management strategies, urban forests, parklands, urban trees, permeable surfaces, and green roofs. Adding a variety of green areas will enhance the experience and maximise continuity and connectivity. It will also increase access to green spaces. Encouraging individuals to utilise these varied green areas can improve public health, and the presence of greenery itself could improve mental and physical wellness (Friedman and Pollock, 2022). The health advantages of green spaces are various and include reduced obesity, better birth weights, as well as enhanced cognitive function. Studies indicate that numerous health advantages of green spaces may be related to changes in immune function (Flies et al. 2017). Immune system function can be strengthened, lasting up to one month, by walking or spending time in a forest (Li, 2010). In addition, vegetation can filter the air, mitigate the consequences of rising temperatures and rainfall through essential ecosystem functions that lessen human exposure to climate change (Friedman and Pollock, 2022).

2.5.1 Case Studies

Table 1 shows different case studies, that implement various GI elements, to address different issues found within the city of studies. Some of these are related to how GI positively impacts the public health within the chosen location.

Case study	Design / Model
Oslo, Norway In comparison with artificial surfaces, GI can drastically decrease surface temperatures, particularly tree canopies. In Oslo, regions with vegetation are 10°C cooler than areas with pavement, thus the GI mitigates the UHI effect. The health of Oslo's residents benefits from this, as each tree within the city could lower the danger of heat exposure by one day for an individual that is heat-sensitive. (Venter et al., 2020)	 (Venter et al., 2020)
Barcelona, Spain Barcelona's Superblocks design uses GI to mitigate UHIs and provide improved air quality and a cooler urban environment. Improved physical and mental health have also resulted from this, and a decline in hospital admissions is anticipated. Furthermore, it is expected that GI will enhance kids' behavioural and cognitive development. (Nieuwenhuijsen et al., 2024)	 (Eggimann, 2022)
Buffalo, NY, United States In periods of intense rainfall, a GI tool known as permeable pavement considerably lowers the combined sewer overflow. The most effective solutions are frequently those that cluster and optimise the permeable pavements. The danger of waterborne illnesses and pollution from sewer overflows has decreased as a result of the implementation of permeable pavements to reduce sewer overflow, therefore improving public health. (Torres et al., 2022)	 (Torres et al., 2022)

Portland, OR, United States Portland uses GI to detain stormwater, eliminate pollutants, reduce the impact of UHIs, and enhance the streetscape attractiveness. The city incorporates trees, gardens, green spaces, green walls, ecoroofs, and vegetated stormwater management systems. The focus on designing with nature promotes a more sustainable and healthier urban environment for people and wildlife, along with supporting ecosystem services. The integration of GI offers several advantages, such as equitable transportation, effective stormwater management, and a decrease in greenhouse gas emissions. (Bureau of Planning and Sustainability, 2023; Tillett, 2017)	 (Bureau of Planning and Sustainability, 2023)
Victoria, Australia In extremely polluted urban forms, the creation of green cities is a typical technique to solve the problem of poor air quality. GI techniques are effective tactics for raising air quality standards since they absorb toxic air pollutants and offer several additional ecosystem services. Trees, which have the maximum air pollutant absorption and are less expensive than green roofs and green walls, are the most effective GI element. While adding trees with green walls or roofs did not significantly increase air pollutant pickup, it did increase energy and liveability advantages. (Jayasooriya et al., 2017; Vidal et al., 2024)	 (Jayasooriya et al., 2017)

Table 1: Case studies that employ different GI elements (Stuut, 2024)

2.6 Spatial Analysis – Neighbourhood Scale

The living conditions of communities are greatly influenced by urban planning, which in turn has a major effect on the communities' general quality of life. Healthy urban planning integrates data and policy to improve the lived experience of urban places and encourage positive changes for people (D'Onofrio and Trusiani, 2018). Two key design scales for healthy cities are identified by D'Onofrio and Trusiani (2018) as the local neighbourhood scale and strategic urban policies. They stress the critical role that neighbourhoods play in starting initiatives that attempt to integrate several health determinants and factors, including community involvement, climate adaptation, mobility, and the creation of diverse green spaces. Therefore, the neighbourhood scale is applied in this study. The choice of location is determined by the combination of which neighbourhood in the city of Groningen experiences the UHI effect and a neighbourhood with a low percentage of greenery. Consequently, when looking at Figure 2 and 3, the Schildersbuurt was selected as focus of this research (location is shown in Figure 1).

Figure 1: Location of Schildersbuurt within Groningen (Stuut, 2024)

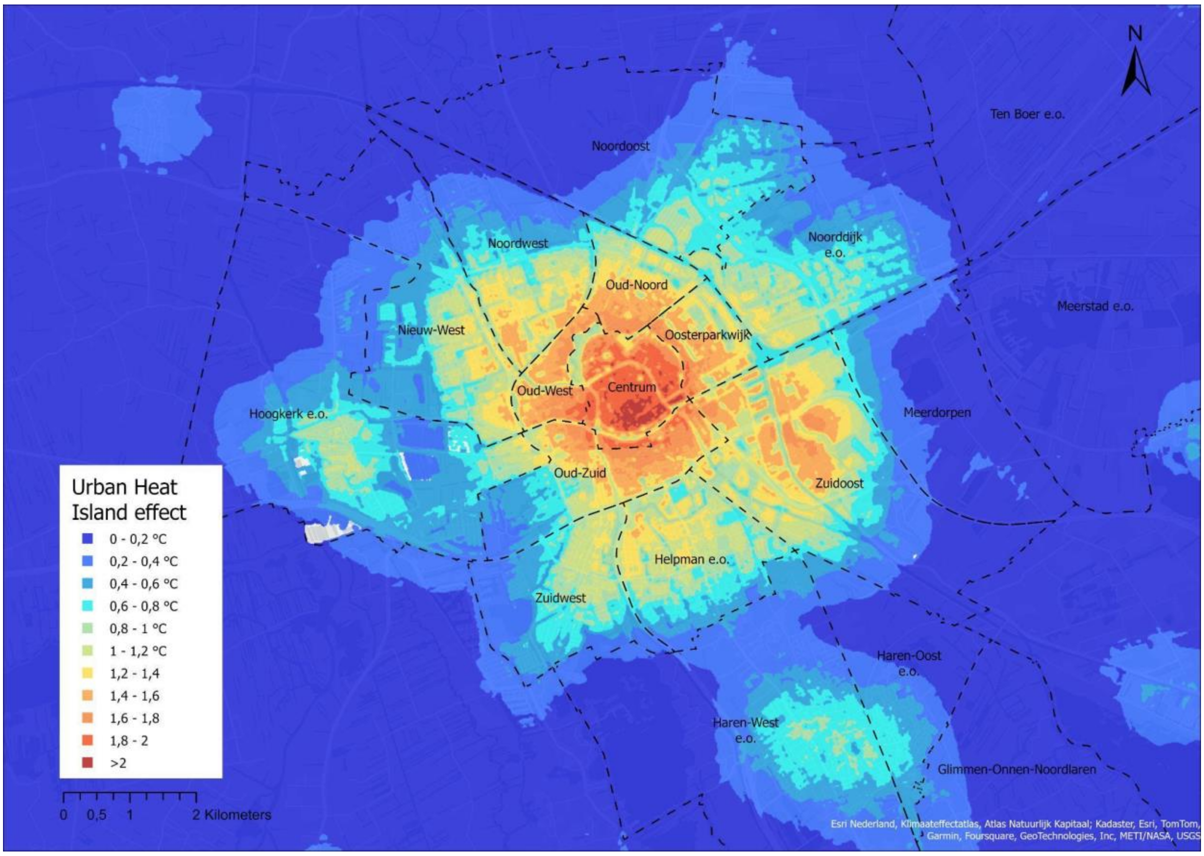


Figure 2: Urban Heat Island effect in the city of Groningen. (Esri Nederland et al. 2021)

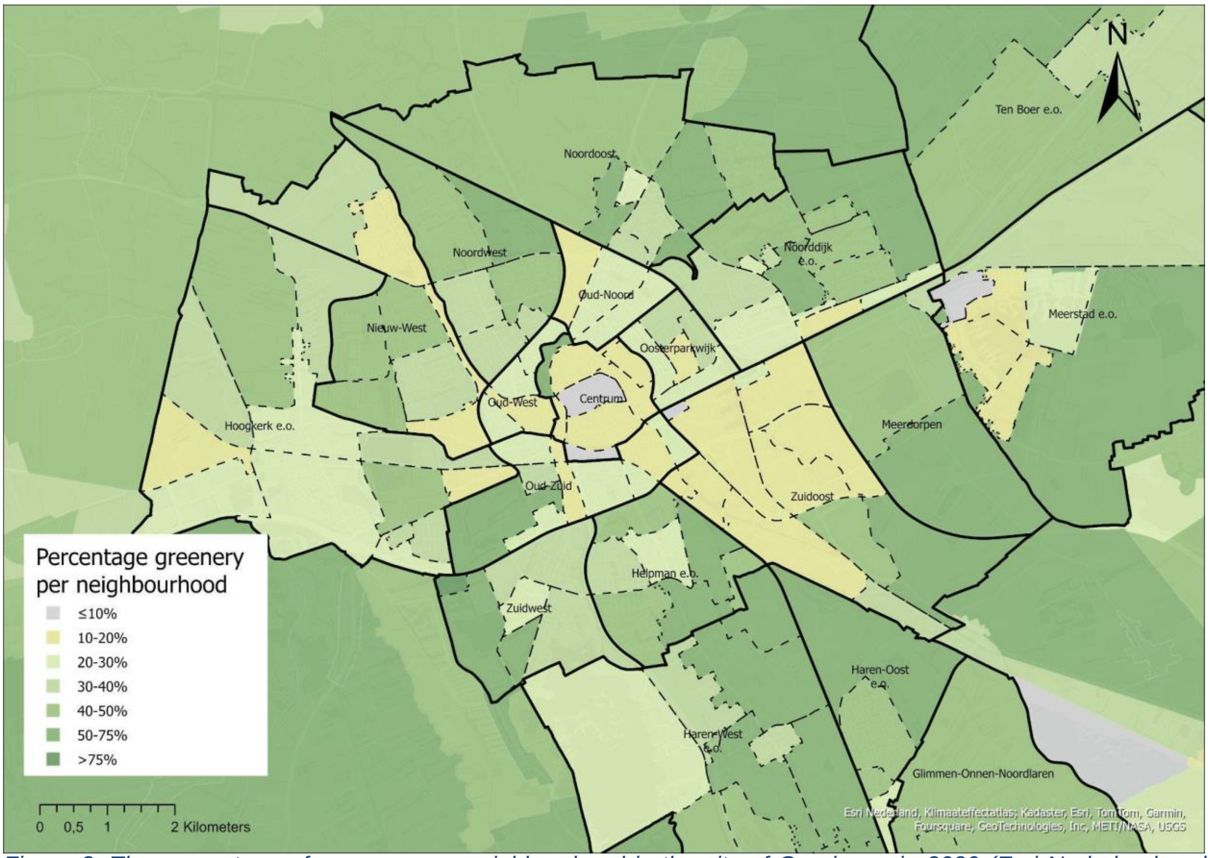


Figure 3: The percentage of greenery per neighbourhood in the city of Groningen in 2020 (Esri Nederland and Klimaateffectatlas, 2021c).

2.6.1 Municipal Goals for Green Infrastructure

According to a report prepared for and in collaboration with the municipality of Groningen (van Driessche et al., 2021), the city hopes to address the challenge of climate adaptation by strengthening the overall correlation within the urban environment and the relationship between the city's cultural and environmental identities. The document emphasises the significance of water infiltration, which supports the newly constructed street grid by converting the municipality from a drainage city to a "sponge city." Apart from contributing to water drainage and retention, the report underlines the importance of biodiversity and wildlife in urban settings. It stresses that biodiversity should be expanded, and this will ensure a resilient green ecosystem with proper management. The report lists a few potential strategies for developing a resilient city, including promoting community gardens and facade gardens, integrating building and street design, and establishing green environmental roadsides (Figure 4).

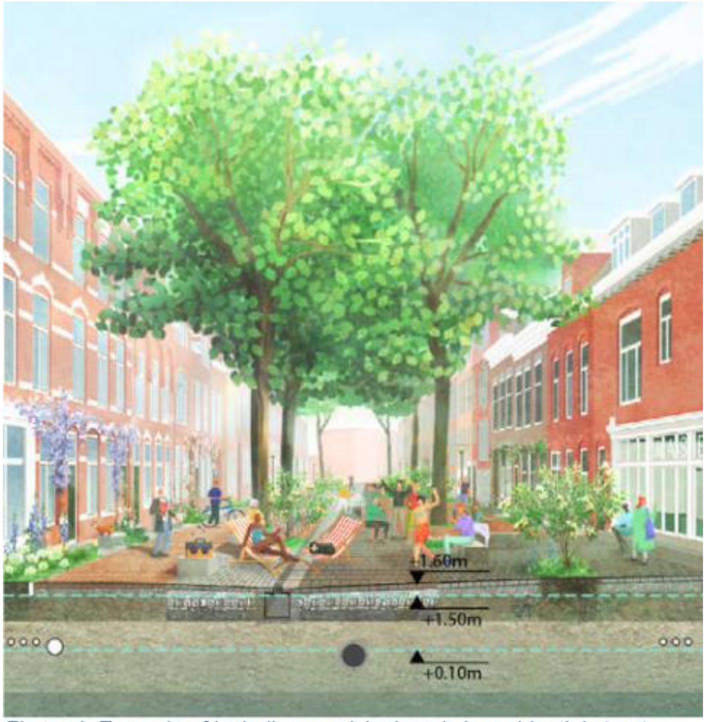


Figure 4: Example of including municipal goals in residential street design (van Driessche et al., 2021)

The municipality also published a report describing the "Groenplan Vitamine G", a comprehensive plan outlining goals and tactics for expanding, enhancing, and improving Groningen's green spaces (Gemeente Groningen and Strootman Landschapsarchitecten, 2020). It focuses on tackling issues pertaining to biodiversity, ecology, greenery, and climate adaptation, especially regarding the reduction of heat stress and water overflow. In addition to stressing the benefits of green spaces for people and animals, the strategy also highlights the environmental, health, air quality, climate resilience, recreational, aesthetic, cultural heritage, and economic importance of these areas. The plan lays out concrete steps, rules, overarching ideas, and creative fixes to accomplish these goals. Together with a long-term (until 2030) vision, it also lists the initiatives and financial commitments scheduled for the upcoming years to achieve these objectives. The goal is to increase the quantity, quality, and accessibility of green spaces to make the municipality greener. This entails adding 30.000 m² of greenery and planting 1.000 trees in the public space yearly. Improving the general quality of the living and working environment, encouraging a healthy lifestyle, and making sure that green places are preserved and maintained are among the primary goals. The "Groenplan Vitamine G" measures are intended to help increase the city's resilience to climate change. In order to improve green and climate-resilient public spaces, the following measures are significant for this research: establishing a municipal ecological structure and a regulation for nature-inclusive building; de-paving public space, which entails removing or reducing hard surfaces; putting green initiatives like the Tiny Forests and Green Roofs Stimulus Programme into action; and funding the renovation of green spaces and the planting of more trees (Gemeente Groningen and Strootman Landschapsarchitecten, 2020).

2.6.2 Historical Background of the Schildersbuurt

The Groningen neighbourhood known as Schildersbuurt has a rich background. The Drentse A, a waterway that occasionally flooded due to tidal impacts, was a defining feature of the region west of the Hondsrug, prior to the establishment of the city of Groningen. The region became covered in clay caused by these floods. Compared to the adjacent higher terrain on the Hondsrug, where the city developed, the area was less ideal for habitation due to its lower height and irregular flooding (Gemeente Groningen, 2012).

Throughout the late 19th and early 20th centuries, the area underwent enormous expansion. To restrict the unchecked building activities of private individuals, a stedenbouwkundig plan (urban development plan) was developed in 1893 for the area located between the Hoendiep and the Reitdiep (Figure 1). Despite not being carried out, this plan indicated the start of more municipal involvement in the future growth of the area.

The Schildersbuurt went through phases of development, the years 1900–1913 were especially important, the Schildersbuurt gained its unique personality during this period when a stedenbouwkundig plan was created for a residential section of the neighbourhood (Gemeente Groningen, 2012).

2.7 Conceptual Model

The conceptual model, in Figure 5, shows the significance of incorporating GI and healthy city design concepts, and it emphasises how environmental issues can be tackled, public health can be improved, and urban areas' resilience to climate change can be strengthened. This model shows a tool for combining research and design, and how theoretical knowledge feeds the design process.

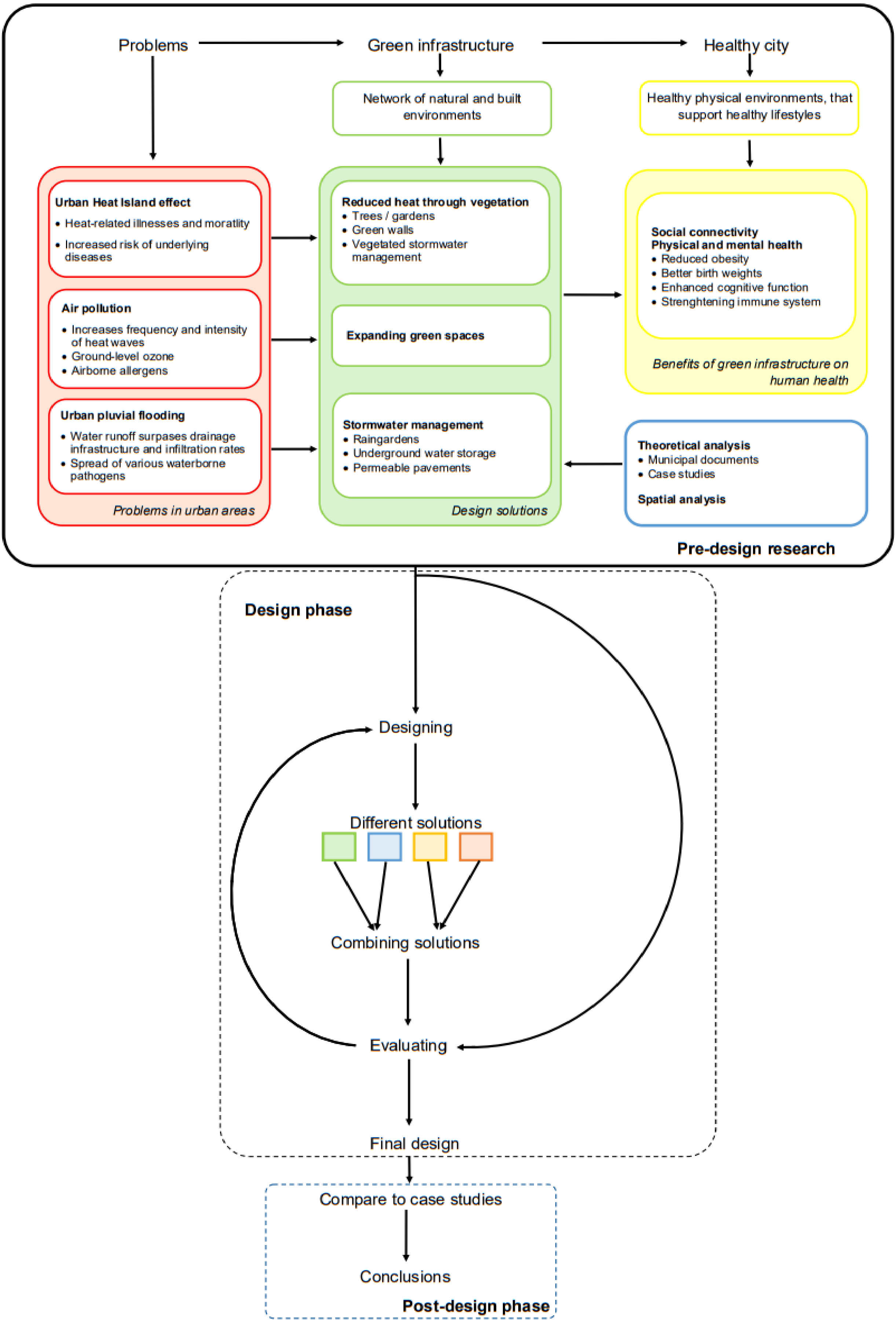


Figure 5: Conceptual model (Stuut, 2024)

2.8 Expectation

Using a designated neighbourhood in Groningen as its focal point, the study investigates the potential and constraints brought about by using GI within urban planning. This research aims to evaluate the viability and efficacy of the municipality's goals and objectives for the region in terms of improving community resilience and health. The spatial challenges associated with putting GI into practice are examined, with an emphasis on how urban design approaches might lessen these obstacles. The objective of this study is to shed light on how GI initiatives might enhance the local neighbourhood's environmental quality, advance public health outcomes, and lessen the impact of the UHI. After the research is finished, the expectation is that GI would have a favourable impact on neighbourhood health and hence promote a healthy city.

3. Methodology

This methodology presents an approach to comprehending and resolving Groningen's urban difficulties. To establish limitations and goals, several reports and policies from the Groningen municipality have been examined. To provide a comprehensive picture of the neighbourhood's past and present, policies for the area has been evaluated. Furthermore, a report regarding the municipality's plans for climate adaptation for the city has also been reviewed. Data from maps created by Klimaateffectatlas and Esri Nederland were used and have been evaluated for spatial analysis with ArcGIS. The data collected concerns the neighbourhood's heat stress, flooding, and different vegetation-related metrics, which includes the percentage of paved surface, the distance to cooler areas (greenery), and the number of trees.

After the secondary data analysis, primary data was collected in the form of designs. This method is known as research-by-design, which is an academic investigation that employs design as a technique of analysis, involving project development and material experimentation (De Queiroz Barbosa et al., 2014). Prior to actual design work, research is done to provide a basic grasp of the study question (Roggema, 2017). Pre-design research in this context refers to the secondary data gathered including literature and spatial data about the Schildersbuurt, which provides a fundamental understanding of the area and initiates the design process (Figure 5).

The reflective practice of design incorporates critical analysis, evaluation, and comparison. It involves a constant cycle of shifting between questioning and proposing, using sketching as a means of problem identification and solution formulation (Hauberg, 2011; Roggema, 2017). As noted by Hauberg (2011), even though research is done using models and drawings, and is conducted in the language of designers, the design process is comparable to research. Nevertheless, design is different given that it is primarily concerned with visualising possibilities for the future and finding answers to design issues (Hinterleitner, 2022). Handmade sketches are used as a starting point in this study, and more refined final designs will be digitally created with ArcGIS, Photoshop, SketchUp and Lumion.
Roggema (2017) states that the objective of research-by-design is to achieve a balance between research methods and experimental design activities. Continually creating, rationalising, and evaluating several design solutions is part of the process. Integration is examined and evaluated critically as the process progresses, resulting in the ultimate

presentation of compelling findings. These findings mark the post-design phase's completion and provide insights into projected futures as well as possible outcomes (Roggema, 2017). The comparative study, which is part of the post-design phase, uses an approach that entails analysing the designs and outcomes by comparing them with case studies mentioned in Chapter 2.5.1. These comparative techniques compel researchers to reevaluate how situational their claims are by nature and to exceed the boundaries of their theoretical framework (Brill, 2022). This comparative method will offer insightful information about the advantages and disadvantages of the suggested solutions, facilitating a more thorough comprehension of their suitability and efficacy in related situations.

It is important to follow the methodology with ethical considerations. The secondary data that has been used for the climatic conditions is publicly available, and no personal data has been utilised in this study. Every data source has been evaluated, making sure that the data is valid and credible. To acknowledge others' property rights, the data sources used in this study are all referenced in the text and listed in the Bibliography.

4. Results

4.1 Climatic Conditions

The Schildersbuurt in Groningen's spatial analysis of climate conditions reveals a complex relationship between environmental elements and urban growth. The neighbourhood has a few spots of vegetation that advantageously impact local microclimates and biodiversity, with 20–30% of the public areas being green space (Figure 6). Nevertheless, with 70–80% of the land made up of built and paved surfaces (Figure 7), there are negative aspects, like less permeability for rainwater absorption and greater heat retention. A 20–30% of trees (Figure 8) can offer only little relief by providing shade and reducing the impact of the UHI effect.

Figure 6: The percentage of greenery per neighbourhood in Groningen in 2020 (Esri Nederland and Klimaateffectatlas, 2021c).

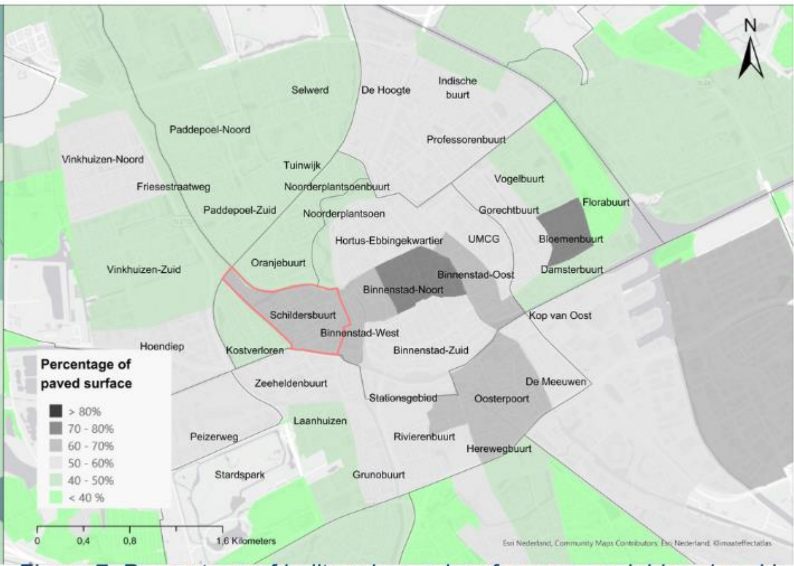


Figure 7: Percentage of built and paved surfaces per neighbourhood in Groningen (Esri Nederland and Klimaateffectatlas, 2021b).

Figure 8: Percentage of trees in public spaces per neighbourhood in Groningen (Esri Nederland and Klimaateffectatlas, 2021a).

The analysis also emphasises how noticeable the UHI effect is in the Schildersbuurt (Figure 9), where significant temperature variations are seen in different zones. Considering the constructed surfaces' high heat-absorbing capacity and the limited amount of greenery, much of the neighbourhood experiences a temperature difference between 1,4℃ and 1,8℃ as compared to rural areas. The neighbourhood's older southeast part reveals a more prominent UHI effect, with a temperature differential of up to 1,8℃ to 2,0℃. On the other hand, the northwestern section stands out as the coolest zone within the community, with a temperature difference varying between 0,8℃ to 1,6℃ higher. This area directly next to the Reitdiep channel is striking since there is a cooler temperature with variations from 0,8℃ to 1,0℃ there due to a considerably mitigated UHI effect caused by the cooling effect of water. Additionally, Figure 10 shows that there is a spatial relationship in the Schildersbuurt between the distribution of cooler places, which are primarily green spaces, and their proximity to housing. The neighbourhood's centre area has the greatest distance to cooler regions, ranging from 300 to 500 metres. In one case, the centre's position is even more than 500 metres away from these cooling areas.

Besides a relatively high UHI effect, the neighbourhood is also prone to experience pluvial floods. With Figure 11 and Figure 12 showing the effect of heavy precipitation on the Schildersbuurt street pattern. These maps display the vulnerability of the centre area of the neighbourhood. Combining Figure 10 with Figure 11, resulted in Figure 13, presenting the problem locations within the Schildersbuurt. Based on this map, a priority location was chosen to be used as design subject. In Figure 14 the selected streets (Jozef Israëlsstraat and Taco Mesdagstraat) are displayed, the large open space (Jozef Israëlsplein) has a distance of 500 metres or more to cooler areas and is surrounded on three sides by streets that are prone to floods. These climatic conditions make this location a suitable place to research the impact and effectiveness of GI.

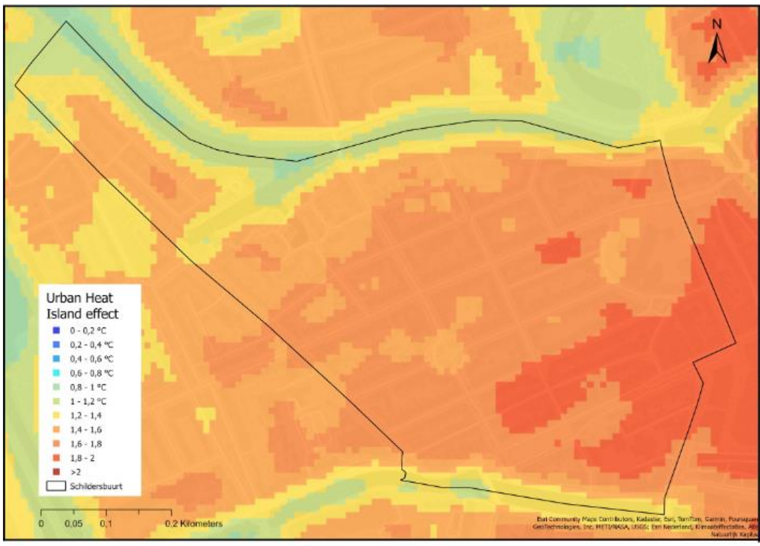


Figure 9: Urban Heat Island effect in the Schildersbuurt (Esri Nederland et al. 2021).

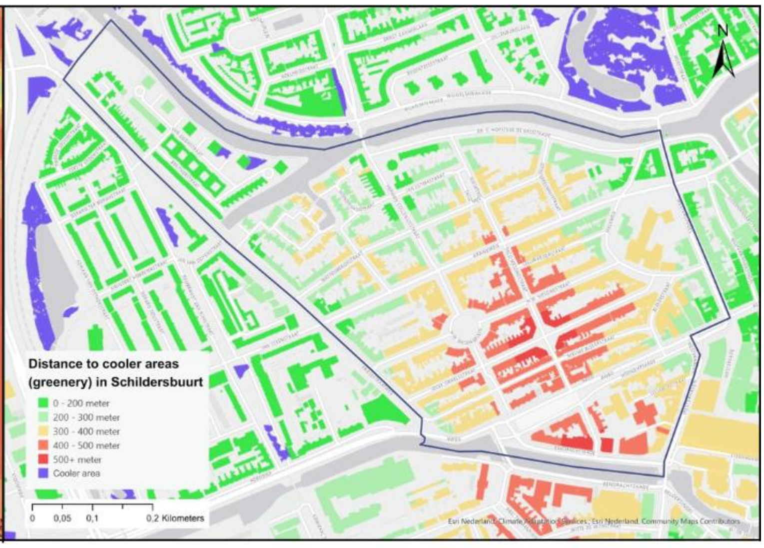


Figure 10: Distance to cooler areas (greenery) in the Schildersbuurt (Esri Nederland and Climate Adaptation Services, 2022).

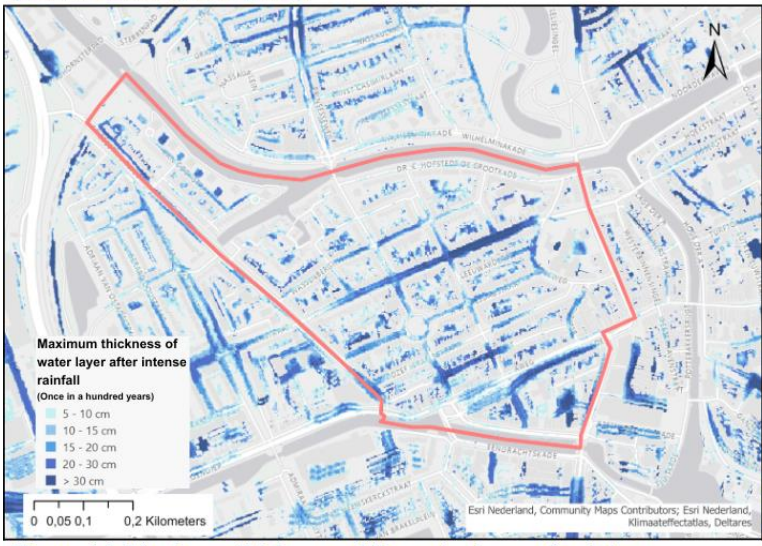


Figure 11: Maximum thickness of the water layer after intense rainfall, in the Schildersbuurt, that occurs once a hundred years (Esri Nederland et al. 2021a).

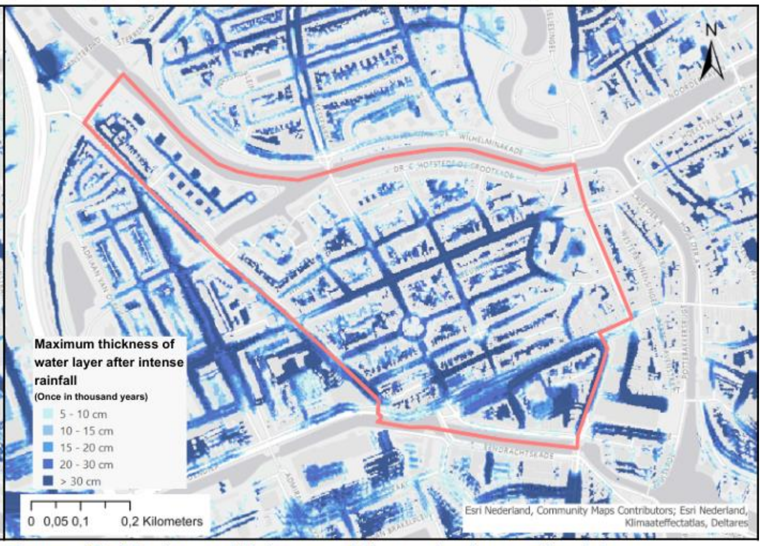


Figure 12: Maximum thickness of the water layer after intense rainfall, in the Schildersbuurt, that occurs once in thousand years (Esri Nederland et al. 2021b).

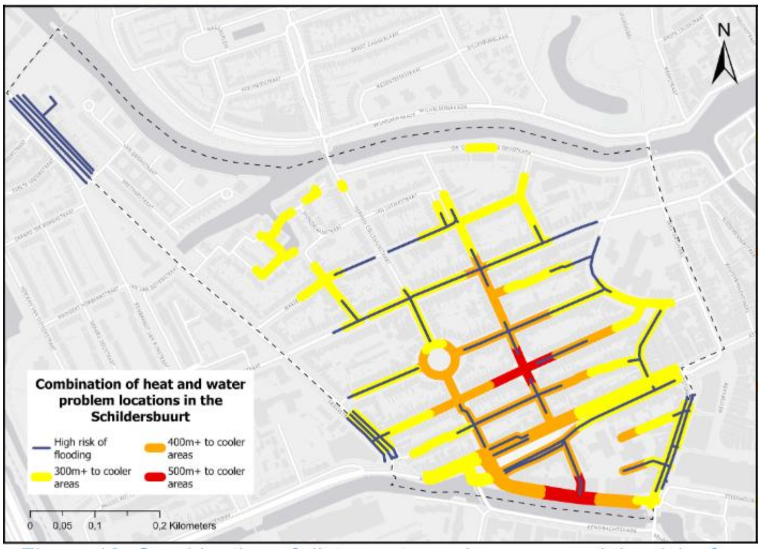


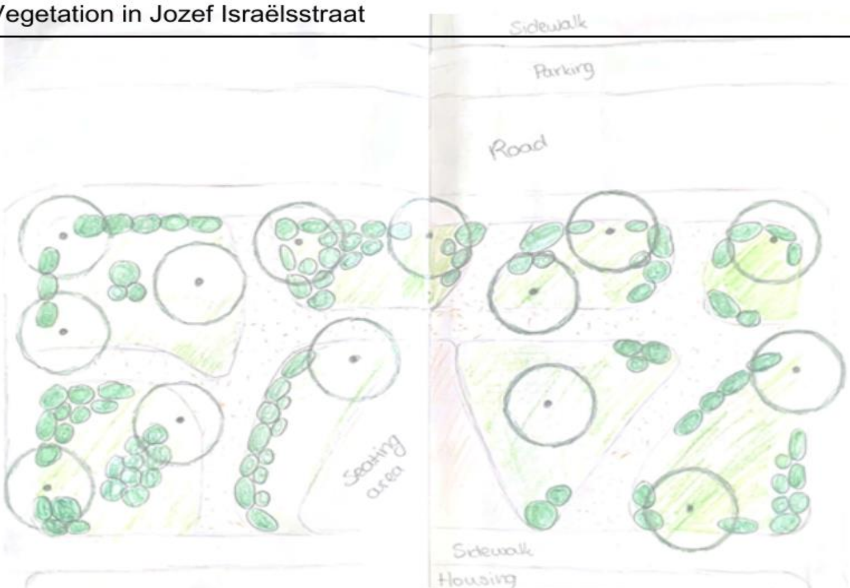
Figure 13: Combination of distance to cooler areas and the risk of flooding in the Schildersbuurt (with rainfall occurring once a hundred years) (Esri Nederland and Climate Adaptation Services, 2022; Esri Nederland et al. 2021a; Stuut, 2024).

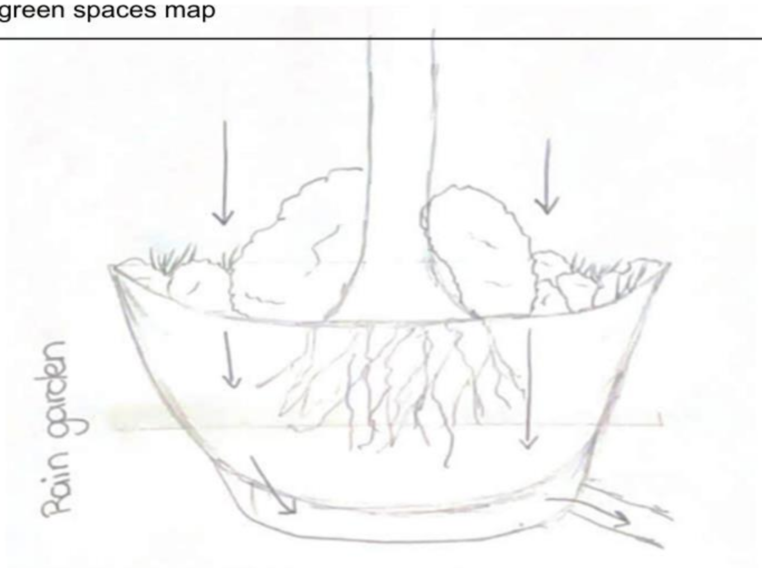
Figure 14: Selected streets and the problems they experience (Esri Nederland and Climate Adaptation Services, 2022; Esri Nederland et al. 2021a; Stuut, 2024).

4.2 Design Solutions

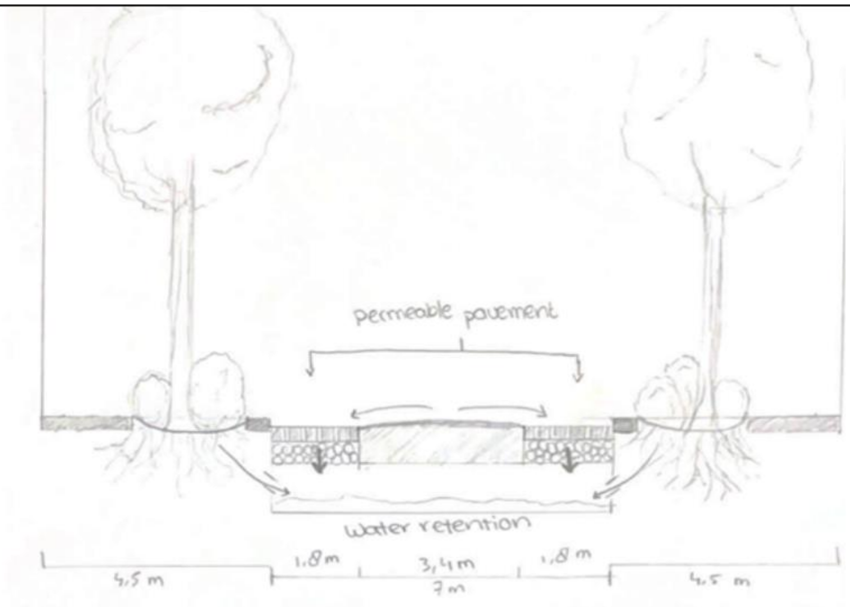
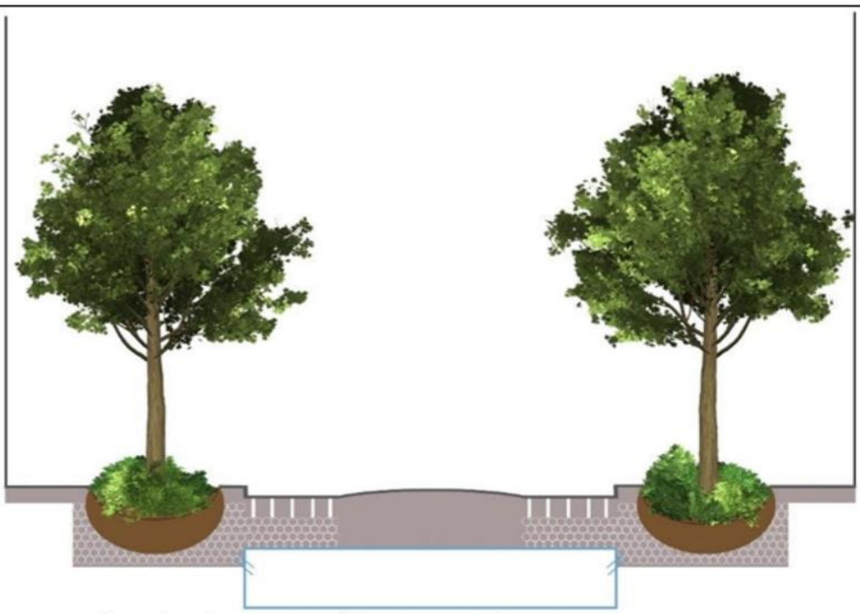
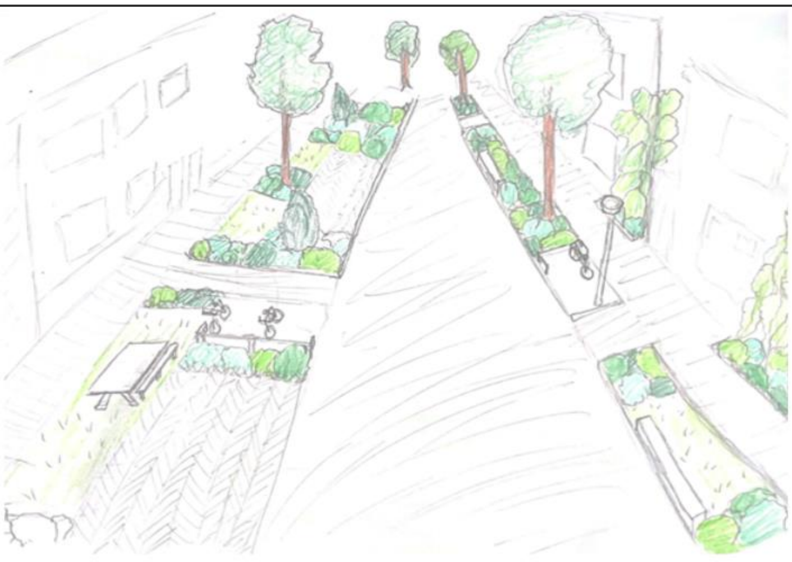
This section presents the exploration of various design solutions for implementing GI within the priority location of the Schildersbuurt. The primary focus is on assessing the effectiveness of adapting to climate change, and the health impact of these designs. To come to a final design solution, first various ideas were devised to make the neighbourhood more climate resilient (Table 2). This process is known as ideation, analysing design solutions to corroborate the effectiveness of the different tools used (Lee and Ostwald, 2022). Later in the design process different solutions, such as raingardens and permeable pavement, were combined to create a resilient and healthy neighbourhood. This combination led to the first design, which was solely based on adding vegetation to decrease the heat and including permeable pavements to retain water. Afterwards, the design was evaluated, and social health aspects were included. When designing the decision was made to keep the layout of the streets the same, with parking on one side and keeping the same traffic flow.

Design	Method / Software	Challenge	Process
 Adding greenery next to housing	Handmade sketch	Reduce UHI effect and improve air quality by adding greenery.	1. Coming up with design solutions.
 Wall garden	Handmade sketch	Reduce UHI effect and improve air quality by adding greenery.	1. Coming up with design solutions.

<table>
<tr>
<td>
Vegetation in Jozef Israëlsstraat</td>
<td>Photoshop</td>
<td>Reduce UHI effect and improve air quality by adding greenery in the Jozef Israëlsstraat.</td>
<td>1.1 Digitalised version of coming up with design solutions.</td>
</tr>
<tr>
<td>

Small green spaces map</td>
<td>Handmade sketch</td>
<td>Reduce UHI effect, pluvial floods and improve air quality by adding small green spaces in streets.</td>
<td>1. Coming up with design solutions.</td>
</tr>
<tr>
<td>

Cross-section of raingarden</td>
<td>Handmade sketch</td>
<td>Reduce pluvial floods by implementing raingardens.</td>
<td>1. Coming up with design solutions.</td>
</tr>
</table>

 Cross-section, showing permeable pavements	Handmade sketch	Reduce pluvial floods and retain water by implementing permeable pavements and underground water storage.	1. Coming up with design solutions.
 Cross-section showing permeable pavements	Photoshop	Reduce pluvial floods and retain water by implementing permeable pavements and underground water storage.	1.1 Digitalised version of coming up with design solutions.
 Street design	Handmade sketch	Reduce UHI effect, pluvial floods and improve air quality by using raingardens and permeable pavements.	2. Combining design solutions into one idea.

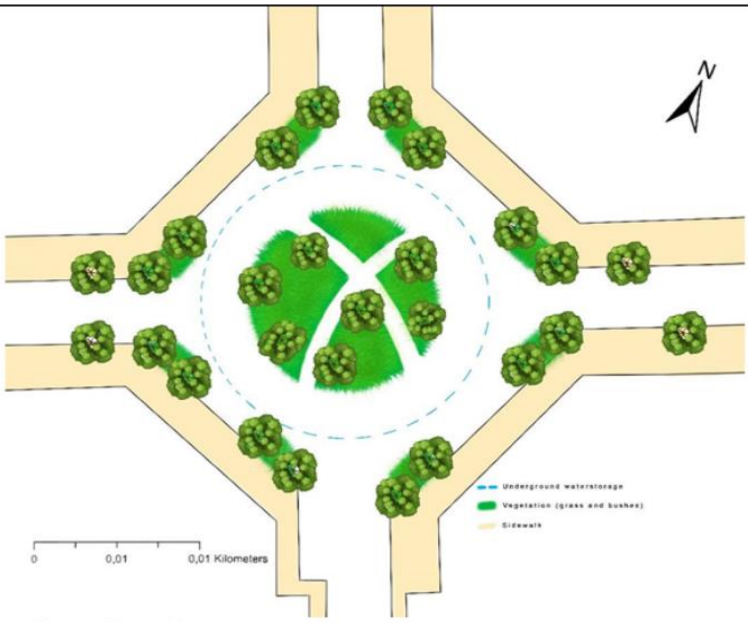
 Design of Jozef Israëlsplein	Photoshop	Reduce UHI effect, pluvial floods and improve air quality by using vegetated roundabout and underground water storage.	2. Combining design solutions into one idea.
 Layout of first design: Jozef Israëlsstraat, Taco Mesdagstraat and Jozef Israëlsplein	Sketchup	Reduce UHI effect, pluvial floods and improve air quality by using raingardens, permeable pavements and vegetated roundabout with underground water storage.	3. Creation of first design.
 Roundabout from above, Jozef Israëlsplein (more renderings in Appendix A)	Lumion	Reduce UHI effect, pluvial floods and improve air quality by adding trees to the vegetated roundabout with underground water storage.	3. Creation of first design, with realistic impression.

Table 2: Evolution of the design process (Stuut, 2024)

4.3 Final Design

After evaluation and integration of different ideas, one final plan for the selected streets within the Schildersbuurt was created. Figure 15 shows the current greenery situation in the neighbourhood, and Table 3 indicates the estimated percentage of greenery, as well as for the new design. This design, illustrated in Figures 16, 17, 18 and 19 (more in Appendix B), combines vegetation with infrastructure, to create a GI network within the streetscape. This being wall gardens and raingardens that serve multiple functions: retaining water, absorbing heat, and filtering the air. Furthermore, the design implements permeable pavements underneath parking spaces and bicycle parking to retain water and minimise water runoff, by increasing the water infiltration. Another feature of the proposal is a vegetated roundabout, serving as a small green space, which also includes a subsurface water basin connected to the system of raingardens. To achieve the chosen focus of the healthy city concept, a healthy neighbourhood has been created through GI, by reducing the UHI effect the health risks associated with high temperatures will also be mitigated. The raingardens and wall gardens are intended to reduce heat and filter the air, creating better air quality for the citizens. The permeable pavement and raingardens, connected to the underground water storage will alleviate the sewer system and decrease the risk of pluvial floods and the contamination of water. The addition of the small green space and vegetable gardens are intended to encourage outdoor activities among residents, promoting a healthy lifestyle. Another aspect that will stimulate people to spend time outdoors and improve social connectivity, is the placement of urban furniture, and the inclusion of a swing for children. Within the roundabout, new trees are located, which will provide shade, thereby contributing to a cooling effect on the neighbourhood. Throughout the new design, a wide variety of plants and flowering plants are placed to increase the biodiversity, contributing to the ecosystem's health.

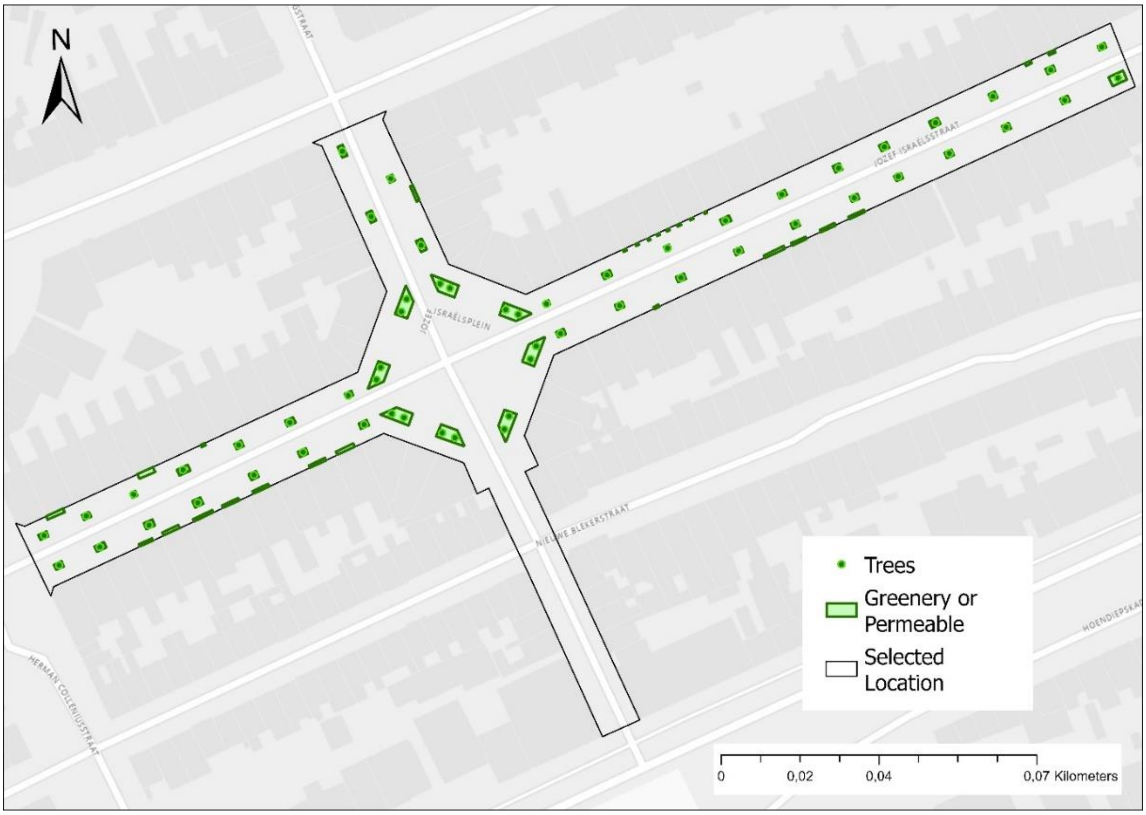


Figure 15: Greenery and permeable surfaces of the current situation in the selected location (Stuut, 2024)

	CURRENT SITUATION		NEW DESIGN
Total m²	5.918,31 m²	Total m²	5.918,31 m²
Permeable or vegetated	4,36%	Wall garden	3,39%
		Permeable pavement	17,68%
		Raingarden	12,48%
		Vegetated roundabout	5,24%
		Vegetable garden	0,81%
		Total %	39,60%

Table 3: Estimated percentages of greenspace and permeable surface in the current situation and the new design (Stuut, 2024)

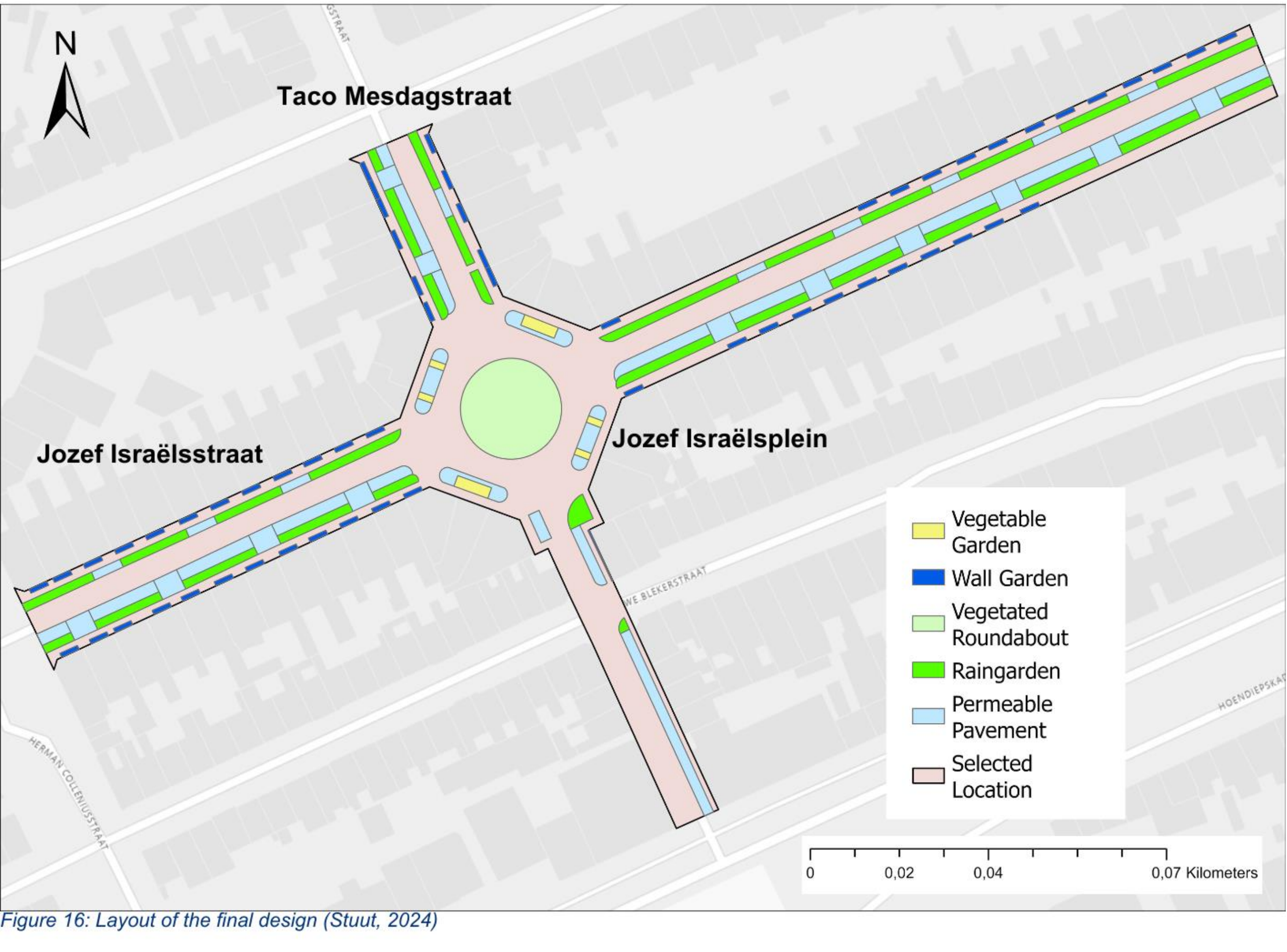


Figure 16: Layout of the final design (Stuut, 2024)

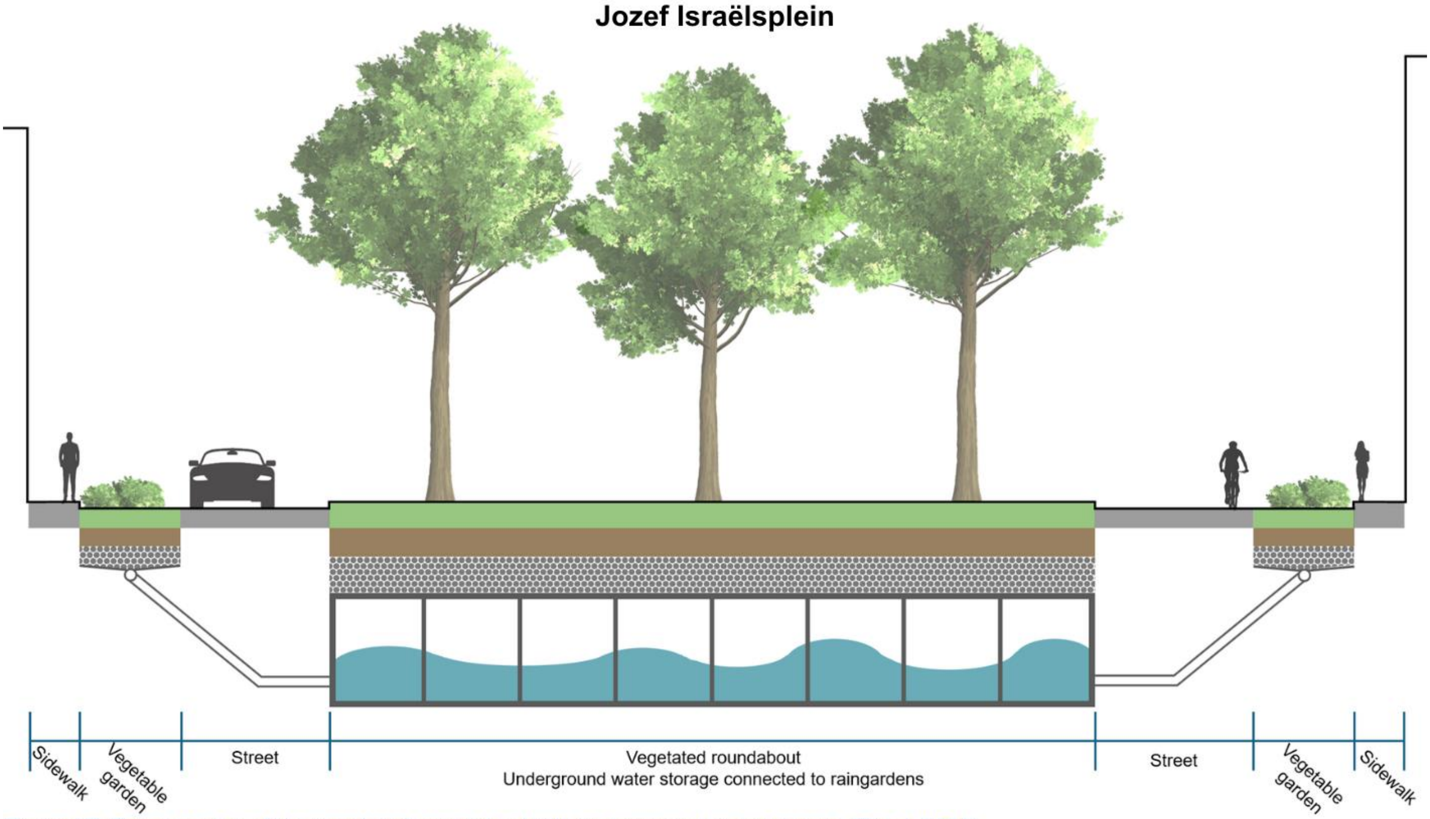


Figure 17: Cross-section of the vegetated roundabout with underground water storage (Stuut, 2024)

Figure 18: Impression of street design (Jozef Israëlsstraat), with wall gardens, raingardens, and permeable pavement (Stuut, 2024)

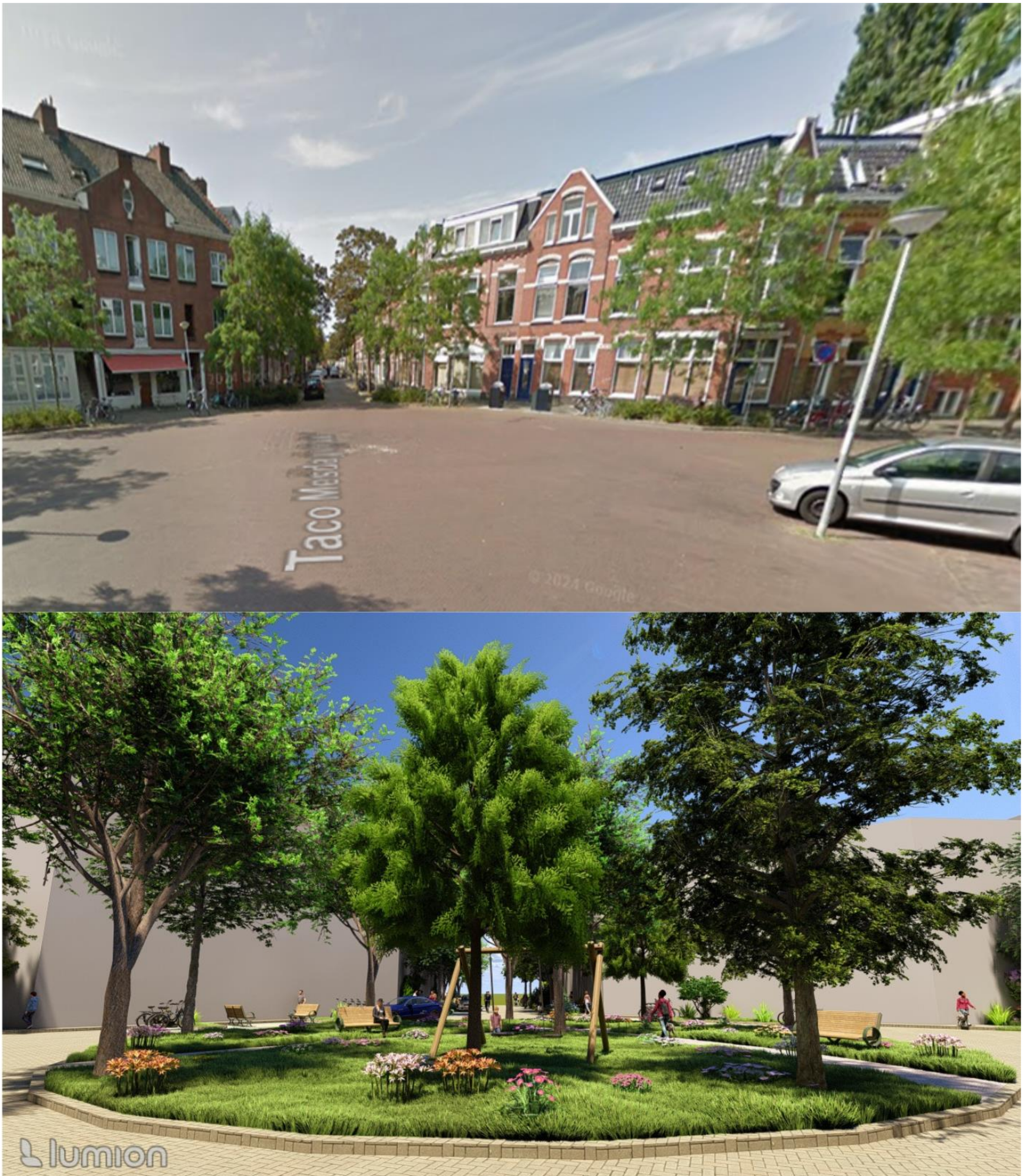


Figure 19: Impression of vegetated roundabout located in Jozef Israëlsplein, before (top) and after (bottom) (Google Maps, 2017; Stuut, 2024)

5. Discussion

The proposed design (explained in Chapter 4.3), which addresses several city-wide problems like the UHI effect, air pollution, and pluvial flooding, includes vegetative stormwater management systems, featuring an underground water basin, raingardens and permeable pavements. The method uses vegetation's natural processes to control precipitation and increase urban resilience, and according to the case study of Portland (Bureau of Planning and Sustainability, 2023), this will create a healthier urban environment. The benefits of GI in filtering water runoff, eliminating pollutants, and improving the urban streetscape are demonstrated by the city's regulation establishing stormwater retention and the incorporation of vegetated stormwater basins (Tillett, 2017). The final design implements more trees to reduce the UHI effect, improve air quality and health. This is confirmed by the case studies of Oslo (Venter et al., 2020) and Victoria (Jayasooriya et al., 2017), as these studies both employ trees and other GI elements to absorb toxic air pollutants and decrease UHIs. The Oslo case study has shown that adding GI will benefit heat-sensitive residents' health, since it lowers the danger of heat exposure (Venter et al., 2020). The case of the Superblocks in Barcelona has demonstrated that GI can also enhance physical and mental health of the residents, besides cooling the urban area (Nieuwenhuijsen et al., 2024). Additionally, the Schildersbuurt design also includes permeable pavement and a network of raingardens to manage stormwater and lower UHI. These GI elements will reduce the risk of floodings and sewer overflow, which will lower the danger of waterborne illnesses and pollution from sewage overflow. The research of Torres et al. (2022) in Buffalo, has shown that permeable pavements are a good way to reduce the risks of pluvial floods and to improve public health by decreasing the chances of infection by waterborne illnesses.

The final design also aids in achieving the municipality's goals to transition into a "sponge city" (van Driessche et al., 2021) by including a network of raingardens and permeable pavement that is connected to an underground water basin. These raingardens will contribute to the aim of 30.000 m^2 of greenery within the city and aids in the de-pavement of Groningen (Gemeente Groningen and Strootman Landschapsarchitecten, 2020). The design also includes vegetable gardens to stimulate community involvement, additionally a diversity of plants are used to increase the biodiversity.

Although there are advantages, there are also limitations and difficulties in implementing this design. The possible implementation cost and upkeep of GI elements, which could require ongoing funding and community involvement, is one concern. Moreover, the degree to which these actions effectively lower UHIs, pluvial floods and enhance air quality may differ based on how widely and densely they are implemented on the city level. On top of that, the successful integration of all GI elements in the whole Schildersbuurt is a challenge, due to the differentiating street patterns, in some situations only certain aspects of the design could be implemented in the streetscape. It is important to place urban furniture and green areas in a way that satisfies the requirements and preferences of the local population to achieve the intended social and health outcomes, which include more outdoor activities and higher social connectivity.

6. Conclusion

The purpose of this research-by-design study was to provide a solution to the following question: "*How can GI improve the healthy city concept while establishing resilient urban neighbourhoods?*" The Schildersbuurt neighbourhood in Groningen presents notable issues due to its high percentage of built and paved surfaces, which reduces precipitation

permeability and increases heat absorption, resulting in the UHI effect. These difficulties, along with the region's susceptibility to pluvial floods, emphasise the importance of stormwater management solutions.
To reduce the impact of UHI effects, improve air quality, and improve rainwater retention, the proposed GI design for the Schildersbuurt includes a vegetated stormwater management network encompassing raingardens, permeable pavements, wall gardens, and a vegetated roundabout with underground water storage. This strategy is consistent with the GI projects that have been carried out in several cities that have shown the value of these interventions in improving air quality, managing stormwater, mitigating temperature rise, and enhancing overall urban resilience. Moreover, the results of the study connect with the wider objectives of the WHO Healthy Cities programme, placing a focus on developing surroundings that are healthy and support healthy lives. The urban environment with GI will reduce the UHI effect, pluvial floods, and enhance air quality, making the area healthier for residents, as the consequences of high temperatures, toxic pollutants, and waterborne illnesses are decreased. Assisting the municipality of Groningen in its goals for green space growth and climate adaptation, the research-by-design process has enabled the creation of design solutions that are suited to the specific characteristics and challenges within the Schildersbuurt.
Nevertheless, there are certain difficulties in putting these GI solutions into practice. Costs, upkeep requirements, the efficiency of GI altering depending on the situation, and the importance of satisfying the social and recreational desires of the residents need to be considered. Despite these obstacles, putting an emphasis on increasing green space and improving vegetative cover provides a viable route towards a Schildersbuurt that is more robust, healthy, and ecologically balanced. The knowledge gathered from this research emphasises how critical it is to continuously assess and modify urban planning techniques to maximise benefits, handle new issues, and eventually promote sustainable and healthy cities.

It is essential that forthcoming studies continue to investigate and improve these approaches, guaranteeing their efficient execution and adjustment to various urban environments. Since mostly secondary data and designs are used, calculations and test need to be done to determine how much the reduction of UHI will be and how much the increase of water infiltration and air quality will be, as well as if this influences peoples' health positively and in what ways. Resident feedback may also be valuable in helping to develop a potential plan that would motivate people to spend more time outdoors, along with input from the municipality to include their objectives.

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Appendix A – Design Solutions

Lumion renderings of the first design

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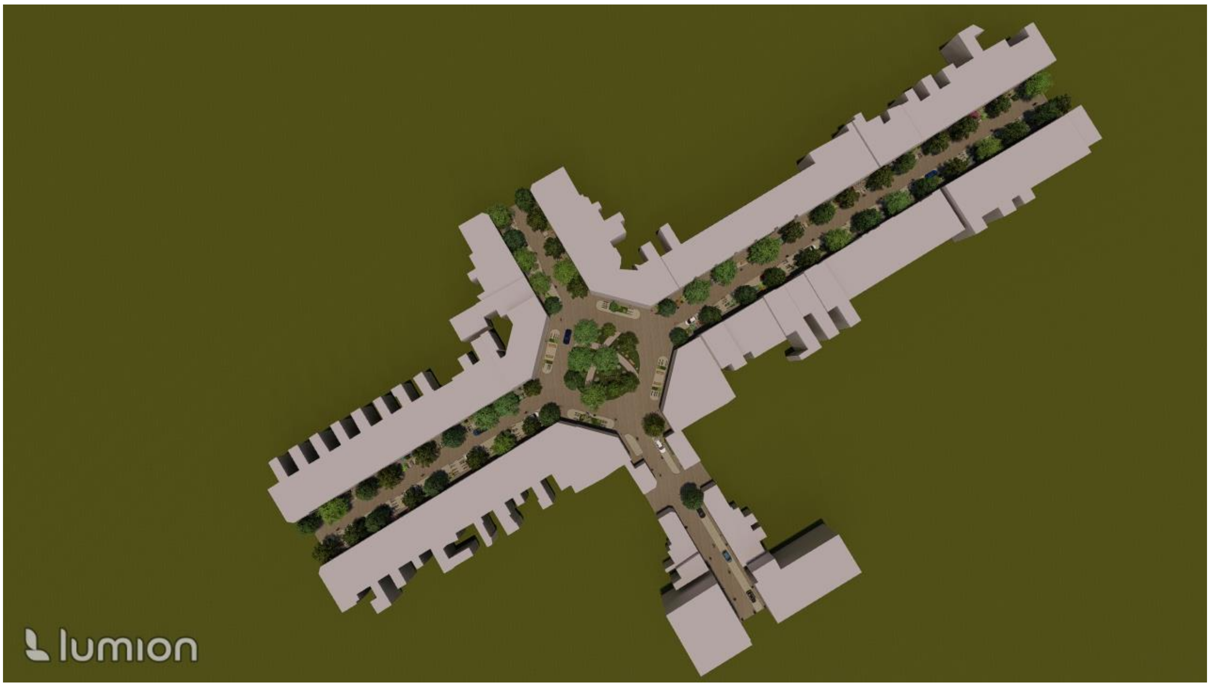
Appendix B – Final Design Solution



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Taco Mesdagstraat

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