Ecological road design

A study on the effects of roads on ecosystem services in Leiden





Colophon

Master Thesis-P2 Report

Ecological Road design

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01
Introduction

1.1 Personal motivation

To come up with an interesting topic to explore more deeply the coming year was a difficult quest in the beginning, because I generally find many things interesting. Starting from my own personal experiences from living and working in a dense city like Leiden, gave me some ideas for my graduation project. Since I am delevering groceries in and around the city of Leiden, I come across many different neighborhoods, where each neighborhood has its own identity, atmosphere and residents. However, what most neighborhoods seem to have in common is that the vast majority of the public space is dedicated to usage of the car. On the contrary, there is less space dedicated to green surface. Being on the road a lot and seeing that there is (in my opinion) not that much green surfaces that are actually a quality for the city, is a interesting given, especially when I think about the challenges cities have to face in terms of climate change, health and biodiversity. My growing interest in how we can make cities greener and my personal experience of Leiden, led to an topic about how we can use the street profiles in a dense city to create ecological corridors between several green areas. Not only to cope with the effects of climate change, but also focusing on urban biodiversity and the inhabitants health. When choosing this topic its important to note that the mobility of the inhabitants is not compromised, as the whole city is designed for personal transportation. Hopefully my project can give people a better view on how the road network don't necessarily just have to be there to transport humans.



1.2 Global urbanization trend

For most of human history, people across the world have lived in small communities. However, this has drastically changed over the past few centuries, especially in the last few decades. People have moved in large numbers from rural to urban areas. By 2030, the world is expected to have around 1.2 million km^2 urban built-up area, on top of the existing amount. Urban land consumption is expected to grow at a rate that is up to 50% faster than population growth. The graph below the text shows an estimation from the UN World Urbanization Prospects, and it shows the number of people globally, who live in urban and rural areas. More than 4.3 billion people now live in urban areas. This number is a milestone, as it shows that for the first time, people living in urban areas outnumber those living in rural areas. According to the UN this event happened in 2007.

As of today, approximately 56% of the world's population live in urban areas. This amount is expected to rise even more, with the global population doubling in its current size, to where up to 70% will live in urban areas. More than 80% of the global GDP (Gross Domestic Product) is produced in city's, and this urbanization trend can have a positive contribution to a long list of effects including human and urban flora and fauna. However, the scale and speed of urbanization also comes with widely ranged challenges. Among others, these challenges include affordable housing, viable infrastructures, basis services, jobs, climate change and urban biodiversity. With today's global challenge to face the effects of climate change and the decreasing biodiversity, these are the most urgent challenges, which cities have to face.

Urban life is significantly impacted by the global phenomenon of climate change. Increasing sea levels, the frequency of extreme weather events like floods, droughts, and storms, and the spread of tropical diseases are all effects of rising global temperatures. All of these have expensive effects on the essential services like housing, livelihoods, and health of inhabitants. In addition, since urban activities are significant contributors to greenhouse gas emissions, cities play a significant role in climate change. It is estimated that cities produce 75 percent of the world's CO2 emissions, with transportation and construction making up two of the biggest contributors.(Programme, 2023)

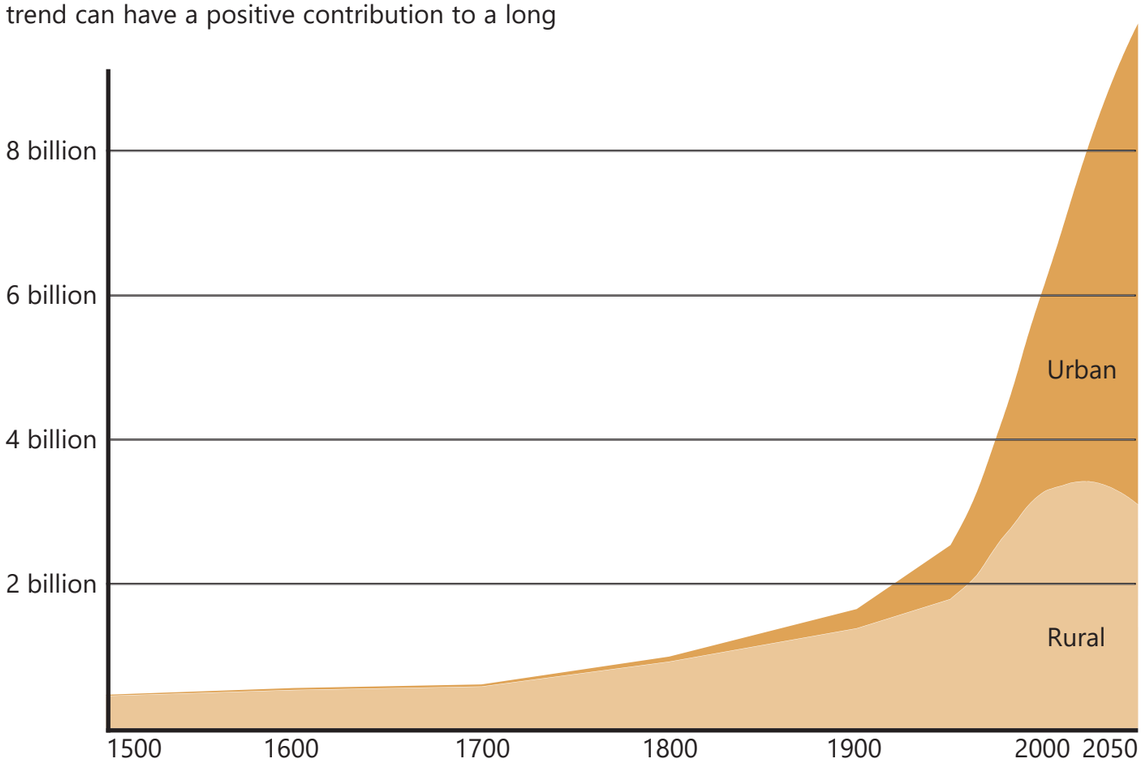


Fig. 1: Global urbanization trend (Programme, 2023)

The global effect of people moving to urban settings also applies in the Netherlands. The density of inhabitants per square kilometer of land area was 455 in 1995. In 2020 this number has increased to 517 inhabitants per square kilometer. The density varies greatly between the provinces of the Netherlands. The map of the Netherlands below shows the population development in percentages of all municipalities. As we can see the municipalities where the population grew the most are located in the Randstad and around Utrecht. Also areas in a more suburban environment tend to less increase in inhabitant numbers.

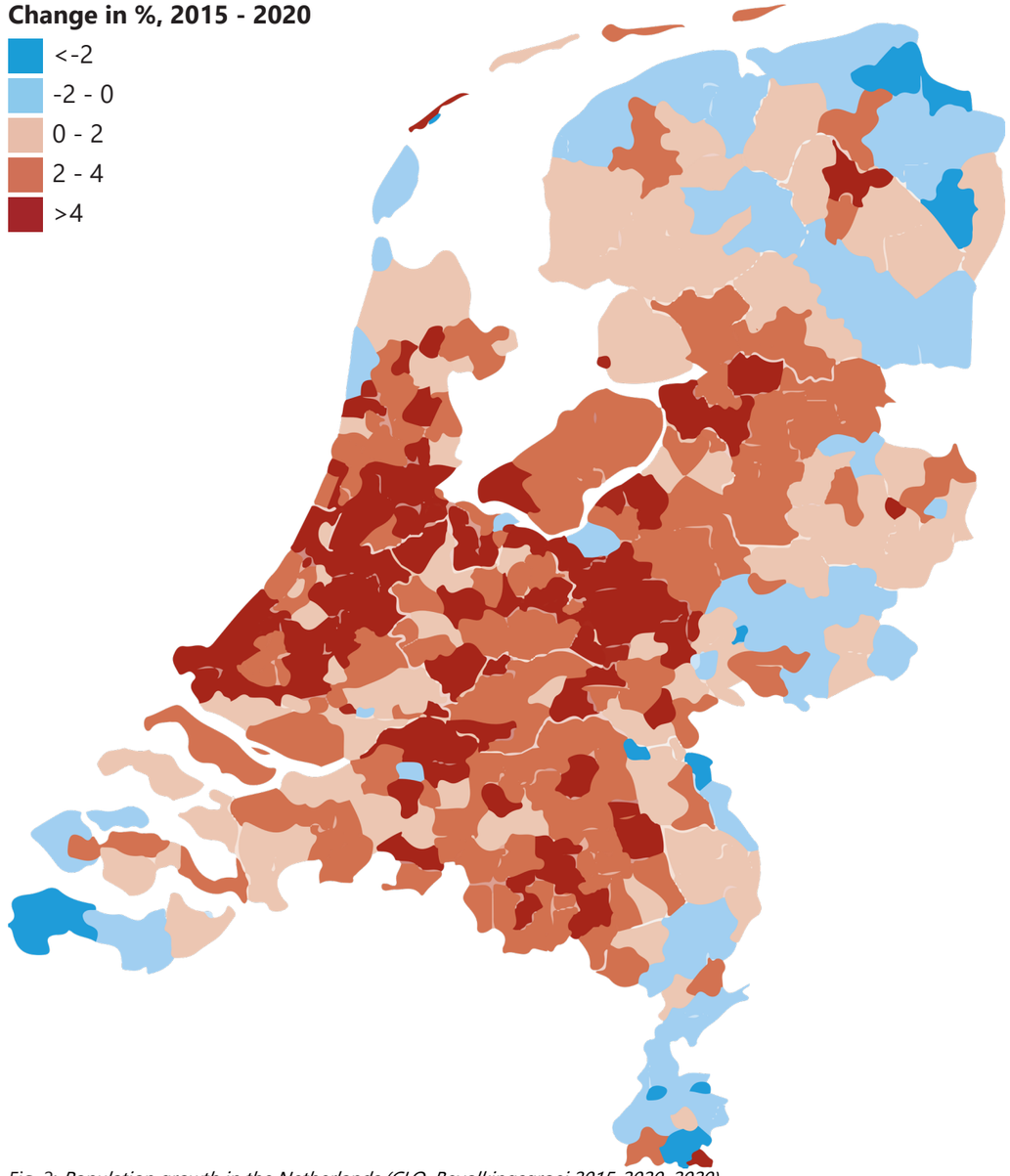


Fig. 2: Population growth in the Netherlands (CLO, Bevolkingsgroei 2015-2020, 2020)

1.3 Country of stone

The Netherlands is a leader in urbanization in Europe. The ESPON SUPER (Sustainable Urbanization and Land-use Practices in European Regions) project provides evidence of this. This multi-national study under the direction of PBL examines, among other things, how land usage has changed in Europe.

The Netherlands ranked fourth in Europe according to the analysis of the ESPON SUPER project's petrified surface growth, which increased by almost 15% between 2000 and 2018. The Netherlands is one of the European countries with the highest rates of stony surfaces, along with Spain, Cyprus, and Ireland. No other country in the EU has urbanized a higher portion of its territory in the last 20 years than the Netherlands, with 1.74%, making it the leader in the European Union, if we compare the stony surface to the total surface area. It is understandable why the Netherlands was named by the European Environment Agency in 2016 as the country with the highest rate of urban sprawl. (Nederland versteent #2 – ook in Europees perspectief?, 2019)

Not only is the rapid urbanization and the pressuring demand for housing the cause for our stony country. The urbanization comes with extension of the road network, which take up a lot of spaces that could be dedicated to green surfaces. The road system has a significant part in the cities structure, and is most often imbalanced with the available green space. Extended road systems in the Netherlands cause for a longer distance to a green area. Shown on the right most of the cities distance to green in the Randstad is about 2-5 kilometer. Thinking about a new way of designing road just as a movement corridor can help with decreasing stony surfaces and improving overall quality of the street profiles.

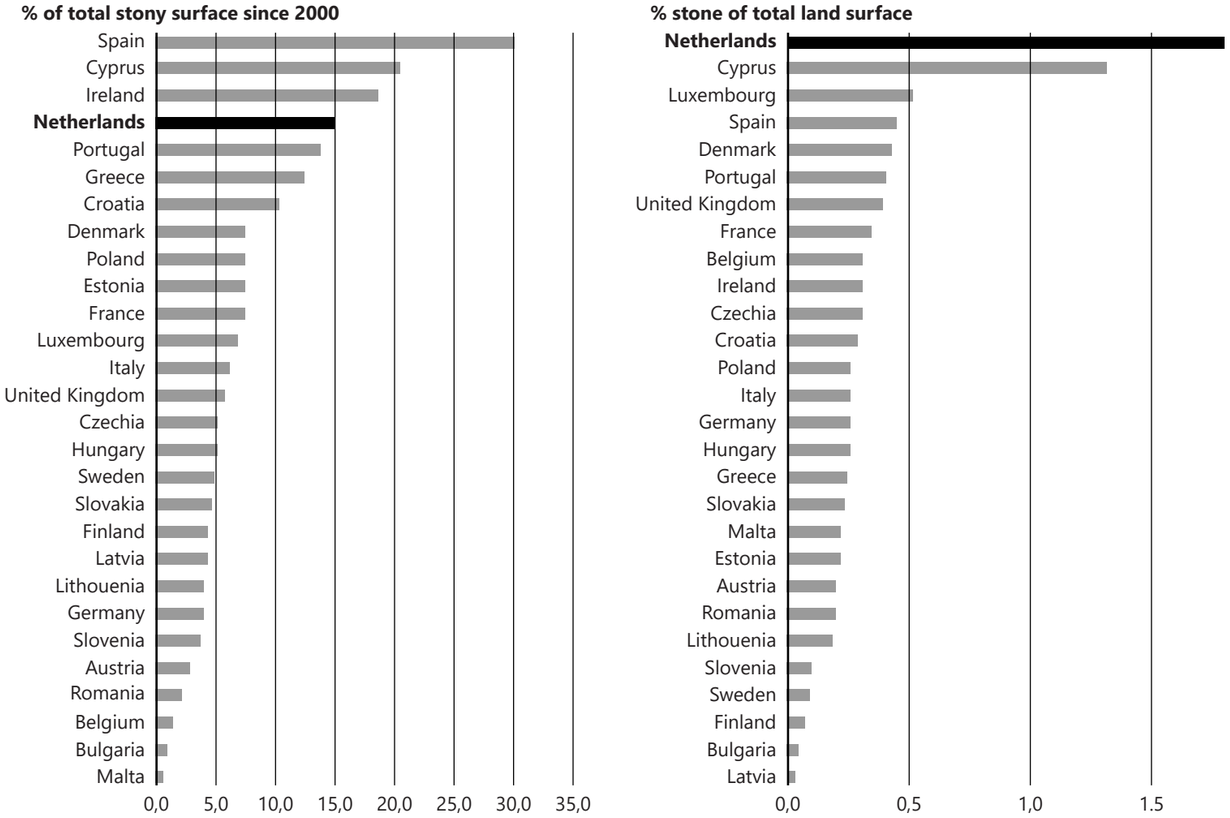


Fig. 3: Percentages of stony surfaces (Leefomgeving, 2019)

"The fact that the Netherlands is rapidly being built up does not fit well with the image of the Netherlands as a guiding country for spatial planning and compact cities"

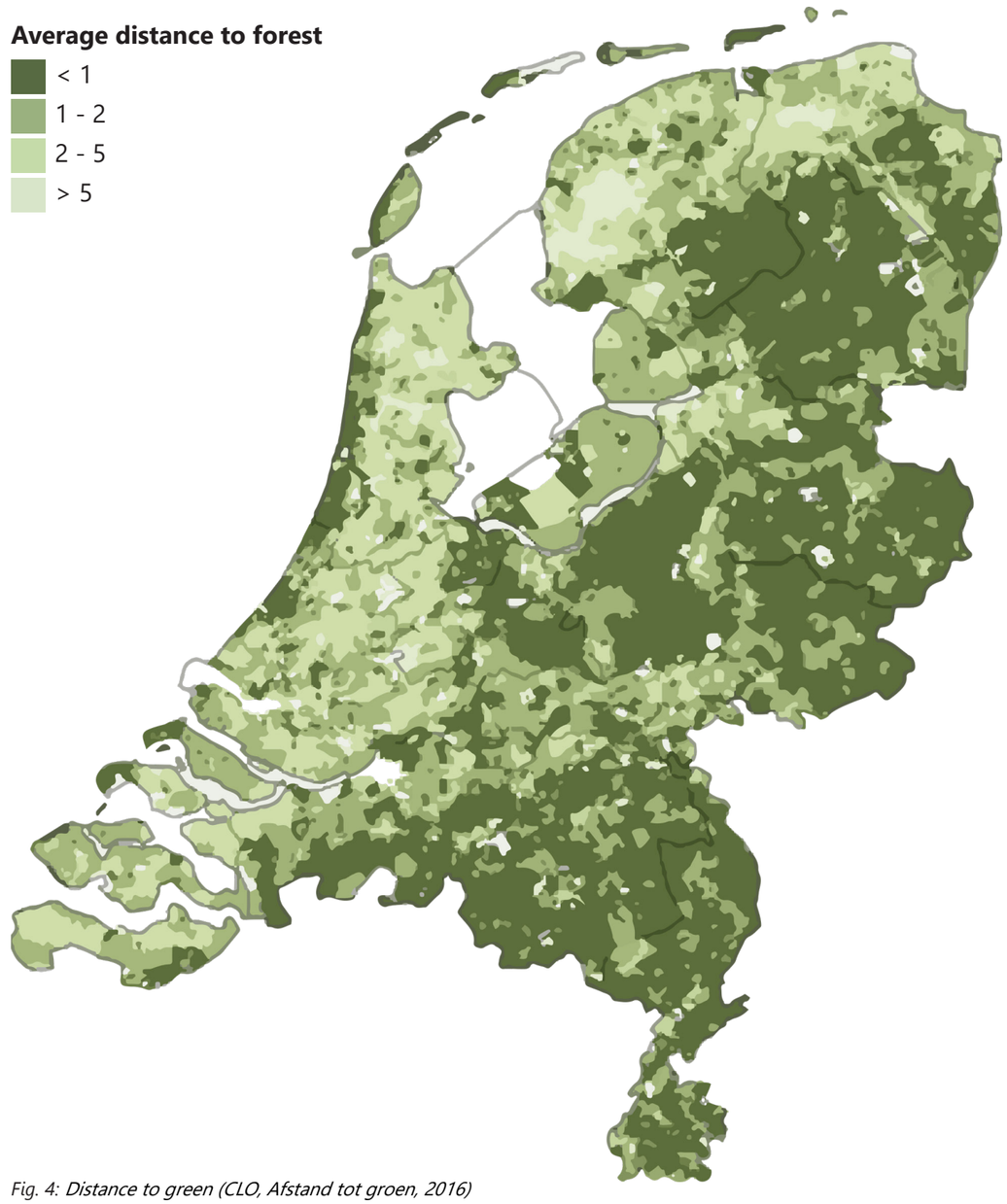


Fig. 4: Distance to green (CLO, Afstand tot groen, 2016)

1.4 Ecological road effect

The global and local urbanization trend comes with a lot of challenges. Cities develop over time, but once a cities has been build, the form and the land patterns can stay the same for decades, or even centuries, which makes it hard to make fundamental changes that will help with facing several challenges. This leads to a possible unsustainable expansion of the limits of dense urban areas. (Bank, 2022)

The high urbanization of cities puts a huge pressure on several infrastructural services. One of the biggest among these services is the **road network.** As cities expand and densify, the number of cars and infrastructure needed for the amount of people will also increase. While buildings can be demolished and being rebuilt, it is harder to completely change the extended road network of a highly densified and developed city. Most cities are still very car-orientated, which means there is an unbalanced ratio between space for cars and space for green areas. Fig. 5 shows that now the trend is that how higher the density of the road system is, the less permeable the landscape is, and thus less resistant to effects of climate change. We, as urban designers, have to deal with this challenges and make an attempt to find a good balance between the needs for the secure and effective movement of people and goods via private automobiles, public transportation, cycling and walking, as well as the provision of green space and the preservation of urban biodiversity.

Estimates for the Netherlands indicate that about one-fifth of the surface is directly affected ecologically by roads and traffic. Numerous metropolitan areas, particularly those on the periphery that are rapidly urbanizing, sustain a variety of species, some of which are rare and endangered. In many cases, little regard is given to the people or the wildlife when expanding road networks linked with urbanization. Even while it would seem obvious that roads are built to facilitate human movement, the effects of badly planned highways on nearby inhabitants could be rather severe. If roads are designed in a more efficient matter it is possible to gain more positive effects for urban biodiversity but also for health and environmental effects of climate change.

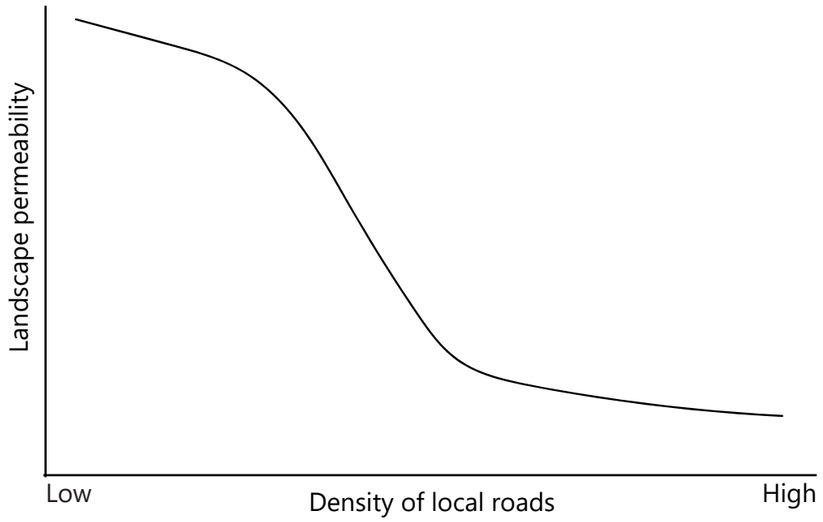


Fig. 5: Hypothesised relationship between arious measures of the road network and ecological effect. (Van der Ree, 2009)

Roads and traffic have an ecological and a biological effect on its adjacent area of flora and fauna, that can sometimes extend for hundreds of meters. Urban areas local biodiversity, green space, safety, and quality of life may all be negatively impacted by the congested road networks that are typical of cities (Fig. 6). Due to changes in peak storm flows, an increase in sediment in stream water, the loss of stream-side vegetation, road-related landslides, and the obstruction of streams by culverts and bridges that were improperly designed, built, or maintained, roads have been linked to declines in economically and culturally significant fisheries.

Roads can significantly affect ecosystem services vital to human welfare and economic prosperity by modifying soils and vegetation. Roads frequently have an impact on a number of environmental issues, including erosion control, flood regulation, coastal protection, water quality, and climate regulation. It is crucial to take into account not just the amount of hectares affected by the impact on ecosystems, but also how such changes affect the benefits flowing to people who may be farther away from the impact site. For instance, when highways pass through protected areas, the benefits to nearby and downstream populations as well as the protected area itself are likely to be impacted by road development or upgrading. By making it easier to access natural places and natural resources, roads can also have an indirect impact on the provision of ecosystem services. Roads can help with greater logging, tourism, and recreational opportunities when they are combined with sustainable management. In the absence of effective government and

Despite proper management, the easier access to natural areas made possible by roads has the potential to deplete natural capital by boosting timber harvest and hunting or lessening the benefits of tourism and recreation in areas that are prized for their seclusion, biodiversity, or aesthetic appeal.

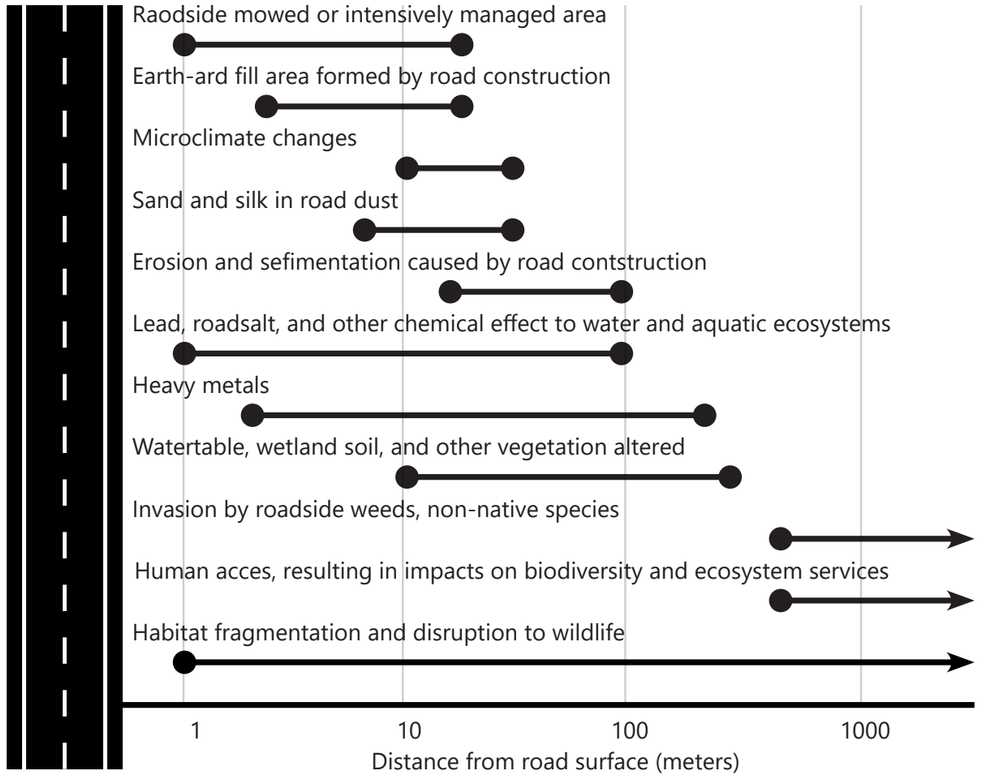


Fig. 6: The range of average and maximum distance from the raod across which impacts on ecosystems and ecosystem services have been documented. (Mandle et al., 2016).

1.5 Ecosystem Services

Cities around the world are linked together through political, economic and technical systems, as well as ecological components. Cities also bear a disproportionate share of the negative effects for the natural environment. And these effects are not just felt locally, but also hundreds of kilometers beyond the cities borders. However, cities provide a crucial role in dealing with global sustainability. Nonetheless, despite the fact that cities now house more than half of the world's population, the attention paid to urban ecosystems in the ecosystem services literature has been relatively modest. The positive impact the urbanized environment has on ecosystems are called urban ecosystem services.

Ecosystem services are products or actions of natural systems that benefit people or advance social welfare, either directly or indirectly (Johnston, 2016).

Four different types of ecosystem services has been identified (fig.7): material products obtained from ecosystems, including genetic resources, food and fiber, and fresh water, are considered provisioning services. All benefits derived from the regulation of ecosystem processes, including the regulation of climate, water, and human diseases, are included in regulating services. Cultural services are the non-material benefits that people derive from ecosystems in the form of spiritual enrichment, reflection, recreation, and aesthetic experience, as well as social relations, and aesthetic values. Finally, supporting or habitat services are those that are required for all other ecosystem services to be produced. Examples include biomass production, nutrient cycling, water cycling, species habitat provisioning, and the preservation of genetic pools and evolutionary processes (Johnston, 2016). A single ecosystem is very complex, so its generally believed that humans benefit from a combination of these services, even though an ecosystem may not provide all four types of services at once. The services provided by various ecosystem types vary in nature. In actuality, some services have a direct impact on the way of life of nearby inhabitants, whereas other services have an impact on general environmental conditions that have an indirect effect on human. (Fastré, 2020)

Most of urban ecosystem services are often produced by ecosystems thousand of kilometers outside the cities. Many of the relevant interactions required to understand the functioning of urban ecosystems extend far beyond the urban boundaries defined by political or biophysical reasons, making it difficult to define clear boundaries for urban ecosystems. As a result, the relevant scope of urban ecosystem analysis extends beyond the city area itself; it includes not only the ecological infrastructure within cities, but also the hinterlands that are directly affected by the energy and material flows from the urban core and suburban lands. While basically everything is affected by ecosystem services, the focus here lays with the road network in urban environments. In the context of urban planning, urban ecosystems are frequently portrayed as incorporating both built and ecological infrastructure. The term "ecological infrastructure" refers to the role that water and vegetation in or near the built environment play in providing ecosystem services at various spatial scales (building, street, neighborhood, and region). Parks, cemeteries, gardens and yards, urban allotments, urban forests, single trees, green roofs, wetlands, streams, rivers, lakes, and ponds are all examples of 'green and blue spaces' found in urban and suburban areas.

Urban ecosystems not only produce ecosystem services, but also ecosystem disservices, defined as "functions of ecosystems that are perceived as negative for human well-being and quality of life" (J.L. Lyytimäki, 2011). Vegetation root systems frequently cause significant damage by breaking up pavements, and some animals are frequently perceived as a nuisance because they dig nesting holes. Green-roof runoff may contain higher levels of nutrient pollutants like nitrogen and phosphorus than precipitation inputs. Further disservices from urban ecosystems may include allergic reactions to wind-pollinated plants, fear of dark green areas perceived as unsafe, particularly by women at night, diseases transmitted by animals (e.g., migratory birds carrying avian influenza, dogs carrying rabies), and blockage of views by trees. Disservice assessment is difficult because the same ecosystem function can be valued as a service or a disservice depending on the person and context. People's preferences are influenced by their age, personal experiences, culture, and level of knowledge. Furthermore, familiarity with various types of green spaces aids in determining personal preferences for what one likes and dislikes.

Roads are an important urban driver to enhance quality of life and are a key factor for urban economic growth. They play a role as connector between essential services, such as employment, markets, education and healthcare. For development and economic prosperity, roads are essential. At the same time, roads, directly or indirectly, have negative consequences for urban ecosystem services and the people who rely on these roads. This puts pressure on the biodiversity and livability of a city. If roads are built without adequate consideration of their potential effects, both direct and indirect, they can undermine the development benefits they are meant to offer and jeopardize future growth opportunities. By considering both the significant advantages of roads and their potential drawbacks, it is possible to minimize unintended consequences of road development while maximizing its advantages. In order to effectively meet societal and environmental needs and make responsible use of the limited resources available for road development, it is crucial to recognize, reduce, and be open about trade-offs between road development and other benefits, such as ecosystem services resulting from natural capital. (Mandle, et al., 2016). Roads can be proved to have a positive impact on ecosystem services, but there needs to be a shift in how the street scape is designed. (Benjamin B. Phillips, 2019)

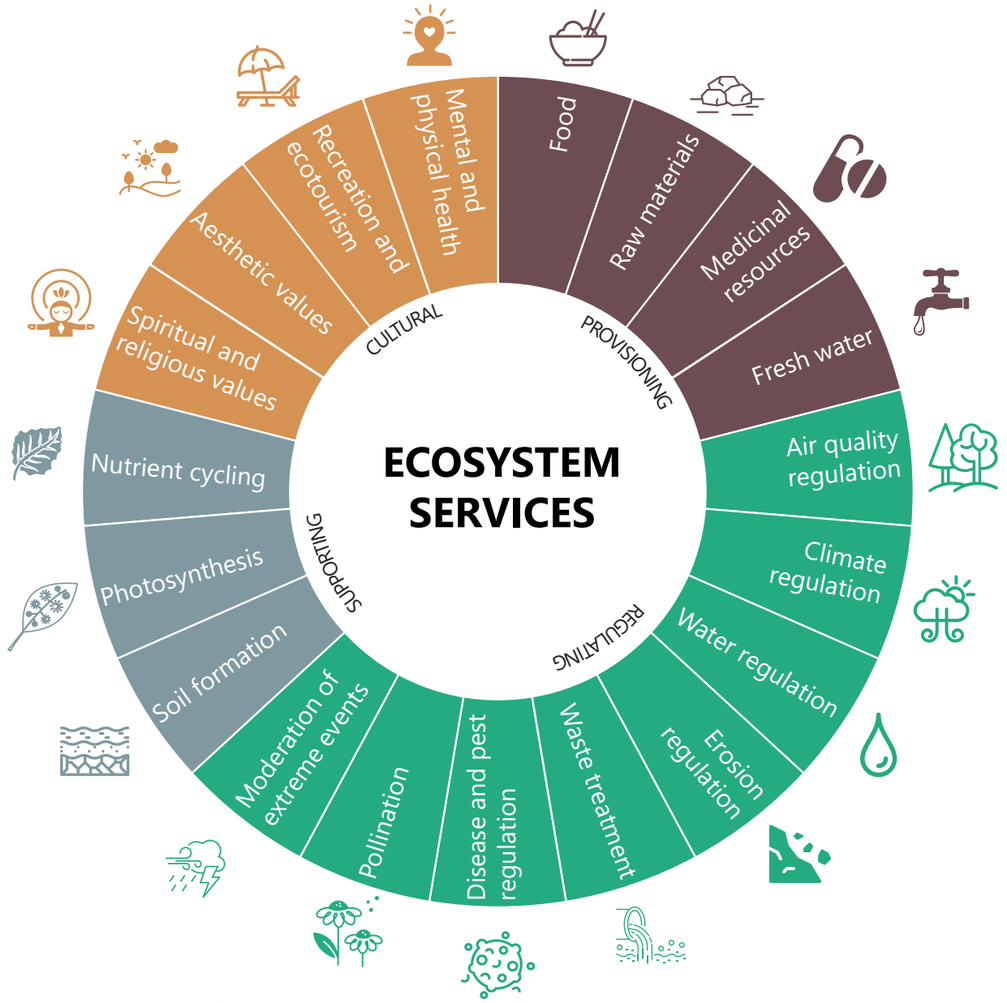


Fig. 7: Ecosystem Services (Fastré, 2020), edited by author

1.6 Problem Statement & Research question

In the past decades, the global population has increased exponentially and is expected to continue increasing. The vast majority of the population live in urban areas, and more people are expected to move to the cities. In the Netherlands also has to deal with the rapidly growing population, especially in the Randstad. This growth puts an huge pressure on the existing infrastructure, of which the road network is one of the larger parts. The road network already has a bad impact on the urban ecosystem services, and this will only get worse as more people move into the city. This trend makes the road network unable to cope with today's urban challenges, such as climate change, health and biodiversity. Roads often form barriers for a strong and robust ecological structure. Since roads are an important part of a city, they form a great potential to improve road-related ecosystem services. Roads will always be an important part of dense cities, but serious discussion about alternative road design with urban landscapes is now necessary.



Health



Climate

Ecology



Flora



Fauna

What is a possible approach to use the road network of Leiden to improve road-related ecosystem services.

PART 1

1a. How is a road described?
1b. Which ecosystem services are related to the road network of Leiden?

PART 2

2a. What are economical benefits by improving ecosystem services?
2b. Which landscape theory can help with creating ecological road corridors?
2c. How can the road-related cultural services be improved?

PART 3

3a. How can the roads ecological function be changed to improve urban biodiversity?
3b. How can the road be adapted to cope with the effects of climate change?
3c. What is needed to improve ecosystem services related to flora and fauna?

PART 4

4a. What spatial intervention can be made to improve road-related ecosystem services?
4b. How can streets be designed to create benefits for road-related ecosystem services?

Objective

The objective of the project is to explore the ecological role a road network can have in improving urban ecosystem services. An exploration of the road network can be made in the following categories:
- Health, how can a road help with a overall increase in healthy inhabitants?
- Climate, how can a road cope with the effects of climate change?
- Ecology, how can a road create ecological corridors for flora and fauna?

1.7 Project location

The location of the project is the city of Leiden, located in the west of the Netherlands (fig 8). Not only is Leiden of personal interest, but it is also the second most dense municipality in the Netherlands, and there are plans for increasing this density even more, not only by expending but by creating more housing within the municipal borders. Since Leiden has and is rapidly densifying (fig 9), the road network should accommodate all these new people. Therefore the negative effects of the roads also apply to the city of Leiden. Although the city wants to greenify and make use of sustainable mobility systems, the surfaces are still dominated by spaced designed for cars. The road network in Leiden has a significant impact, with a lot of pressure on traffic. This makes Leiden a perfect case study, to explore and investigate if indeed roads can contribute to improving ecosystem services in a dense city.

Leiden is a city with a great history, which has his roots already in the Roman times, where it functioned as a main fortress of the Roman Limes Line. Since then the city slowly expanded and came to known as the key city (sleutelstad) or the city of discoveries (stad van ontdekkingen), referring to the large number of important scientific discoveries in this city.

Rapid urbanization

The figures below show that since around 1950 Leiden has been greatly expended. Leiden is now not a city on its own but is part of a larger urban area, including municipalities of Leiderdorp, Voorschoten, Katwijk and Zoeterwoude. The need for more homes in the Netherlands also comes down on the shoulders of the municipality of Leiden. They wish to densify but not necessarily outside its current city edges. This means there will be densified inside the already existing build area. This will put more pressure on the already existing road network, but also puts more challenge on providing its citizens with sufficient and qualitative green space.

The following page states plans for the municipalities for the coming future. This shows that the municipality of Leiden is addressing the problem identified in the research question.



Fig. 8: Municipalities of the Netherlands ((CBS, 2021)

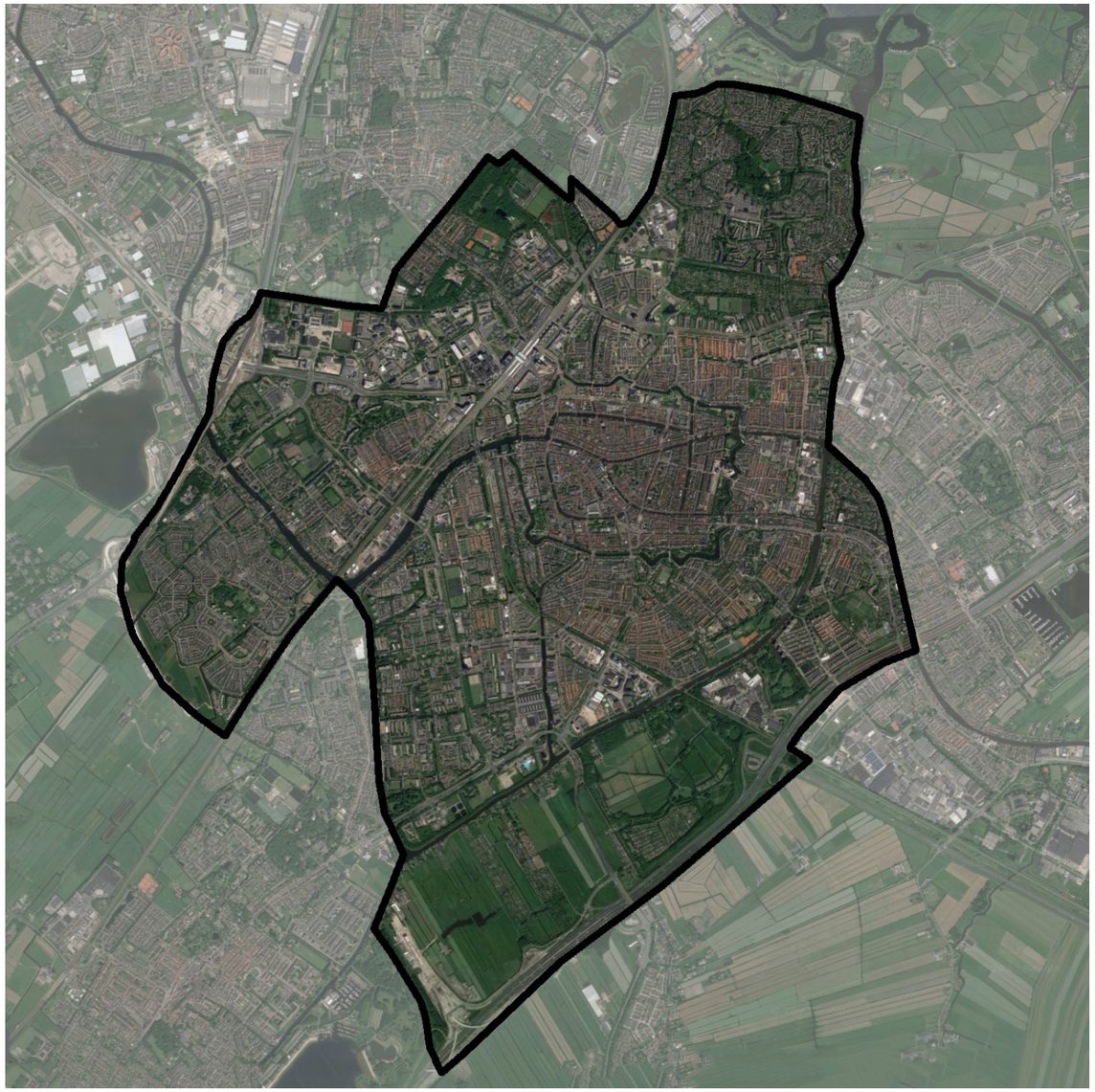


Fig. 10: Map of Leiden (Google Earth, z.d.)

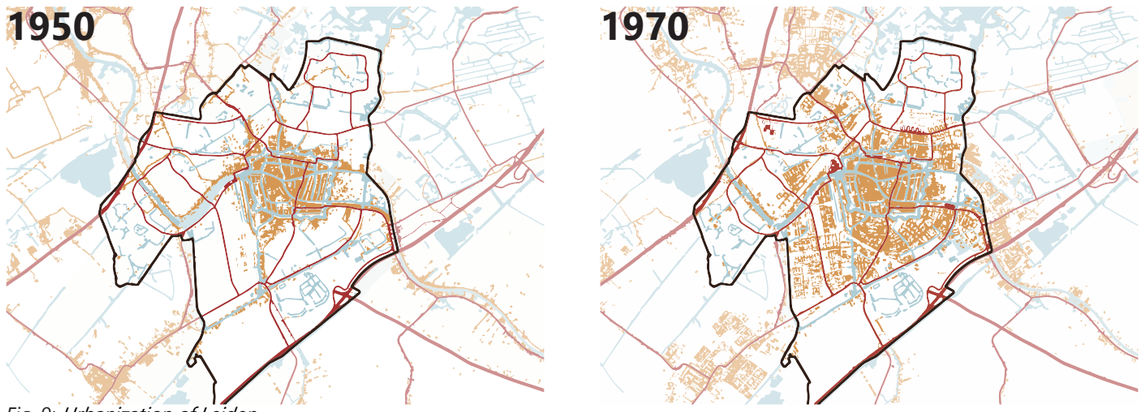


Fig. 9: Urbanization of Leiden

Water
On the right is shown how much percentage of water is present in the different neighborhoods. Not only represent this the amount of water bodies but also the percentages of water that will stay on the streets after a heavy rain.

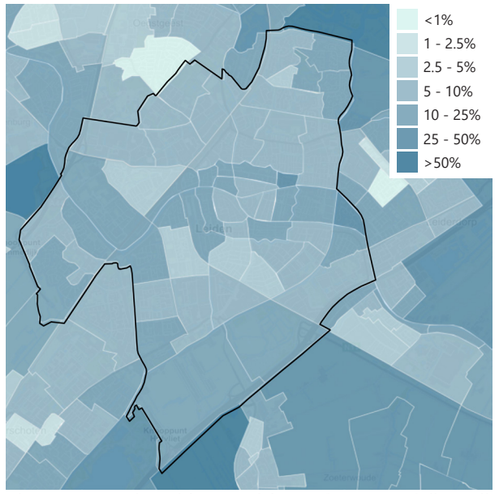


Fig. 11: Water in Leiden (Basiskaart Groen en Grijs - Klimaateffectatlas, z.d.)

Grey surface
Leiden is an very stony city. The city center is one of the most stony ones in the Netherlands, with covering at least 80% of the surface being stone. All these stony surfaces have negative effects on effects of climate change, health and biodiversity. Therefore the municipality want to focus the next coming years on greenifying the stony surfaces, and not only putting verges and some trees, but construct an overall green structure in the city.



Fig. 12: Grey surface (Basiskaart Groen en Grijs - Klimaateffectatlas, z.d.)

Percentage of green
Previous map show how much percentage of stony surface is present. This has consequences for the percentage of green areas in the city. The city center, in combination with the very stony surfaces has the least percentage of green available. The surrounding neighborhoods are a little bit better but still there is a low percentage of green available.

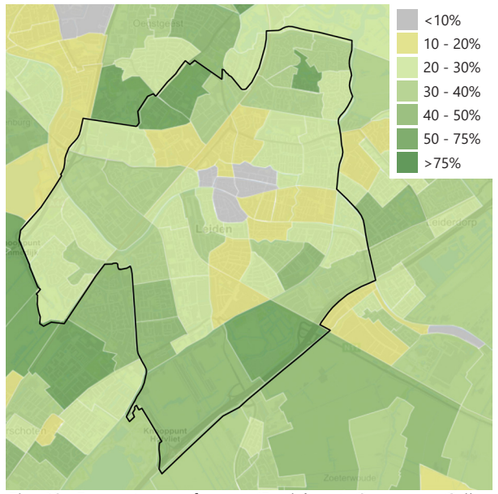


Fig. 13: Percentage of green(Basiskaart Groen en Grijs - Klimaateffectatlas, z.d.)

Green - Blue Framework
The current green structures and water sources in Leiden are insufficient for the urgent problems like climate adaptation, biodiversity, health, sustainable mobility, and space for green recreation. The current urbanization and densification work in the city is already putting strain on green spaces and watercourses, and they do not comply with the criteria coping with the effects of climate change. As a result, it's crucial to consider ways to improve the city at the scale of Leiden's city green-blue structure, both in terms of space need and quality.



Fig. 14: Green - Blue framework ("Omgevingsvisie Leiden", 2021)

Sustainable mobility
The city opts for a sustainable mode of transportation that is safe, secure, clean, and space-efficient. Leiden seeks to transition to more compact, space-efficient forms of transportation that complement the city's rich history. Different divisions of the space have been made in response to the increase in pedestrian and bicycle traffic, the city's residential and meeting needs, and the effects of climate change. Additionally, we must transition to a cleaner form of mobility in which we use less fossil fuel and restrict emissions of nitrogen, particulate matter, and nitrogen. Additionally, regional coordination and collaboration with other authorities and parties are required due to the city's and region's growing populations.



Fig. 15: Sustainable mobility ("Omgevingsvisie Leiden", 2021)

Attractive business climate
The dynamic and robust economy and employment growth are priorities for Leiden. A varied economic system is one that is strong. That is why we place equal emphasis on maintaining talented workers as well as particular economic groupings. Leiden's regional and (inter)national contexts are distinguished by this. Additionally, the city has a wide-ranging economic foundation. The design of living and working places in the city must take into account the continued development in the percentage of micro- and independent businesses.



Fig. 16: Attractive business climate ("Omgevingsvisie Leiden", 2021)

02
Methodology

During this urbanism graduation project, methods that are used to conduct this project constantly shift between research and design. This chapter focuses on what these methods are and how they intertwine during this project, and what the relation is between research aims and outcomes. First of all, the societal, scientific and ethical relevance is being discussed, followed by the conceptual framework that will help with structuring the project as well as the answering of the sub-research question. Finally a scheme is made to demonstrate the progress of the project.

2.1 Relevance

Societal relevance

News articles of the last decade were dominated by subjects about decreasing biodiversity and the effects of climate change, and the effect these two have on our daily life. However, in the case of Leiden, there is a turning point happening. The municipality comes up with a lot of solutions to deal with aforementioned problems, and most of the news related to these issues is now about how the municipality is dealing with issues (fig 17). This project fits well within the future plans of the municipality of Leiden. By creating ecological corridors, and adapting the street scape to deal with climate change, will improve flora and fauna, but will also greatly improve people's mental and physical well-being. Being around green make people happier, but the green surfaces are also an inviting way to let people walk or bike more often, which has a direct effect on the overall health of the inhabitants. In addition to the mental and physical well-being, the economic damage that often occurs with climate-related problems be much lower than if we continue to petrify the cities in this way. So in the end, this project can be good for the society's overall health, give long-term economical benefits and will greatly improve the urban flora and fauna.

Scientific relevance

Climate change, decreasing biodiversity and low health are one of the urgent challenges a dense city have to deal with. A lot of the cities surfaces dominated by stone and concrete will not help with coping with these challenges. However, while so much space is dedicated to stone, it is challenging to find surfaces which can be transformed into a greener solution. The road network is one of the most important infrastructural surfaces a cities has, but this also contribute to the urban problems. Roads can even exacerbate these problems. While most roads are now designed with mobility and safety as the number one priority, it is now time to look at what ecological role a road can fulfill. Therefore this project will focus on how an extended road infrastructure, in this case in the city of Leiden, can be used in order to create green urban corridors and can serve as an connection between green urban areas. This way urban biodiversity (flora and fauna) will increase, the effects of climate change will be less disastrous, but it will also have positive effect on people living in cities.

Ethical considerations

Since I've started doing the masters 5 years ago I've come to realize how bad the state of earth's biodiversity is. Green areas are not only very important for us human beings, but even more for flora and fauna, since they depend on green areas. When driving through Leiden, I started to notice in most cases how little space is dedicated for actual quality green surfaces, and how the car still gets all the attention. Although the discussion nowadays is about if the car needs that much space, little is still visible in the city. Most of the time I think about how much green we can add to the cities road system. And this is not just putting some trees and bushes in open spaces, but it is about the whole green urban structure of the city. For me its interesting to look at how we can take greenifying to the next level and actually create spaces where biodiversity can thrive, which can also have its economic and societal benefits. This project is a perfect opportunity to investigate how we can use the extended and most often underexposed street network to our advantage, and use street design to strengthen the urban biodiversity.



Fig. 17: News articles in Leiden about climate change, health and flora and fauna. (RadioGuys.nl, z.d.)

2.2 Conceptual framework

The conceptual framework (fig 18) shows the expected relation between the three different subject as stated before; ecology (flora and fauna), climate and public health. This framework includes the components that are variable during the progress of the project. Road ecosystem services can be divided in three related services, which are the regulating, the supporting and the cultural services. All of these overlap because they are indirectly or directly connected to each other. These services can be divided into the three main subjects of the project, which are also overlapping, both with each other as well with the services. The complete overlap (the middle) will give an answer to the research question and therefore will all be a combined solution to improve road-related ecosystem services. This project will all be done within the borders of the road network, which will be further elaborated on in the chapter 3.

Limitations

The conceptual framework has its own limitations, which is in this case are the borders of a road network. The three main subjects also have their own form of limitation. To mitigate these limitations, a combination of methods should be combined in order to get the most complete picture of the problem. However, in some cases it is not possible to use a combination of methods, since a particular part of the data or theoretical information is only accessible by only using a single method. Therefore it is necessary to have a critical look at the source, and asses if this source represents a larger part of the problem, rather that a single opinion or statement. The field of road ecology and the relation between roads and ecosystem services is still rather poor researched, and a lot of information is about one's opinion. Moreover, the terms ecology, climate and public health are quite general term, so there should be extra care given to what is meant by these terms. Additionally, public health is an objective term, since this is different for everyone. This will make it more challenges to come with statements about improving health. However, in this term, general information can be taken in consideration to come up with overall interventions, that will improve the overall health. For instance: it is generally known and researched that actively viewing nature can improve personal health. Finally, since the project lasts a year, hard choices need to be made to make sure the project can be finished within this timespan.

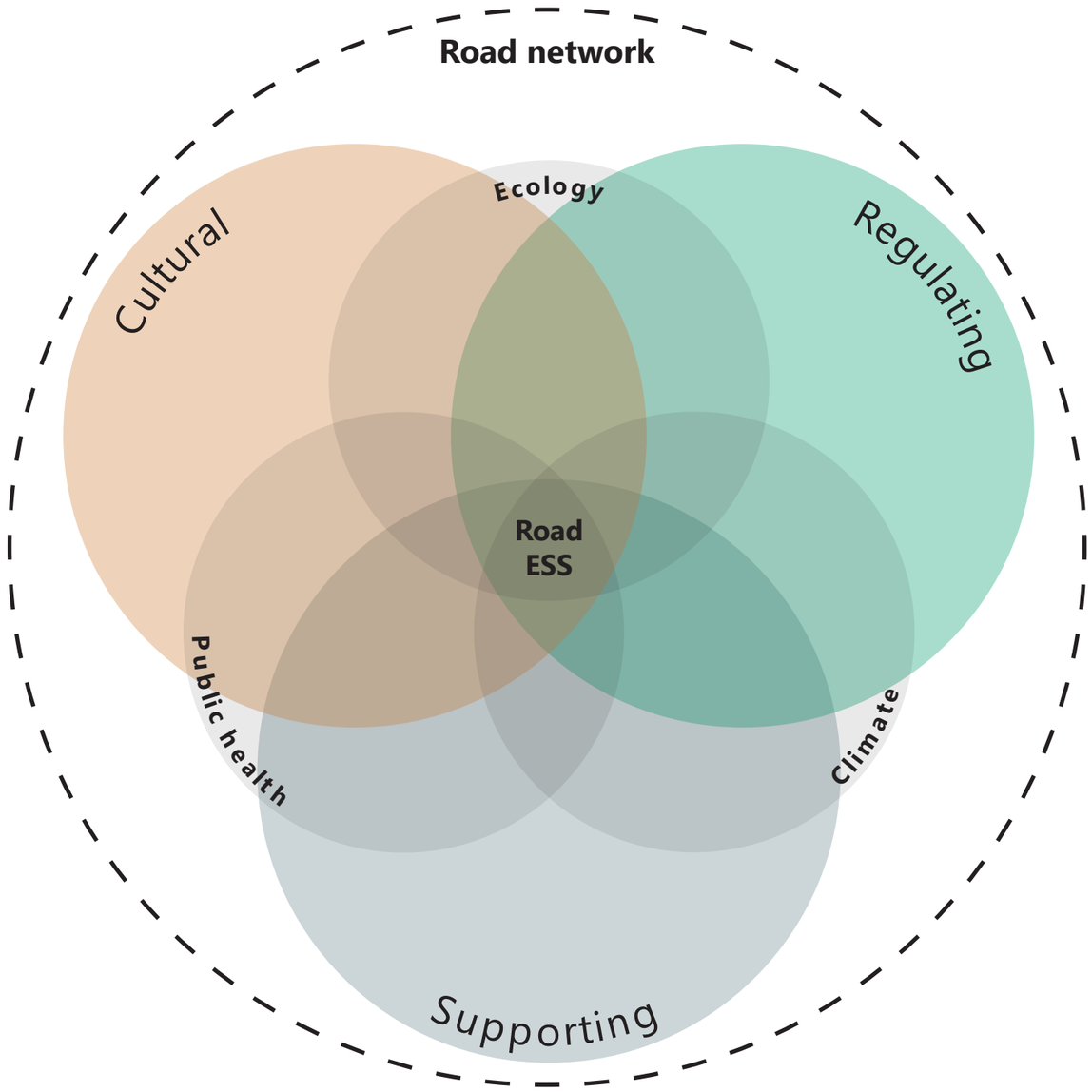


Fig. 18: The conceptual framework shows the relation between the three subjects

2.3 Research approach

In order to answer the research question and the sub-questions, different types of research methods are being used. The research methods that are being used during the project process are shown in fig 19. Quantitative and qualitative data is being used to understand more of the theory behind the topic, while objective and subjective data give more understanding about the site specific components. The project approach is illustrated in the form of a scheme in fig 20. The scheme shows the different components of the whole project and shows which method is being used and which research question is related to that component. As stated before the main research question is:

What is a possible approach to use the road network of Leiden to improve road-related ecosystem services?

This next section will elaborate on how the sub-research questions are being approached as well why the question is important.

1a. How is a road described?
- To understand what the context is in terms of a road network, the term road should be described in the form of spatial borders.

1b. Which ecosystem services are related to the road network?
- Important to explain which services are related to the road system in order to narrow down the topic and come with targeted solutions.

2a - What are economical benefits by improving ecosystem services?
- Since municipalities only have certain amounts of money to invest in green solutions it is important to elaborate on why ecosystem services have a high investment priority.

2b - Which landscape theory can help with creating ecological road corridors?
- To validate the outcome of the project landscape theory should be conducted to support the outcome of the project.

2c - How can the road-related cultural services be improved?
- Streets can have a significant effect on public health and this is not always a good effect. Therefore its important to look at how the road network can be used in order to improve the health of the inhabitants of Leiden.

3a - How can the roads ecological function be changed to improve urban biodiversity?
- Roads don't necessarily have to only have a function of movement of goods and people, but can also serve as an ecological corridor between several green patches. This question focuses on how this could be done.

3b - How can the road be adapted to cope with the effects of climate change?
- Streets are an important part of the city, and are often non-adaptive for climate change. The answer to this question will help with understanding what possibilities there are on the roads.

3c - What is needed to improve ecosystem services related to flora and fauna?
- Animals and plants also need their fair spot in the city, since they are a major part of a robust ecosystem. Therefore a research has to be done on what is needed in order to improve this.

4a - What spatial interventions can be made to improve road-related ecosystem services?
- Making clear which interventions can be made, can help with putting this in a real-life example.

4b - How can streets be designed to improve road-related ecosystem services?
- A combination of spatial interventions will be applied to a real neighborhood in Leiden to show what is possible in reality and what this would look like.

Policy analysis
This method will be used to get a better understanding of the current documents that the municipality has made about the city of Leiden. It gives an perspective of the local ambitions on a certain topic. These will be used to create a more feasible design

Mapping
Mapping is part of the field trip method and consists of using available maps online to understand the different layers of the projects location. These can be used to create patterns and extract specific information about a topic.

Reference analysis
Exploration of similar projects around the world that deal with the same challenges as this project. Used to get a better understanding of what works in which situation and what doesn't work. Also used to get inspiration for designing.

Data analysis
This method is being used to get quantitative and qualitative data and reveals patterns and relationships in certain topics. This mainly used to create hard numbers.

Designing
The theoretical information is used now to create actual spatial elements. This can give new insights on the topic and can also inspire others to get involved in the topic. It also serves as a test of the research that has been done.

Literature research
A lot of sources are available for the public. This method focuses on reviewing these sources on existing knowledge of the projects topic and analyses them in order to create personal conclusions.

Typology study
This method is used to create a comprehensive understanding of complex situation, and gives insights in relations between these situations.

Field trip
Going to the site of the projects gives an real-life experience of the current situation. Pictures are being made and a good feeling of the environment can be stated.

Fig. 19: Research methods being conducted during the course of the project

2.4. Project approach

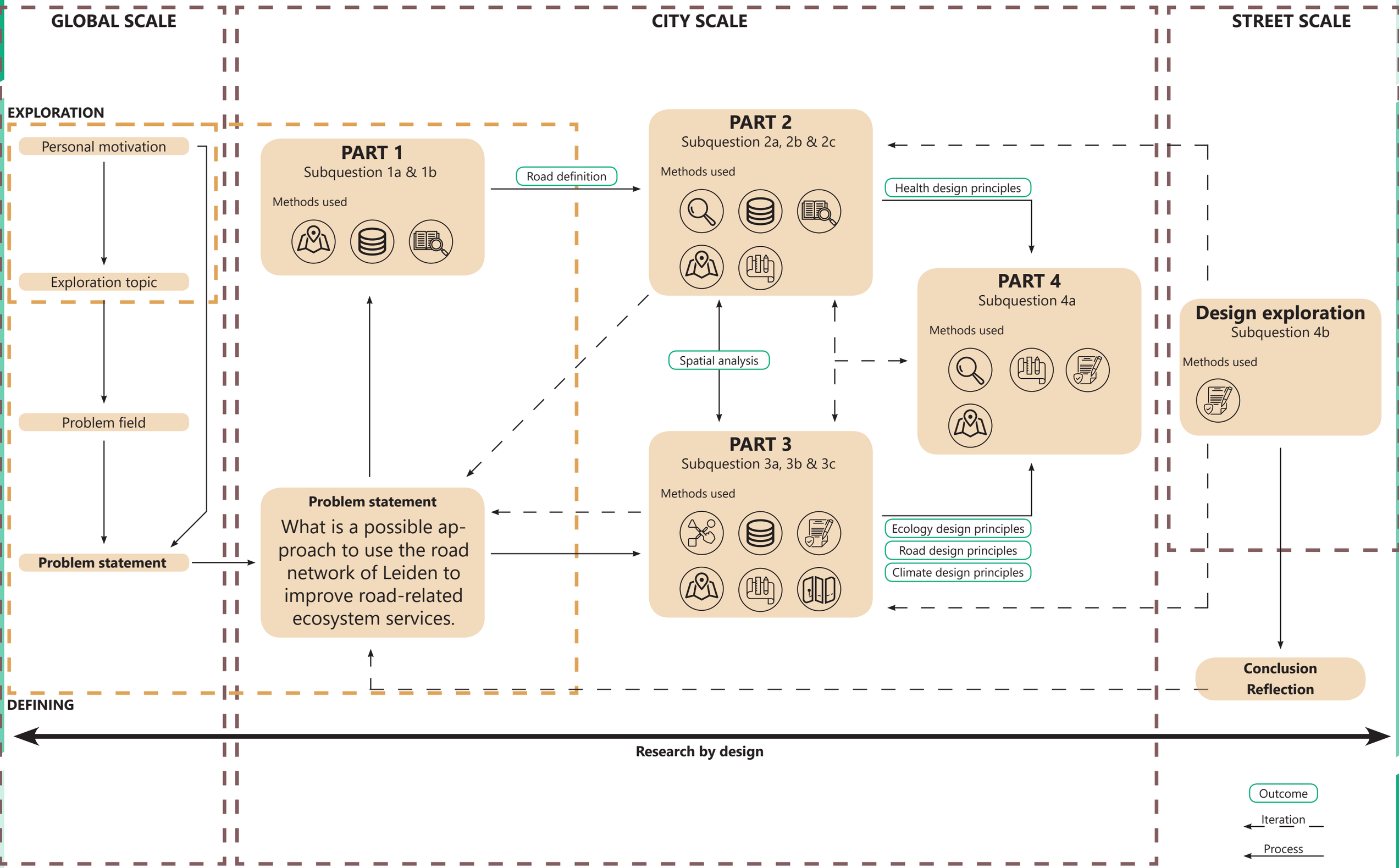


Fig. 20: The research framework shows the progress of the graduation project

03
Theoretical framework

Urban ecosystems have only (relatively) recently been implemented in urban planning. First of all this chapter explores which services are related to the road network and theory about ecology and furthermore dives deeper into the matter of economics, health and how humans experience green in the city, with the corresponding benefits.

3.1 Road ecosystem services

First of all it is necessary to define what a 'road network' is. To answer the main question, it is necessary to first define what a 'road network' is. A clear description of a road is provided to avoid confusion. In this report, a road is defined as:

Any spatial or non-spatial component that is in-between the two outer buildings, streams, or meadows (or a combination of these).

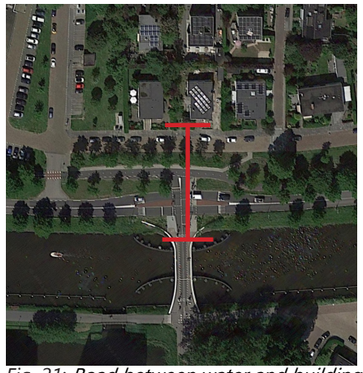


Fig. 21: Road between water and building

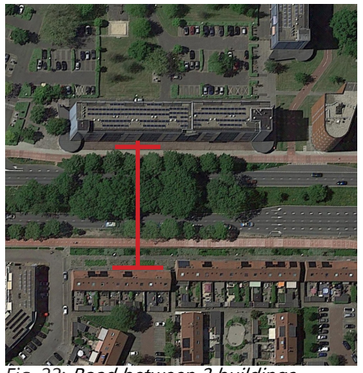


Fig. 22: Road between 2 buildings

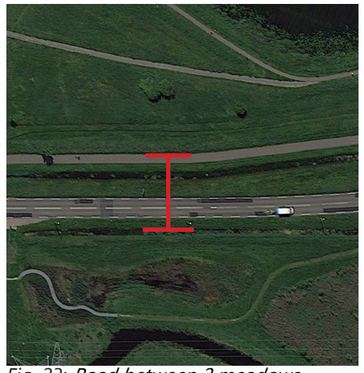


Fig. 23: Road between 2 meadows

To get an understanding of road ecosystem services it is important to know which systems actually relate to the road network. Since roads play an important role in the city's structure, they can integrate different aspects of theory, allowing multiple beneficial functions to coexist in the street profiles. **Road ecosystem services** are the services that directly or indirectly relate to the road network. Roads provide an important opportunity to show how to develop more climate resilient and economic beneficial projects, by incorporating techniques that benefit from the advantages of the environment. Roads are often vulnerable to effects of climate change, such as heat, floods, heavy rain but also are bad for people's health and urban biodiversity. By reducing the exposure of roads to these effects, can lower the costs of building and maintaining a road project. Road projects that are economically interesting, come with benefits for road users, inhabitants, are more resilient for the effects of climate change and have positive effects on urban biodiversity. This interdisciplinary approach emphasizes the advantages for both people and the environment, and it serves as a tool for more informed and sustainable planning and decision-making. When considering how roads are exposed to hazards from their surroundings and how to turn this understanding into a risk mitigation strategy, the idea of ecosystem services offers a useful perspective. The concept of ecosystem services provides a useful perspective for considering the vulnerability of roads to hazards in the surrounding landscape and translating this understanding into a risk mitigation strategy. Consider the example of a road that is prone to flooding. Wetlands adjacent to and upstream of the road could be an important component of an ecosystem services-based flood-control strategy. Conversely, if the wetlands were degraded or paved over, the flood regulation service would be severely jeopardized, putting the road, its users, and surrounding communities at greater risk and necessitating more frequent and costly repairs when flood damage occurred. As demonstrated by this example, proper identification of ecosystem service dependencies necessitates a landscape-level perspective that extends far beyond the road's right of way. Important and cost-effective opportunities to reduce hazard exposure can be missed if project developers only consider the road's right of way.

Most of the time roads have some form of verges next to them. Road verges are likely to provide a diverse range of services that primarily benefit road users, both drivers and pedestrians. Road verges are an ideal example for providing ecosystem services for three reasons: 1. Roads and traffic pollute the air, water, and soils, which can be mitigated by regulating Eco system services; 2. Road verges by definition occur where people live and/or move, creating a high demand for ecosystem services; and road verges generally occur at higher densities in more human-modified landscapes, where there is a low background supply of many types of ecosystem services. The potential suite of ecosystem services provided by a specific road verge will be determined by the verge's characteristics (e.g., size and habitat type), the road, the surrounding landscape, the geographical region, and the local people's behaviors and cultures. Road verges can primarily provide provisioning services, fundamental regulating services, more contextual regulating services, and cultural services. However, road verges are likely to provide ecosystem disservices, and the net benefits must be weighed against the loss of services from habitats displaced by road verges (Phillips et al., 2020).

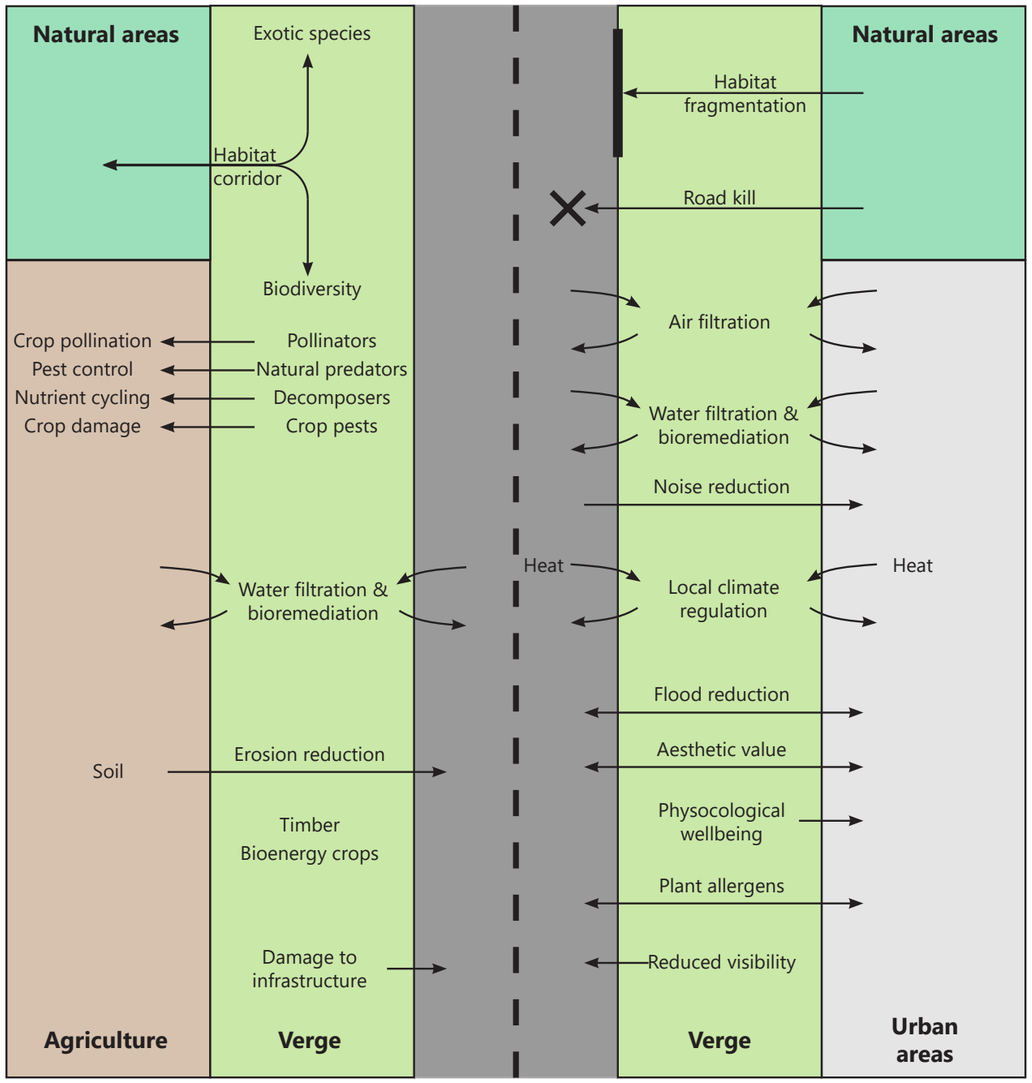


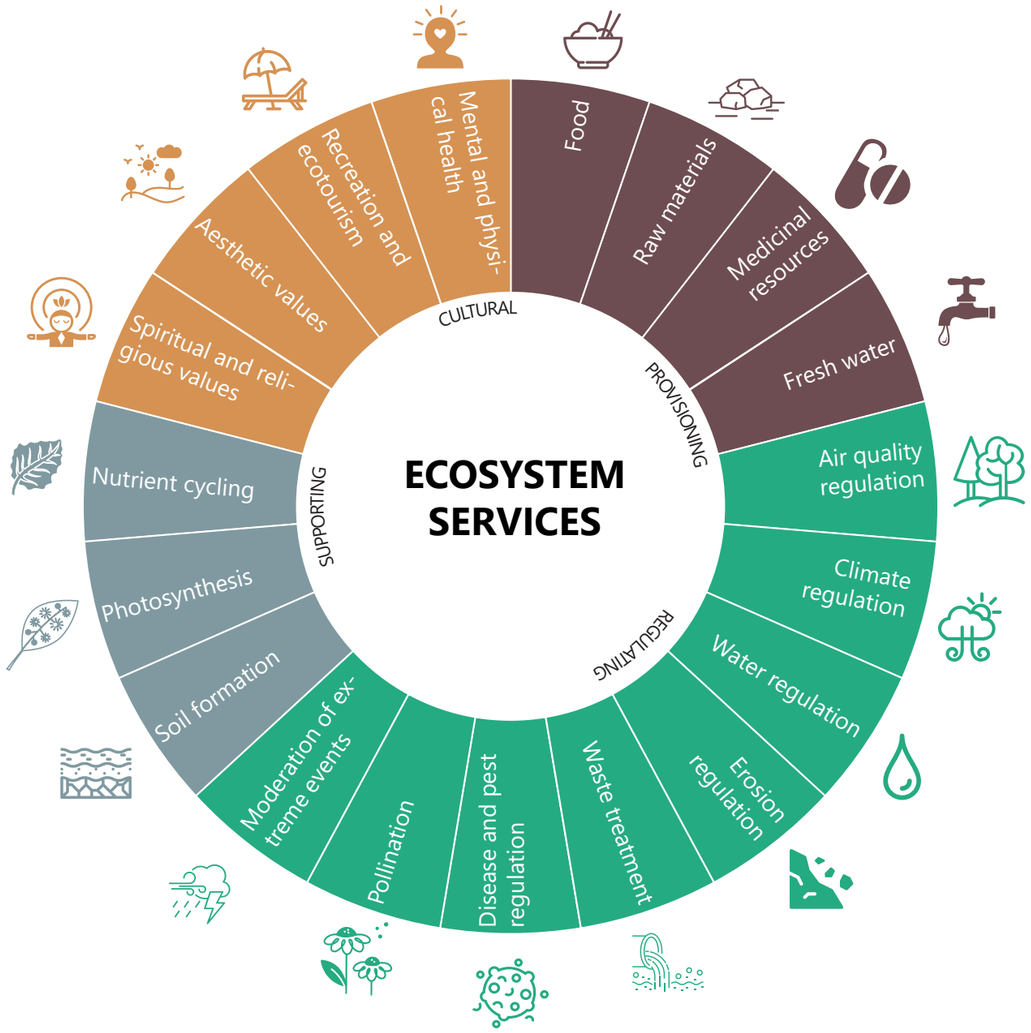
Fig. 24: Ecosystem services and disserveses provided by roads verges (Phillips et al., 2020), edited by author

Not every previous mentioned service is related to roads. The table on the next pages shows which service do relate to road networks and why they are important. What is important to note is the addition of two services; **wildlife habitats and wildlife corridor**. The road network of Leiden connects ecological hot-spots and has the potential to become a ecological corridor between these areas. Creating these corridors is essential for the ecosystem, especially in an urban environment where habitats are divided. In terms of population size and persistence at balance, any connection between two isolated patches is preferable to none at all (Henein & Merriam, 1990). The ecological corridor's unique habitat conditions provide both widespread species and rare and endangered species with the necessary biodiversity protection. Since they are supportive to urban wildlife they are added to the supporting services. Furthermore, the provisioning services are not related to the road network. Fig. 26 shows the same image as before, only here the ones that have little to no relevance to roads are faded. Most services related to roads are the regulation services, like air quality regulation, climate regulation, water regulation, erosion regulation and moderation of extreme weather events. Also the cultural services are represented, since road design has a direct effect on people's mental and physical well-being, as well as aesthetic value. (Mandle, et al., 2016).

Addition to supporting services

Wildlife habitat

Wildlife corridor



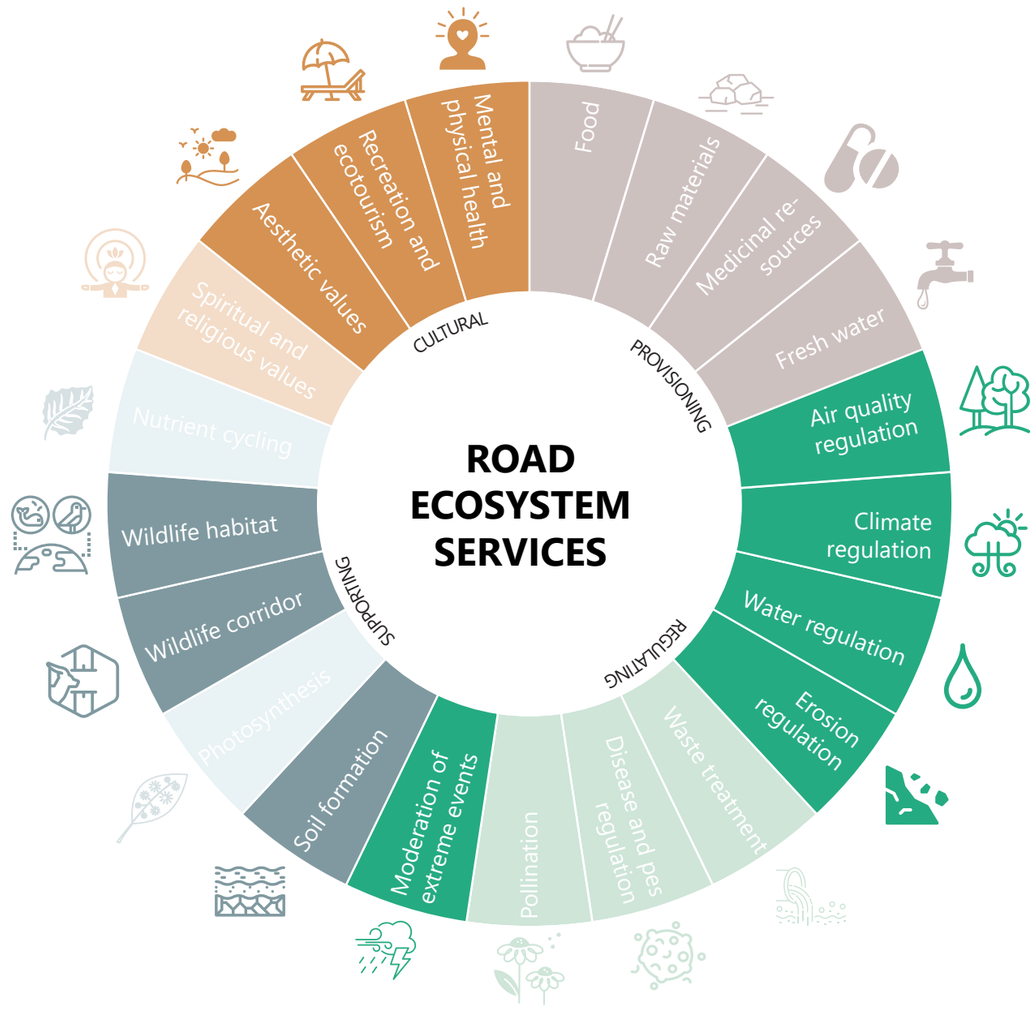


Fig. 25: Ecosystem Services (Fastré, 2020), edited by author

Fig. 26: Road-related ecosystem services

Ecosystem services	Relation to roads
Air quality regulation	The air quality is harmed by roads, especially by the traffic and people's health is negatively impacted by this air pollution. By capturing and filtering pollutants, vegetation can assist in reducing these negative effects of roads on air quality. A cost-effective way to mitigate the effects of roads on air quality and ensure that the road project complies with regulations is to restore vegetation that cleans the air.
Climate regulation	Because a lot of surface in cities are dedicated to roads, climate change impacts may be exacerbated. The global population are all affected by the effects of climate change. These effects are, among other things, caused by increased levels of carbon dioxide and other greenhouse gases. Ecosystems prevent this from happening. Indirect or direct effects of road construction on vegetation conversion and increased road traffic can both contribute to the CO2 offset.
Water regulation	Ecosystems are less able to filter and hold onto pollutants when roads are being placed. This has effects on the water regulation. Restoring or creating vegetation that enhances water quality can be a cost-effective way to lessen the effects of roads and guarantee that road projects comply with legal requirements.
Erosion regulation	To keep sediment out of waterways and drainage systems, vegetation both holds soil in place and traps it. This lowers the maintenance costs of road infrastructure and vehicles by reducing sediment scour on the roads. Unpaved roads and exposed roadside areas are frequent sources of sediment.
Moderation of extreme events	Climate change is increasing the frequency and intensity of environmental extremes, posing new adaptation challenges for cities, particularly those located near the coast. Heat waves have been the leading cause of human fatalities in Europe over the last decade. Landslides are less likely when the ground is stabilized by vegetation. Climate change has an impact on roads as well. Roads are unable to withstand these effects due to their stony surface. By implementing smart solutions in both road construction and street profile, roads can operate as systems that deal with the effects rather than aggravating them.

Fig. 27: Importance of ecosystem services related to roads.

Ecosystem services	Relation to roads
Soil formation	The earth system depends heavily on the soil, and losing the soil poses a serious threat to many of the services the system offers. By compacting the soil surface, removing the vegetation that protects the soil, and disturbing the forest floor during construction, roads increase the likelihood of soil erosion.
Wildlife corridor	Roads often form a straight line between ecological hotspots, and therefore between wildlife habitats. By implementing these ecological structures into road design, wildlife can pass these roads and safely move from one habitat to another.
Wildlife habitat	While roads can serve as a connector between two ecological structures, it can also serve as an habitat on its own. Animals that have a smaller range of movement can use roads as their own habitat. Therefore different solutions on road level have to be designed, for animals so they can safely live alongside roads. Species diversity may peak at intermediate levels of urbanization, where many native and non-native species thrive, but it typically declines as urbanization becomes more intense.
Aesthetic values	A road is an aesthetic object with its own characteristics: straights, curves, cambers, rises and falls. This value can influence inhabitants in their opinion about the environment they live in. Also it influences the overall look of the city's view, since the road is a significant part of a city's structure.
Recreation and eco-tourism	Not only do roads provide efficient movement for people, they can also function as a touristic attraction. By providing high-profile leisure opportunities, tourists can be attracted to the city. This also creates more opportunities for recreation of the inhabitants.
Mental and physical health	Roads directly influence people's mental and physical well-being, negatively or positively. Chapter 34223513 will elaborate more on this service.

3.2 Landscape ecology

To get an improvement on road ecosystem services, a theoretical underpinning is necessary. What ecological role can a road system play in the future? And how can we sustain this role? Questions like this need theoretical support to answer them correctly. Landscape ecology theory provides this support. Roads, being one of the largest urban infrastructural systems, have the opportunity to integrate ecology, urban planning and engineering, with the supporting theory of landscape ecology.

"Landscape ecology emphasizes the interaction between spatial pattern and ecological process—that is, the causes and consequences of spatial heterogeneity across a range of scales" (Turner et al., 2001)**.**

Patch corridor matrix

"Animals, plants, water, wind, materials, and people move through spatial patterns characteristic of virtually all landscapes and regions. This up to-date synthesis explores the ecology of heterogeneous land areas, where natural processes and human activities spatially interact to produce an ever-changing mosaic...This subject is of enormous importance to today's society, and indeed for molding the future of areas surrounding each of us"(Richard T.T. Forman). This means that there are several spatial parameters that are crucial for the relationship between biodiversity and landscape spatial structure. The patch-corridor-matrix landscape model can help with evaluating these spatial parameters (Levin et al., 2014). The model consists of four main elements:

Mosaic: a pattern made up of patches, corridors, and matrices that are all made up of smaller, related objects that have been aggregated together.

Matrix: the background ecosystem or land-use type in a mosaic, distinguished by significant control over dynamics, high connectivity, and/or extensive cover.

Patch: a region that differs from its surroundings by being relatively homogeneous.

Corridor: a strip of a specific type that is distinct on both sides from the surrounding land.

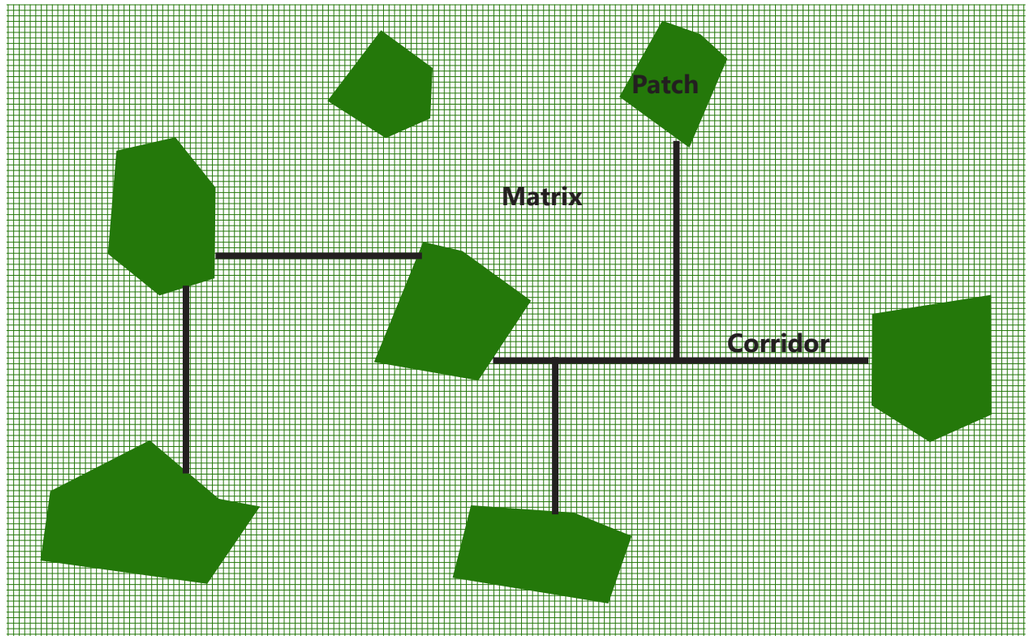


Fig. 28: The patch-corridor-matrix landscape model. The landscape consists of habitat, patches, corridors connecting habitat patches and a surrounding matrix, which is unsuitable for the species in the habitats (Levin et al., 2014). Edited by author.

This model can also be applied in urban settings, like Leiden. The matrix is then all the built environment, the patches are for example the parks, and in this research will focus on how the road network can serve as corridors between these patches. In the cities there are countless flows happening at the same time. These flows create structure in the city. However not only do flows create structure, the structures also directs the flows. The location and composition directs the movements of animals, fluids and humans across the landscape. Urban designers have to study these movements and patterns in order to learn from them and apply them to future projects, to improve them.

Patch fragmentation

The patches in the city all differ in size and shape, and therefore have different ecological value. Basically, the large a patch with continuous vegetation is, the higher the biodiversity there is. Species have their own specific spatial needs for survival. Habitat fragmentation has been a trend in the past decades. This means that over time, larger patches became smaller, disconnected patches. Patch fragmentation raises the edge-to-interior ratio, which lowers biodiversity and affects the distribution of species (T.T Formann, z.d.).

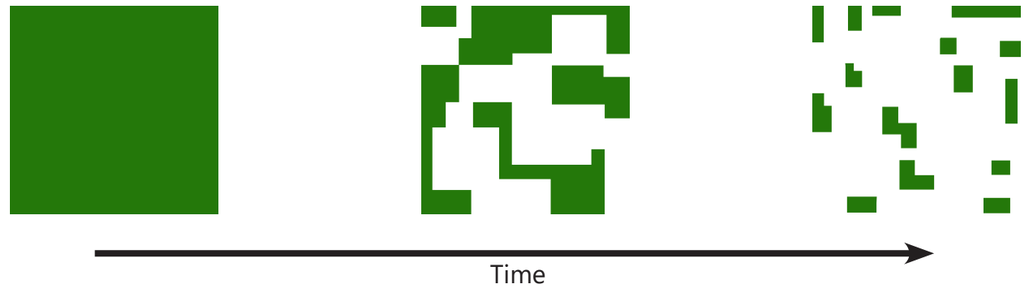


Fig. 29: The progress of habitat fragmentation (T.T Formann, z.d.) Edited by author.

Patch scale

Also the scale of a patch and a corridor is important. Large opening can let more species through than smaller openings, because of the different habitat and corridor needs. This applies also for humans. Where there is a wide open area, more people can pass through and they will pass through quite dispersedly, while smaller ones might let people choose to take another route (T.T Formann, z.d.).

Movement between patches

When two patches are close enough to each other or are connected, animals can move from one habitat to another one. Small populations are fragile and less likely to survive on tiny patches of land. Survival rates are higher in small populations that are close to large patches. The patch needs to be close enough to another patch so that, once a year or once in a lifetime, the phenomenon known as "The Joe Versus the Volcano Phenomenon" can occur. The distance that each species travels between patches varies, and wildlife corridors enhance connectivity between patches (T.T Formann, z.d.).

Corridors

Corridors can occur naturally, like a river, or can be man-made, like a power line. They can vary from just a couple of meters to a wider strip, where they can serve as an habitat on their own, or serve as a movement corridor for wildlife. The width of a corridor is very important, since this determines if wildlife is likely to move over it. For some species that travel along them rather than over them, road corridors can serve as connectors. Biodiversity can be greatly improved if corridors are implemented in street design, because they can serve as connectors between patches (T.T Formann, z.d.).

"Using principles is not difficult, and leads to more integrative designs and plans. It helps reduce the landscape fragmentation and degradation so evident around us."
-Richard T.T. Forman

Island Biogeography

In extend of previous section about the patch-corridor-matrix landscape model, Jared M. Diamond produced design principles to minimize wildlife extinction rates. Fig 30 shows these design principles, identified as A, B, C, D, E and F. Principle A shows that a large patch is better than a small patch. This is mainly because of two reasons: a larger patch can hold more species, and species have more opportunities to continue to exist. Also more space can be used for human activities. When a certain amount of space is available, we always need to try to make as less as disjunctive patches as possible (principle B). If the same area were divided among several smaller reserves, many species that would have a good chance of surviving in a single large reserve would have a reduced chance of surviving. The statement that separate reserves may each favor the survival of a different group of species in an inhomogeneous region and that even in a homogeneous region, separate reserves may save more species of a set of similar species, one of which would ultimately exclude the others from a single reserve, are necessary to qualify Principle B. If there is no other option than to disperse patches (which is often the case in urban settings), they should be as close as possible to each other (principle C). When patches are close enough to each other immigration could still happen, if of course provided with the right spatial components in a corridor. When the patches are quite dispersed, at least try to group them, rather than create a linear row of patches (principle D). Where is gets interesting in this research is option E, where there are dispersed patches in Leiden. Connection via strips is in every case better than no connection at all. This is so that wildlife from the protected habitat can move between reserves without having to travel through vast expanses of unsuitable habitat. Particularly with regard to sedentary species that have specific habitat preferences. To reduce dispersal distances within the reserve, any given reserve should be as nearly circular in shape as other considerations permit (principle F).

The theory of the patch-corridor-matrix and island biogeography is a good starting point of understanding what ecological role the road network can play in the future. This role can now, with related theoretical background, be further explored in chapter 7. With use of the theory, a integrated design can be made for the road network in Leiden relying on existing transportation functions to give people opportunities for recreation and a healthier way of life in addition to better assuming the ecological function of providing movement corridors and habitats for particular species.

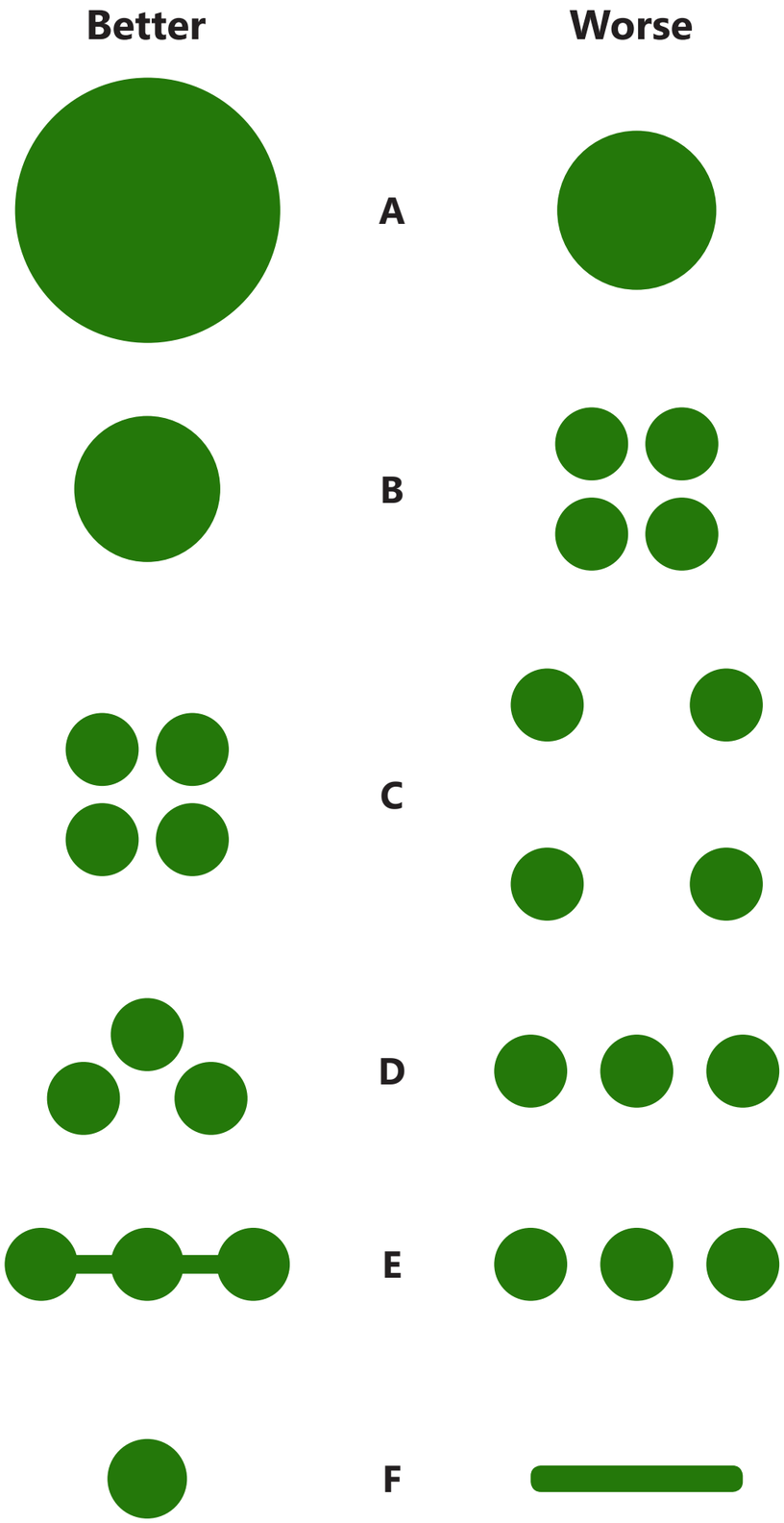


Fig. 30: Suggested design principles, derived from island biogeographic studies (Diamond, 1975). Edited by author.

3.3 From EGO to ECO

Humanity has been relatively short in the age of existence, yet in this short period of time we managed to rapidly lose a huge amount of global biodiversity. We have seen ourself at the top of the chain and most often separately from nature, while our impact on nature has been immense destructive. The planet's biodiversity has evolved to at least 30 million different species, and each species has their own ecological function in the complete biodiversity chain. But the creativity and evolution that allowed all of the life on Earth to coexist side by side for billions of years have been destroyed by us. The thought that we were on top of the chain started during the scientific discoveries, the introduction of technology and the industrial revolution. By using technology and science to our own benefits, humans could manipulate nature. This led to a believe that mankind had complete control over nature and the earth, and that nature had to serve humans, rather than co-existing. Great Philosopher and mathematician even believed: "Man is at the top and Earth is here for us to use, to exploit".

We have seen the same happening during the past decades of urban expansion. Rather than planning with nature, we simply just got rid to create spaces for our own needs. Particularly with regard to roads, attention was initially paid to mobility, flow and safety, where implementing green was most often the last item on the list. Numerous issues confront our cities, including unsustainable urbanization, climate change, human health issues, the deterioration and loss of natural capital and its corresponding ecosystem services (clean air, soil, and water), and an unsettling rise in the risk of natural disasters. But with the enormous reduction of urban biodiversity, the climate crisis and the overall decrease of nature, a new awareness is emerging, where people start to firstly think about nature, rather than putting our personal needs on the first place. In other words: **go from ECO to EGO**

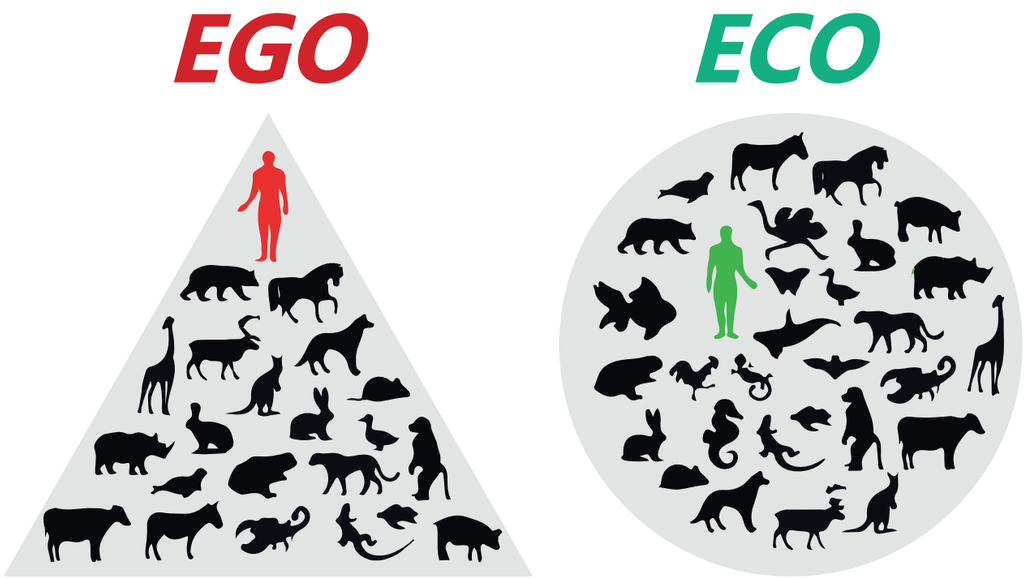


Fig. 31: From ego to eco (Lehmann, 2019)

With this shift, our perception of the nature surrounding us, changes drastically. Not only biodiversity and nature will thrive, but the society's physical and mental well-being will also greatly improve. Society's mental and physical well-being can also benefits from services provided by streets. Urban environments expose people to many stressors, such as traffic noise and congestion, crowding and fear of crime, and are often a source of continual demands prohibiting restoration from mental fatigue. To restore our capacity for directed attention, we need to spend time in settings that utilize involuntary attention requiring no cognitive effort. Incorporating green structures in streets and having contact with nature and green spaces promotes this type of attention. There are numerous studies that conclude that urban inhabitants and communities benefit to a considerable degree, and in a variety of ways, from having everyday contact with nature. (Matsuoka & Sullivan, 2010). A distinction can be made between direct and indirect contact with nature. Direct contact involves activities such as gardening, or walking in a park. Indirect contact includes viewing natural settings through a window or looking at a painting of a landscape. Local park users reported less doctor visits for reasons other than routine check-ups than non-park users in terms of overall health. Even after adjusting for the effects of age, income, education level, health status, and other potentially confounding factors, this difference was still noticeable. Additionally, frequent park visitors had higher self-reported health scores and thought they were in better health than passive visitors and non-park visitors. As a result, those who enjoy leisurely activities in nearby parks appear to be in better overall health than non-users and are less likely to be obese than the general population. Three nature engagement themes can be distinguished: view nature, functional engagement and active participation. They all come to the same result where communities getting healthier and public health costs are being avoided. (Barton & Pretty N., 2012)

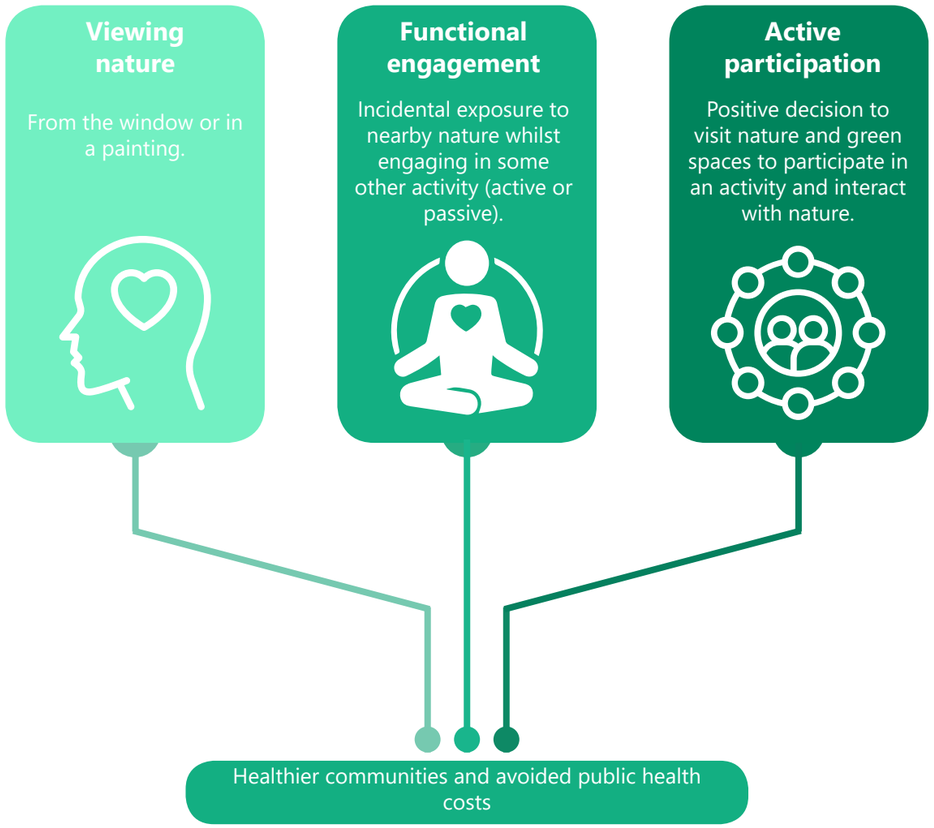


Fig. 32: Nature engagement themes

These three nature engagement themes have an impact on our mental and physical well-being, but they serve more roles in our daily life, like educational roles, more exercising, reduced crime rates and helps us with interacting.

Mental well-being:
Viewing nature through a window or in a photograph is an important way of engaging with nature, when direct access is restricted. This type of passive engagement allows the mind to digress and stimulates reflection and recovery, aids recovery from illness, improves mood, reduces stress, improves mental wellbeing and improve patience and enthusiasm for work (Leather et al. 1998; Kaplan 2001). Workers with views of trees and flowers have been shown to feel less stressed in their jobs and to derive greater job satisfaction than workers overlooking built environments (Kaplan 1993). A similar study also reported that natural views buffered the negative impact of job stress on intention to resign (Leather et al. 1998). People working in windowless workplaces were four times more likely to compensate by displaying pictures of landscapes and outdoor natural scenes or indoor plants (Heerwagen & Orians 1993). For many the greatest value of urban woodlands and natural vegetation is as an escape or refuge away from urban life and probably human urban activity. (Barton & Pretty N., 2012)

Physical well-being:
One of the physical health benefits includes increased human outdoor exercising. When compared with indoor physical activities, exercising in natural environments is associated with a greater feeling of revitalization and positive engagement. Also it has a decreased effect in tension, confusion, anger and depression. (Barton & Pretty N., 2012). People show greater enjoyment and satisfaction with outdoor activity and declare a greater intent to repeat the activity. Access to urban green spaces has been shown to promote healthy living by encouraging participation in green exercise activities, such as walking, jogging and cycling (Coon, et al., 2011). Cycling can be even more encouraged by implementing green street elements. When routes, whether it is to work or to social activities, that include green urban spaces make streets more attractive and therefore making it more appealing for cycling (Nawrath, Kowarik, & Fischer, 2019).

Education
Urban green areas can also function as an outdoor classroom, to facilitate learning and enhance knowledge about the natural world and the local environment. Repeatedly being exposed to natural environments could enhance people's experience with nature in cities and could help with achieving conservation goals more fully. Outdoor classrooms are important for children, with creative social play, concentration and motor-ability positively influenced by playing in green space (Barton & Pretty N., 2012).

Crime rate
A considerable difference between residents with access to adjacent nature and those who lived in areas with little to no vegetation was seen in the levels of hostility and violence (Kuo & Sullivan 2001b). Greater concentration, which mediates the link between mental exhaustion and violent behavior, decreased aggression by making it easier to access greener environments. As a result, neighborhood settings devoid of nearby greenery and nature had a significant impact on how people interacted with one another. (Barton & Pretty N., 2012)

Social networking
People may see urban green as having a specific purpose, such as a sensory garden or a golf course, but they all provide, to varying degrees, different ecosystem services. This multi-functionality turns urban green areas into hubs of community activity. (Burls, 2010). The presence of trees and grass in neighborhood spaces increases the use of those spaces and the number of individuals involved in social interactions within them, so contributing to the social cohesion and vitality of a neighborhood. The communal green spaces provided opportunities for more face-to-face contacts and encouraged social interaction. Social connections are important for gaining health benefits, especially having friends who encourage exercise, and having at least one friend with whom to explore green spaces. Activities in green places often occur in social groups, or indeed people undertake activities in order to interact with others.

3.4 Natural Capital

A paradigm shift in thinking might be necessary. We can start making efficiency savings that previously would not have been obvious by starting to assign a value to natural capital and by looking at our key systems as a whole rather than as individual components. Nature is of great value for our society. The fact that people use nature to produce and consume things is one aspect of this value. Ecosystems, such as forests, heaths, rivers, or agricultural areas, are responsible for nature's contribution to the economy and our well-being. This value is called: natural capital. Natural capital is the stock of natural resources that have the ability to provide ecosystem services. Ecosystems that are resilient are needed both inside and outside of nature reserves for the conservation of natural capital. According to recent TEEB (The Economics of Ecosystems and Biodiversity) studies and the 2005 Millennium Ecosystem Assessment (MEA), the value of the natural capital is highly on the agenda, because all global ecosystems are under pressure. Around the world, 60% of ecosystem services are declining (Van Egmond et al., 2016). It is possible to shed light on the economic impact of nature by expressing ecosystem services in monetary terms. In order to do this, the GDP, which measures the size of the economy, can be used to compare the value of ecosystem services. Additionally, a joint unit enables comparisons between various ecosystem services and the overall value produced by various ecosystem types. The Netherlands' ecosystem services will be worth 10.9 billion euro in 2020, up from 9.3 billion euro in 2013. The underlying price increase, such as rising costs for outdoor recreation (such as admission fees and transportation costs) or housing costs, is a significant factor in this increase. The rise in outdoor recreational activities is further evidence that there is a significant role for the increased demand for specific ecosystem services.

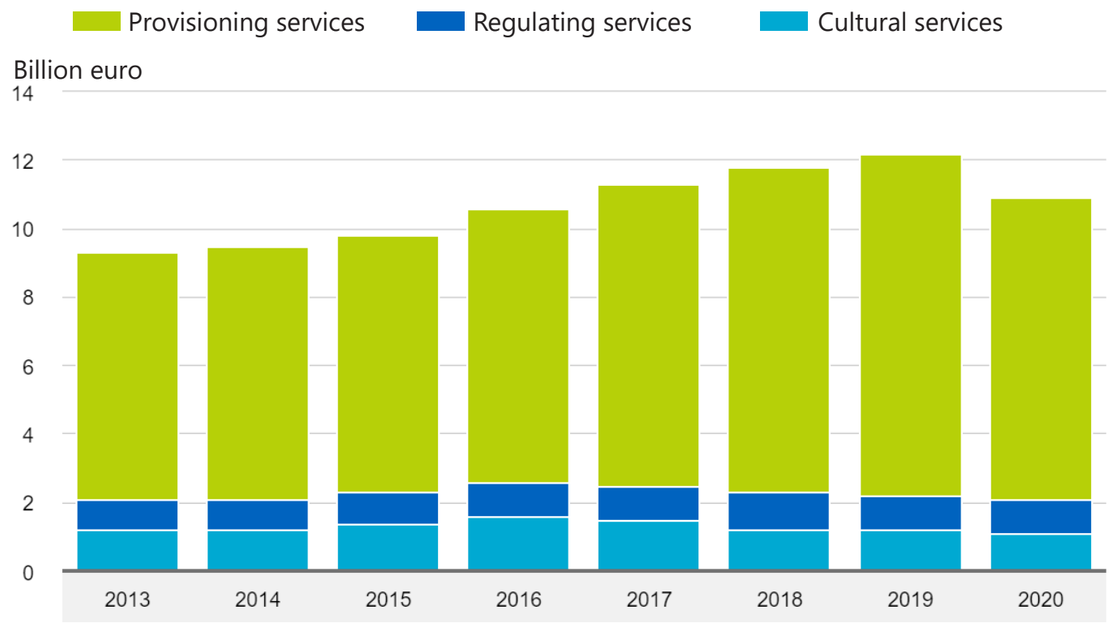


Fig. 33: Monitairy value ecosystem services in the Netherlands (Centraal Bureau voor de Statistiek, z.d.)

Capital assets, such as land, buildings, machines, tools, and transportation vehicles, are used to produce goods and services. The services produced using ecosystem capital are referred to as ecosystem services. For instance, a forest is a capital asset that can be used to produce wood, provide recreation opportunities for people, and capture CO2 and particulate matter. Between 2013 and 2020, an increase of 19%, the value of ecosystem capital increased by 101 billion euro. Based on eleven ecosystem services, the total value of ecosystem capital in 2020 was estimated to be 643 billion euro. Because not all pertinent ecosystem services have been valued, this total value does not yet give a complete picture, but it does serve as a useful starting point for comparison with the economic capital stock from the national accounts (fig 34). The beach and dunes of the coastal region have high monetary values. The Veluwe and the Utrechtse Heuvelrug, as well as smaller areas in Drenthe, Overijssel, North Brabant, and Limburg, are significant examples of large nature areas that have relatively high values that exceed 400,000 euros per hectare. The values of large cities like Amsterdam, Rotterdam, and The Hague are low, but the values of the more open and green areas that are immediately adjacent to the cities are high. This proves that these areas serve a crucial purpose, especially for urban residents seeking recreation. (Centraal Bureau voor de Statistiek, z.d.)

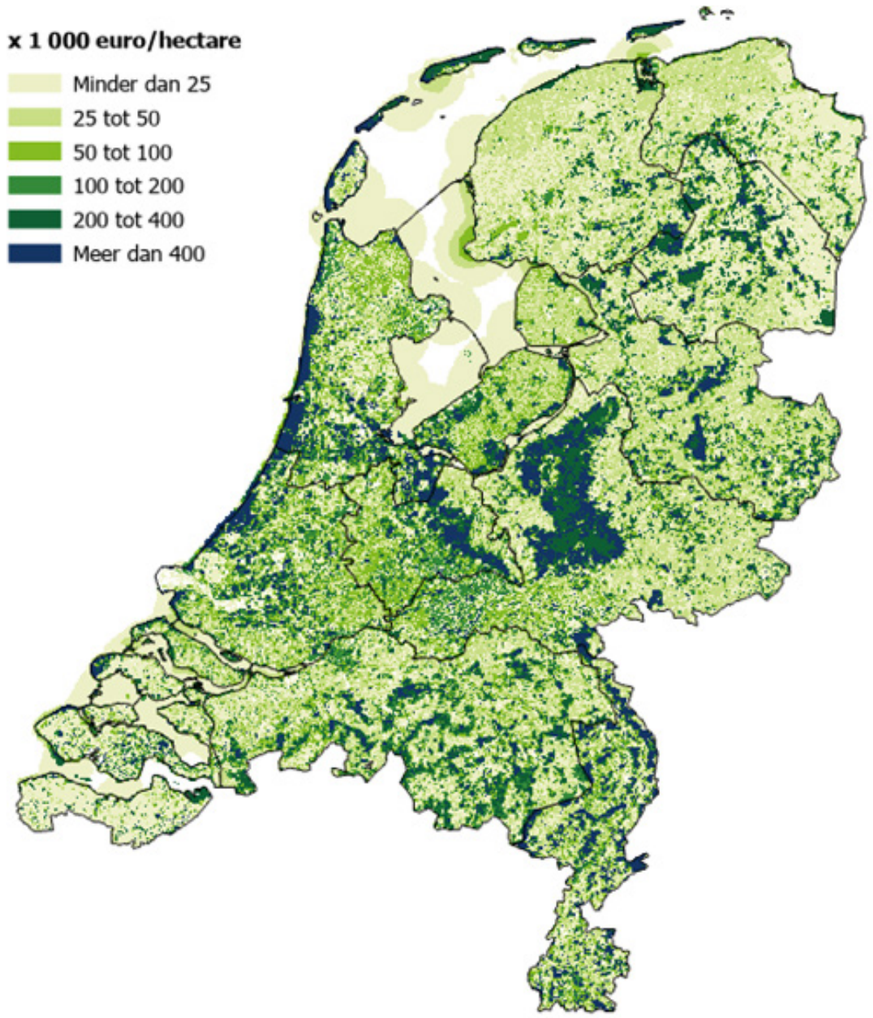


Fig. 34: Value ecosystem capital, 2020 (Centraal Bureau voor de Statistiek, z.d.)

It can be stated that different environmental features give different economic benefits (fig 35). One of the most influential feature is the presence of water nearby residents. As is stated by Kaplan and Kaplan: "Water is a highly prized element in the landscape" (Kaplan & Kaplan, 1989). Also green surfaces in a residential area show to increase property values. Attractive green features have a considerable impact on the pricing of housing. This encourages the preservation of current green spaces in residential areas and their incorporation into new urban developments (Luttik, 200).Another study asks the question if its worth to invest in green urban areas. The outcome of this study suggests that the benefits of the green-ways extend to everyone and that the privilege of living in a neighborhood with greenbelts have value (Peiser & Schwann, 1993).

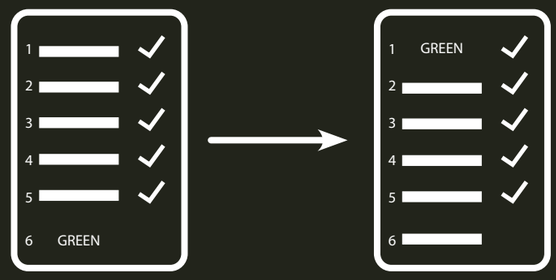
Area of benefit	Estimated economic value
Lifespan of infrastructure	Green infrastructure complements grey infrastructure and lengthens the lifespan of grey infrastructure.
Reduced energy costs	Reducing local temperatures and shading building surfaces, green infrastructure reduces the cooling demand of buildings.
Better workplace productivity	€2000 per employee per year from daylighting. €2990 per employee over 4 months when desks angled to view nature.
Improved health and healing	€93 million per year in reduced hospital cost if natural features provided.
Increased retail potential	Skylighting in a chain store would result in a 40% sales increase. 25% higher sales in vegetated street frontage.
Decreased crime and violence	Public housing with greenery had 52% reduction in fellonies.
Increased property values	Biophilic buildings attract higher rental prices, 7% in effective rents, and selling at prices 16% higher.
Employee attraction	Green street design attract and retain high quality workers.
Increased liveability in dense areas	Green features increase salability of densely built apartment blocks.
Carbon sequestration	In singapore above ground vegetation sequesters 7.8% of the total emitted daily carbond dioxide.
Reduced urban heat island effect and reduced energy consumption	Urban street canoyons full of greenery can reduce particulate matter by up to 60% and nitrogen-dioxide by up to 40%.
Water management and quality	Up to 70% of stormwater retention capability, depending of the local climate and other conditions.
Air quality	Urban street canoyons full of greenery can reduce particulate matter by up to 60% and nitrogen-dioxide by up to 40%.
Biodiversity conservation	A study of 115 wildly colonized green roofs in the north of France found that 86% of species were native to the area.

Fig. 35: Biophilic streets: a design framework for creating multiple urban benefits (Peiser & Schwann, 1993)

Design principles to improve overall health



Create green spaces where people can actively see the vegetation.



Rather than putting green as the last item on the list, start a project with greenifying and then do other tasks.



Provide enough space where people can exercise, as well as improving green structures to promote exercising.



Provide people with enough information for them to educate themselfs about the nature around them.



Encourage biking by creating safe roads and implementing green structures to make the route visually attractive.



Encourage walking by creating safe pathways and implementing green structures to make the route visually attractive.

04
Spatial analysis

This chapter addresses the ecological structures as well as the road network of Leiden. Understanding the current situation in Leiden helps with making stronger justifications for change where it's needed. The results of this chapter provide the basis for a urban strategy based on a combination of ecology and the road network.

4.1 Ecological analysis

Figure 36 shows Leiden in relation to its surroundings. Leiden is a highly populated area situated between larger green spots on the north and south, as well as on the east and west. The land around Leiden was previously open, with rivers and tiny communities, but it has since become extensively urbanized and fragmented. The landscape is now in or between the cities, rather than the landscape in the city. In reality, the traditional contrast between the city and the landscape no longer exists. It is possible to say that the city and the landscape have melded into one.

Leiden is one of the cities in the province that is part of the province's aims to build a more environmentally friendly structure. The river Oude Rijn, which runs straight through Leiden, is a major supporter of the urbanization plan for the heart of Holland. Katwijk, Leiden, and Alphen a/d Rhine concentrate their structures along this historical line, which was formerly the Roman Empire's boundaries. The line goes parallel to the shore and connects the beach to ancient sites, spirit grounds, bog region, and traditional dairy farming. (Weipoort).

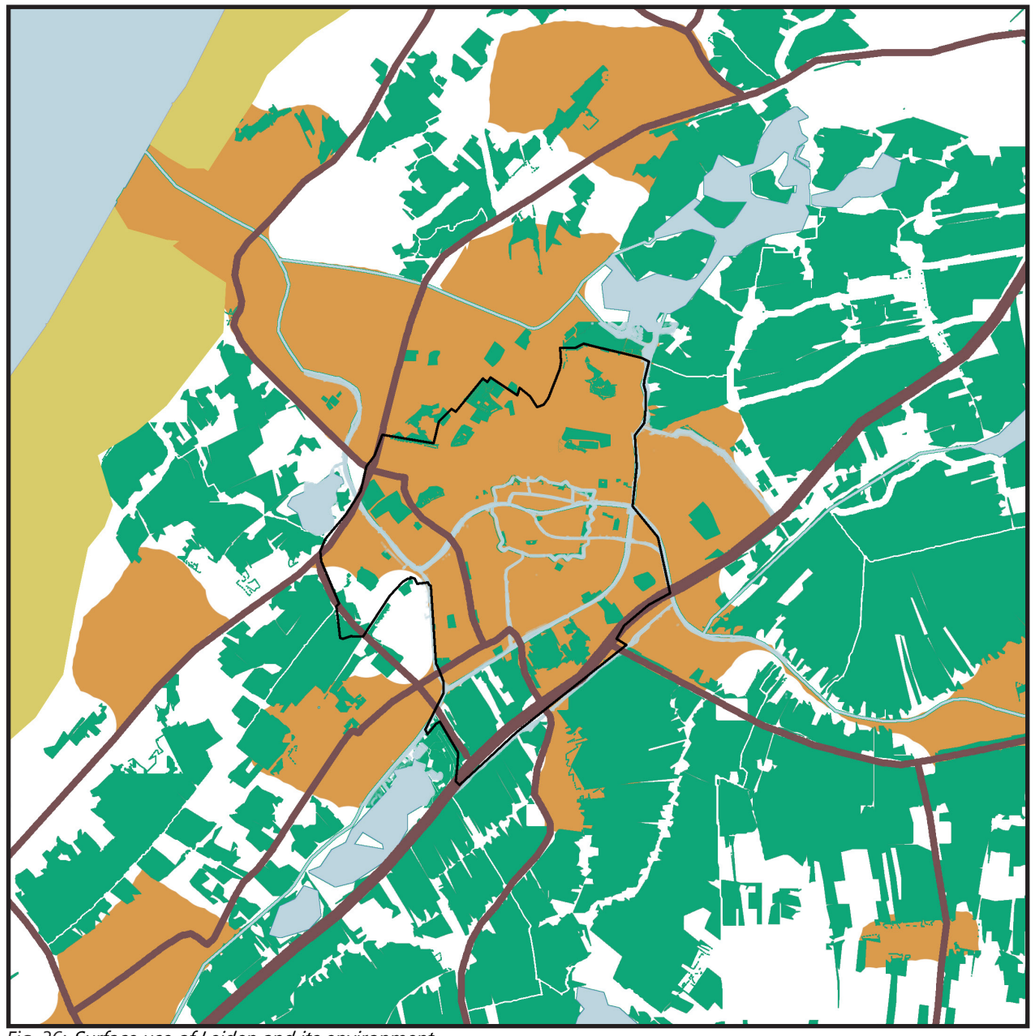


Fig. 36: Surface use of Leiden and its environment

Locally, there are prospects for large-scale developments like as the Valkenburg Air Base, as well as particular destinations in strategic places that make advantage of the urban setting.

While there are several green patches within the heavily built-up area, Leiden has become mostly a barrier between bigger natural areas. These ecological zones are home to a diverse range of animals and plants, and hence play a significant role in the green structure of the province of South Holland. These places thus have a vital ecological role, yet Leiden is sandwiched between the majority of them. Because the quickest route is through Leiden, the city of Leiden might function as a link between the two places. However, animals now have to take a different route through the city to get from one habitat to another (Provincie Zuid-Holland et al., 2017).

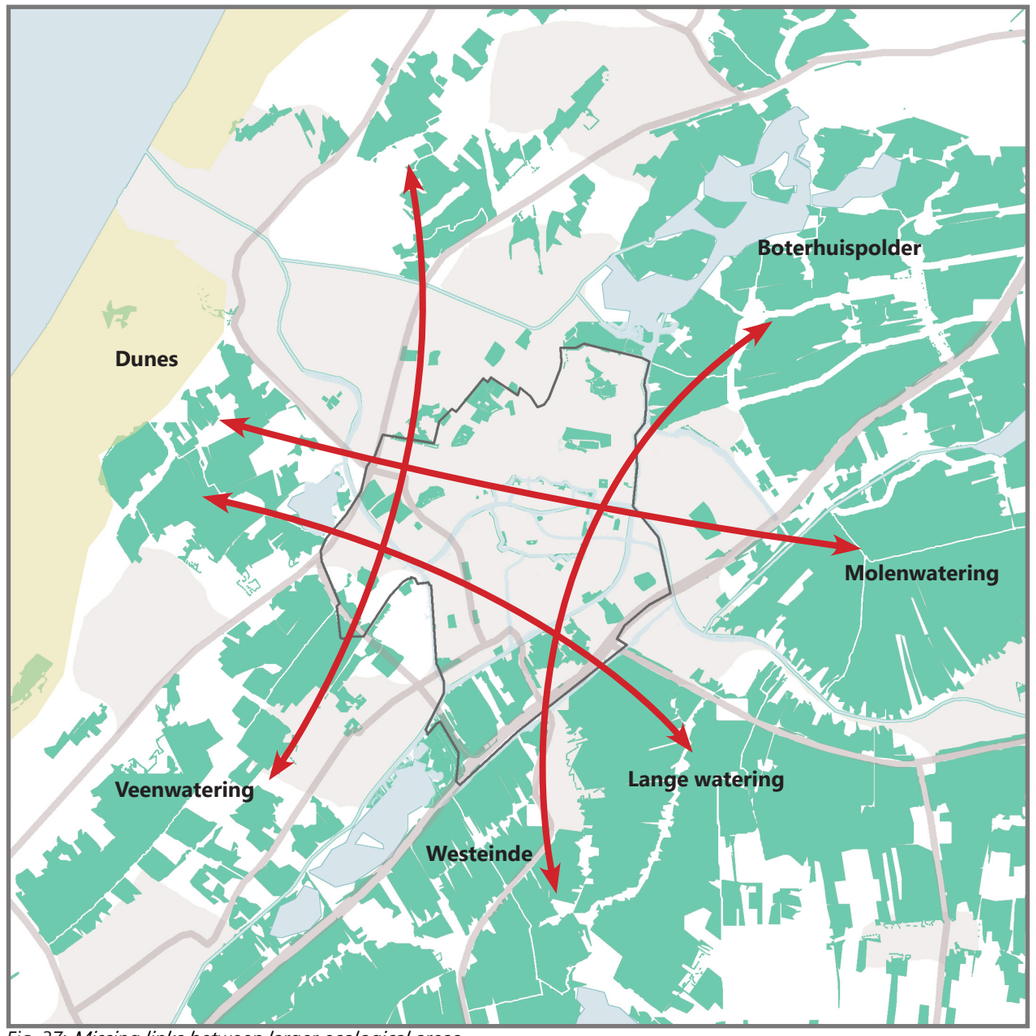


Fig. 37: Missing links between larger ecological areas

4.1.1 Green structure

Green surfaces and vegetation are important parts of the cities structure. They help with providing habitats for flora and fauna, but also help with effects of climate change and public health. Fig 38 shows the green surfaces in Leiden. This map contains verges, trees and small green patches, as well as larger green patches like parks, cemeteries and sport parks. However, although they are part of the overall green structure of the city, not every single green surface is ecological valuable. The most biodiversity can be found in parks, cemeteries, the communal garden and edges of sport field (see next page). Other green surfaces most often have no to very little ecological value. (See examples below).









Fig. 39: Not all green surfaces have equal ecological value

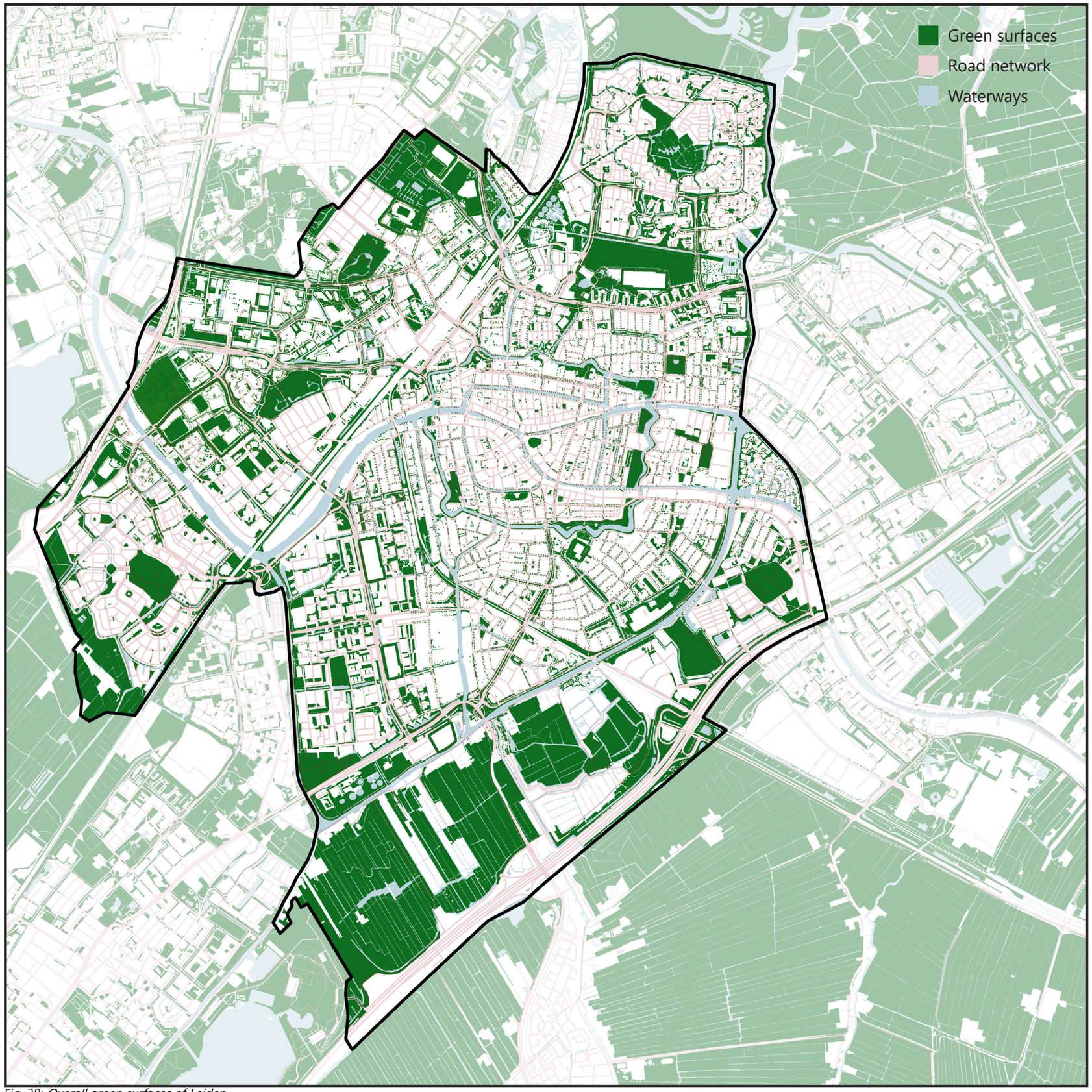


Fig. 38: Overall green surfaces of Leiden

Parks

A specific type of urban green space are parks. These areas are great hot-spots for biodiversity. Park space in particular has a powerful effect when compared to other green spaces. Urban parks' heterogeneous micro-habitat diversity and habitat diversity appear to be the most important determinants of overall species richness. One of the single most efficient ways to boost urban species richness and species diversity among species of birds, invertebrates, mammals, amphibians, and reptiles is to turn urban land into park space. The city of Leiden has several parks accessible to the public. The city center is now surrounded by the Singelpark, but as shown below, its not yet a completed circle. Other parks, and thus spaces with high biodiversity, include the Neighborhood park Merenwijk in the north, the Leidse Hout in the west and the larger recreation area the Vlietlanden in the south. These park areas are most important for urban biodiversity but are not connected yet (Anders Busse Nielsen, 2013).

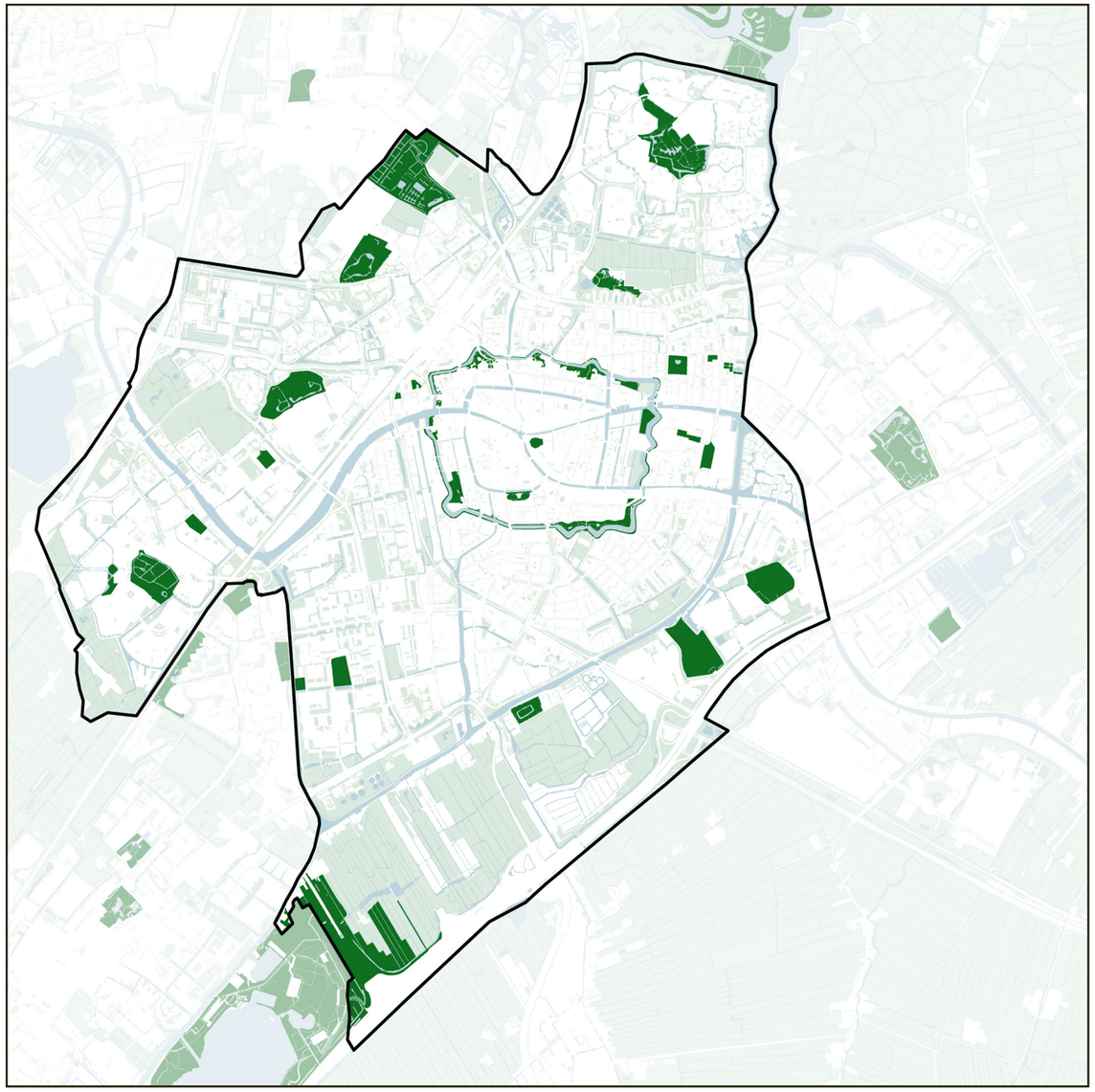


Fig. 40: Parks

Cemeteries

Cemeteries have close ties to local history and are often referred to "repositories of natural and cultural diversity". Cemeteries play important conservation roles in urban environments. Natural ruins associated with sacred groves and other culturally protected areas support the preservation of rare species and their natural habitats around the globe. Old cemeteries may also serve as habitat islands for local species that are otherwise rare in heavily populated urban areas. Due to their size, habitat diversity, and habitat continuity, cemeteries may be crucial for the preservation of urban biodiversity. They might also offer crucial ecosystem services, just like other habitats with a lot of trees (Löki, Deá, Lukács, & Molnár, 2019).

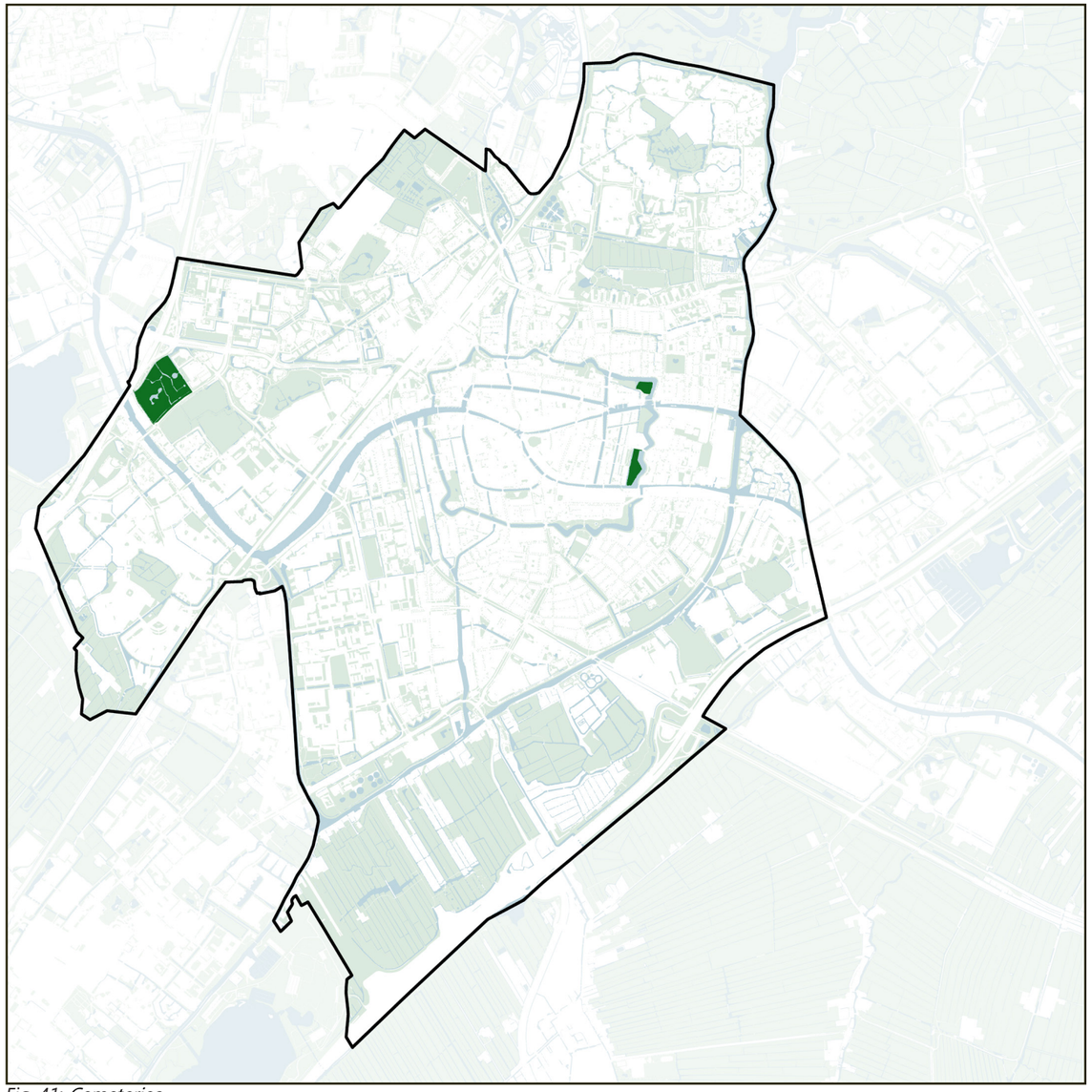


Fig. 41: Cemeteries

Communal gardens
Community gardens have a lot of potential for the urban green infrastructure compared to other types of urban public green spaces, considering their small surface area. Community gardens are more stable than urban wastelands, but less stable than public green spaces. Less than 100 meters, separate most community gardens from a railroad track or a major road system. These factors contribute to the stability of these gardens while also serving as a key component in evaluating their potential for the urban green infrastructure: the marginalization of these community gardens in urban areas may be bad for some residents but beneficial for the city's ecological sustainability (Glatron & Granchamp, 2018).

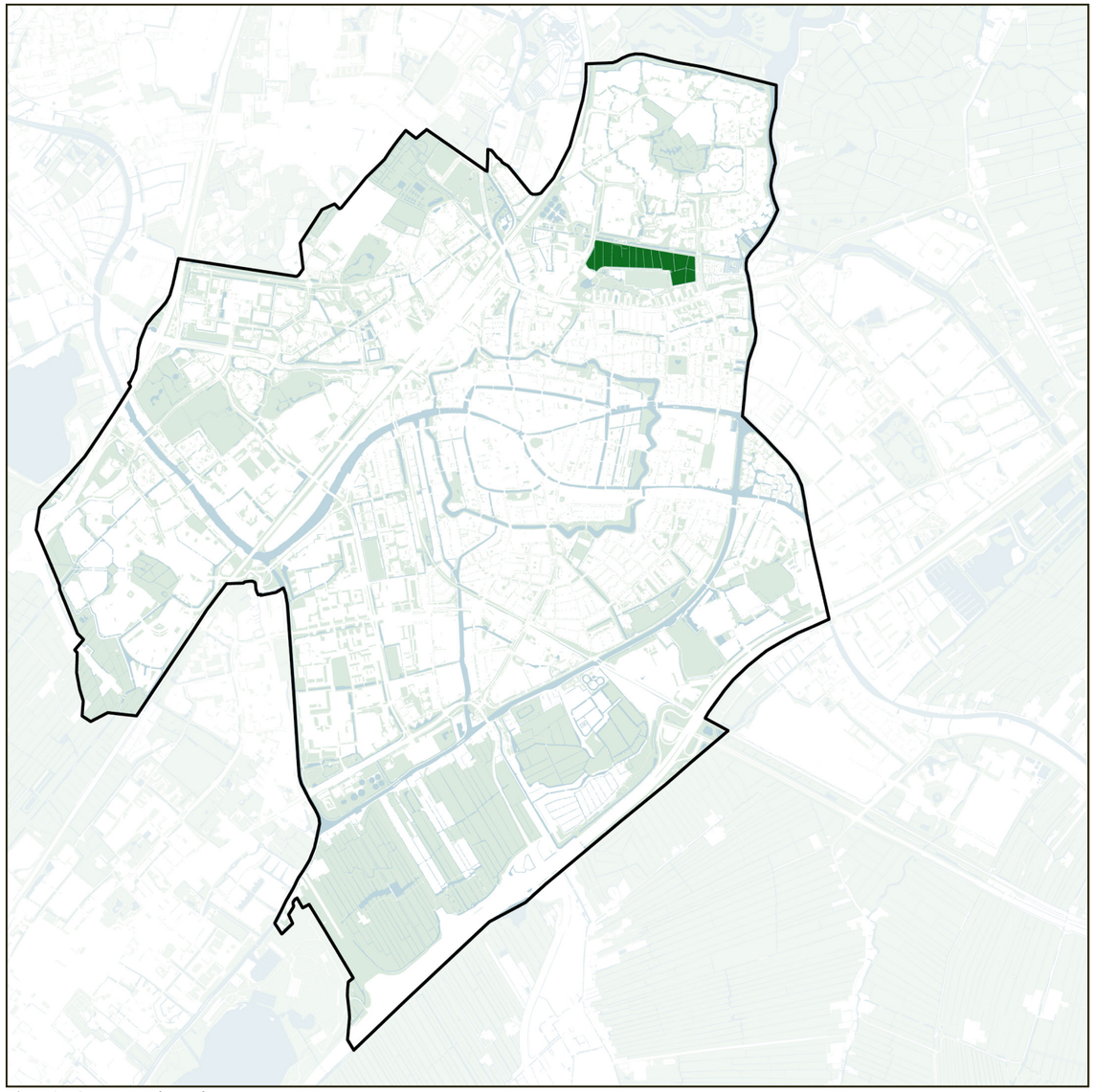


Fig. 42: Communal garden

Sport fields
Sport can have negative impacts on biodiversity through the need for land area to construct permanent and/or temporary sports venues and support facilities. Further adverse impacts on biodiversity can arise from the demand for natural resources such as water, the generation of high quantities of solid waste and water pollution linked to the use of chemicals and the generation of municipal wastewater, and high levels of noise and light pollution triggered by the presence of supporters. However edges of the sport fields often are highly vegetated which shows a potential of high biodiversity along side these edge (Wheeler, 2020).

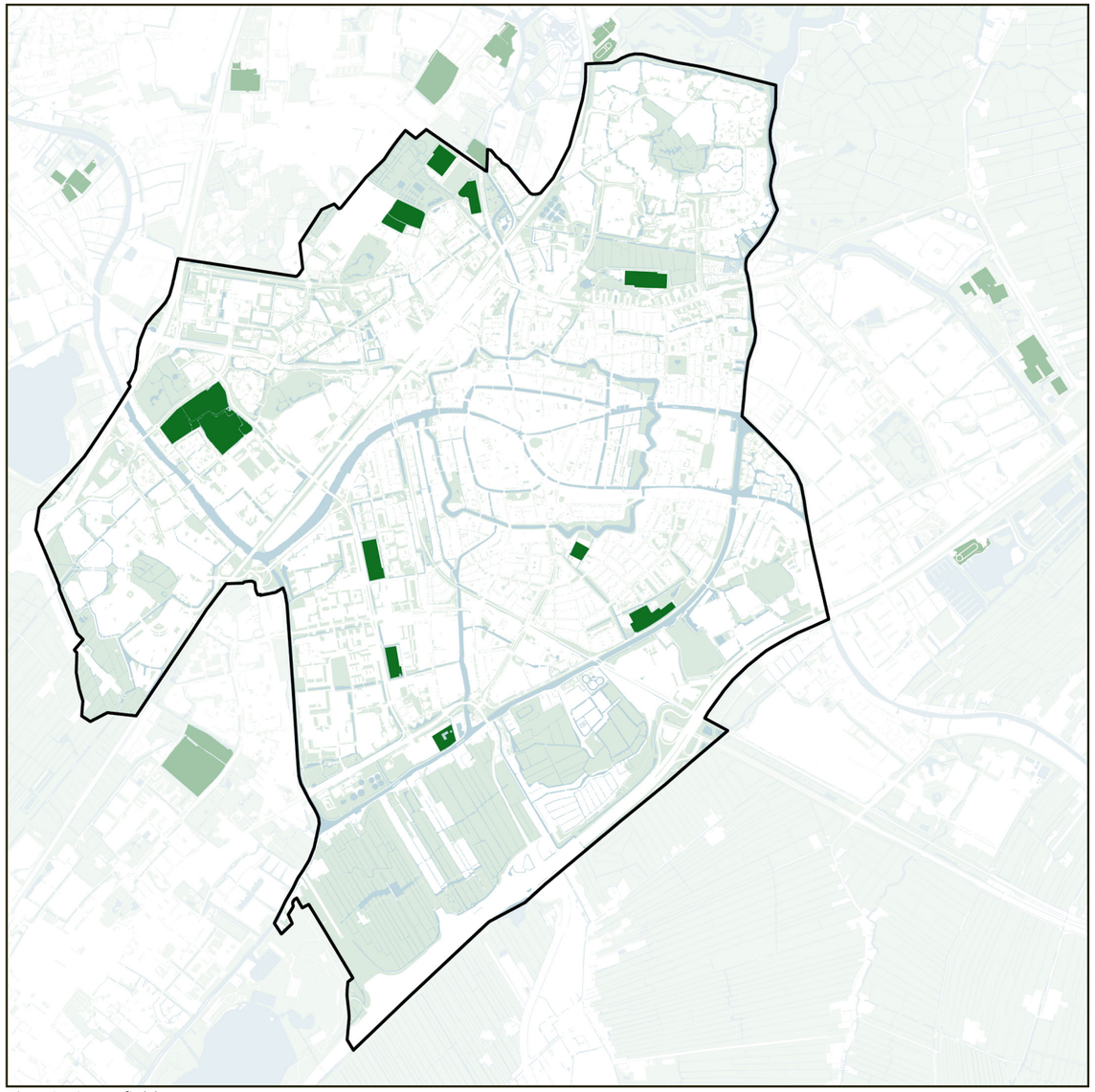


Fig. 43: Sport fields

4.1.2 Patch-corridor-matrix

Chapter 3 focuses on the theory of the patch-corridor-matrix, where patches are the green areas, corridors are connections between them and the matrix is everything in between, which is not suitable for wildlife movement.

This theory is now applied to the city of Leiden (fig 44). However, there has been a slight adjustment being made relative to the theory. The patches in Leiden consists of early mentioned biodiverse hot spots, which are urban parks, cemeteries, the communal garden and the edges of sport fields. Whats different relative to the theory, is that the theory explains that the corridors have a natural base. In the case of Leiden however, there are very little to non existing corridors. Therefore in this map the road network is shown as a possible corridor between patches. Since the research focuses on road-related ecosystem services, it is interesting to look at what their position is, in comparison on where the biodiverse hot spots are. This makes the relationship between patches and corridors clearer and priorities can be set on which roads are most important to transform into an ecological corridor.







Fig. 45: Clearly defined road corridors in the urban fabric



Fig. 44: Patch-corridor matrix in Leiden

4.1.3 Blue structure

Leiden can be described as a city with several small canals and some larger ones. The most notable is the Rijn, that originates all the way from Switzerland. This river flows straight through Leiden and joins with the Vliet, which runs all the way to Voorburg. Furthermore the city center is surrounded by the singels, which for a long time was the defensive line of the city. Alongside the singels, the singelpark is now being constructed, which serves as a complete continuous park around the entire city. However, alongside most of the Rijn there is a hard border between land and water, which does not promote the urban biodiversity.

Larger water bodies are not common within the cities boundaries. Larger water bodies can be found in the north (Het Joppe), the west (Valkenburgse meer) and the largest one in the south (Vlietland). While these areas are found outside the city, they have a high form of biodiversity. They are surrounded by large green spaces which attract many species and are a perfect place where animals and plants can thrive.



Fig. 47: Het Joppe: a highly biodiverse area



Fig. 48: Hard borders between water and land



Fig. 49: Singelpark as continious park around the city

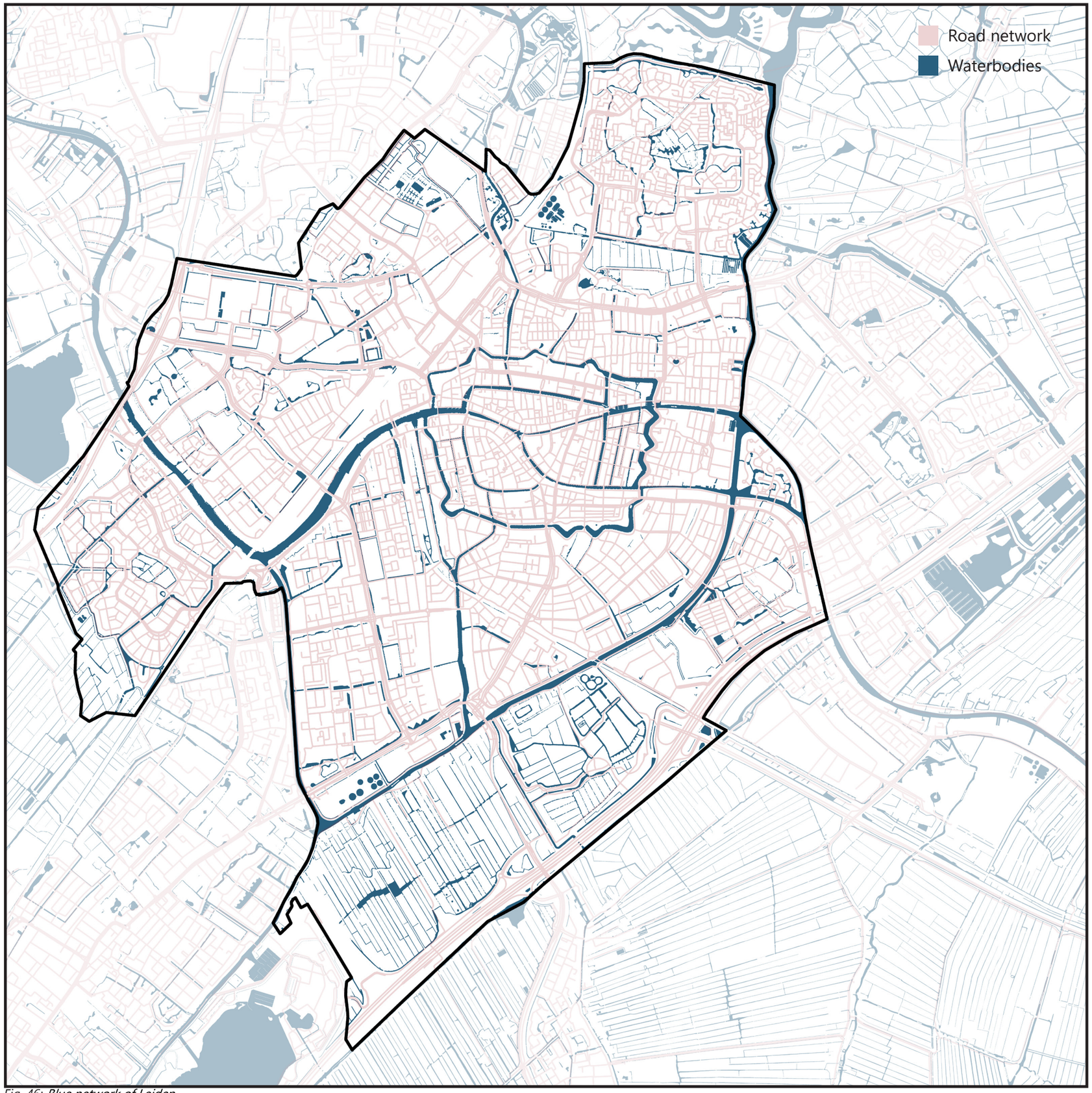


Fig. 46: Blue network of Leiden

4.1.4 Built environment

Buildings are often forgotten when it comes to opportunities for wildlife to rest and occupy. Animals also use buildings to find shelter, as they are often heated and well sheltered. The type of buildings and neighborhoods have a large influence on the biodiversity. Also surroundings of those buildings are important, since for example birds need space to find food. Large open areas with little to no vegetation is a less appealing area than highly vegetated surfaces. Buildings, especially with a garden, can also serve as habitats and corridors between larger patches. Hedgehogs, for example use gardens for shelter and food.



Fig. 53: High buildings as shelter



Fig. 52: Backyards as wildlife habitat



Fig. 51: Bats under roof construction

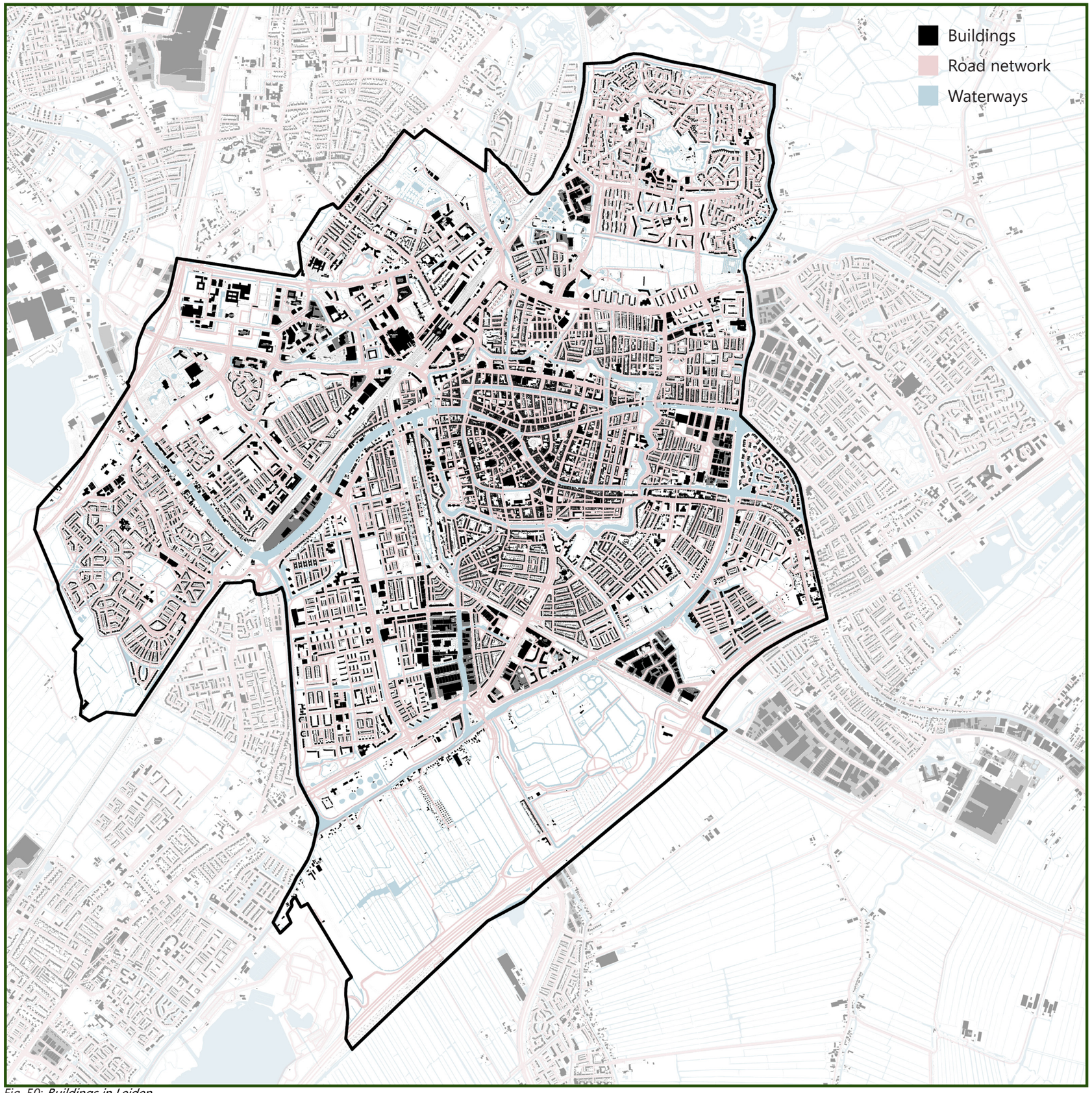
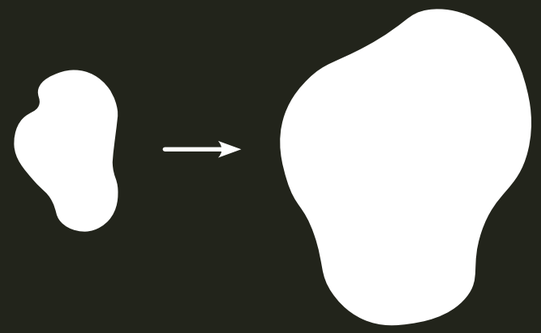


Fig. 50: Buildings in Leiden

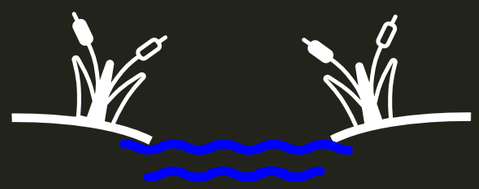
Design principles to increase ecological resilience



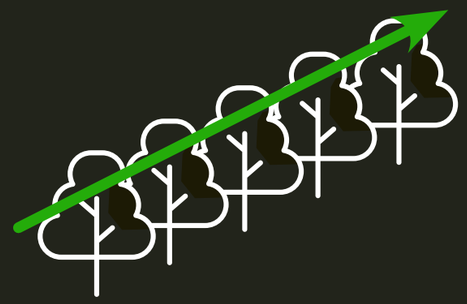
Adding vegetation will not only help with ecological resilience but will also help with the effects of clime change



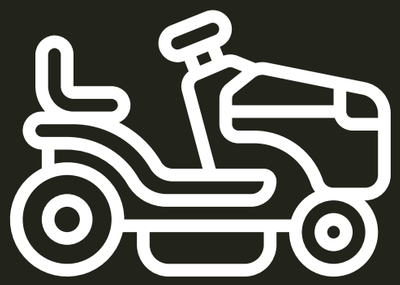
Large green areas are preferred over smaller ones



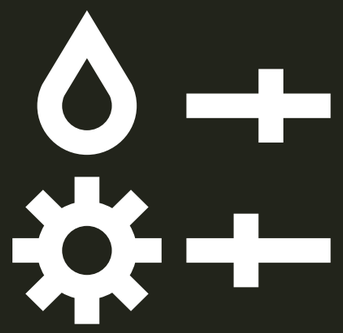
Transforming hard quay borders into soft borders improves waterfront bio-diversity



Providing a continuous green structure will help animals move and creates spaces where nature can thrive



Creating a balanced maintenance plan for natural surfaces can greatly im-prove biodiversity.



Don’t try to design a complete eco-system, but rather design conditions where the ecosystem can form its own robust form

4.2 Road analysis

Leiden is the second most dense city of the Netherlands. This also includes an extended road network. On the other hand, this makes the city incredibly accessible, with services such as a large train station and several buses that can take you everywhere within the city, as well as to surrounding towns within the province. Leiden is distinguished by the exclusive right of buses, which have their own lane in some areas, but there are also streets that are solely fit for bus traffic. For the rest, Leiden is easily accessible by car, as the A4 and A44 bypass the city and have direct links to the center. The municipality is currently replacing and enhancing the sewerage system in several locations, and they are immediately considering how the existing road surface might be better planned to further greening the city.

The road network structure and road design have a significant impact on road safety: first, they make certain conflicts impossible or unlikely (for example, physical separation of driving directions, separate cycle paths, barrier-free shoulders); second, they direct desired traffic behavior (recognizability, predictability). To further understand the road network of Leiden, this analysis uses the Dutch road classification, as stated by the SWOV, which is a national scientific institute for road safety research (SWOV, 2023).
The road network is first classified by functional network structure, and will help with understanding the hierarchy of the road network of Leiden. Each of them has its own set of design ideas, both for the road sections and the intersections. The following classification is being made:

1. Highways and N-roads

2. Distributor roads

3. Residential roads

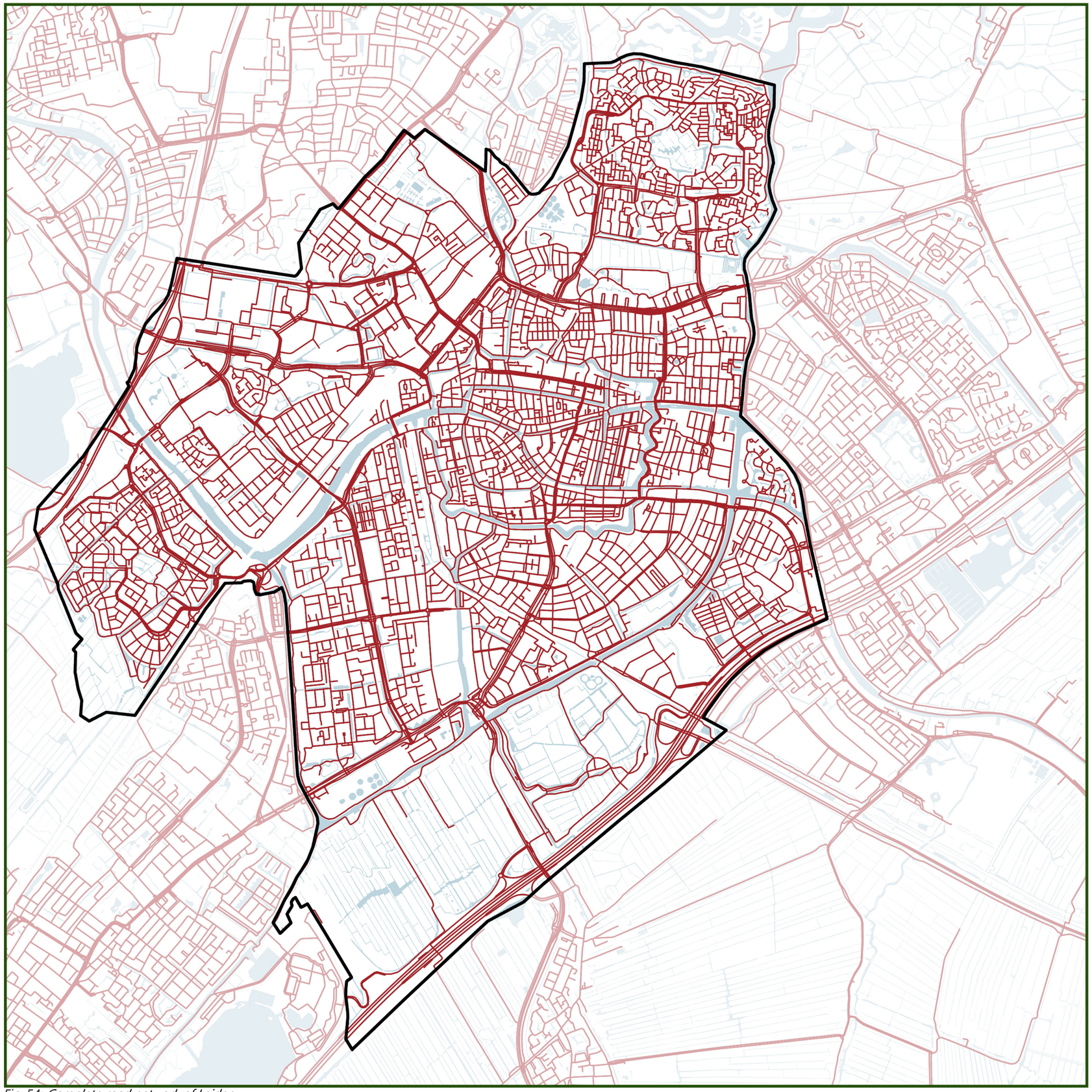


Fig. 54: Complete road network of Leiden

4.2.1 Road Typologies

The design of the roads in the Netherlands is based on the functional network construction philosophy, which is bases on two major traffic functions: flows and stays. In the case of flowing, motorized traffic is managed promptly, efficiently and safely. In the case of staying, the road allows all forms of traffic to access residential areas, shopping areas, office areas and company areas. A third (ancillary) function for a road is connecting roads with a flow function to roads with a stay function. It is very important for road safety that each road has only one function, which is called mono-functionality. As stated before the road network can be divided in three classifications:

1. Highways and N-roads (fig 55) allow traffic to go between origin and destination as swiftly and safely as feasible. Car traffic takes precedence here. Through roads are only possible outside of urban areas.

2.Distributor roads (fig 56) connect the estate's through roadways and access roads. Traffic flows on road segments, and interchange occurs at intersections. Distributor roads can be found both inside and outside of cities. These are in particular the 50 and 70 km/h roads within built-up regions and the 80 km/h routes outside built-up areas.

3. Residential roads (fig 57) connect residential neighborhoods at the point of origin and destination. Staying here is central and car traffic must adjust (especially owing to low driving speeds) to the 'residents' such as cyclists and walkers. There are access roads both within and outside of built-up regions. This applies to 30 km/h roads and yards (15 km/h) within built-up regions, as well as 60 km/h roads outside built-up areas.

The function-form-use triangle, which is widely employed by designers outside of the 'traffic' industry, is the foundation of road design in theory. This triangle indicates that the designs function or goal must be expressed in the design and layout, and that the design must result in the intended and desired behavior and use. In terms of traffic, this means that an ideal road design is linked to each of the three traffic functions. (flow, accommodation and connection). This leads to road users' planned and desired use. From the perspective of a road user, the design must make obvious what the intended function is and what the desired behavior is. This is referred to as "recognizability." The design criteria were developed in accordance with the Sustainable Safety concept and the Sustainable Safety principles of functionality, homogeneity, and predictability.

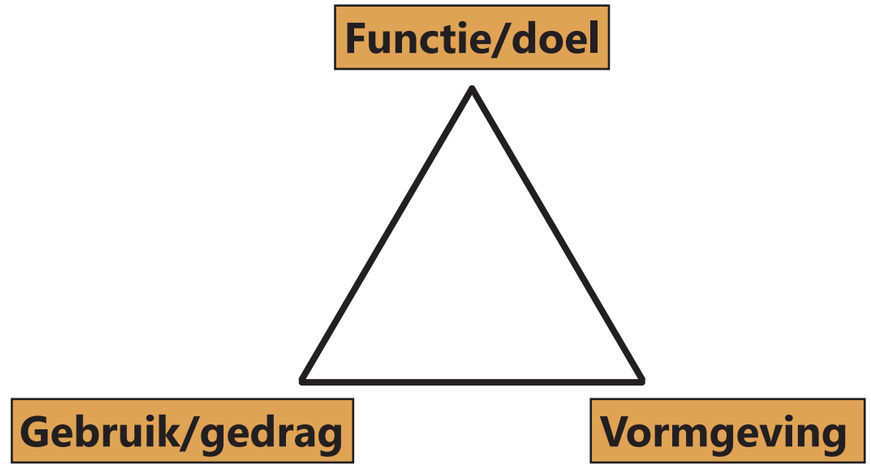


Fig. 58: The function-form-use-triangle for road design

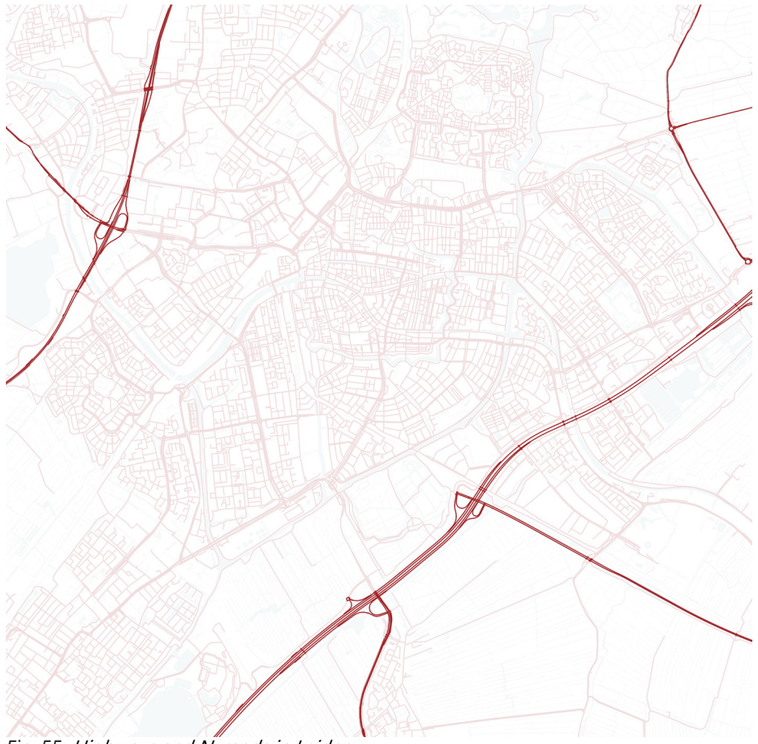


Fig. 55: Highways and N-roads in Leiden

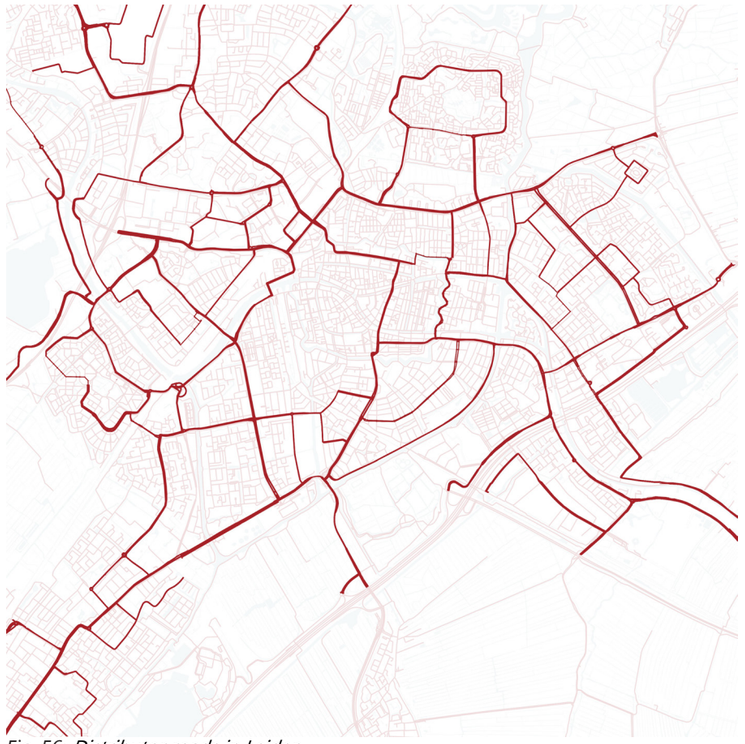


Fig. 56: Distributor roads in Leiden



Fig. 57: Residential roads in Leiden



Fig. 59: *Provincialeweg, a typical N-Road in Leiden*



Fig. 60: *Hoge Rijndijk, a typical distributor road*



Fig. 61: *De Meij van Streefkerkstraat, a typical residential road*

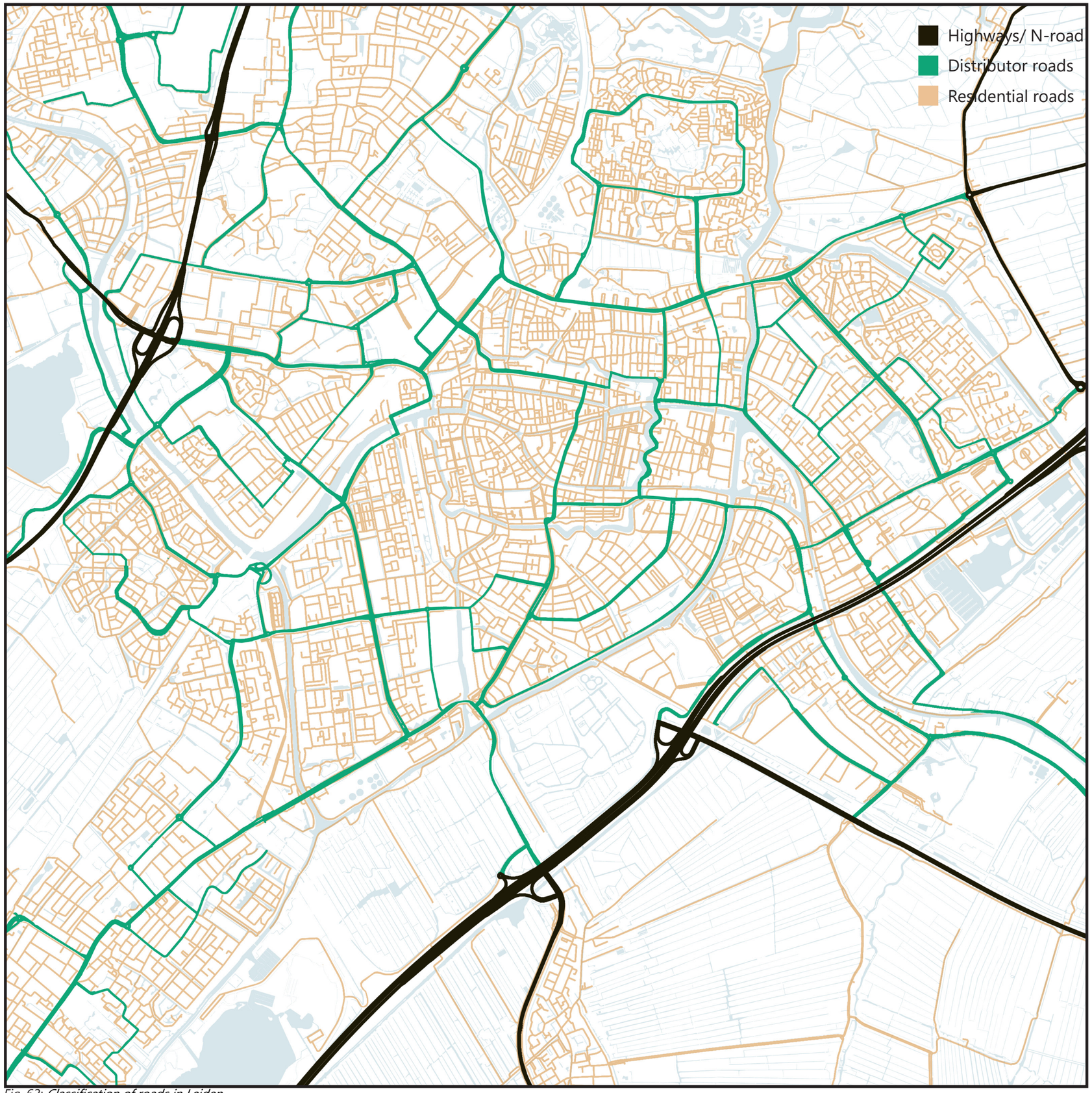


Fig. 62: *Classification of roads in Leiden*

4.2.2 Built vs non-built

In order to use the road network as ecological corridors, it is important to know where space is available to change the roads role. Therefore a so-called Nolli map has been created (fig 63). This is a plan where the accessibility and flows of the spaces within a city are being illustrated. However, since this project focuses on the street profiles and therefore public space, the map is a little bit different from its original. In this case every building (private) is being shown in black and every white space (public) is being shown in white. This way an insight is given in where opportunities, beyond the road network, lie and different types of roads can be made.

The map shows on first sight already some interesting possible corridors, related to the road network. What the maps makes clear is that the white lines all vary in width and size. This has to do with the function of this road, and several functions can be distinguished (Allan, 2022):

Way: A small side street off a road.
Street: A public way that has buildings on both sides of it. They run perpendicular to avenues.
Avenue: Also a public way that has buildings or trees on either side of it. They run perpendicular to streets.
Boulevard: A very wide city street that has trees and vegetation on both sides of it. There's also usually a median in the middle of boulevards.
Lane: A narrow road often found in a rural area. Basically, the opposite of a boulevard.

This distinguishing can be helpful with creating street-specific interventions, and apply them to a particular form of street.



Fig. 63: Classification of roads in Leiden

4.2.3 Intersections & roundabouts

The road network also includes a lot of intersections. The Dutch national scientific institute for road safety research (SWOV, 2022), describes 5 different types of intersections: four-branch intersection, three-branch intersection, bayonet intersection, roundabouts and a priority square. Because an intersection is a point where roads converge, there is obviously a lot of asphalt and stone present. These hard surfaces form a barrier in an ecological corridor (fig 65)

From a traffic point of view, intersections need to have certain standards to maintain safety for all users, as well as a decent mobility flow. However, these intersections also have ecological impacts on the environment and on the corridors. Because there will always be intersections breaking through an ecological corridor, it is important to consider design interventions that will minimize the impact and size of this barrier. Too large of a barrier will ensure animals cannot cross and will therefore not move from one habitat to another. However, by improving the ecology of intersections, safety and mobility flow might lose their balance and the intersection is not working anymore. It is therefore also very important to find a balance not just between safety and flow, but also take ecology in consideration.

Traffic wise, the SWOV indicates in which situation, which type of intersection is preferred. In almost every case a roundabout is preferred, since this has the fewest contact points, and they are much safer for cyclers and pedestrians. Speeds higher than 50km/h will prefer a roundabout, rather than a traditional intersection (fig 64).

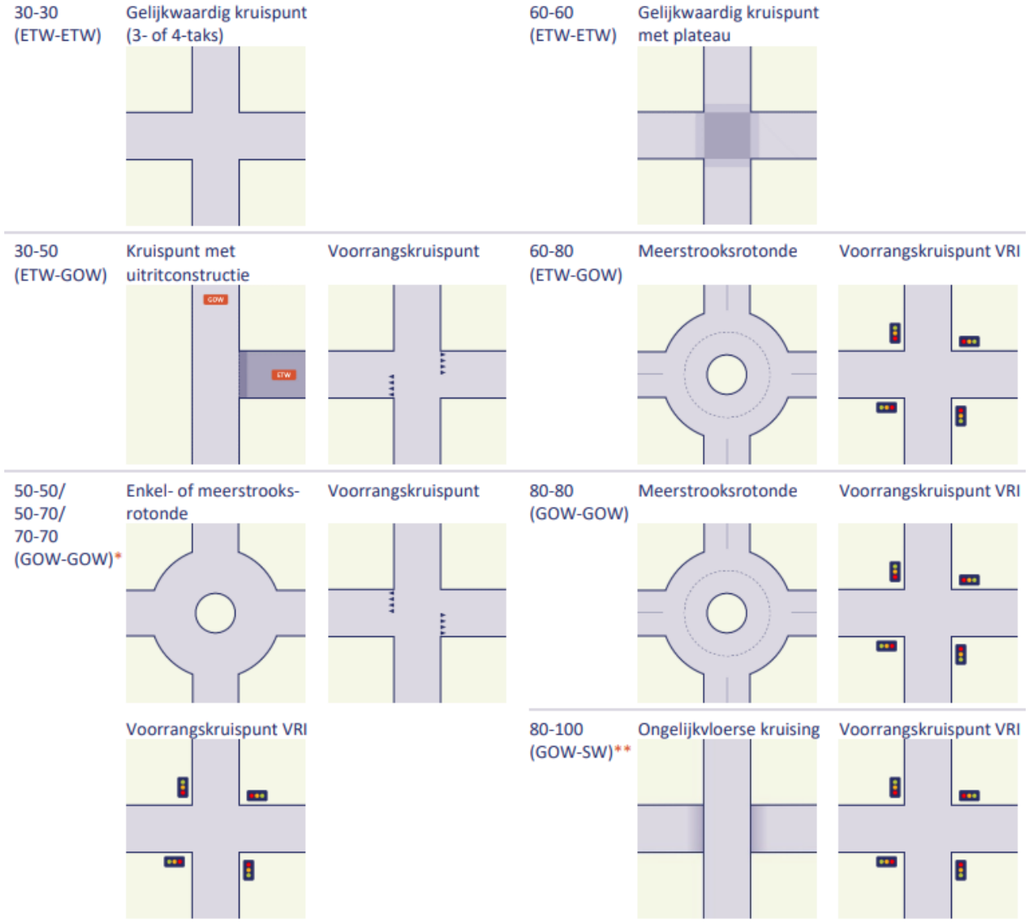


Fig. 64: Recommended intersection types by location. If there are several options, the most desirable intersection type from a safety point of view is listed as mentioned first. (SWOV, 2022)



Fig. 65: Intersections form a barrier in ecological corridors due to their presence of a lot of asphalt and stone

First of all it is necessary to know how much space is now needed for cars, bikes and pedestrians, and where can green surfaces be implemented. Fig 66 shows the difference of space needed between a roundabout and a traditional intersection, and where the ecological corridor need to go through in order to maintain continuity. Minimizing the barrier effect that roads have, several interventions can be made. For example, cattle grids can be implemented for smaller animals to cross the roads underneath. Also placing trees as close as possible to each other minimizes the distance in between for flying animals. Furthermore, decreasing speed and promote biking and walking will actively contribute to less roadkill, healthier people and lesser negative impact on the direct and indirect environment, which will benefit animals and nature in the ecological corridor.

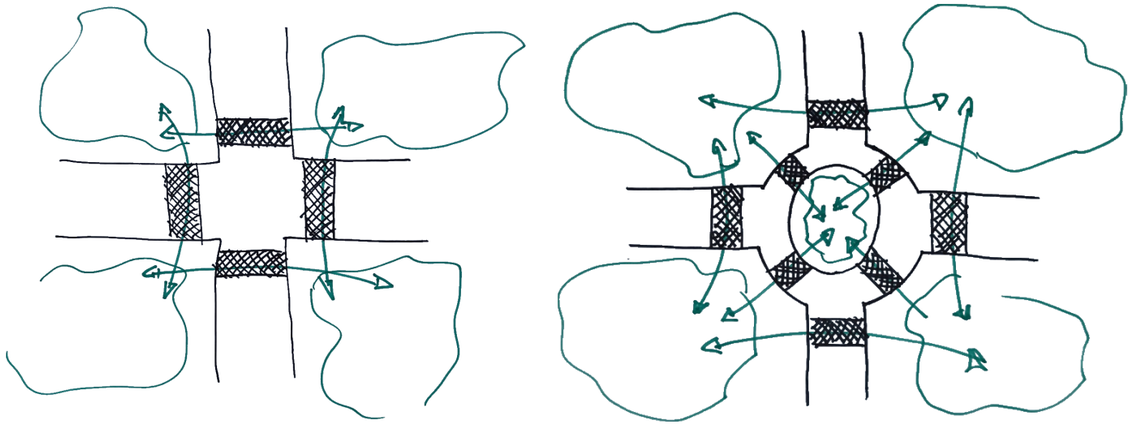


Fig. 66: Spatial movements wildlife at intersections

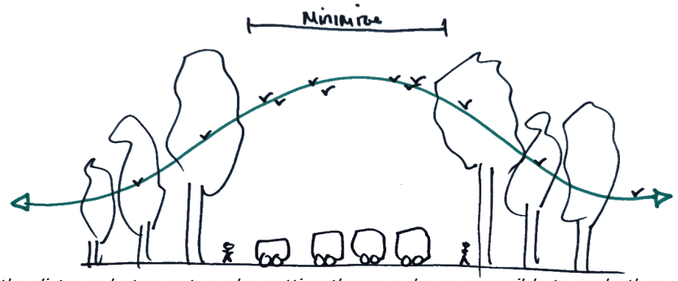


Fig. 67: Minimizing the distance between trees by putting them as close as possible to eachother

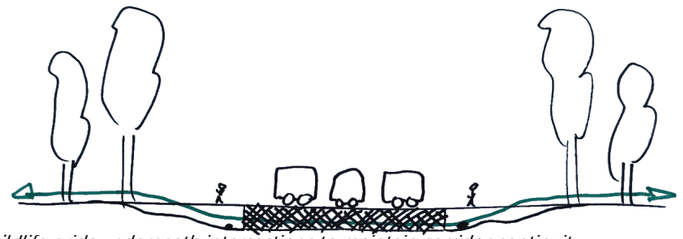


Fig. 68: Integrate wildlife grids underneath intersections to maintain corridor continuity

4.4.4 Conclusion

In addition to promoting biodiversity in large green spaces like natural parks, connectivity between isolated habitats is also essential for promoting biodiversity in urban areas. Enhanced gene flow is one of the mechanisms of connectivity. The genetic diversity of isolated populations is typically lower than that of connected populations, which reduces the population's resistance to threats like disease and environmental change and undermines conservation efforts. Additionally, connectivity increases species diversity in urban environments. Buildings and other urban features obstruct the movement of highly mobile animals just as they do for larger mammals. For instance, connectivity has an effect on insects like spiders and beetles. In a study, gardens connected by green corridors outperformed isolated gardens in terms of species richness and abundance. Even birds benefit from connectivity despite their high mobility. Simple changes like adding tree-lined streets between urban parks have been linked to higher native bird populations than parks alone. The connections between the green patches are the most efficient when they are connected via the shortest link between them. The image below shows the shortest links between the biodiverse hot-spots is shown. These connections don't necessarily are parts of the arterial road network. In fact, several connections are on the smallest roads of Leiden.

When looking at how the arterial network of Leiden plays a part in connecting biodiverse hot-spots, it is interesting to see that almost every road is connecting some sort of green patch. The roads can be a good a addition to the green structure of Leiden. Since humans can not precisely direct where animals need to go to, we can however give them certain features that steer them in the direction we want to go to. Therefore the road network can play an important role as connector, since these streets are the widest and most of the time there is space leftover to create ecological features for the corridors. By using the road network, and in addition make use of the minor arterial and collectors road a green network can be created to sustain and support urban wildlife.

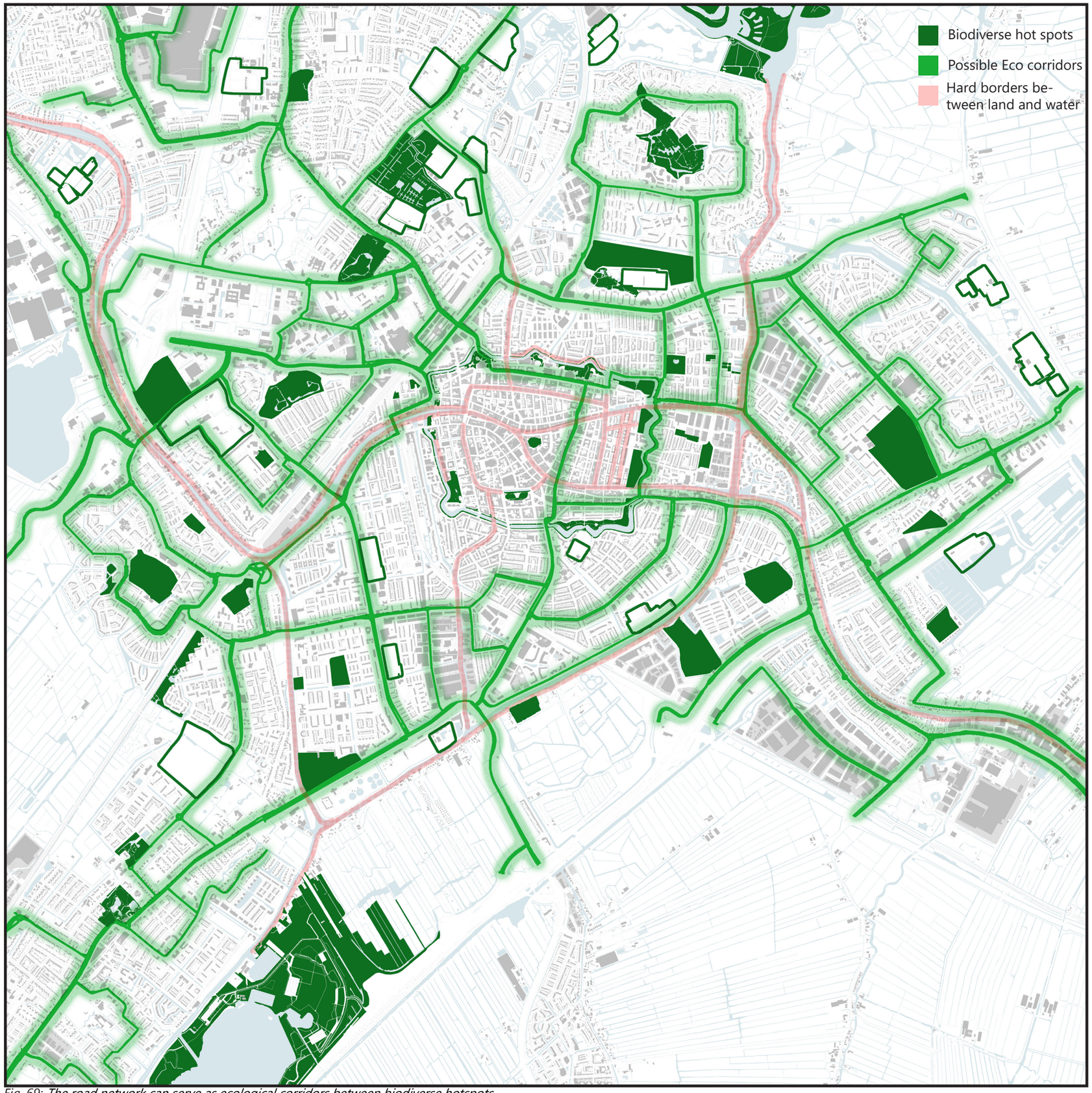
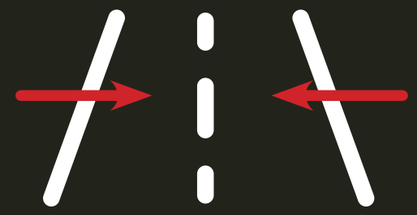


Fig. 69: The road network can serve as ecological corridors between biodiverse hotspots

Design principles to reduce impact of road network on ESS



Creating car free zones will helps with reducing the emission of dangerous gases.



Bunling lanes minimizes the negative effect roads have on their enviroment



Removing parking zones creates more space for green surfaces, as well as make people choosing the bike or walking more often.



Removing lanes will create more space for green lanes, but has a negative impact on mobility.



Reducing the speed that cars can drive will help with decreasing negative effects to a roads direct environment

4.3 Flooding

Because of climate change, in the coming years, we will experience more intense, longer and heavier rainstorms. This rainstorms cause problems in the city, such as standing water on the streets or water coming into buildings. This is due the fact that the amount of water during such a rainstorm can not be drained quickly enough through the sewage system of waterways, or, because of a lot of stony surface, can drain quickly enough into the soil. This includes paved private gardens, large stony squares, sidewalks, asphalt roads, buildings an parking lots. Flooding can cause damage to homes, gardens, and basements. Water can also remain in tunnels and streets, impeding emergency services and other traffic. Polluted sewer water may end up on the street if the sewer system can no longer handle the volume of water. As a result, people may come into contact with polluted water. Water pathogens have the ability to enter the body and cause infection.

Climate change will increase the likelihood of heavy rainfall. Figure 70 shows where in Leiden water remains on the street and which buildings have a chance of getting wet against the facade. The deeper the blue, the more water that may end up on the street

When replacing the sewage system, the municipality considers heavier downpours. When the sewer system is replaced, a larger-capacity sewerage system is installed. This sewer, however, is insufficient for the most intense rainfall. It is often impossible to install a sewer capable of absorbing intense rainfall because it does not fit into the subsoil. Furthermore, retaining rainwater in the soil aids in drought prevention. A new separate sewer will be installed during the replacement, allowing clean rainwater to be discharged separately from wastewater, ensuring that dirty waste water does not end up on the street during a heavy rainstorm. (GaGoed Leiden, z.d.)

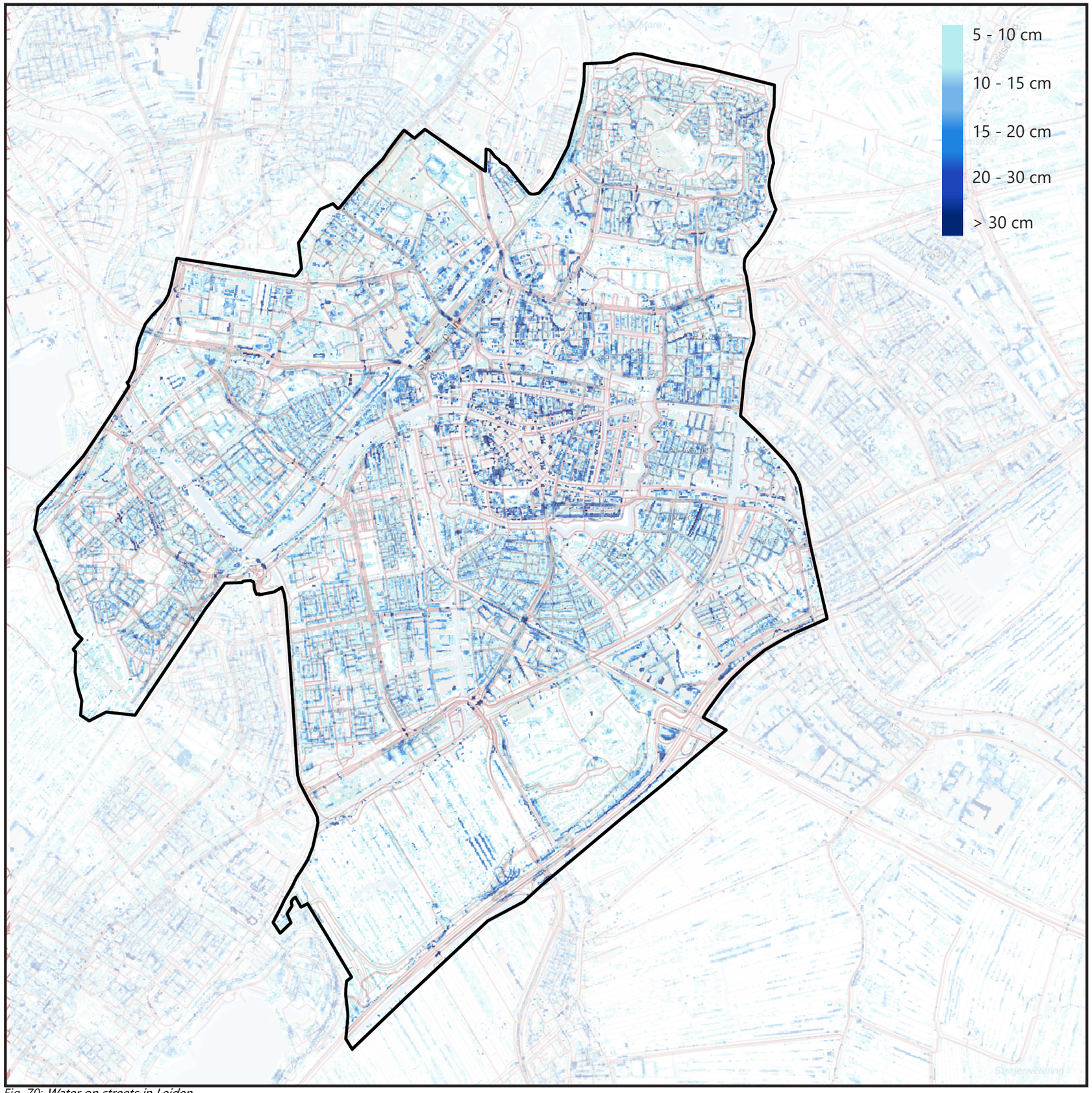


Fig. 70: Water on streets in Leiden

4.4 Urban heat island effect

When dealing with climate change, the urban heat island effect will also occur more often and will also increase in temperature. Hot summers like 2018, where temperatures soared above 40 degrees will become more common. Buildings, roads an other pavement not only warm but they also retain heat. As a result, the feeling temperature can rise above 60 degrees, especially in areas with little to no green surfaces (fig 71). Heat has an impact on how fit we feel. Extra heat can lead to a poor night's sleep, concentration issues, headaches, dehydration, overheating, and decreased productivity at work. Heat stress can cause more illness and even death in vulnerable groups.

To combat heat stress the municipality of Leiden is working on greenifying and soften up the public spaces that now consist mostly of asphalt and stone. Greenery provides cooling in the summer, allows water to sink deeper into the soil, and provides a safe haven for small animals (bees, butterflies, and other insects) and birds. As a result will Leiden not only become more climate resilient but will also improve in aesthetic values. Residents and businesses own a large portion of the city (roughly half). As a result, they are also urged to begin greening and making their garden or terrain heat-resistant (GaGoed Leiden, z.d.).

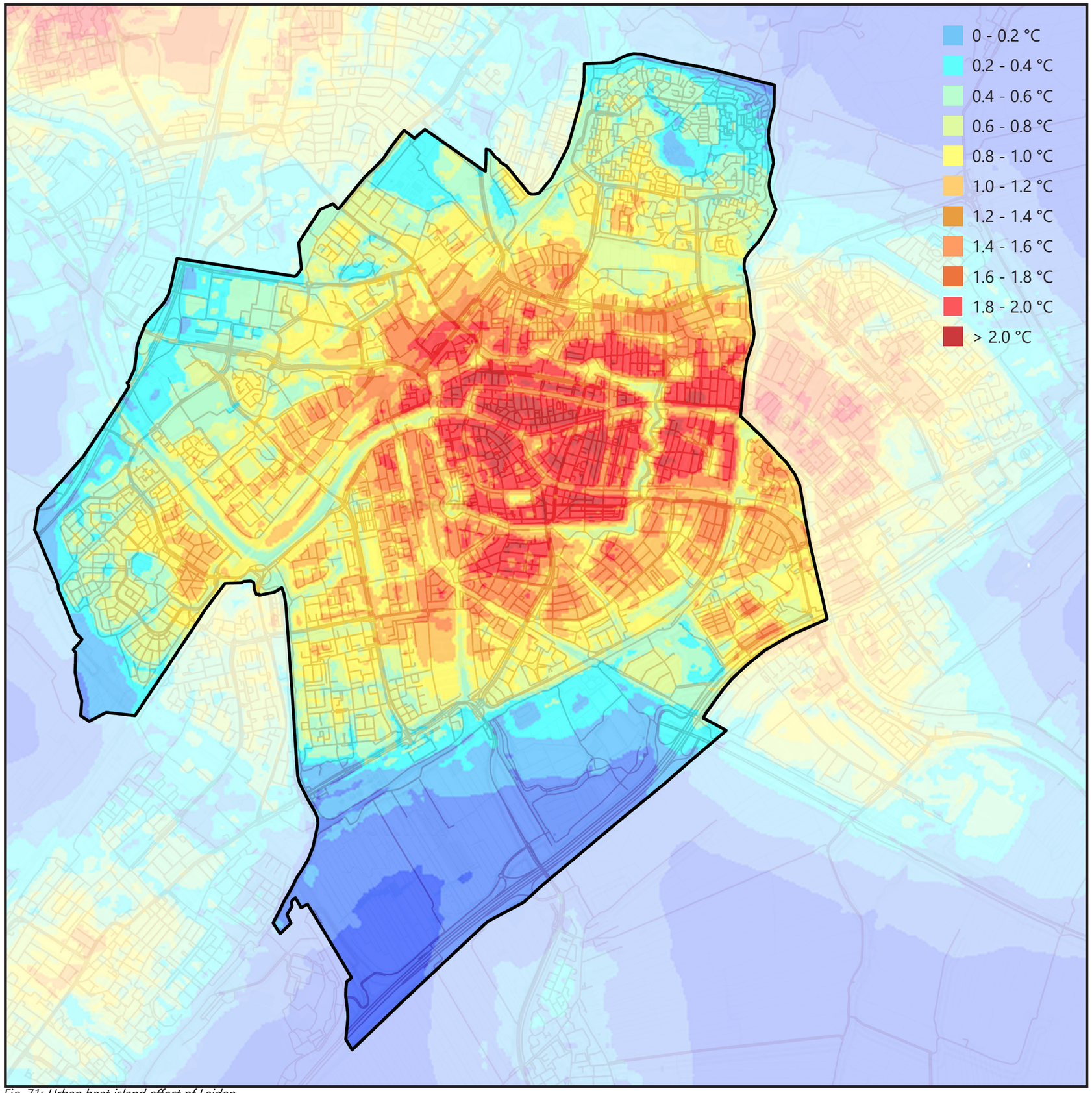
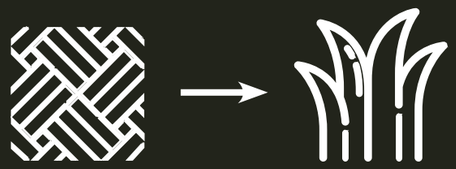
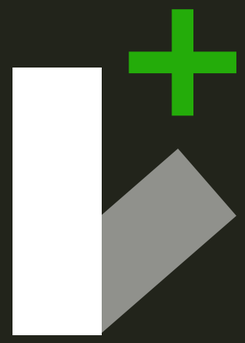


Fig. 71: Urban heat island effect of Leiden

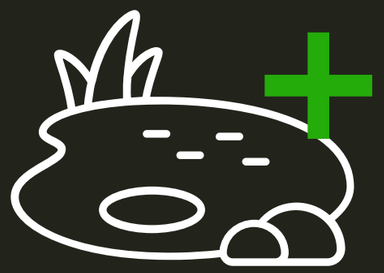
Design principles to make Leiden more climate resilient



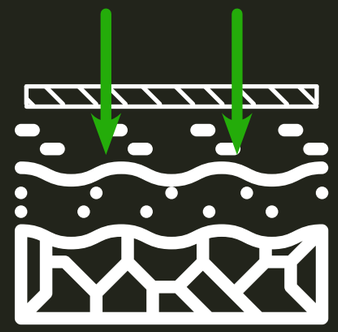
Transforming useless hard surfaces into soft surfaces will help with several climate issues



Where trees can not be planted other forms of shadows need to be created to have a cooling effect on the immediate surface



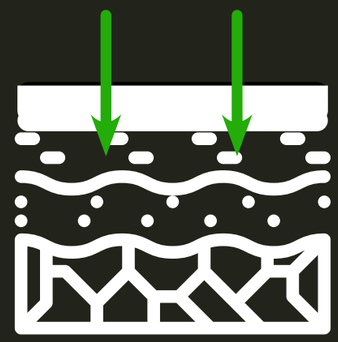
Implementing waterbodies in street profiles will help with cooling the city but also helps with dealing with heavy rainfall



Permeable pavements will help with dealing with an abundance of water during heavy rainfalls



Planting trees will create shadows that help with the cooling effect, as well with creating habitats for animals



Porious asphalt slows down the downpour of water into sewage systems, so that they can process the water in a proper manner.

05
Flora & Fauna



This chapter focuses on two natural components: plants and the target species for Leiden. By analyzing spatial needs of specific target species and looking at which plants are most feasable for the street profiles, a natural basis can be created for the urban strategy. These spatial needs will be demonstrated in chapter 6.

5.1 Leiden's target species

In order to get design principles related to nature and wildlife, it is important to know which green patched need to be connected, which plants and wildlife is chosen and what is possible in terms of using the street profile as a tool for a ecological corridor. To get an understanding of what these corridors have to consist of (related to plants and wildlife), target species are being selected. These target species each have their own specific spatial needs, which then can be transformed to design principles. What is important to note is that not every target group lives in the same layer of nature (fig 73). Size, shape, amount, distribution, ecological function, feeding preferences and desirability all vary among the species. Trying to create ecological corridors where every specie can benefit from is simply not possible. It is necessary to identify the city's desirable target species that are high on the pecking order and make a positive contribution to interactions are preferred over the more absent species. To select the target species of Leiden the umbrella approach is being used. "Umbrella species are at the top of food chains or with large home ranges so that by protecting these species we protect all species on which they depend or the species with similar requirements but smaller home ranges." A coarse change method is proposed, in which we conserve urban natural habitats and the majority of the species that rely on them. This method can be applied at various scales throughout the city. Increasing the volume and diversity of flora, for example, would increase the number of bird species. Because the coarse grain technique does not adequately protect all species, a more specialized strategy dealing with specific species is required to enhance it. This is especially critical in urban ecosystems because their habitats are the most isolated and fragmented. Some vital resources required by the species we want to preserve may be absent from protected fragments. (Jean-Pierre & Savard, 2000). With the selection of the target species, a selection is being made of the most sufficient and preferred plants that will be implemented in the street profiles. This way the wildlife and the nature part will be covered, and will give input for the natural design principles.

The target species for Leiden are selected based on the hierarchy of the taxonomic ranks. A selection is being made on the species level, which cover a wider range of the phylum level. The target species are based on the site of waarneming.nl. This sites notes all observations, categorized by sort, and shows how much they have been seen in which area of the city. Six target species are selected, and include one bird (spreeuw), one amphibian (brown frog), one insect (Honeybee), one butterfly (Atalanta) and two mammals (west European hedgehog and dwarf bat). These animals are the most common animals in Leiden and therefore fit the umbrella technique. In consultation with an external ecologist these species represent a large part of the biodiversity of Leiden.



Fig. 73: Different layers of habitat of target species



Fig. 72: Selected target species for Leiden

5.1.1 Common dwarf bat (Pipistrellus pipistrellus)

Common Pipistrelles colonies in the Netherlands are mainly found in **trees and caves** but also in man-made structures, like **cracks and small openings of buildings, cavity walls or beneath roof tiles**. They have also been discovered in cracks in the walls of church towers, as well as cracks in caverns, quarries, concrete bridges, parking garages, and structures of a similar nature. Although frequently observed in huge groups, they are thought to hibernate alone. Occasionally, enormous groups of up to several hundred animals can hang together in these clusters. There isn't a definite hibernating phase to point to. They are not reliable sleepers during the relatively warm Dutch winters. They frequently awaken and regularly hunt in moderate weather. They pick places for hibernation that are temperature-sensitive. They frequently seek out heated homes when it freezes. Although they travel about a fair amount and use various roosts, common pipistrelles are **site devoted**. They primarily hunt between **two and five kilometers** from the habitat. Flight trajectories, as far as feasible, adhere to **linear frameworks**, which means the road network could work as one of these linear movements. In order to protect the dwarf bat in their movement behavior it is important to plant linear rows of **dense trees** which protect them from hard winds, as well as **protection from street lighting.** The dwarf bat prefers to hunt in enclosed or partially open areas. They hunt at a comfortable distance (1 to 8 m) along the foliage in an irregular flight pattern with several spins and loops. Although they may soar as high as 15 m, their typical **altitude is 2 to 5 meter**. They prefer to hunt in green built-up areas, along canals, in gardens and parks with ponds, in avenues, between tree tops, above open spaces in the forest, along the edge of the forest (especially old, nutrient-rich deciduous forests), in and along avenues, rows of trees, canals, hedgerows, and sunken roads, common pipistrelles hunt in the protection of upright elements. In terms of plants and trees the dwarf bat has **no preferable tree or plant species**, as long as there is enough foliage available. They take what is offered, which includes a variety of largely smaller prey, from the air. They primarily prey on mosquitoes, midges, and sedges, but they occasionally also consume beetles, mayflies, and lacewings.

Fig 75 shows the relation between the buildings and the main habitats of the dwarf bat. They are several areas where the bat is most commonly seen. The red lines imply where connections should be made. These lines follow certain road network that are most feasible for the a specific connection. It is important to connect these patches because they can serve as a movement corridor for bats for forging and mating. The road network of Leiden can fulfill this role.

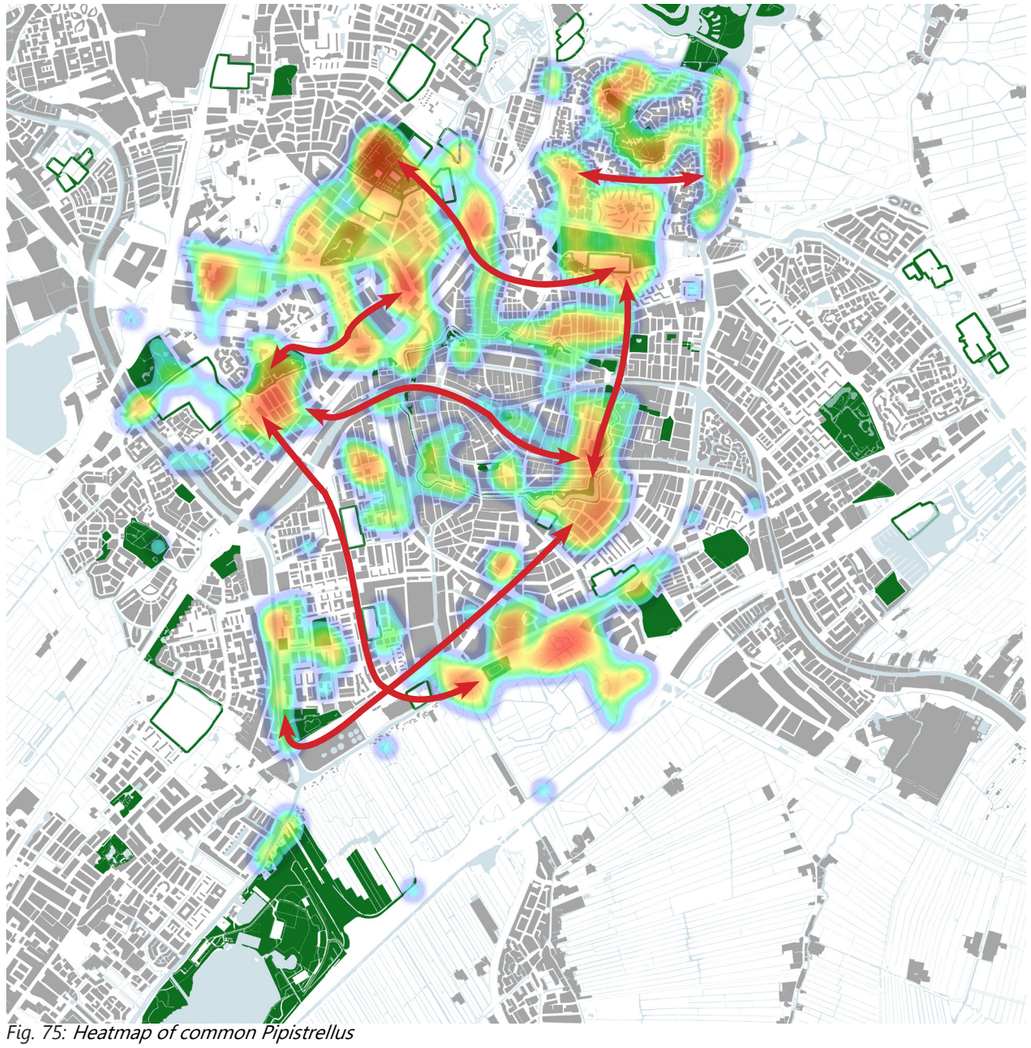
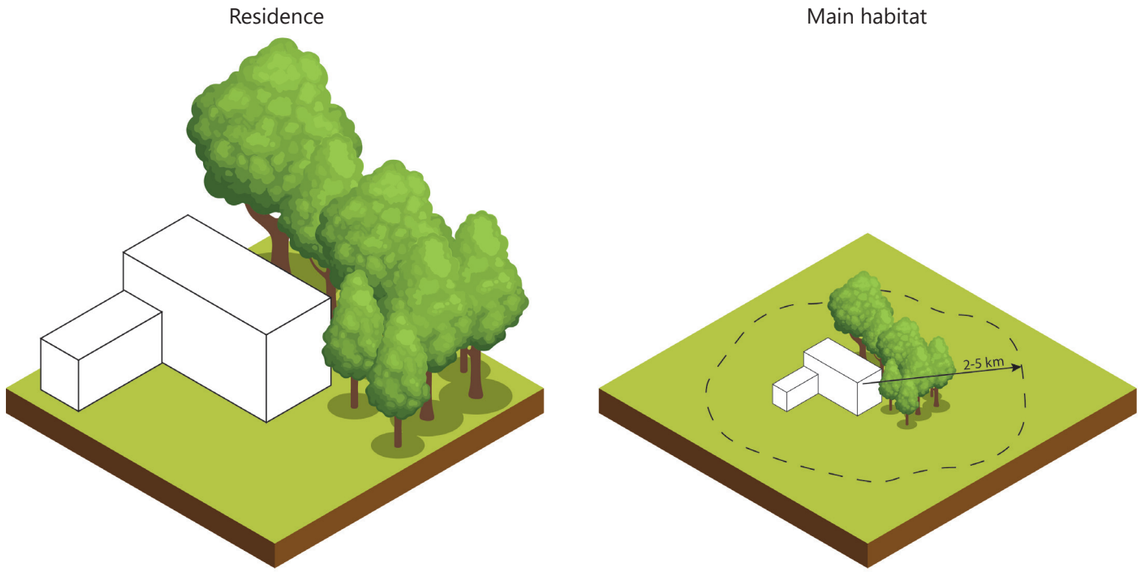


Fig. 75: Heatmap of common Pipistrellus



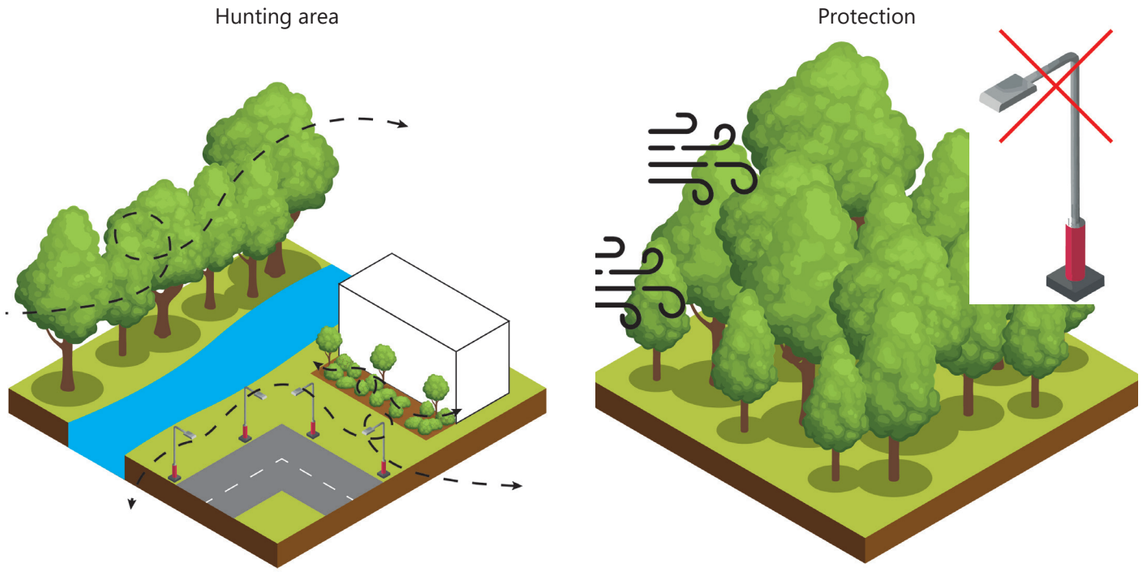


Fig. 74: Spatial needs for the dwarfbat shows what is necessary to create a feasible habitat

5.1.2. Bumblebee (Bombus)

The bumblebee is commonly found in colonies with fifty to several hundred individuals per nest, with usually a single queen. These nests can be found in **underground burrows**, such as abandoned rodent burrows or holes in the ground, old bird nests, compost piles or tree cavities. Bumblebees, like all other bees, survive on **nectar and pollen**; the bumblebee's energy source is sugar-rich nectar. A bumblebee prefers to visit biennial plants, but also perennial plants, because the flowers on these plants produce more nectar. Because bumblebees do not produce a large amount of honey, flowering plants must be present throughout the **spring and summer** (March to September). Bumblebees, by the way, do produce honey, but this is in small quantities. Bumblebees are not picky and will drink nectar from plants of all families. When it comes to pollinating flowers, bumblebees are not as efficient as bees. The colonies are much smaller, and bumblebees eat pollen from immature flowers, indicating that they are not properly pollinated. When nectar is too deep in a flower, the bumblebee bites a hole in the side of the corolla to access it. Cutting open flowers is harmful to the flower because the bumblebee damages or even destroys the flower. Although the bumblebee eats from all kinds of nectar giving plants, they do prefer certain plants like: **Foxglove, sage, wild marjoram, mint, catnip, petunia, pansies, lupine, comfrey, lungwort, deadnettle, and the figwort**. Bumblebees prefer flowers that are **white, lilac, purple, or blue**. Bumblebees are excellent pollinators of plants and **fruit trees**, and they play an important role in the development of seeds and fruits. This is also true for vegetables like peppers and tomatoes. Bumblebees can fly up to twenty kilometers from their nest to find food, but they rarely fly farther than **five kilometers** (KNNV, 2021).

Figure 77 shows where bumblebees mostly reside. Again the red lines form the most important connections, based on where space is available in the road network. What is important to take in consideration by street design is that bumblebees need enough diversity of nectar giving plants, and have enough space to spread the seeds of these plants. Therefore wide enough verges should be implemented in the street profile, giving the bumblebee enough space to reside and to move from one habitat to another, as well as using this space as their own habitat.

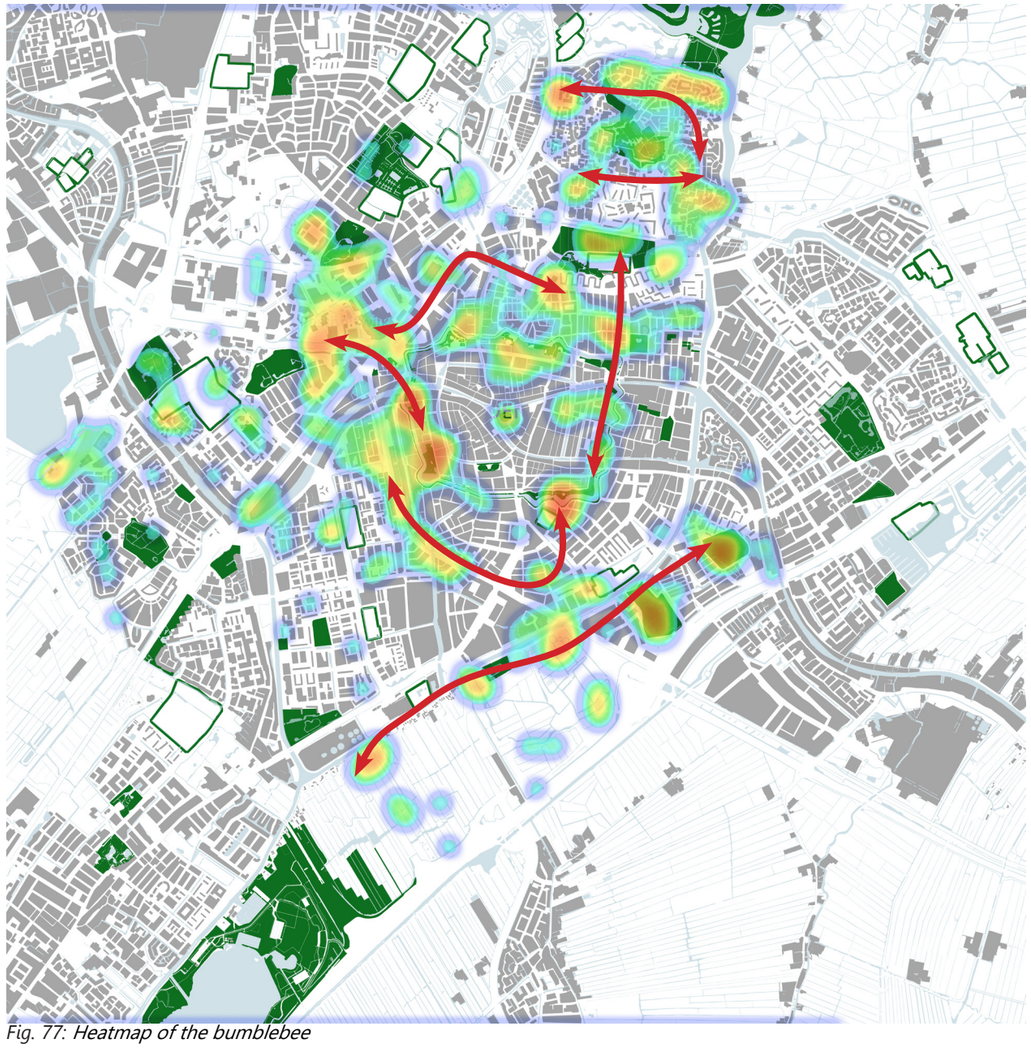


Fig. 77: Heatmap of the bumblebee

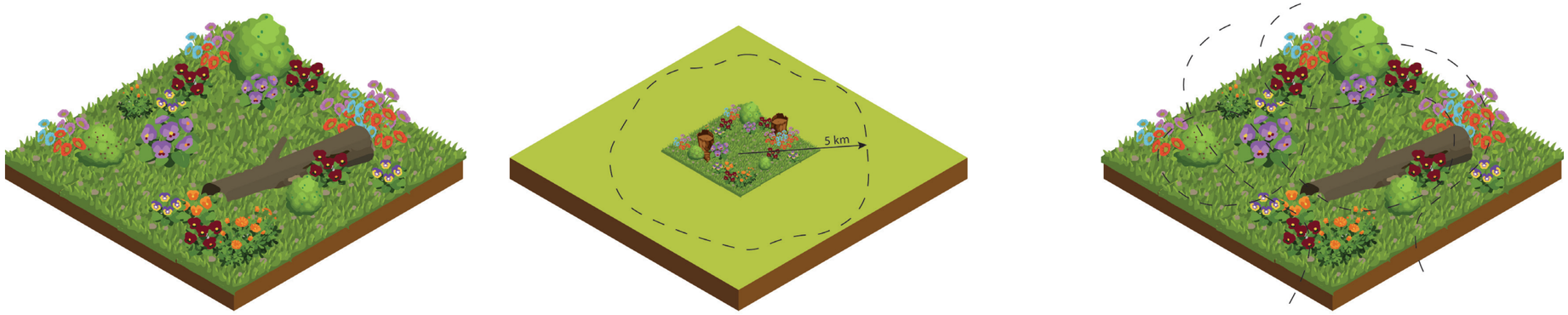


Fig. 76: Spatial needs of the bumblebee

5.1.3. Atalanta (Vanessa Atalanta)

The Atalanta butterfly is a migratory species, and can be most often be found between **April and November.** Every year in the summer, the Atalanta migrates from northern Europe to southern Europe to give birth to a new generation. Especially alongside the coast and in autumn, large groups of the butterfly can been seen. They are also commonly found in the autumn feeding on **rotting fruit from bleeding trees and on leaves with honeydew from aphids.** The population density of the Atalanta is rather high, with approximately **10 to 34 butterflies per hectare.** Wandering Atalanta's can be found almost anywhere, especially in areas with a high concentration of **nectar-rich plants**. A larger group of Atalanta's can be seen feeding together at times, for example, in areas where a lot of royal herbs grow. Other places where they can been seen in larger groups are in the proximity of a **sunny wall or near ivy that blooms in the full sun**. Males feed themselfs all day and defend their territories from late afternoon to early evening. Every day, they occupy a new area, the boundaries of which are marked by patrol flights. Each territory usually has one or two sunny roosts. Other animals are chased to the territory's border, while males are chased away in an upward spiral flight. Some butterflies migrate south again in the autumn, while others try to hibernate here. In both the cases a large portion of the group dies, without producing a new generation.

The butterflies frequently search for food on plants such as **royal herb, ivy, thistles, and butterfly bush, but also on stinging nettle such as hops and glasswort. They also come to rotting fruit and sap from bleeding trees,** especially in the autumn. According to the National Butterflies Monitoring Network, the number of the Atalanta has been increasing in the recent years, so there is **no special protection necessary**. (e-Vision.nl, The Netherlands, z.d.)

Since the Atalanta can be found almost everywhere, as long as there are enough nectar rich plants, it is important to implement these in the street profiles. Also corridors can be made to make it easier for the butterfly to migrate from north to south. Verges in the street profile can accommodate this movement and help with a safe migration. Figure 79 shows where the Atalanta is most seen in Leiden and which areas should be connected via the road network in order to get a complete ecosystem.

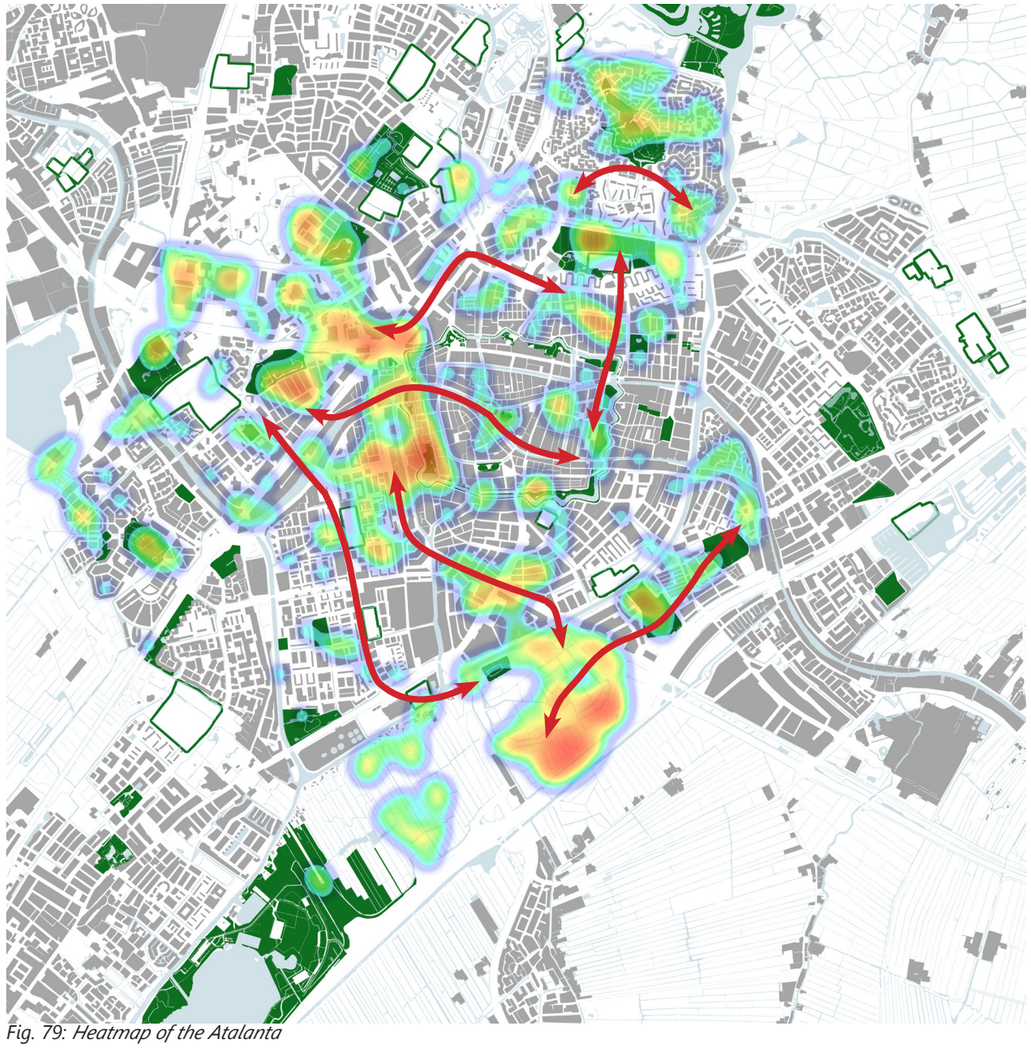


Fig. 79: Heatmap of the Atalanta

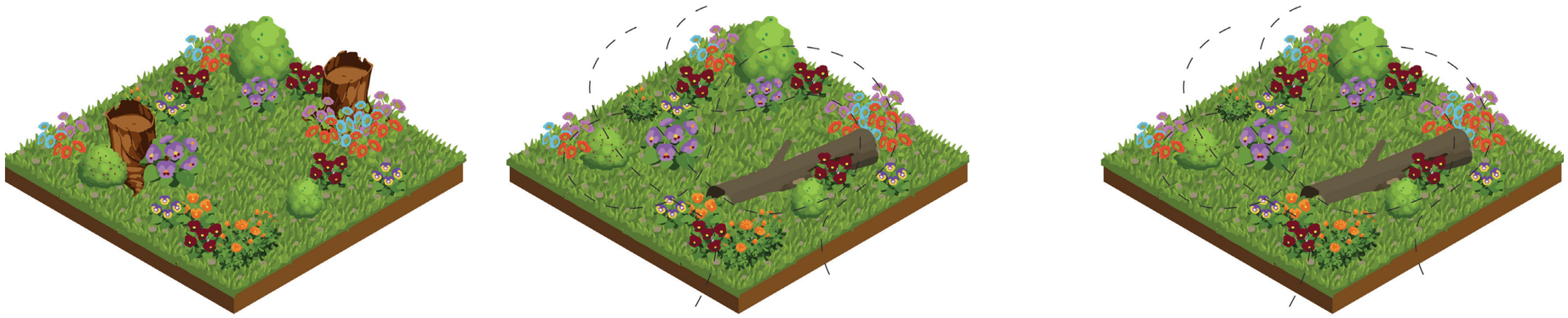


Fig. 78: Spatial needs of the Atalanta

5.1.4. Starling (Sturnus vulgaris)

Starlings are one of the most common breeding birds in the Netherlands. They breed from April to June, and has nests of 4-6 eggs at a single time. Although the starling is not a colony bird, they enjoy breeding around several congeners. The starling is a opportunistic bird, so they are commonly found in urban areas, for example at train station. But often the starling build their nests in natural cavities in trees, nest boxes but also in buildings. The starling is a typical grassland bird, where grassy fields provide insects and their larvae for the starling. They sift through the soil of meadows and lawns looking for insect larvae such as crane flies. Starlings are omnivores, but in grassland, they primarily eat insects and insect larvae. In the summer, autumn, and winter, there are also plenty of berries and fruit, such as apples. They are natural combatants of leather-jackets in the turf on lawns and golf courses. They congregate in large roosts after the breeding season. Many sprouts arrive in our area in the autumn from Northern and Central Europe. Dense clouds of thousands of starlings form around the roosts, creating a beautiful 'wave' in the sky. Some breeding birds migrate away in the winter, but others remain relatively close to home, in Belgium, northwestern France, and southern England. Many starlings migrate through the Netherlands from northern and eastern Europe, and many of them spend the winter in our country. As a result, there are even more starlings in the Netherlands during the winter than during the breeding season. Spring migration occurs primarily in March, with autumn migration occurring from June (young birds) to November.

The population of starlings in our country is rapidly declining. The causes are being sought in agricultural intensification and the disappearance of suitable nesting places in urban areas. This desiccation, combined with other intensification methods, is disastrous for benthic life and appears to be a contributing factor to starling population declines. A more natural agriculture provides a chance for insects, bees, butterflies, flowers, and birds to survive. Offering nesting sites is an important way to protect starlings. Consider nest boxes in trees or old-fashioned starling pots against a building's facade (Vogelbescherming Nederland, z.d.).

For the starling it is important that there is enough vegetation for them to reside in, but also provide them with enough space to move from one habitat to another (fig 81). Furthermore grasslands (or in terms in the street profiles; the verges) should include space for them to hunt on insects.

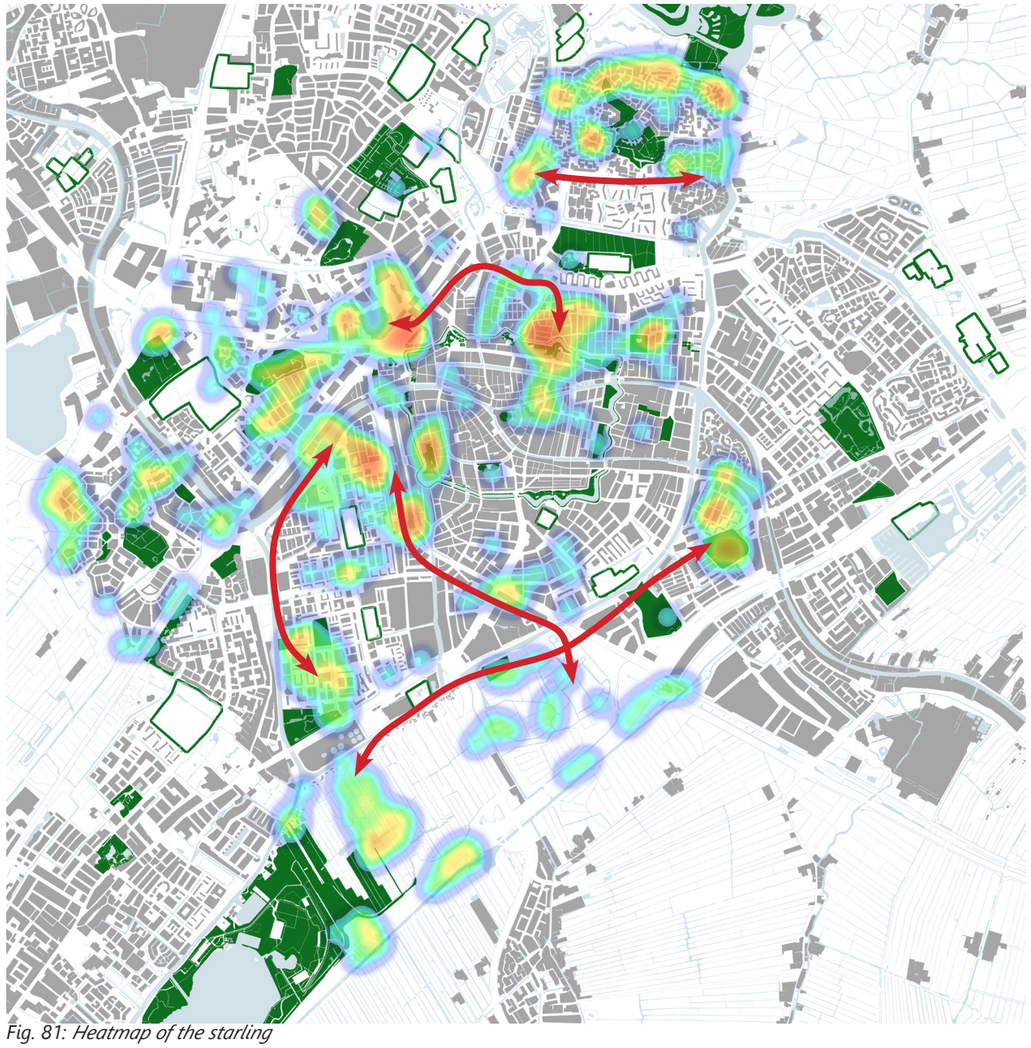


Fig. 81: Heatmap of the starling

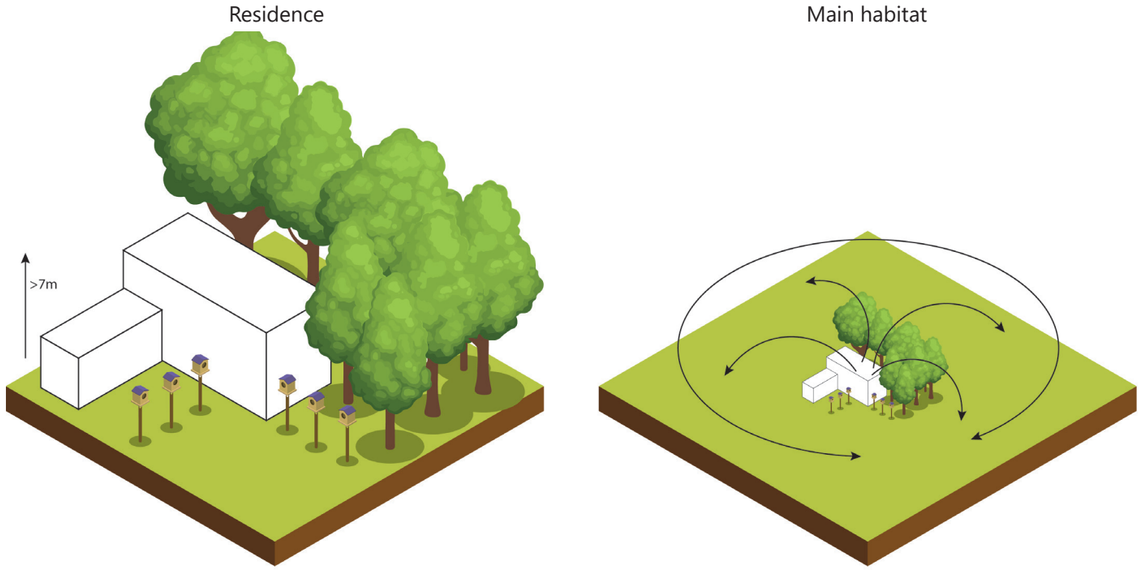
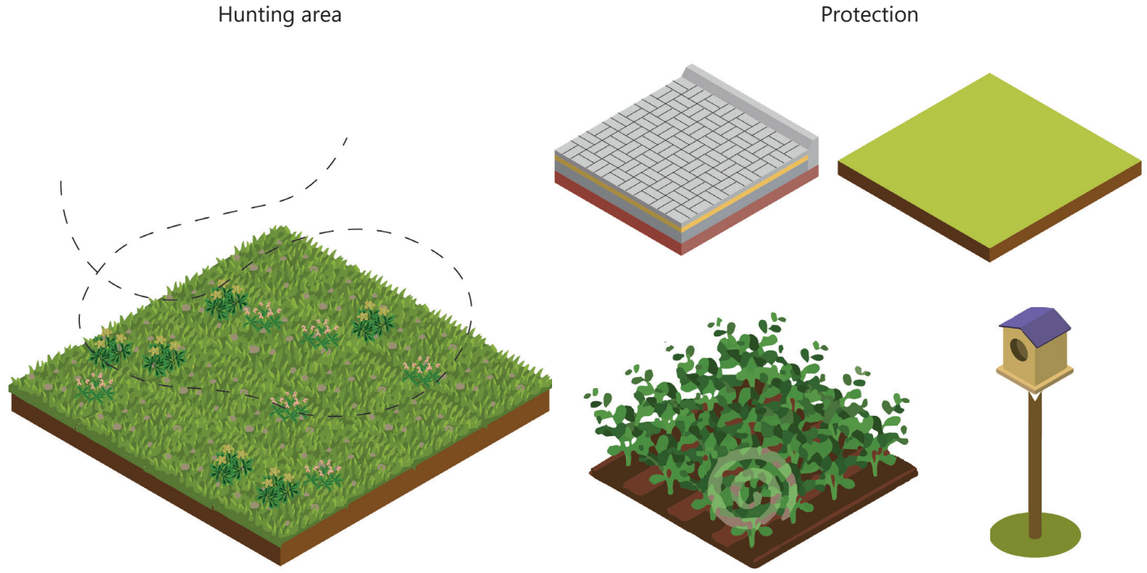


Fig. 80: Spatial needs of the starling



5.1.5. West-European hedgehog (Erinaceus europaeus)

The west-European hedgehog prefers to reside and move in edge zones with shrubs and trees but also in open areas such as grasslands. The shrubs and trees form an important protection tool in the event of danger, and is also suitable for sleeping. Hedgehogs eat mostly small invertebrates like beetles, earthworms, snails, and caterpillars. Small vertebrates such as young mice, amphibians, and birds, as well as carrion, plant material, and various remnants of abandoned human food, all contribute to their diet. Furthermore, these animals enjoy eating eggs. There have been numerous reports of hedgehogs scavenging eggs in chicken coops. According to international research, hedgehog egg robbery can endanger local populations of ground-nesting birds. This suggests that the role of hedgehogs in the failure of ground-nesting bird broods is also under-appreciated in Flanders, to the detriment of species such as squirrels, magpies, and foxes. Depending on its environment, a few prey types make up the majority of the hedgehog's diet. Hedgehogs use their highly developed sense of smell to find food. This allows them to locate buried larvae. During the day, hedgehogs sleep in a leaf nest. Regularly used nests are usually solidly built and in the shape of a hedgehog's dome nest. The majority of nests are well concealed beneath bushes (such as blackberries) or in a small depression. Caves, such as an abandoned rabbit hole or a self-dug hole, are occasionally used as sleeping places. Hedgehogs become active at night and leave their nests. Females move within a habitat of several hectares on average during their nocturnal forays. They cover 500-1,000 m in one night on average. A male's habitat can span up to 30 hectare. Adult males typically travel longer distances than females, particularly during the reproductive season. Hedgehog habitats overlap, but they otherwise live solitary lives with no territorial behavior. Hedgehogs will take short breaks during their nocturnal journey to digest the food they have just eaten. They return to their nest at dawn and stay there until the following night. Hedgehog dispersal is uncommon and mostly limited to the first few months of life. During their first months of independence, young animals usually find their own habitat and stay there for the rest of their lives.

The hedgehog is the most common road casualty among mammals. The majority of victims occur during the summer, with a peak in June and July. During this time, males in particular are found dead because they actively seek females and frequently cross roads. Later in the season, young hedgehogs are particularly vulnerable to being run over. In recent decades, the road network has become increasingly dense, and traffic intensity has increased, including at night. Increased traffic may be to blame for the disappearance of hedgehogs in areas where they are scarce. (Western Hedgehog - Erinaceus europaeus, z.d.)

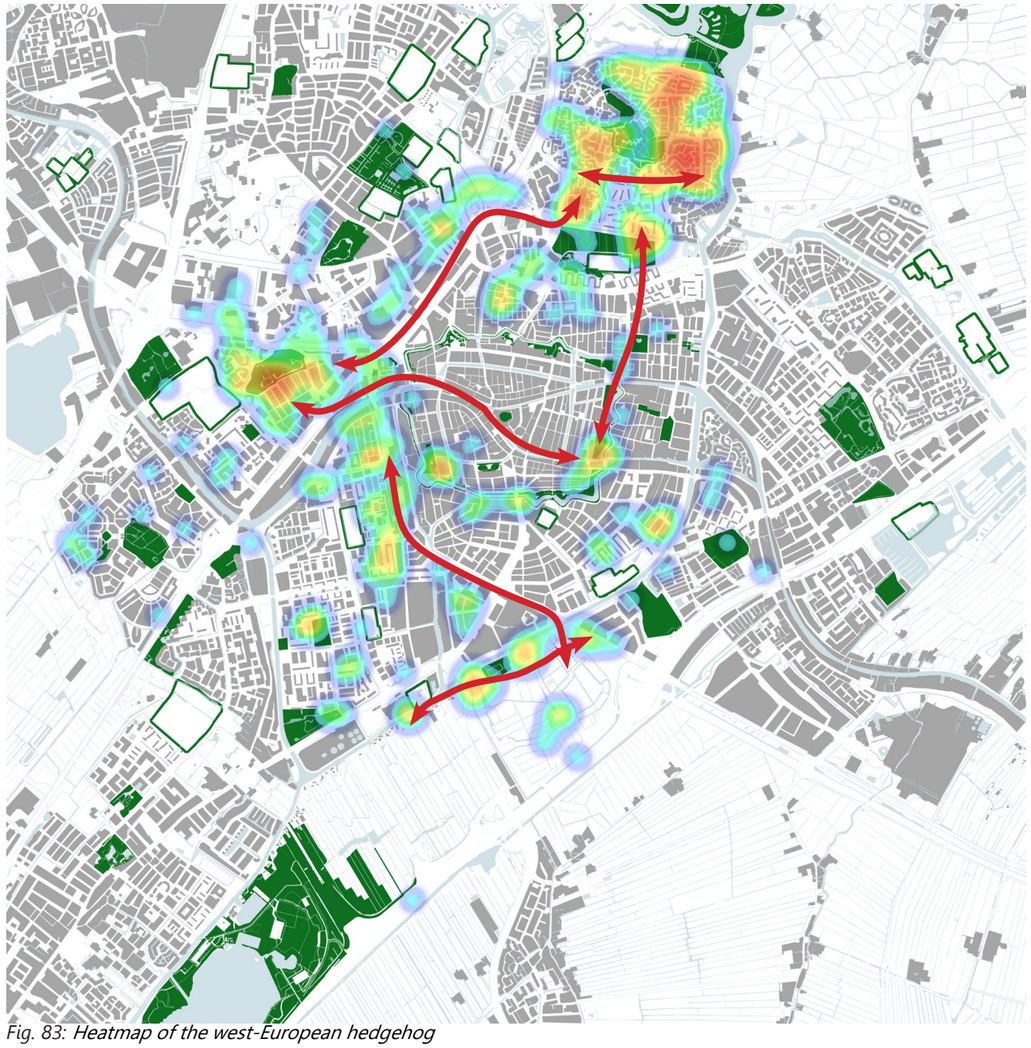


Fig. 83: Heatmap of the west-European hedgehog

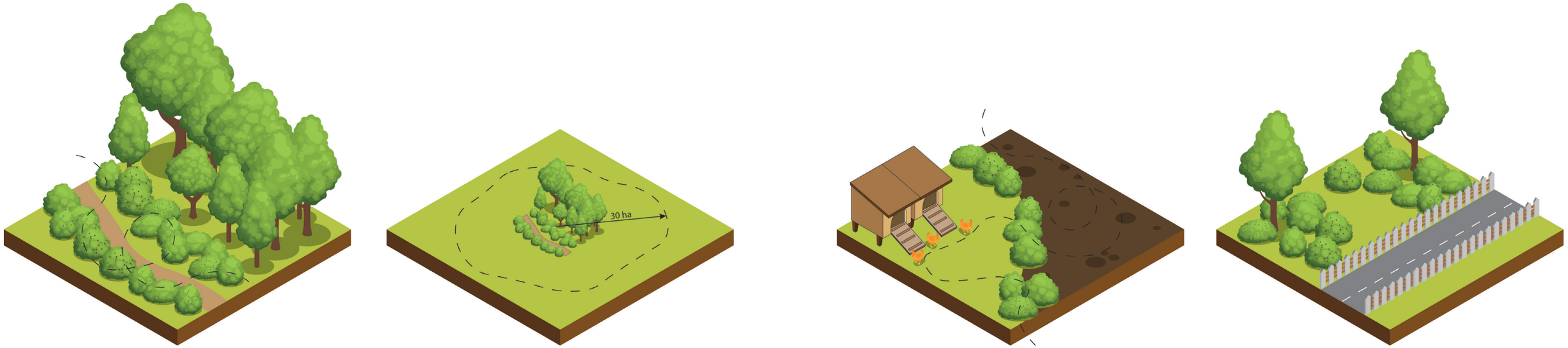


Fig. 82: Spatial needs west-European hedgehog

5.1.6. Brown frog (Rana temporaria)

Brown frogs live on land outside of the breeding season. The brown frog can be found in a variety of biotopes, including forests, heaths, grasslands, ruderal terrains, and dunes. The presence of vegetation and a layer of litter or other moist places where it can hide during the day is the only requirement. The species is not found in very open areas such as agricultural landscapes or in extremely dry areas. In the autumn, this latter group migrates to the water. The brown frog is only found in water during reproduction and hibernation, and it spends the rest of the year on land. The brown frog prefers cooler, moister environments than its southern European relatives, and it is one of the most common species in mountain streams. Hibernating animals can become active and come above ground on sunny winter days. They then form easy (due to their slowness) prey for blue herons or polecats to hunt. Prey remains, such as star shot or witch's notch, are frequently derived from common frogs. Animals that hibernate on land migrate to the water after hibernation, often at the same time as the common toad. The brown frog has a strong affinity for trees and shrubs. The brown frog has a diverse range of habitats and can be found in cities and towns. The specie can be found in all types of water, but prefers small isolated and linear bodies of water. Large open water is rarely used, and the species is uncommon in fens. City and garden ponds, which are less natural, are also frequently used for this purpose. The land biotope is frequently composed of adjacent hedgerows, forests, and other vegetated areas with a layer of litter that serves as a shelter. Food includes a wide range of invertebrates, particularly snails, beetles, and insect larvae. After hatching, the larvae feed on frog spawn remnants, then on a variety of small organisms such as algae and other plant material. They gradually consume more animal food, such as water fleas, snails, worms, aquatic insects, and carrion, as well as amphibian eggs and larvae, including those of their own species (Van Leeningen, 2022).

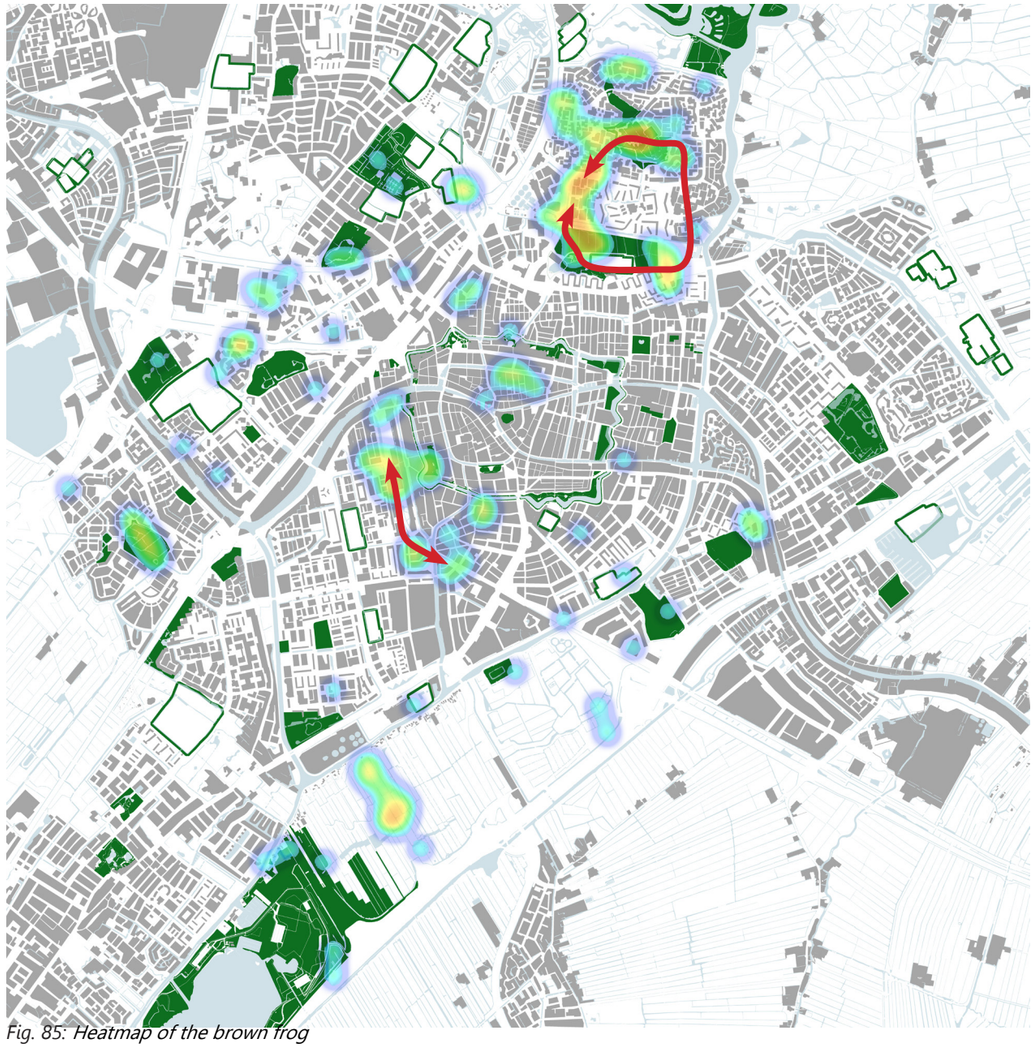


Fig. 85: Heatmap of the brown frog

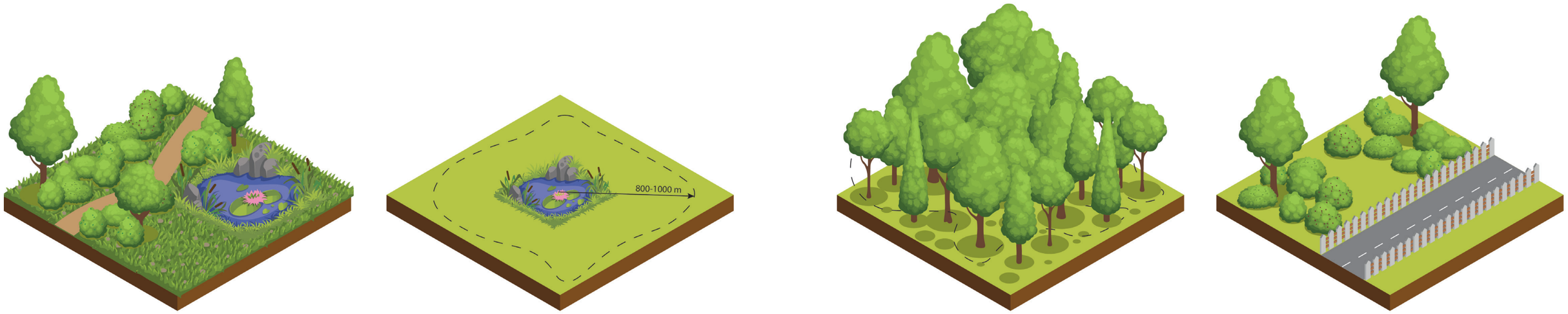


Fig. 84: Spatial needs the brown frog

5.1.7. Habitat and movement verge

Moving through a dense urban area, wildlife faces numerous challenges. One of the most serious issues is habitat fragmentation caused by urbanization, which creates barriers that prevent wildlife movement. Urban wildlife requires corridors that connect different habitats in order to move from one to the other.

In order to encourage the movement of urban wildlife between habitats, verge width is a crucial consideration. A verge is a small area of land that divides a road or pavement from a park or other open area. As corridors connecting various habitats and enabling animal movement through the landscape, these areas can offer vital habitat for urban wildlife. The ideal width of a verge, however, is dependent on a number of variables, including the types of wildlife that can be found nearby, the width of the road, the amount of traffic, and the frequency of pedestrian use.

Generally speaking, the better the verge is for wildlife movement, the wider it is. Animals can have more habitat and cover on a wider verge, which enables them to move more freely through the environment. A wider verge can also increase the variety of plant species and give animals more places to feed, rest, and breed. A wider verge, for instance, can support a wider variety of plant species, such as tall grasses, shrubs, and trees that can serve as shelters, nesting locations, and sources of food for birds, small mammals, and insects. Additionally, a wider verge can offer a more significant buffer zone between the road and the nearby habitat, minimizing the effect of traffic-related noise, pollution, and disturbance on wildlife.

Depending on the requirements of various species, a verge's ideal width varies. Some small mammals, like voles and shrews, may only need a small patch of habitat to traverse the landscape. Larger mammals, like deer and coyotes, might need a wider verge or a bigger passageway to travel safely between habitats. Therefore, when determining the width of a verge, it is crucial to take the size, mobility, and behavior of the local wildlife into account. In order to provide enough habitat for the majority of wildlife species, a verge width of at least three meters is generally advised. For the selected target species for Leiden, the preferred minimal width of a corridor is illustrated in fig 86.

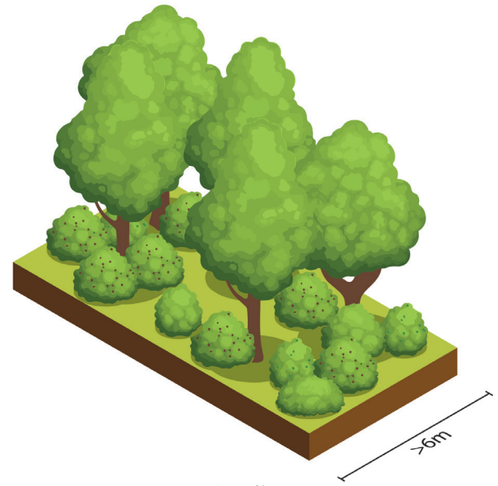
Considering the width of a verge other elements, such as the width of the road, traffic volume, and pedestrian use, must be taken into consideration. For example, a narrower verge may be required to maintain safety in areas with high pedestrian traffic or heavy traffic. A wider verge might be feasible in areas with low traffic volume or restricted pedestrian access.

Another important element in encouraging wildlife movement is the type of vegetation that is present on the verge. Non-native plants are less suitable for wildlife habitat than native plants that are adapted to the local ecosystem. Native plants are better at providing food and shelter for local wildlife than non-native ones. Additionally, native plants are frequently better adapted to the local climate, making them more resistant to environmental stresses such as climate change. Other elements, in addition to verge width and vegetation type, can influence how well wildlife corridors facilitate movement between habitats. For instance, obstructions like walls, fences, and thick vegetation can prevent animals from moving freely. Therefore, it is crucial to preserve the habitat's connectivity and reduce hindrances to wildlife movement. Furthermore, the effectiveness of the wildlife corridor can be improved by creating a continuous corridor that links various habitat patches.

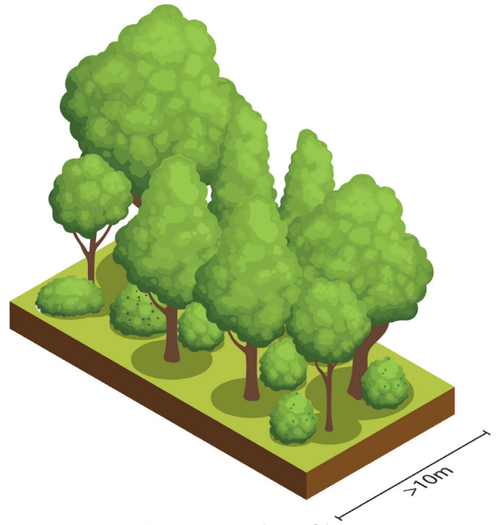
In conclusion, a verge's width plays a significant role in encouraging urban wildlife to move between habitats. Animals can move more freely through the landscape thanks to a wider verge's ability to offer more habitat and cover. However, other elements, such as the width of the road, traffic volume, and pedestrian use, must be taken into consideration when determining the width of a verge. Native plants are better for wildlife habitat than non-native plants, so it's also important to consider the type of vegetation that is present on the verge. Ultimately, it takes careful consideration of both wildlife and human needs to develop sustainable urban environments that support urban wildlife.



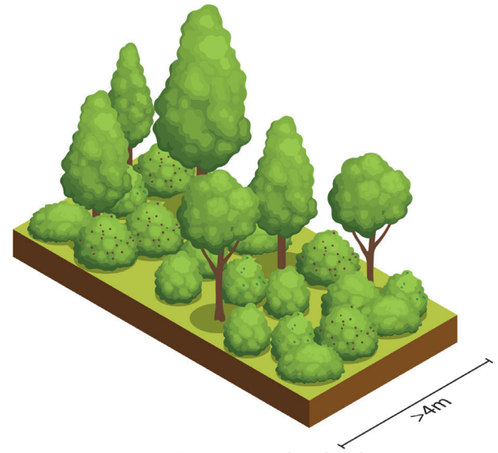
Atalanta



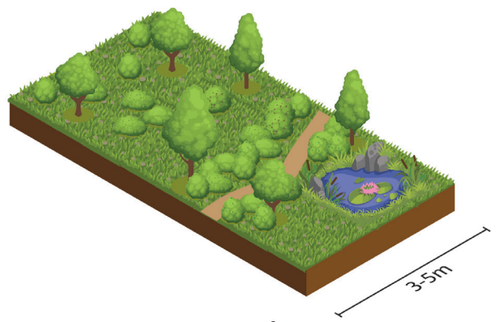
Starling



Common dwarf bat



West-European hedgehog



Brown frog



Bumblebee

Fig. 86: Preferred verge width of the target species to move from one habitat to another

5.1.8. Verge typology

Previous page elaborates on the preferred width of a verge in order for wildlife to move from habitat to habitat. This is now put into illustration for the city of Leiden. The extended road network of Leiden has a great variety of verges, however they can be categorized into four types of verge width:

- 0 - 3 m.
- 3 - 5 m.
- 5 - 10 m.
- >10 m.

This map shows that in order to create fully corridors between patches, every type of road is necessary to complete the corridor. In almost every corridor that can be created with the road network a road with a verge between 0-3 m is present. These are most of the time the more narrow streets in the city. For each category, specific intervention are needed, since the available space in these streets are different. Starting with a road with enough width to provide animal movement is a good start, however, it must be taken into account that at some point this width will change to a road where the width of the verge is at its lowest. Careful consideration must be given to how they can best be connected to each other so that the corridor has a has minimal interruption.



Fig. 87: Road network divided into the width of the road verges

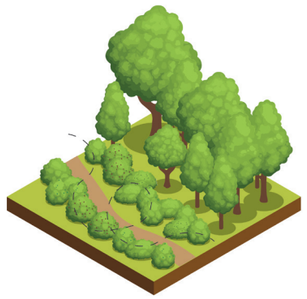
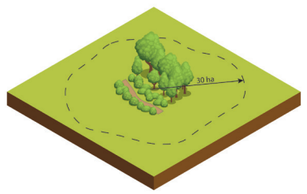
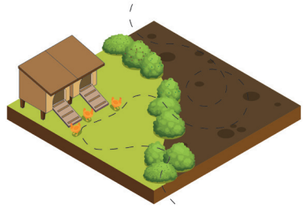
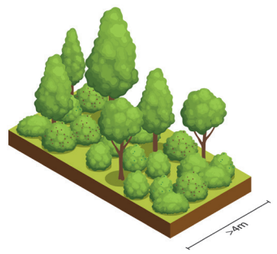
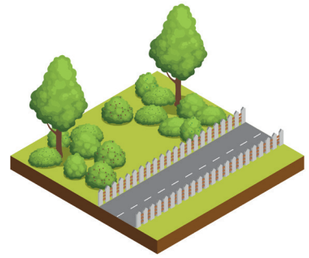
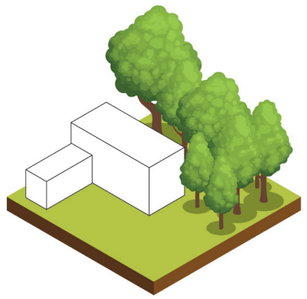
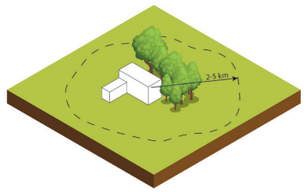
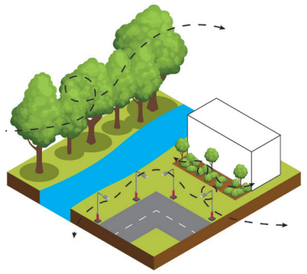
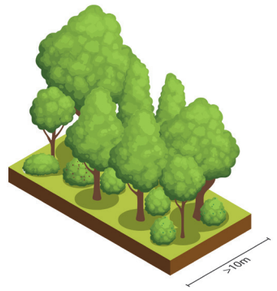
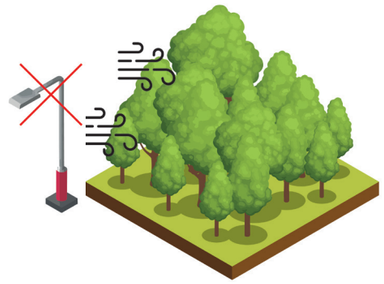
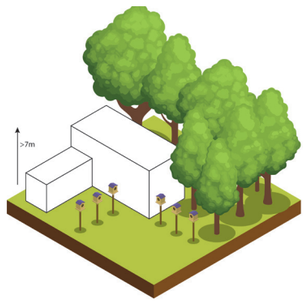
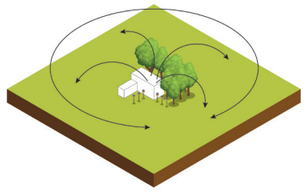
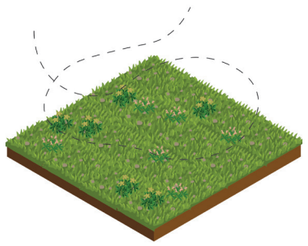
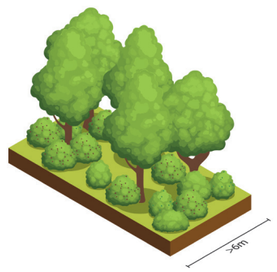
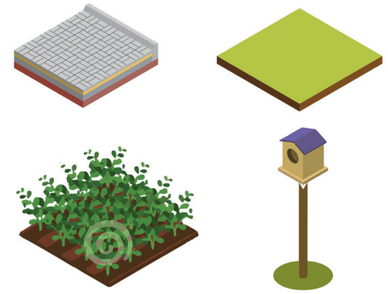
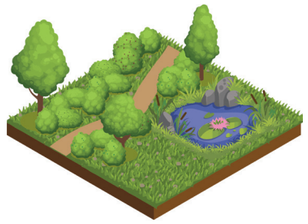
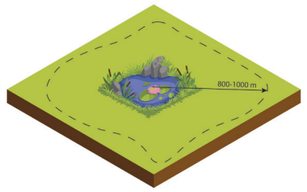
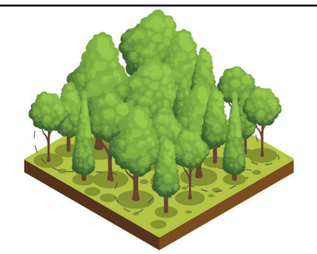
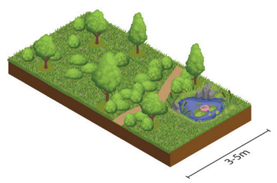
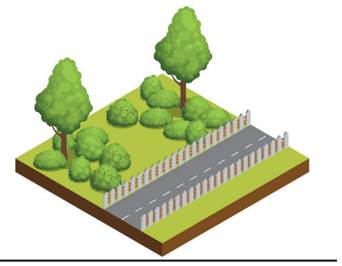
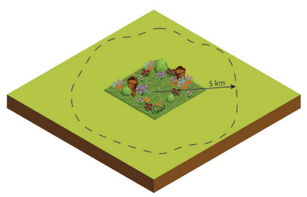
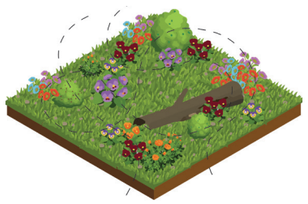
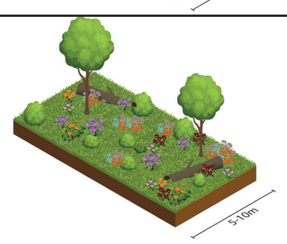
	Residence	Habitat	Hunting	Minimal width	Protection
					
					
					
					
					
					

Fig. 88: Overview spatial needs target species

5.2 Flora

While the target species got their preferred vegetation, plants on their own also contribute to urban biodiversity. Implementing vegetation in the street profiles, will help attract certain wildlife, improve overall health, and will increase urban biodiversity. Vegetation can come in different layers (fig 89) and each layer has different requirements.

Insects, spiders, and small mammals like shrews and voles, for instance, can find food and a home in the **ground layer**. Additionally, this layer aids in soil stabilization, erosion prevention, and water and air pollution filtering. A suitable environment for seed germination can also be provided by the ground layer, which could result in the establishment of new plant species.

For the **herbaceous layer** it is important to implement wildflowers since they require minimal maintenance and can grow in a variety of conditions. These wild plants are also perfect for wildlife habitat and pollinators, like the bumblebee and the Atalanta. In addition to this, native vegetation should always be chosen over foreign vegetation, since the native vegetation is already adapted to the local climate and soil conditions, and these better meet the needs of urban wildlife. Also some herbs can be planted, like basil and thyme, which can provide fresh herbs for cooking.

The shrub layer is more important for the slightly larger animals. Shrubs and small trees provide a range of benefits, including improving air quality, reducing noise pollution, and providing habitat for birds and other wildlife. They can also add visual interest to urban landscapes. The use of indigenous plant material is critical for the health of ecosystems. Animals, plants, trees, and shrubs are all highly dependent on one another in nature. Changing the times of sprouting, flowering, or growth of plants can disrupt ecological processes.

The **tree layer,** consisting of tall trees over six meters in height, is vital for providing food and habitat for birds and mammals such as squirrels and bats. Trees also help to reduce air pollution, provide shade, and reduce heat island effects in urban areas. Additionally, the vertical structure provided by trees creates a more diverse habitat and improves the aesthetics of the urban landscape. In the Netherlands several trees can be planted to have a variety of benefits. These include for example the oak, which provides habitat and supports a range of fungi and other organisms in their root system and the beech, which maintain soil fertility and provides food supply.

For the preservation of urban biodiversity and the support of a robust urban ecosystem, vegetation layers must exist in urban areas. However, the persistence of vegetation layers in urban areas is threatened by human activities like development, alterations in land use, and pollution. In order to preserve and improve the current vegetation layers, it is crucial to incorporate green infrastructure into urban planning and design.

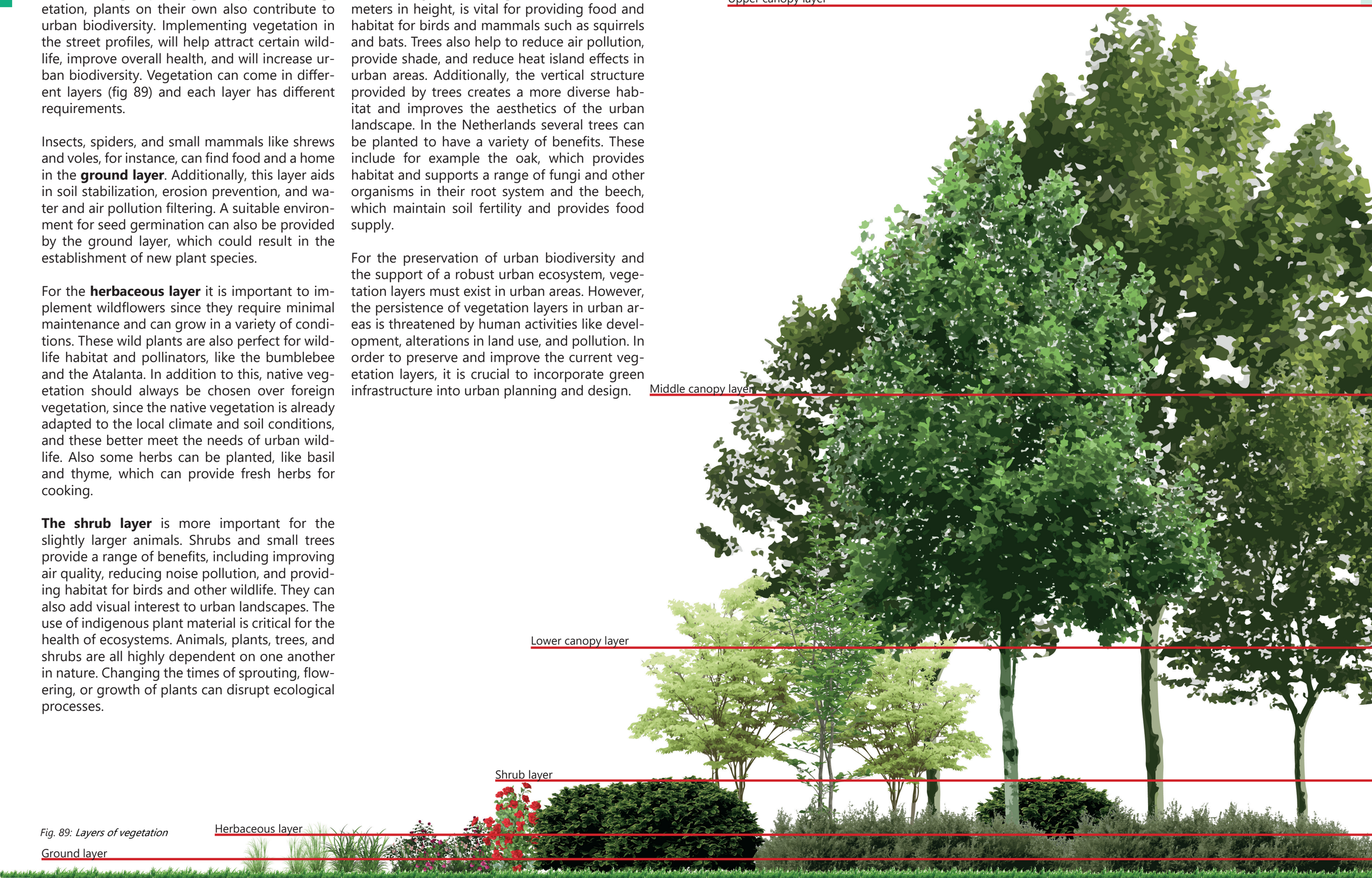


Fig. 89: Layers of vegetation

A vital step in creating and maintaining a healthy urban ecosystem is the phased planting of urban flora (fig 89). It entails organizing and scheduling the planting of vegetation over time in order to allow for the gradual establishment of various vegetation layers. This strategy is crucial for a number of factors, such as the development of a variety of habitats, enhanced soil quality, and decreased maintenance costs.

The development of a variety of habitats is one of the main advantages of phasing planting. A wider variety of flora and fauna can be supported by the urban ecosystem by planting various types of vegetation at various stages. Insects and small mammals, for instance, can quickly establish themselves by planting ground covers and grasses first, providing a food source for birds and larger mammals. The habitat is then made more diverse by the addition of shrubs and trees, which provide nesting locations and cover for birds and mammals. By giving insects and birds a place to live, the addition of vertical vegetation, such as green walls or climbing plants, can improve the habitat even more.

Planting in phases benefits soil quality as well. The soil can have time to adjust to the changes in organic matter, nutrient levels, and water requirements by planting various vegetation types at various times. Ground covers and grasses can be initially planted to help increase the organic matter in the soil and strengthen its structure. The soil's nutrient levels improve with the addition of shrubs and trees because the deeper roots of trees draw nutrients up from the soil's lower layers. Additionally, the development of vegetation aids in reducing soil erosion, which is crucial in regions vulnerable to heavy rainfall.

Reduced maintenance costs can also be achieved through phased planting. Maintenance expenses can be spread over a number of years rather than being incurred all at once by planting vegetation in stages. This strategy enables more focused maintenance with an emphasis on newly planted areas as opposed to the entire site. Furthermore, planting in phases can ensure that the vegetation takes hold properly, minimizing the need for later planting or maintenance.

Planting in phases also makes it possible to manage urban development more efficiently. Urban planners and developers can make sure that the vegetation does not compete with the built environment by planning the planting of vegetation in stages. One way to soften the sharp edges of the built environment and make it more hospitable for people and wildlife is to plant low-growing vegetation in parking lots or around buildings. Additionally, planting vegetation gradually enables more effective use of resources, such as water, which is crucial in areas with scarce water supplies.

Conclusion

In order for urban environments to function sustainable, road ecosystem services—which are crucial for supporting urban flora and fauna—must be supported. Ecosystem services are the advantages that people and society gain from nature, such as the availability of food, clean air and water, as well as opportunities for culture and recreation. Given their critical roles in preserving the health and functionality of urban ecosystems, urban flora and fauna are necessary for the provision of many of these ecosystem services. Urban flora, like trees and shrubs, for instance, offers a variety of ecosystem services, such as air purification, carbon sequestration, and temperature regulation. As a result, they support a variety of urban fauna, such as birds, insects, and small mammals, who in turn support ecosystem services like pest control and pollination. These ecosystem services are crucial for preserving the health and wellbeing of urban environments as well as for sustaining urban residents' activities and way of life.

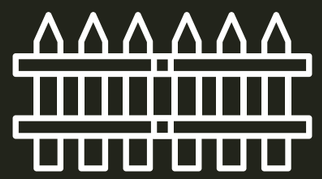
In a similar manner, urban fauna, like birds and insects, supports the provision of ecosystem services by pollinating plants, eradicating pests, and assisting in the nutrient cycle. Additionally, they offer vital cultural and recreational opportunities for city dwellers, such as birdwatching and nature walks that can enhance both physical and mental health.

In general, the provision of road ecosystem services, which support the health and functionality of urban environments, depends on the presence of urban flora and fauna. Therefore, gardens, parks, and other green spaces should be taken into account when planning and designing urban areas in order to support biodiversity and ecosystem services. This can be accomplished by incorporating green infrastructure into the design of roads, such as green walls and roofs, as well as by preserving and enhancing current green spaces. Urban environments can become more sustainable, resilient, and better suited to meet the needs of urban residents both now and in the future by giving ecosystem services a higher priority.



Fig. 90: The more time passes the more variety of species will grow and create robust and resilient ecosystems

Design principles to improve wildlife habitats/ corridors and vegetation



Protect animals from crossing the roads, but rather create conditions where they can savely pass.



Protect animals from harmfull lighting, but create animal-friendly lighting



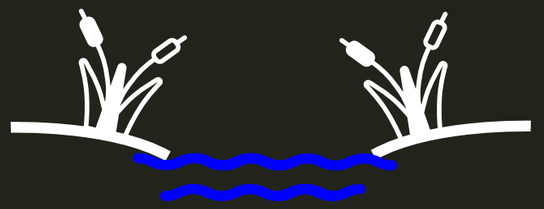
Using roads as habitats for animals can help with improving urban biodiversity.



Mitigate ecosystem disservices by avoiding specifi c species that cause nuisance



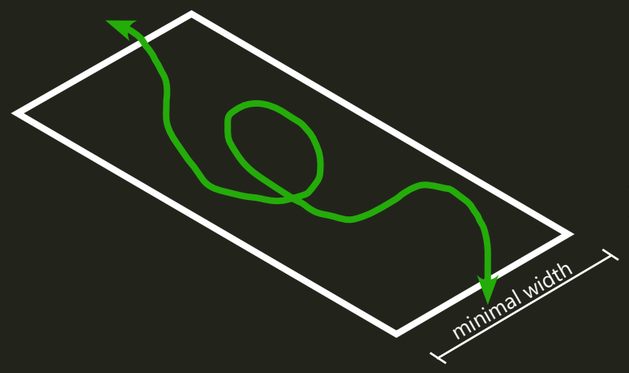
Create diversity of flora and fauna will help with building a robus ecological environment.



Soft borders between water and land will create extra habitat for animals that prefer being around water.



Using roads as corridors between green patches helps improving urban wildlife movement.



Soft borders between water and land will create extra habitat for animals that prefer wet environments.

06
Design principles



6.1. Design princples

The previous chapters clearly explained the challenges and opportunities involved in using the road network for ecological corridors. Based on theory, analysis and an analysis of the flora and fauna, it is now necessary to convert the information into spatial principles. These were briefly discussed at the end of each chapter and page 128-129 provides an overview of these design principles. The principles form a basis for the design experiment in chapter 7, where the design principles are applied in practice to a neighborhood in Leiden. These principles can be divided into the categories discussed in Chapter 400. These were as follows: health, climate and ecology (which includes flora and fauna). The design principles in the overview are assigned to the category it fits most in (fig 91). However, this is not as black and white as it seems, since a single design principle can be beneficial for more than one category. Therefore figure 92 is created to get an understanding of the relationship between the design principles and the categories that are stated before. For example, promoting walking and biking can greatly improve health, but the ecology of the city can hardly benefit from this. For example, on the other hand, reducing car speed is beneficial for all categories, since this will help decrease roadkill from animals, less car emissions (so good for health) and will help with reducing the effects of climate change.

Health

Promote exercise
Promote biking
Seeing green
Promote walking
Education
Put green first

Flora

Plant diversity
Avoiding nuisance
Design conditions
Maintenance plan
Continuous green structure
Add vegetation

Climate

Add waterbodies
soft water-land borders
Add trees
Permeable pavements
Stone to green
Porous asphalt

Fauna

Animal friendly lighting
Minimal width verge
Wildlife corridors
Wildlife habitats
Protection from roads

Fig. 91: Design principles categorized into the main themes of the project

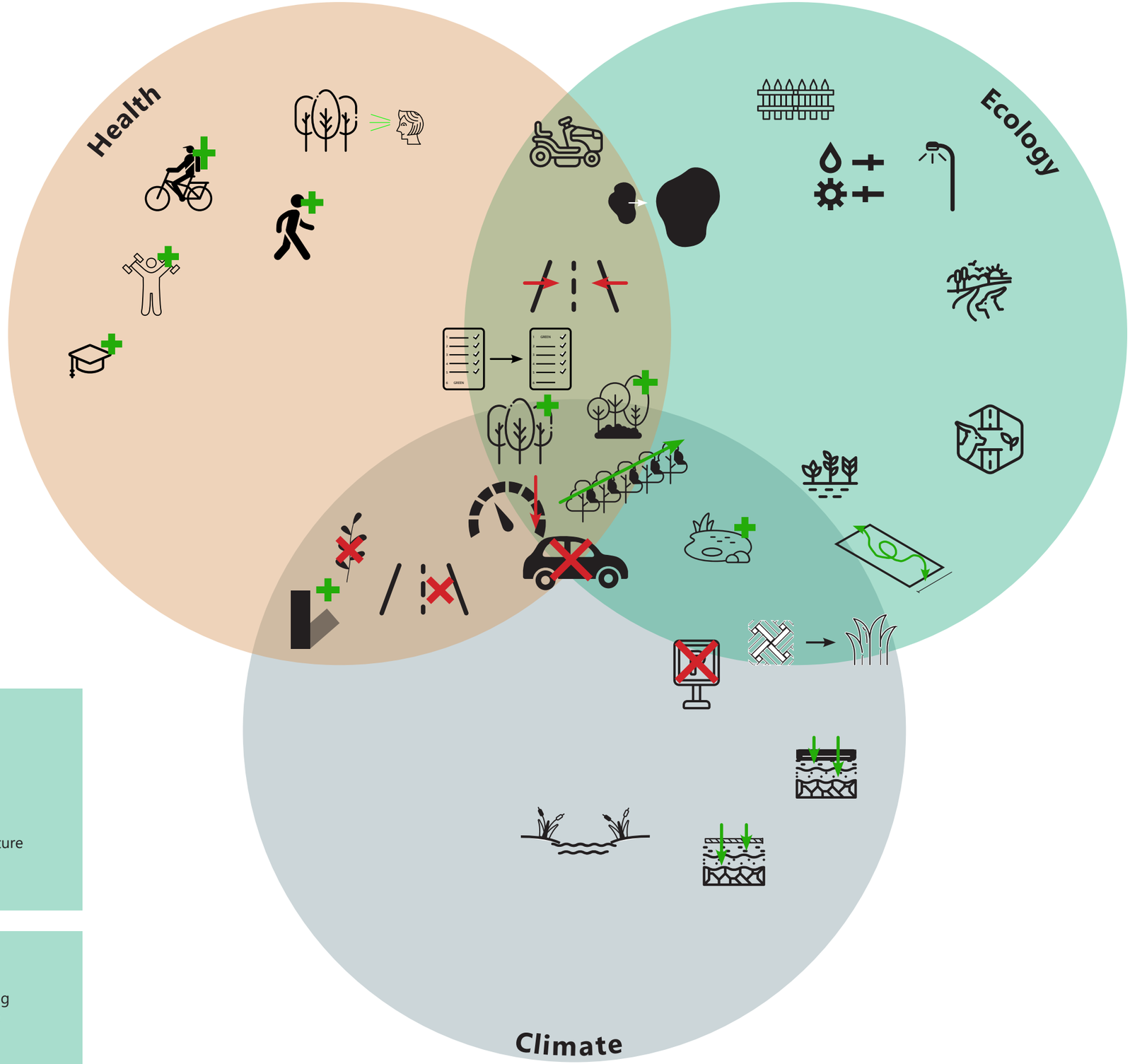
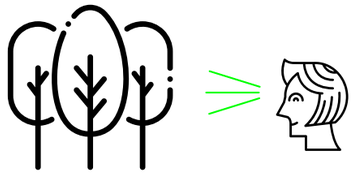


Fig. 92: Relationship between the design principles relative to the main themes of the project

Promote exercise



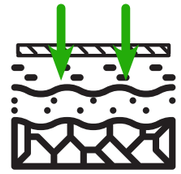
Seeing green



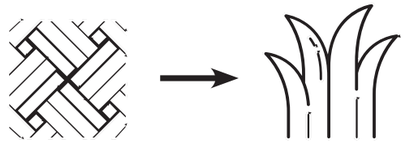
Promote biking



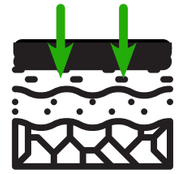
Permeable pavement



Stone to green



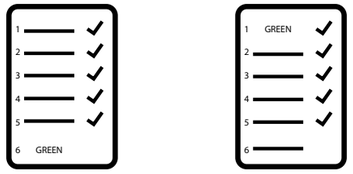
Porous asphalt



Promote walking



Put green first



Education



Remove parking



Car-free zones



Decrease speed



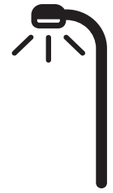
Add vegetation



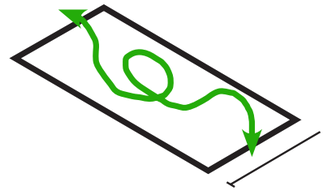
Soft borders

Maintenance plan

Animal friendly lighting



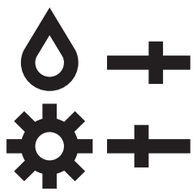
Minimal width



Wildlife corridor



Design conditions



Continuous structure



Add trees



Fence protection



Bundling lanes



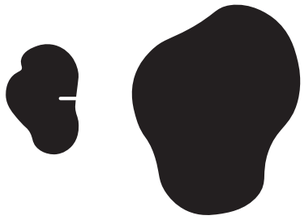
Plant diversity



Waterbodies



Large over small



Create shadows



Wildlife habitat



Remove lanes



Avoiding nuisance



6.1.1. Policies

Not all design principles can be expressed in spatial interventions. Some of them have the form of a policy. Municipal policies play an important role in designing, developing and managing urban environments, and therefore also play an important role in improving road-related ecosystem services. There are a variety of municipal policies that can be implemented to help with improve road-related ecosystem services. This section briefly discusses which policies these are and why they are important.

One of the most important policies that should be included is an active engagement with the community. By including the inhabitants a support base is created in which the residents can think along and, above all, understand why certain choices are made and what they are good for. It is important that the plans are explained in a clear and well-arranged way so that everyone can understand them. Strongly connected to this are the maintenance plans the municipality should have for roadside vegetation and the overall green areas in the city. This is very important for the residents, as they want to feel that the municipality cares about its residents. If mowed too little, the neighborhood may look wild and unkempt, but on the other hand, this is bad for the flora and fauna in the area. When mowing too much, crucial vegetation is lost, which means that some species can no longer survive well. A good balance will have to be found between these two that takes into account both the feelings of the residents and the spatial needs of the target species.

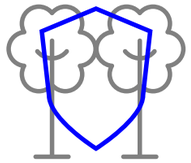
Municipalities can develop and implement sustainable transportation plans that prioritize the use of public transportation, active transportation, and low-emission vehicles. These plans can help to reduce the environmental impact of transportation, improve air quality, and support the provision of ecosystem services. For example, sustainable transportation plans might include the development of bike and pedestrian networks, the expansion of public transit infrastructure, and policies to promote the use of electric vehicles.

Furthermore a policy about protected and enhanced green spaces should be implemented. Green spaces such as parks, nature reserves, and greenways provide a range of ecosystem services, including air and water quality improvement, carbon sequestration, temperature regulation, and habitat for wildlife. Municipalities can adopt policies that prioritize the protection and enhancement of existing green spaces, such as policies to prevent the fragmentation and loss of habitat, and to ensure that green spaces are designed and managed in a way that maximizes their ecological and social benefits. For example, policies might require that green spaces be connected by wildlife corridors, that invasive species be managed in a way that supports native vegetation, and that the public be engaged in the planning and management of green spaces.

Invest in smart mobility



Protect green areas



Invest in public transport



Maintenance plan



Low emission cars



Active engagement



The design principles have a significant impact on the road ecosystem services. By implementing these principles, a integrated design can be made to show how these principles can be applied to a real situation. The next chapter will focus on how to apply the principles to a real neighborhood in Leiden.

To validate whether a design principle will indeed improve the road-related ecosystem services, a spider chart is made to give a score to a specific ecosystem service (fig 93).

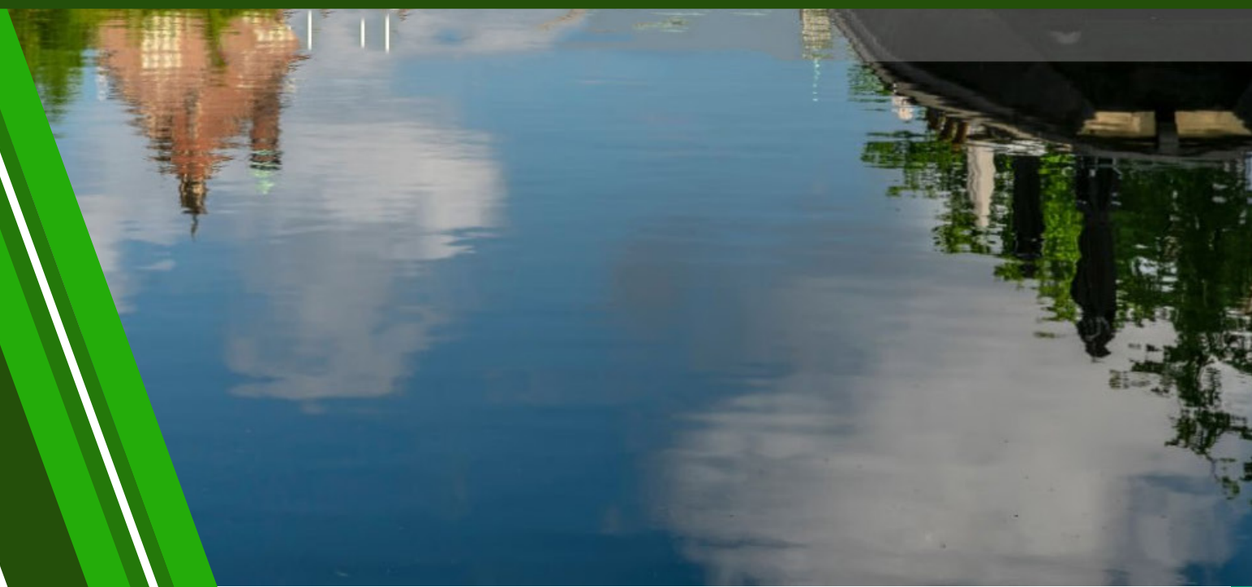
A score can be given from zero to five where the following score applies to:
0-1: Non-existing
1-2: Weak
2-3: Acceptable
3-4: Very good
4-5: Excellent



Fig. 93: Spider chart to give a score whether the interventions will improve the road-related ecosystem services



07
Design exploration



7.1. Framework forNoorderkwartier

Based on the theoretical background and the analysis, previous chapter illustrates design principles for road corridors. These principles need to be demonstrated in a real context. This chapter focuses on how the design principles can be integrated in a part of the Noorderkwartier neighborhood, where well-considered decisions have to be made. This experiment shows how different design principles can improve the ecosystem services in this specific area, but is also provides an example of what a neighborhood can look like in the future.

Noorderkwartier is a neighborhood located in the north of Leiden and the large street profile of the Willem de Zwijgerlaan is dividing the district into two parts. This design exploration will focus on the southern part of the district. This part of the district is a vibrant residential area with a mix of different types of housing. You can find a blend of historical canal houses but also modern buildings. Furthermore it is a popular neighborhood among families, because of its calm appearance but also among students for its location close to the city center.

One of the reasons for choosing this district is because there is a lack of green patches inside this neighborhood, while it is surrounded by green patches. Therefore this neighborhood is a important part of the urban fabric and has the opportunity to serve as an ecological connector between the Noorderpark in the north and the Singelpark in the south, but also as a link to the Kooipark in the east (fig 94). As it is now the neighborhood is enclosed by three main roads; the Willem de Zwijgerlaan (north), the Kooilaan (east) and the herensingel and maresingel (north). Since these form the barrier it is interesting to apply the design principles and look at how these barrier can open up the possible ecological functions these road can have. Not only does the district form a barrier between the nearby green patches, it also forms a gap between several wildlife habitats (fig 96). Five out of the six target species have their habitat either north or south of the district but they have no opportunity to move between them. There is a lack of corridors and the roads surrounding the district make it hard to even enter this part of the district. Therefore, it is necessary to look at how these barrier can be prevented but also have a connection with corridors within this neighborhood.

Besides the ecological barrier this district also has to deal with the effects of climate change. The urban heat effect is strongly present here and ensures that temperatures sometimes rise above 40 degrees (fig 97). Also, when there is heavy rain, a lot of water stays on the streets because there is no way to drain it efficiently (fig 98).

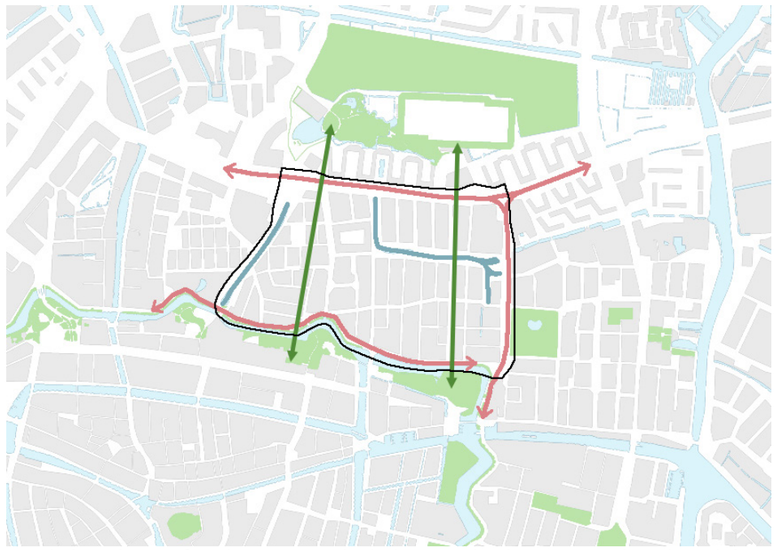


Fig. 94: Noorderkwartier can function as an ecological connection between north and south but is now divided by large street profiles



Fig. 95: Location of the Noorderkwartier in the north of Leiden

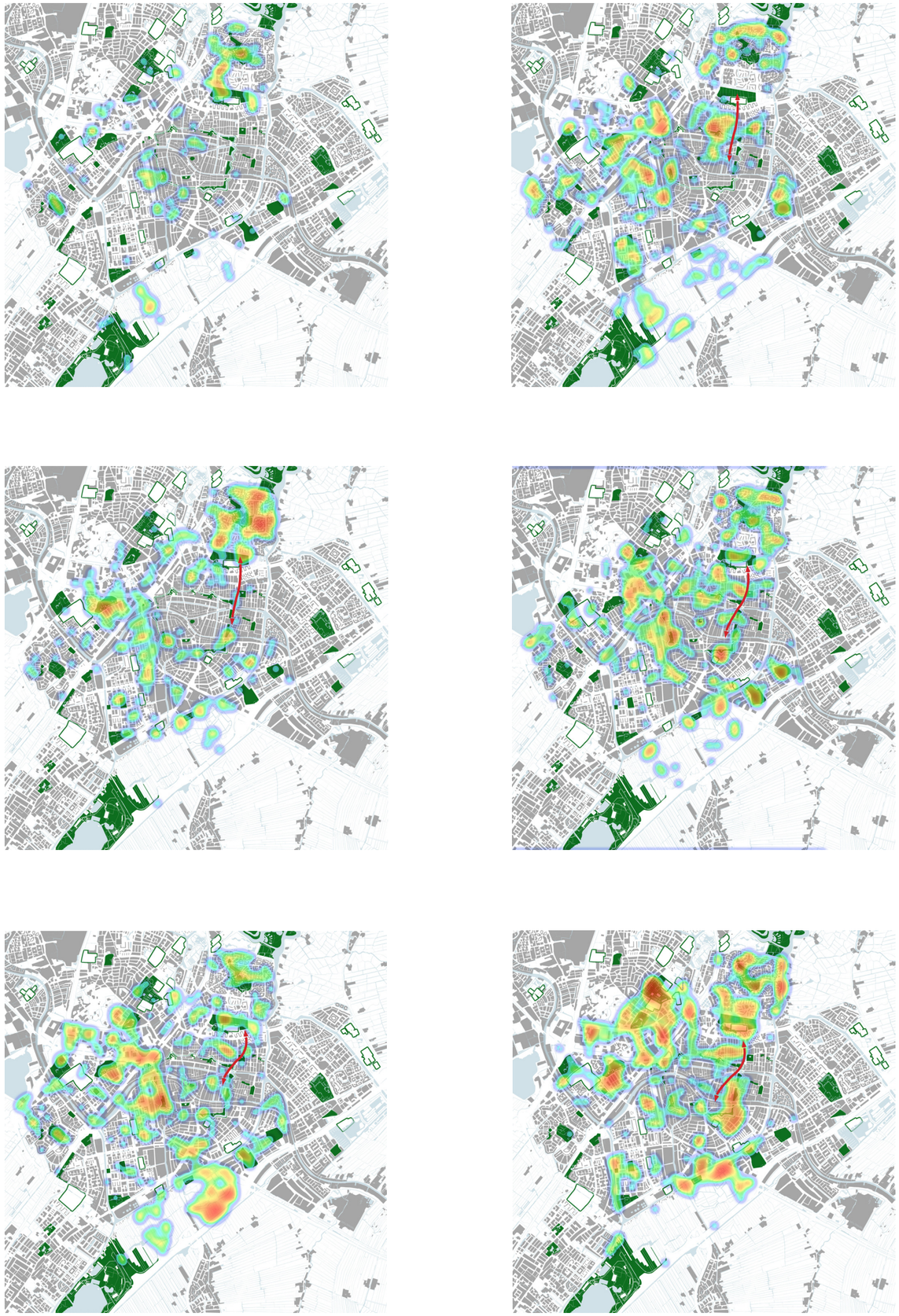


Fig. 96: *Wildlife movement lines go straight through the Noorderkwartier district*

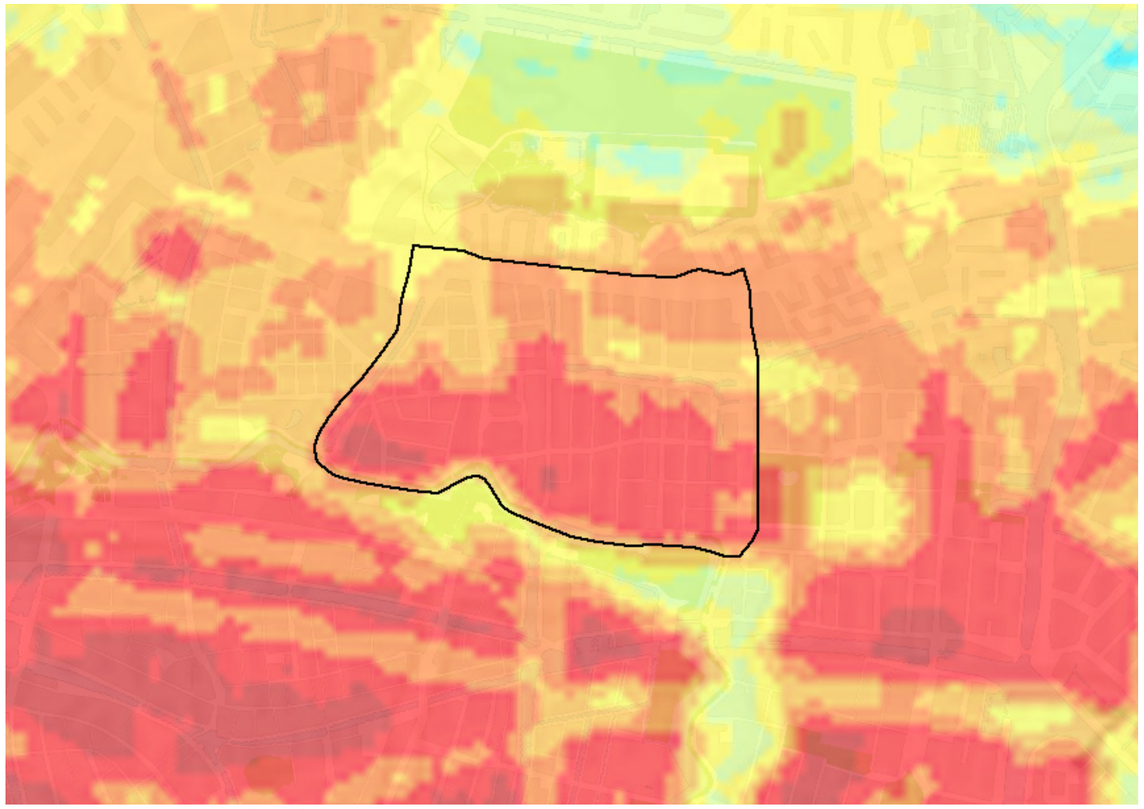


Fig. 97: *Urban heat island effect of the district*



Fig. 98: *Flooding issues in the district*

7.1.1. Climatic strategy

Applying climatic related design principles to the neighborhood will improve its resilience for climatic issues, such as the urban heat island effect and flooding.

There are several areas in the neighborhood where action is needed. On effective interventions is the implementation of green infrastructure. Adding trees, shrubs and transforming stony areas to grass, provide shade, reduce the urban heat island effect and improve air quality. These interventions not only create a more pleasant and comfortable living environment but also help mitigate the impact of climate change by reducing energy consumption and carbon emissions.

Furthermore creating rainwater storage can help to gradually drain the excess water. In addition, implementing rainwater harvesting systems and permeable surfaces can help manage storm water runoff, mitigate flooding, and recharge local water resources.

Finally, removing the car in its total will greatly help with environmental impacts of the car. However since this is not possible for the whole neighborhood, this has to be distributed into smaller no car patches in the neighborhood. In large street profiles it is possible to reduce lanes or reduces the speed.



Fig. 99: Climatic related design principles

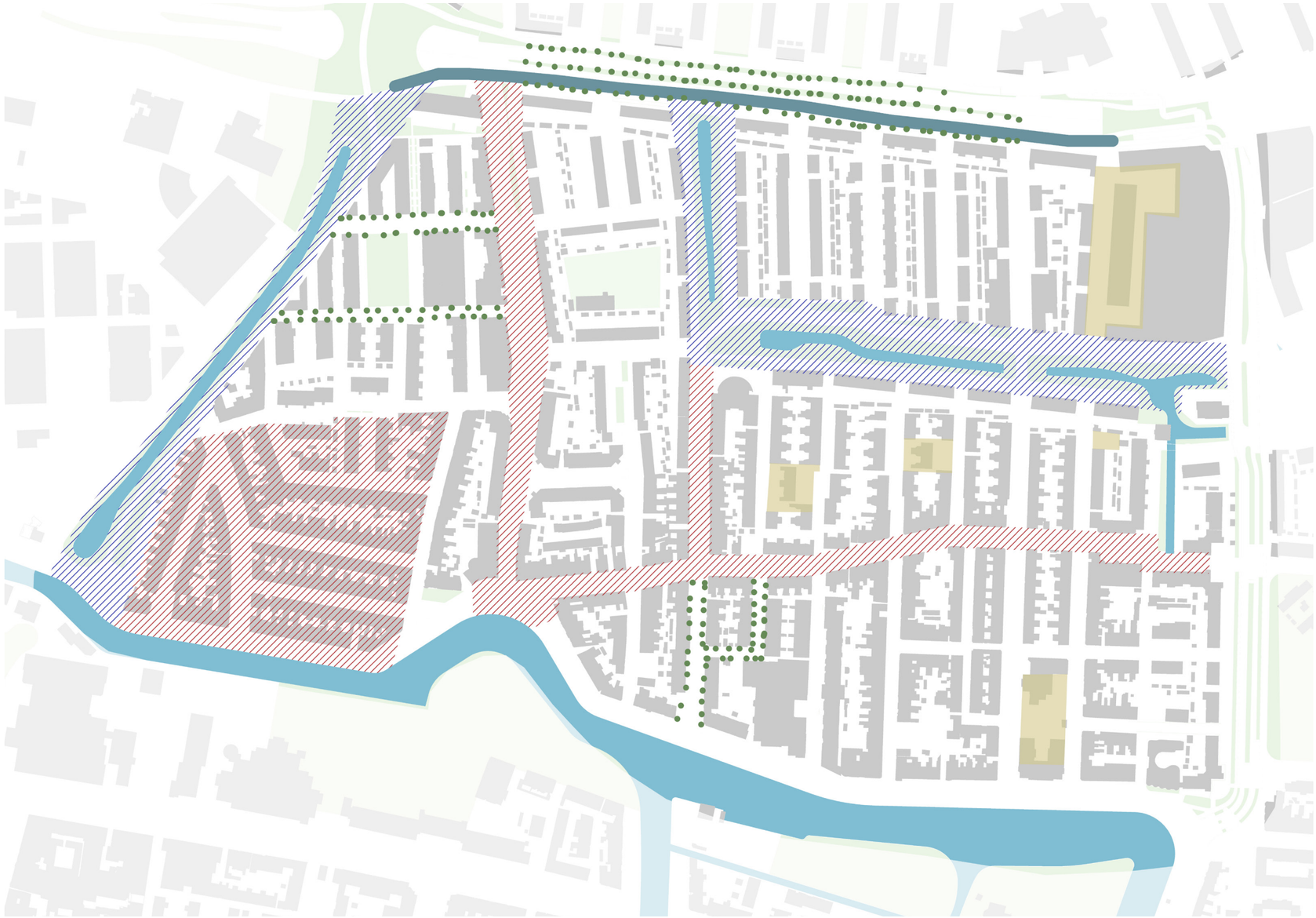


Fig. 100: Climatic related design principles applied to Noorderkwartier

7.2. Health

Leisure and health play a crucial role in enhancing the quality of life in a small neighborhood, and walking and biking are popular activities that contribute to both aspects. In a small neighborhood, the availability of pedestrian-friendly paths, cycling lanes, and green spaces encourages residents to engage in these activities, promoting their physical and mental well-being. Walking and biking are not only enjoyable pastimes but also sustainable modes of transportation. By incorporating dedicated walking and biking paths within the neighborhood, residents are encouraged to leave their cars behind for shorter trips. This reduction in car usage not only reduces traffic congestion but also helps decrease air pollution and carbon emissions, contributing to a cleaner and healthier environment.

Furthermore, walking and biking within a small neighborhood foster a sense of community and social connection. As residents traverse the streets and paths, they have the opportunity to interact with their neighbors, creating a stronger sense of belonging. Walking and biking can also be social activities, with groups of friends or families coming together. This social interaction enhances the overall well-being of individuals and strengthens community ties.

Noorderkwartier now has several spaces dedicated to leisure in the form of playgrounds and an official playground association. The walking and biking routes are mainly around the neighborhood, since they provide more safe and more green corridors where people like to walk and bike. Also they are straight connectors to the Singelpark in the south of the district. The marnixstraat gives opportunity to serve as such a connector.



Fig. 101: Leisure spaces and the most common walking and biking routes in Noorderkwartier

7.2.1. Health strategy

Health interventions in an existing small neighborhood can significantly improve the well-being and quality of life for its residents.

One of the most important intervention is the creation of outdoor spaces for physical activity. Developing parks, playgrounds, walking paths and bike lines will encourage active lifestyles and promotes regular exercise, contributing to improved physical fitness and overall health. Also creating nice walking and biking routes will help with people with exercising in a healthy environment.

Furthermore, implementing measures to enhance pedestrian and cyclist safety is crucial. This can involve traffic calming measures, such as speed bumps and crosswalks, to create safer environments for walking and biking.

Additionally, promoting mental health and well-being is essential. Providing spaces for relaxation, meditation, and social interaction, such as community centers or gathering areas, can foster a sense of community and support social connections. Integrating green spaces and nature elements within the neighborhood can also contribute to stress reduction and improved mental well-being.



Fig. 103: Health related design principles



Fig. 102: Health related design principles applied to Noorderkwartier

7.3. Road network

The roads in the neighborhood play an important role in the mobility and the accessibility of the neighborhood. The roads serve as the primary means for its residents to commute to workplaces, schools, homes and other essential destinations. The road network support the local businesses and services, and enable a smooth flow of goods and services, allowing delivery vehicles and service providers to reach their destinations efficiently. This accessibility is particularly important for small businesses that rely on local customers, as well as for emergency services, such as ambulances and fire trucks, which need quick access to different areas within the neighborhood.

The neighborhood has several main axises (fig104). The Willem de Zwijgerlaan in the north is an important road in the whole city but especially for this district since it is the only way to enter the neighborhood from the north. The Kooilaan in the east of the neighborhood is a connector between the north of Leiden and the singels, which lead to the city center. An interesting fact however is that, although this road should function as the main connector, most road users use the Marnixstraat, which goes straight through the neighborhood. At first glance you would expect that the Marnixstraat is just an ordinary residential road. However, because it is a shorter way between the north and the city center, this road is often very busy and congested. This means there is a lot of opportunities to transform this road into an calm and strong ecological corridor.

Furthermore, there are two corridors leading from the Marnixstraat to the Kooilaan, which are ordinary residential road. Finally, the yellow patches indicate where very narrow streets are present, where drivers have a hard time taking corners or even drive past parked cars.



Fig. 104: The road network in Noorderkwartier show potential ecological corridors.

7.4. Flora & fauna

The presence of flora and fauna in a small neighborhood plays a significant role in supporting biodiversity and ecology. The diversity of plant and animal life within a neighborhood creates a harmonious and thriving ecosystem, providing numerous benefits to both humans and the environment.
Each target species plays a unique role in the food chain and contributes to the ecological processes. For instance, birds help control insect populations, while insects are essential for pollination and decomposition. The presence of diverse fauna ensures a healthy and functioning ecosystem, promoting resilience and sustainability within the neighborhood.

Noorderkwartier has several features that compliment specie existence. However, due to a lot of stony surfaces these features have little ecological value. There are several corridors in the neighborhoods, and they are specified for the selected target species. For example, tree rows exist around the water body, and at the Kooilaan, but they never fully cover a whole street to form a reliable corridor. Furthermore, the west-European hedgehog has more space for their habitat, however this is now mostly due to overgrown gardens, rather than features in the street profile.

To support and enhance the flora and fauna within a small neighborhood, it is important to implement sustainable landscaping practices and promote the preservation of natural habitats. This can include planting native species, creating wildlife-friendly spaces, and minimizing the use of pesticides and chemicals. Residents can also contribute by participating in community initiatives such as birdwatching programs, butterfly gardens, or community gardens, fostering a sense of environmental responsibility and active engagement.

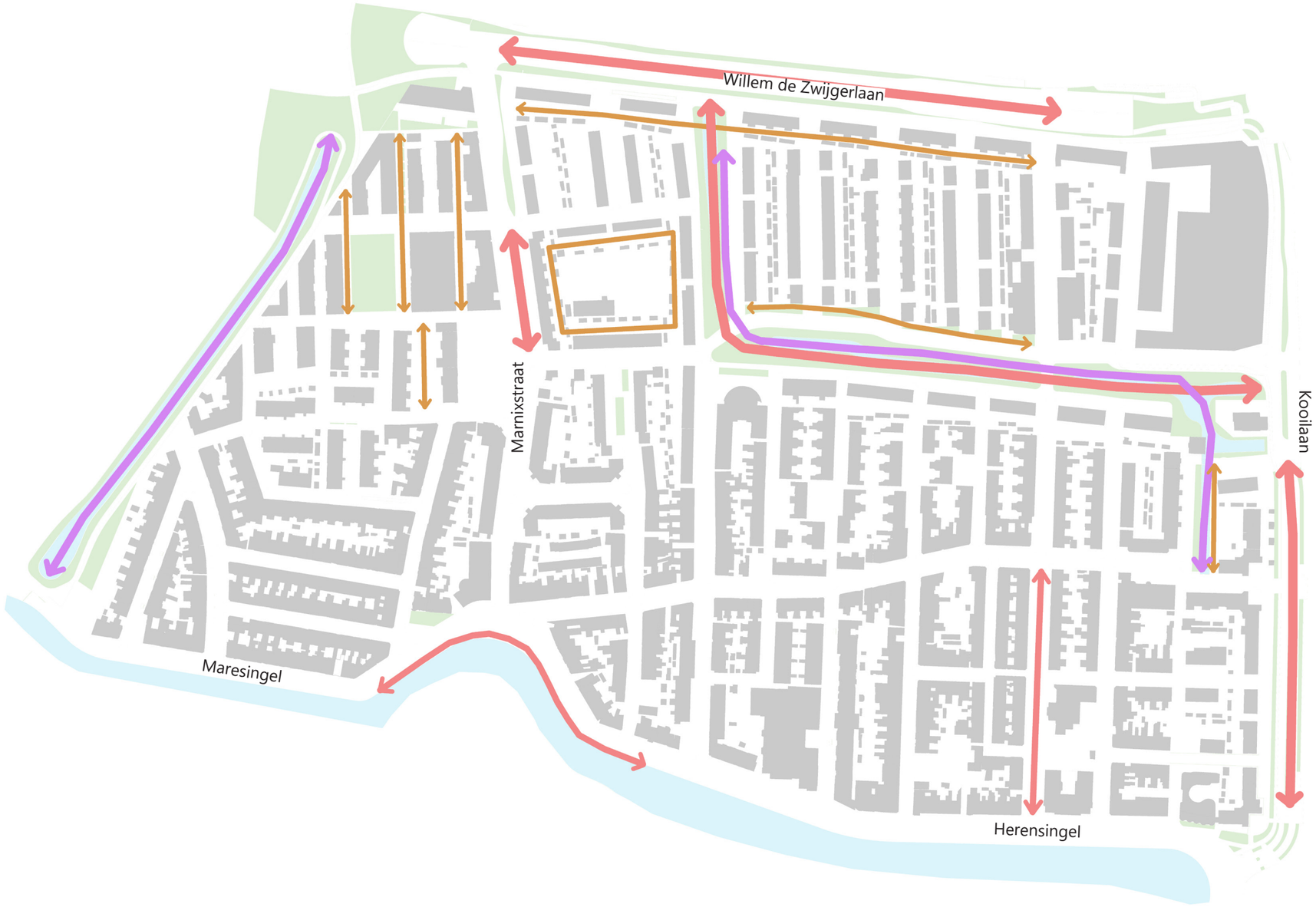


Fig. 105: Existing features for flora and fauna

7.5. Wildlife movement

Incorporating design principles into the design of a neighborhood will result in advantageous options for animal movement between habitats. It is important to note, however, that when moving between habitats, animals tend to take the shortest and most convenient route. Several strategies can be used by urban planners and designers to accommodate wildlife movement. Creating wildlife corridors or greenways that connect different habitats is critical first and foremost. Wildlife is more likely to use these designated pathways if there is a clear and accessible route, reducing potential conflicts with human activities.

Furthermore, when designing urban features, it is critical to consider wildlife's natural behavior and preferences. Natural topographic features, such as rivers, streams, or ridgelines, are frequently followed by animals because they provide familiar and advantageous routes. Incorporating these natural features into urban landscape design can help guide wildlife movement and provide animals with recognizable pathways.

Another factor to consider is the strategic placement of vegetation and green spaces throughout the urban environment. Green infrastructure, such as parks, gardens, and street trees, not only provide critical habitat for wildlife but can also act as stepping stones for animals moving between larger habitats. These green spaces should be linked and designed to support a diverse range of plant species that attract a variety of wildlife.

Furthermore, removing barriers and obstacles is critical for encouraging wildlife movement. Wildlife-friendly elements, such as underpasses, culverts, or wildlife bridges, can assist animals in crossing busy roads or other human infrastructure safely. By removing or reducing barriers, the most convenient route for wildlife becomes the ecologically beneficial one, ensuring effective habitat connectivity.



Fig. 106: ALthough design creates wildlife movement opportunities, wildlife will always choose the most convenient way of moving

7.5.1. Ecological strategy

Ecological interventions in an existing small neighborhood can provide significant environmental benefits and promote biodiversity.

The incorporation of native plants and vegetation is one effective intervention. The neighborhood can create habitats that support a diverse range of flora and fauna by selecting species that are adapted to the local climate and ecosystem. Pollinators, birds, and other wildlife find food and shelter in native plants, which contributes to the overall ecological balance.

Creating wildlife corridors and green connections between existing natural areas is crucial for ecological interventions. By designing and preserving green spaces that connect habitats, such as parks, nature reserves, or green corridors, the neighborhood can facilitate the movement of wildlife, enhance biodiversity, and promote genetic diversity among species.

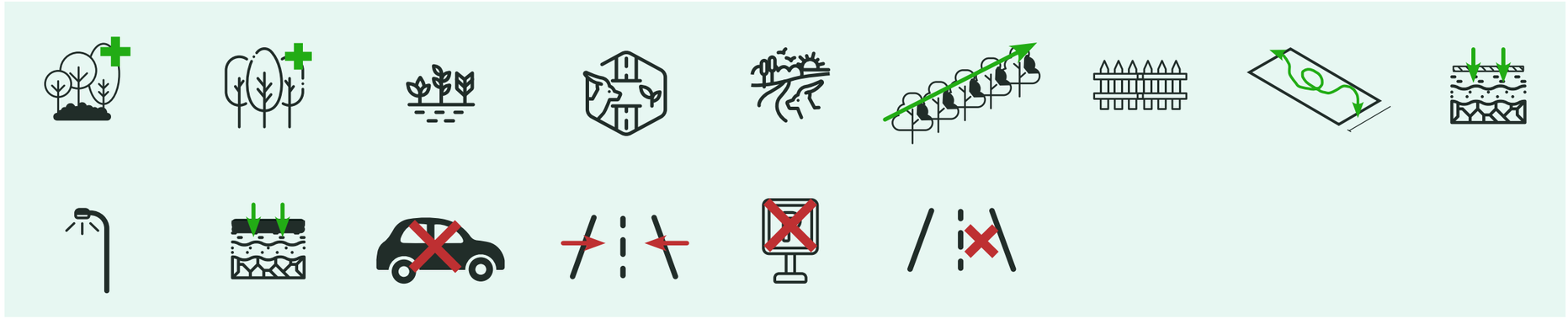


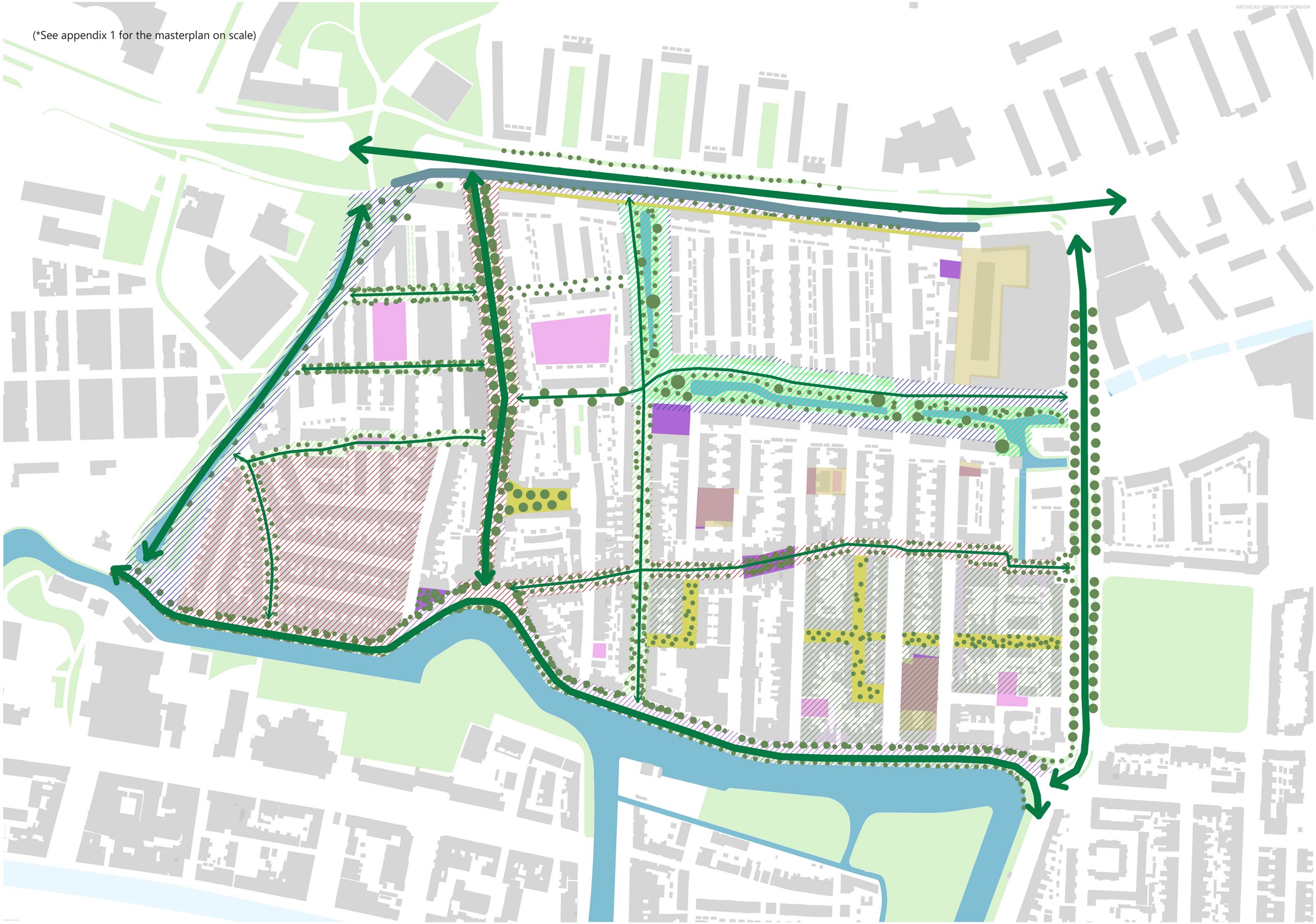
Fig. 108: Ecology related design principles



Fig. 107: Ecology related design principles applied to Noorderkwartier

(*See appendix 1 for the masterplan on scale)

ARCHICAD EDUCATION VERSION



7.6. Design experiment Marnixstraat

The marnixstraat is the street that goes straight through the neighborhood from north to south, and because of its appearance and layout it is often a busy and congested street, where people are invited to drive faster than is allowed. It also is a direct connection between the Noorderpark and the Singelpark, which gives it great opportunity to serve as an ecological corridor.

Although this street has a lot of potential, not all target species will benefit from the interventions in this street. The brown frog prefers being around any water body, so this street is not suitable for them, since there is no water present, neither will there be water implemented in the new design of the street. Therefore it lacks conditions for the frog to survive in this street. The brown is disregarded in this design experiment.
The marnixstraat has a street profile of 18-25 meters, where cars can pass each other easily with higher speeds than is allowed. There is no dedicated bike lane, expect for a small part leading to the north, which sometimes creates dangerous situations. Furthermore a lot of space is dedicated to parking and sidewalks, which leads to a very stony street. Some small verges are notable but they never extend more than 2 m^2. There is one line of large trees which serves excellent at bird habitat, but this tree line doesn't cover the complete street, so bird have nowhere to go after crossing this tree line. There is potential surfaces that can extend this tree line so that it can serve as an actual corridor.

The current score of the road-related ecosystem services is illustrated in fig 108. The stony surfaces, little to no vegetation and the wide profile makes it a street with high potential for improvement on basically every road-related ecosystem services.



Fig. 109: Road-related ecosystem services score for the Marnixstraat



Fig. 110: Lot of surface is dedicated to parking and sidewalks in the Marnixstraat



Fig. 111: A tree line is visible which is excellent for bird movement



Fig. 112: Small vegetation is visible but provides no conditions for a robust corridor

The space dedicated to the car will be minimized in order for other components to have a fair amount of space in the street profile. Where cars are now parked perpendicular to the road, parking space is in the new situation parallel to the street, which instantly gives three meters extra to give another function. Furthermore, a six meter wide sidewalk is unnecessary, so this will be brought down to two meters, which gives four extra meter to add up for vegetation. These extra meters will all be dedicated to green surfaces in extensions of the existing front yards and have a minimal width of 9 meters, which fits perfectly with the preferred width of the verge for the target species. This will greatly reduce car mobility in the street, which is exactly what is necessary to improve road-relate ecosystem services. (See appendix 2 for applied design principles)



Fig. 113: Current situation



Fig. 114: New situation

Based on the spatial needs for the target species, there are several interventions implemented in the new street profile. These are divided in three levels: the ground level, shrub level and the tree level. The landscape is in a constant state of evolution. The influence of plant succession should be considered, and intervention measures should be implemented in stages, to achieve the canopy continuity and species richness mentioned in the design principles, to keep the proposed landscape structure.

For the starling and the dwarf bat trees are added throughout the whole street, creating a canopy corridor for them to move, and the trees them selfs can serve as their own habitat. For the west-European hedgehog, several shrubs are placed as well as an widening of the verges, so that they can move freely alongside the road. The bumblebee and the butterfly will be accommodated by implementing various flowers, grasses and a wide enough verge to safely hunt for nectar.

The road space belongs to the high pavement area, and the selection of shallow-rooted trees may contribute to the destruction of the built area and the loosening of the soil. To increase species diversity, shrubs and deep-rooted plants will be planted in the verges. Management, in addition to the planting stage of plants, will be an important means of maintaining the landscape structure during the subsequent succession process. The primary management methods in this design are construction, spacing, thinning, pruning, and moving. The construction and spacing phases dominate the planting stage. Following that, gradually implement the remaining management methods.

By implementing the design principles shown in the sections and the floor plan the following score can be given to the road-related ecosystem services, where there is an improvement in all services.

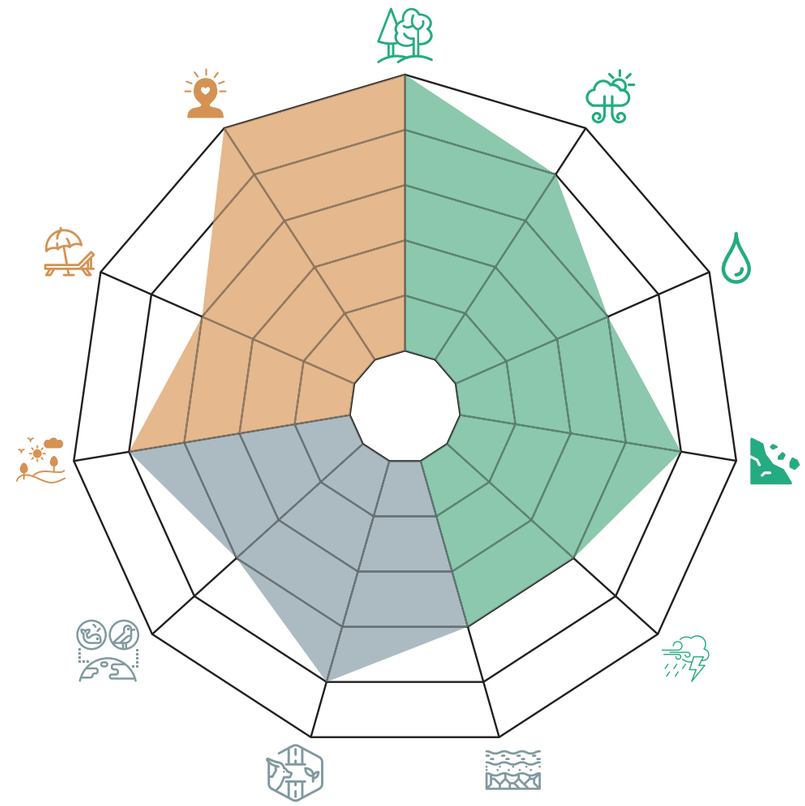


Fig. 115: Road-related ecosystem services score for the new design of the Marnixstraat



Fig. 116: The marnixstraat current situation



Fig. 117: Design principles applied to the marnixstraat


Q8-533-P
548-I




X6-548-I


C6-693-U

7.7. Design experiment Willem de Zwijgerlaan

The Willem de Zwijgerlaan is a wide street that splits the Noorderkwartier in two parts. This lively and busy street, named after the famous Dutch statesman Willem van Oranje, is an important road leading from east to west. The Willem de Zwijgerlaan stretches from the canals of the historic city center to the Kooilaan in the east of the Noorderkwartier. With a length of 500 meters and a width of 45 meters, this street is the largest in the Noorderkwartier.
On both the north and the south of the streets are mainly residential houses, ranging from characteristic old buildings in the north to more modern apartments in the south. Many of these homes have a beautiful view of the nearby Noorderpark, which offers a green oasis in the busy city. The park attracts residents and visitors alike, who enjoy nature, hiking trails and play areas here. As for the green aspects of Willem de Zwijgerlaan, there are several trees along the street that provide shade and visual appeal. These trees contribute to the aesthetics of the avenue and also provide some cooling during hot summer days. Although there are no large green areas, residents and visitors can still enjoy the nearby Noorderpark, which is easily accessible from Willem de Zwijgerlaan.



Fig. 118: Location Willem de Zwijgerlaan in the Noorderkwartier



Fig. 119: Existing tree rows in the verge provide good habitat for birds



Fig. 120: The four lanes are a ecological barrier between north and south



Fig. 121: Two laned roadway invites people to drive faster than they are allowed

Ecological analysis

The Willem de Zwijgerlaan is a wide street where a lot of different flows happen at the same time. However, a lot of these processes are car-related. This means there is little space left for ecological surfaces. The street now consists of a little over 5.000m^2, which is only **22%** of the total surface of the street profile (black outline). Plain grass and shrubs seem to be simple elements in the street, but they play an crucial role in the overall ecological balance, aesthetic appeal and environmental quality of the urban landscape.

This lack of green surfaces first of all causes problems for nearby air quality. Grass and shrubs are effective at filtering and absorbing pollutants from the air, such as dust, particulate matter, and harmful gases. Without these natural filters, levels of air pollution near the road increases, posing health risks to residents, pedestrians, and motorists. Furthermore, grass and shrubs help with mitigating the urban heat island effect, and with a lack of these elements this effect will only increase. In addition, vegetation helps with water problems, prevent soil erosion and have great impact on the visual aesthetics of the urban landscape.

The Willem de Zwijgerlaan has several green strokes in its street profile. Alongside the main road two verges are present which consist of small shrubs in order to prevent people to get to the busy street fairly easy. In between the four lanes is a five meter wide verge, which consists of just plain grass, and ensures there is enough space for cars if collisions occur. Furthermore the Willem de Zwijgerlaan has solid tree rows on either side, which are a great route for birds. However the tree line is not supported on the ground level, since the verges are to narrow and undergrowth to form a potential wildlife corridor.

While it is an important road, it now also serves as a ecological barrier between north and south. With eight lanes and a width of 45 meter this road ensures almost no wildlife can cross it. Here lies opportunities to make sure this road no longer serves as a barrier but as an ecological passage into the neighborhood.

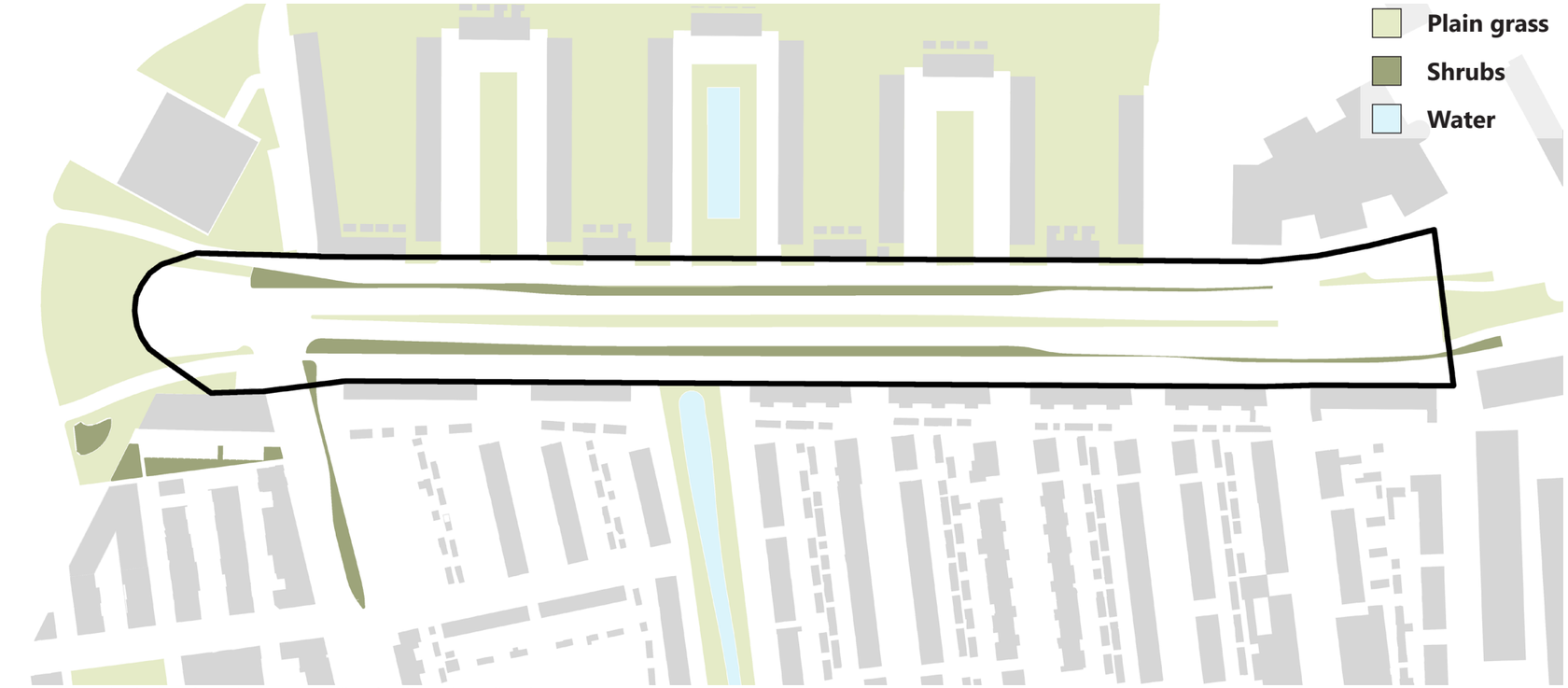


Fig. 122: Ecological surfaces in street profile of Willem de Zwijgerlaan



Fig. 123: Wildlife borders prevent animals to use the road as an connector between north and south

Tree species
The diversity of tree species is critical in providing a variety of essential ecosystem services within the complex structure of everyday life. Each species has unique features and adaptations that contribute to the overall health and resilience of ecosystems, ensuring the survival of both human and ecosystems (page....) .

The variation of the tree species in a street profile promote habitat richness. The different trees provide shelter, food sources and breeding grounds for different urban wildlife species. Furthermore, tree species diversity improves ecosystem stability and productivity. Growth rate, root structure, and leaf characteristics vary, resulting in efficient resource utilization and nutrient cycling. This results in increased soil fertility, decreased erosion, and improved water infiltration and retention, reducing the impact of floods and droughts.

Furthermore, diverse tree communities help with carbon sequestration and climate regulation. Carbon dioxide, a major greenhouse gas, is captured and stored differently by different species. Ecosystems can maximize their carbon sequestration potential by incorporating a variety of tree species with varying growth rates and carbon storage capabilities, thereby aiding in climate change mitigation.

In the surroundings there is a good variety of tree species and all trees have their own specific strengths (page ...). The map on the right shows the most common trees present in the Willem de Zwijgerlaan. The location of the trees is highly connected with animal movement and the animals borders that is shown in the previous page.

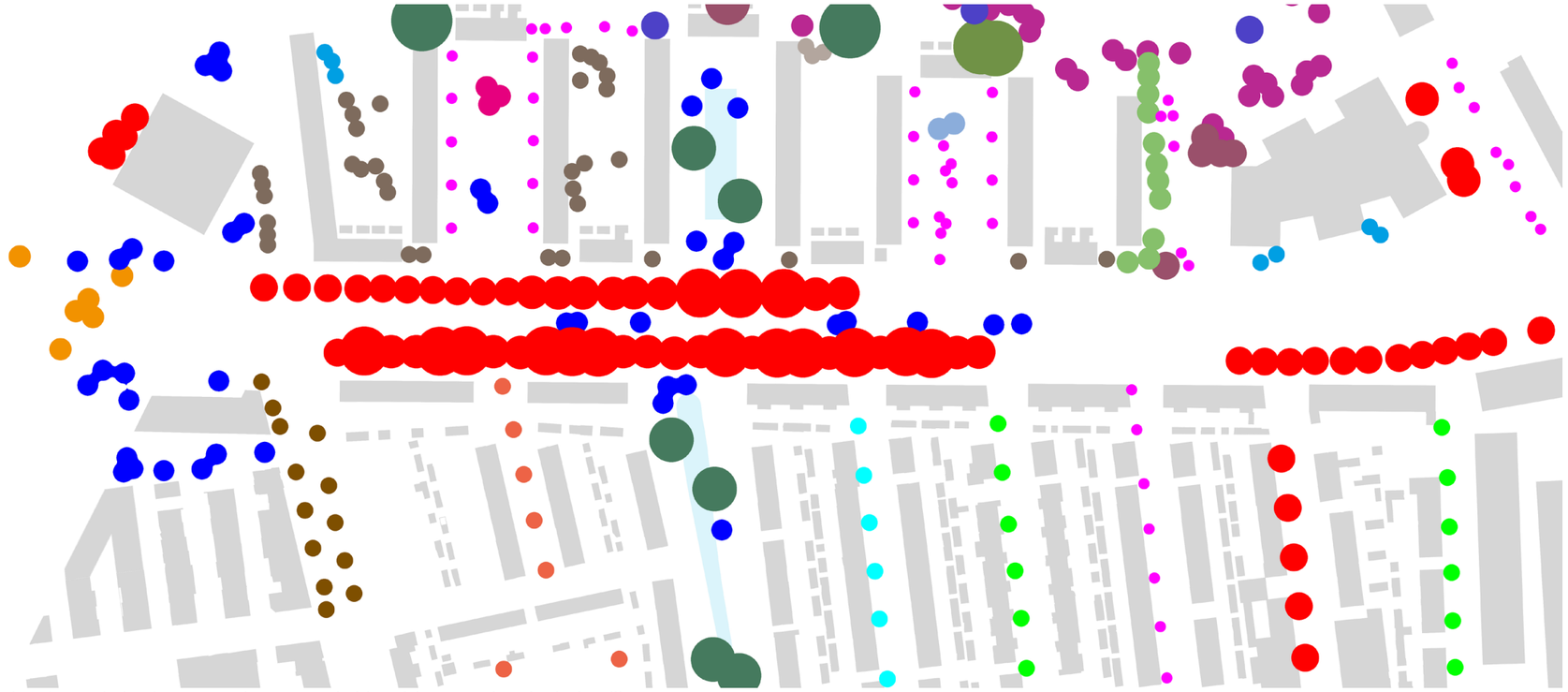


Fig. 124: Variation in tree species ensures habitat richness and ecological resilience

Acer rubrum



Fraxinus Ornus



Magnolia kobus



Gleditsia triacanthos



Salix ×sepulcralis 'Chrysocoma'



Prunus serrula



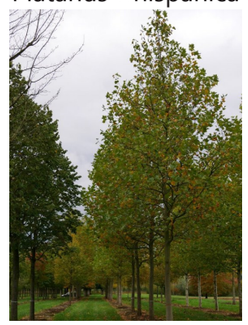
Liquidambar styraciflua

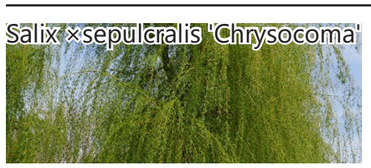


Betula papyrifera



Platanus ×hispanica



 Fraxinus Ornus						×	8 - 15m			×			×			×		
 Gleditsia triacanthos				×	×	×	20 - 25m	×		×		×	×			×	×	
 Prunus serrula		×	×		×		6 - 8m		×			×					×	
 Liquidambar styraciflua		×	×	×	×	×	25 - 30m	×		×	×	×		×	×			
 Magnolia kobus		×		×			8 - 12m			×		×		×		×		
 Salix ×sepulcralis 'Chrysocoma'		×			×	×	20m		×		×	×		×	×	×	×	
 Platanus ×hispanica		×	×			×	20 - 30m	×		×		×	×	×	×			
 Betula papyrifera			×		×	×	18 - 20m	×	×			×				×		×
 Acer rubrum					×		15 - 20m		—	—		×		×	×		×	

Road analysis

There are various road surfaces to be seen, each with a specific purpose to ensure safe and efficient transportation. The street profile is divided into three sections: traffic lanes, shoulders, and pedestrian sidewalks. The Willem de Zwijgerlaan is an important arterial artery for cars, cyclists and public transport. The street is easily accessible and connects different parts of Leiden with each other. Bus lines cross the avenue, making it easy to travel to other neighborhoods or the train station.

The lanes in the middle of the street are the most important, because they are part of the arterial road network of Leiden. People are allowed to drive 50km/h, and there is a single crossing for pedestrians and cyclers. However, since there is no safety camera, people tend to drive faster than they are allowed. These lanes are made of asphalt and on their own cover more surface than the total green surfaces in the street profile, namely 38% of the total surface.

In addition to the four middle lanes, there are also two lanes on each side. These are residential roads and people have to drive 30km/h in these streets. These streets is also where pedestrians and cyclists move alongside the street. These are so-called 'fietsstraten' (bike roads), and the bike should have the dominant factor. However, when no bikers are around, people tend to drive way faster, due to the width of these lanes. These lanes on their own also cover a larger surface than the total green surfaces in the street profile, with a 23% coverage of the total surface.

Finally, pedestrian sidewalks flank the entire width of the street, catering to the needs of foot traffic. Sidewalks are typically made of concrete to ensure durability and a smooth walking surface for pedestrians. They may also include ramps for easy access and tactile paving to help visually impaired people.



Fig. 125: Current lanes show the speed and the road acces around the Willem de Zwijgerlaan

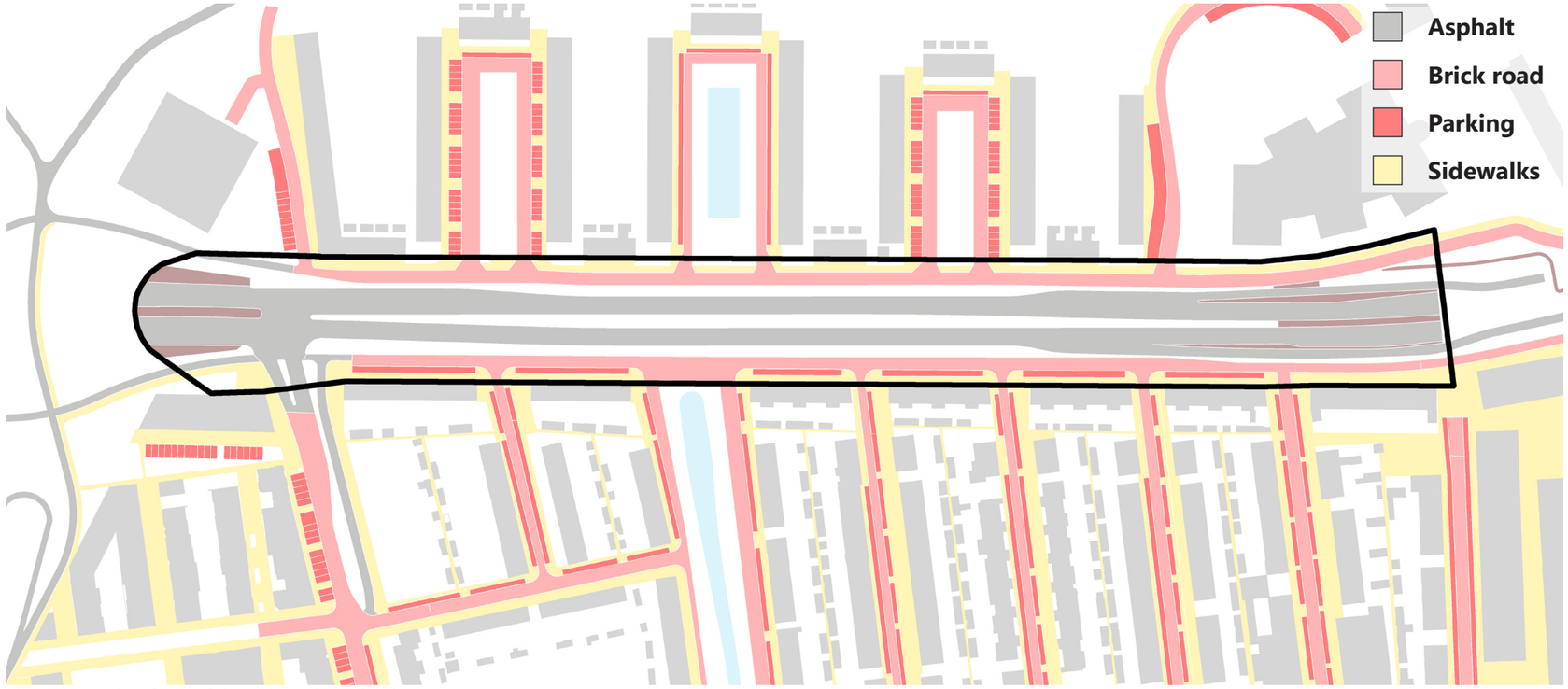


Fig. 126: Hard surfaces of the Willem de Zwijgerlaan

Climatic analysis

Climate issues play a significant role in shaping the design and accessibility of street profiles in a dense city. Heavy rainfall and its impact on road accessibility, as well as the urban heat island effect, pose particular challenges in such urban environments. When heavy rain falls, it can cause a variety of issues with street profiles. One major source of concern is the possibility of flooding. Excess water can accumulate on road surfaces if the city's drainage infrastructure is insufficient or overburdened, impeding vehicular and pedestrian movement. In extreme cases, this can lead to road closures and transportation network disruptions.

To address this problem, urban planners and engineers implement measures to reduce the impact of heavy rain on road accessibility. Stormwater drains, culverts, and underground pipes, for example, are designed to capture and channel rainwater away from the street surface. These systems help to prevent excessive pooling and keep roads open during and after heavy rain events.

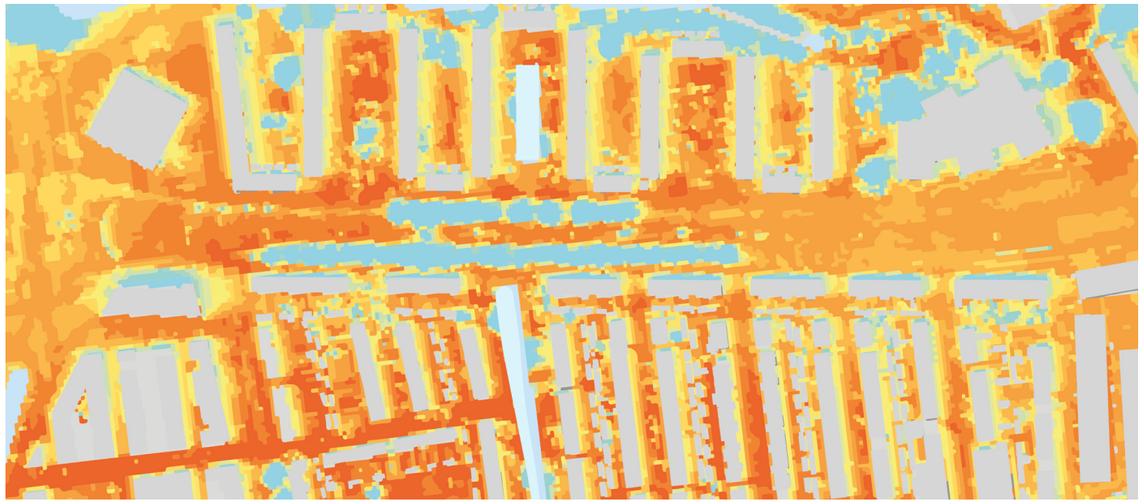
Another factor to consider in the event of heavy rain is the durability of road surfaces. Water exposure can hasten the deterioration of road materials, resulting in potholes, cracks, and uneven surfaces. Maintaining road quality is critical in a dense city with high traffic volumes to ensure safe and efficient transportation. As a result, city officials prioritize the use of long-lasting materials for road construction, such as asphalt or concrete mixes specifically designed to withstand local climatic conditions.

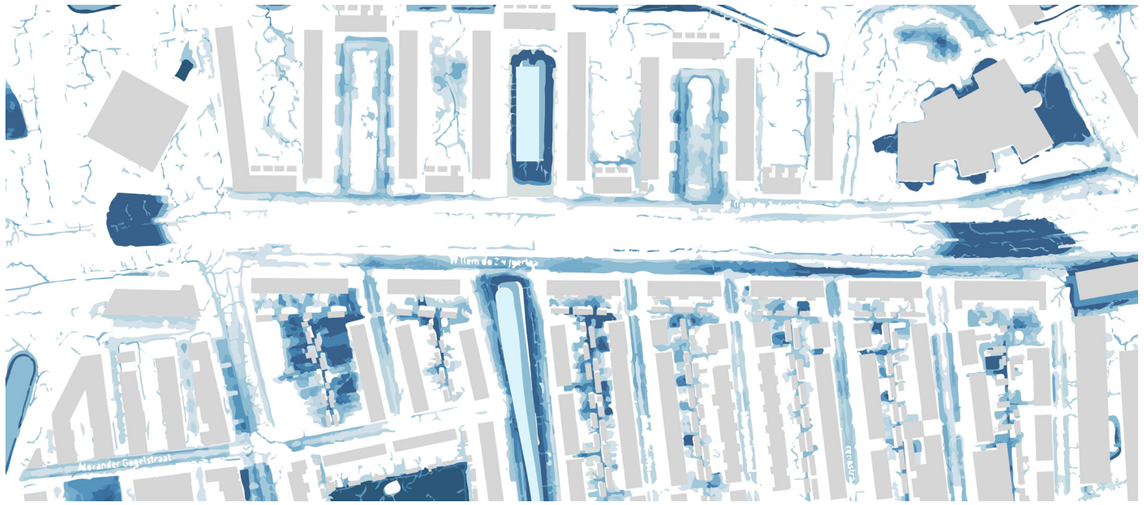
Furthermore, road surfaces are frequently designed with slope and camber to facilitate rainwater runoff. The natural topography of the area is taken into account when designing street profiles, ensuring that the roads have a slight slope to encourage water to flow to the sides and into the drainage system. This helps to reduce water accumulation on the road surface, lowering the risk of hydroplaning and ensuring accessibility even during heavy rain.

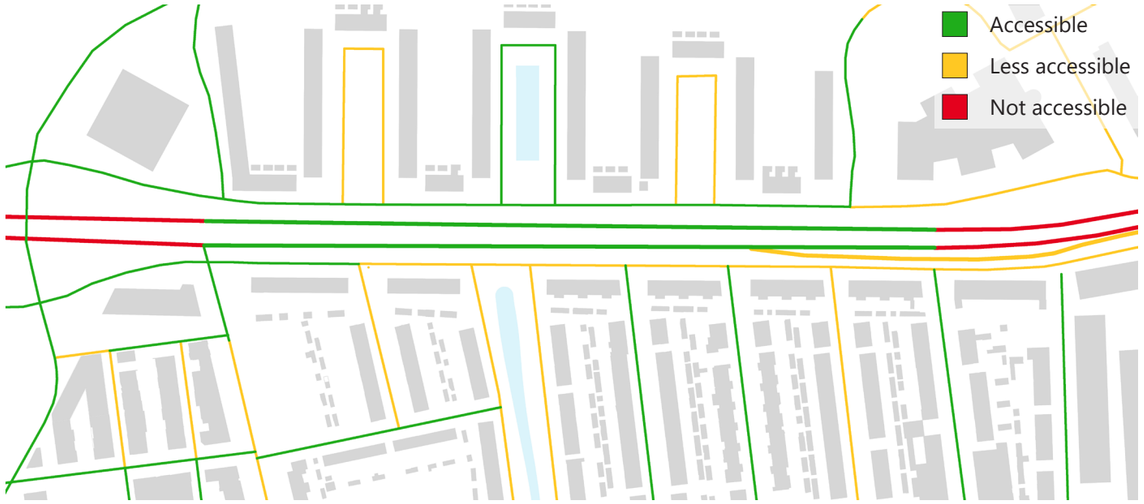
Considerations for accessibility also include the provision of safe pedestrian walkways during heavy rain. Sidewalks are typically built with materials that provide good traction and prevent slips and falls. They may also have appropriate drainage systems, such as channels or grated inlets, to direct water away from the walking surface. In some cases, covered walkways or canopies are installed to provide rain protection, allowing pedestrians to navigate the city comfortably and safely even when the weather is bad.

Additionally, city planners may include additional features to improve road accessibility during heavy rain. Speed bumps or traffic calming measures, for example, can help slow down vehicles and reduce the risk of hydroplaning. Another important component is street lighting, which improves visibility during rainy conditions and increases safety for both drivers and pedestrians.

In a street profile, the urban heat island effect poses significant dangers. Excess heat accumulation in these areas can harm human health, infrastructure, and the overall ecosystem. High temperatures can cause heat-related illnesses, especially in vulnerable populations like the elderly. Heatwaves in urban areas can also put a strain on energy systems, increasing the likelihood of power outages and putting additional strain on cooling systems. High temperatures hasten the deterioration of asphalt, causing cracks in road surfaces and increasing maintenance costs. Furthermore, the urban heat island effect disrupts the natural balance of ecosystems by influencing vegetation growth, decreasing biodiversity, and altering wildlife habitats. Mitigating the urban heat island effect through green infrastructure, cool pavement, and other strategies is critical for protecting public health, increasing resilience, and creating more sustainable and livable cities.







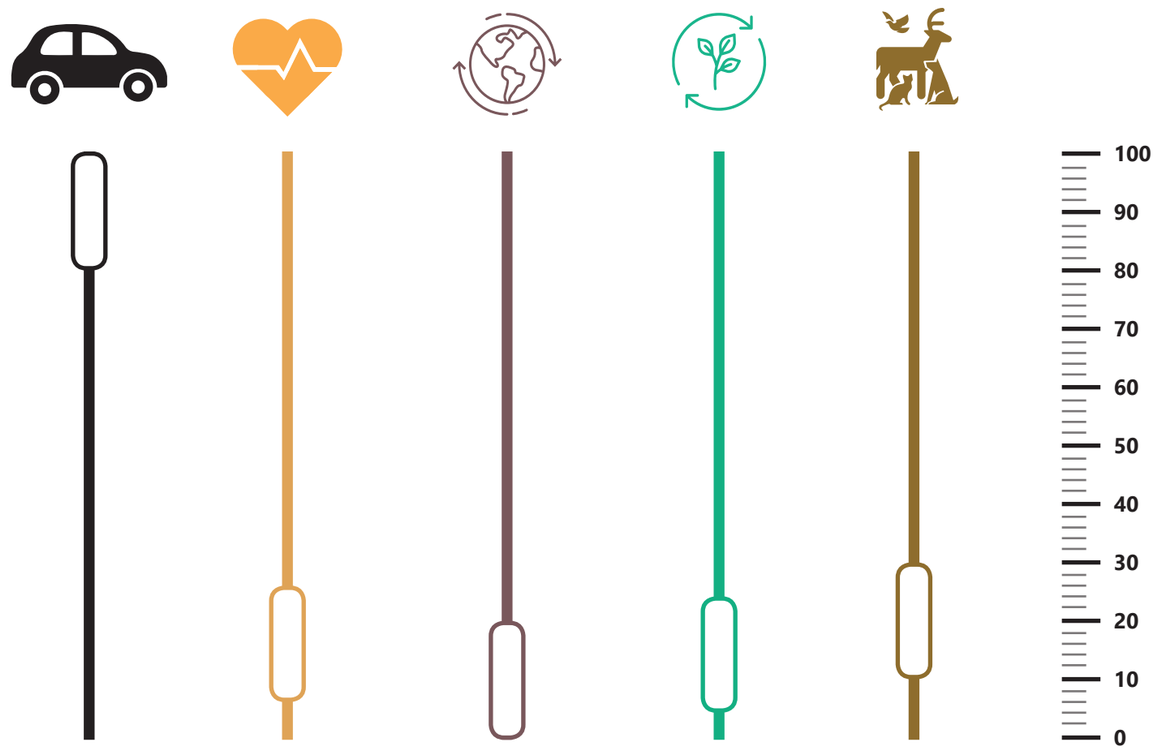
Adjusting the sliders

The Willem de Zwijgerlaan one of the important arterial roads in Leiden. In a highly dense urban environment like Leiden, this street can be described as a typical street, that is first and foremost designed for fast and efficient movement of cars, public transport and goods. The 45 meter wide street provides eight lanes for the cars, with limited space for pedestrians and cyclers.

The sliders on the right show how the four main themes (health, climate, flora, fauna) are represented in the current street profile. Space dedicated to the car is also represented since this is (for now) a very dominant factor. The bars on the sliders show what the current score is, expressed in percentages. The bars represent an estimated value of each of the themes. For example, in case of the climate theme, a score between 0 - 20% can be given. These scores are based on a critical look at the current street profile, in which the street now scores poorly on all fronts, except, of course, for the passage for cars, trucks and public transport.

When designing with multiple themes which are poorly represented, it is of value to look at what would happen if we just upgrade a single theme to the maximum. This way we can fully implement the design principles of a single theme and this makes it possible to look at how these design principles influence the other themes. On the other hand, when fully upgrading a single theme, certain other design principle are no longer applicable. A balance should be made in order to get the optimal street profile design.

In the next coming pages, an exploration is being made of maximizing a single theme. In this example the flora is being upgrade to the maximum, and this will show the influence it has on the other themes. What would happen if a single theme is fully upgraded? The flora is gradually improved to the maximum and the design principles that are applied are explained.





The first scenario describes an approximate 25% improvement from the current situation. In terms of flora-related issues in this street, the diversity in plant species is the most lacking. Therefore an small intervention like planting more diverse flowers and plants in the existing verges will already give a new look to the street.

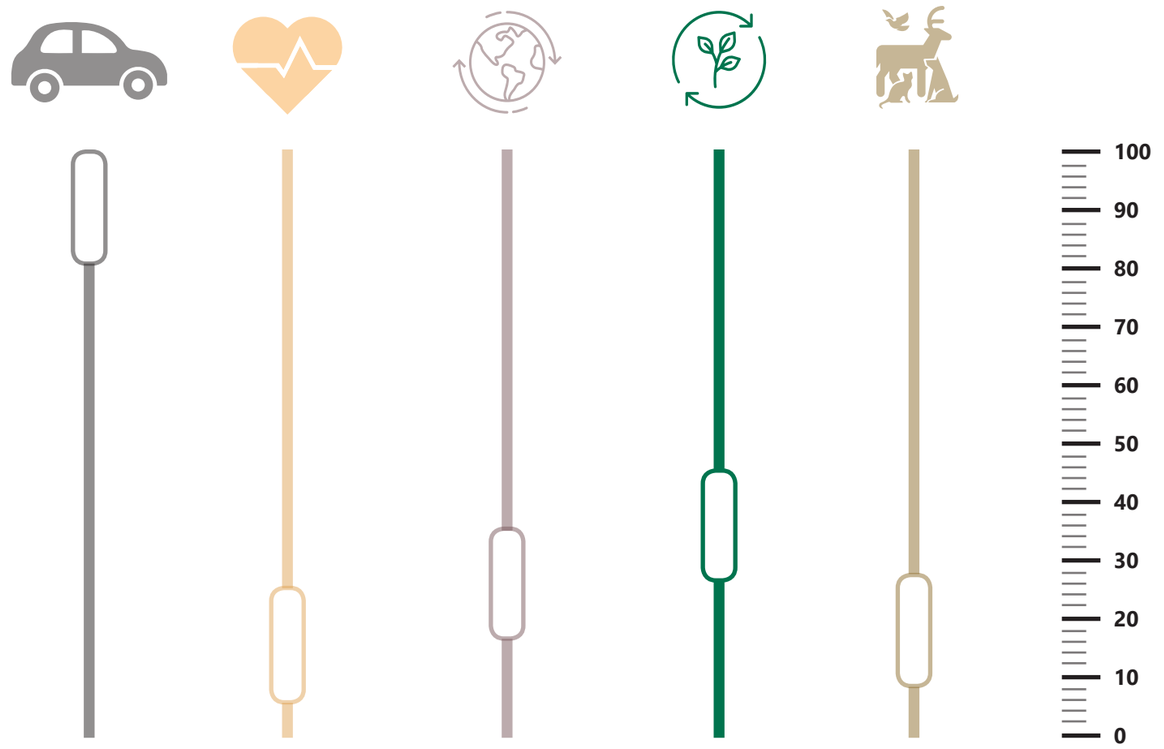
By planting different flowers and plants in both side verges and the middle verge, the plant diversity is already grown relative to the existing situation. This flora diversity will also improve climatic components, such as air quality, temperature regulation and biodiversity conservation. Therefore the slider of climate will improve just as much as the slider for flora.

Besides improvements for flora and climate, diverse flora in highly dense urban environments improves wildlife numbers by providing essential habitat and food sources. Native plants attract a variety of insects, which serve as a food base for birds and other animals.

It is important in this stage to already look at how this road will manifest itself in the future. These future conditions must be taken into account when deciding which flora should be present on the verges.
On either sides the roads are narrowed, to create an extra meter for each verge, where more plants and flowers can be planted. In this situation, mobility is still high on the list, but the diversity of plants has already grown strongly.

This scenario shows that with small interventions, already a boost can be given to the four main themes, without degrading a lot of mobility.







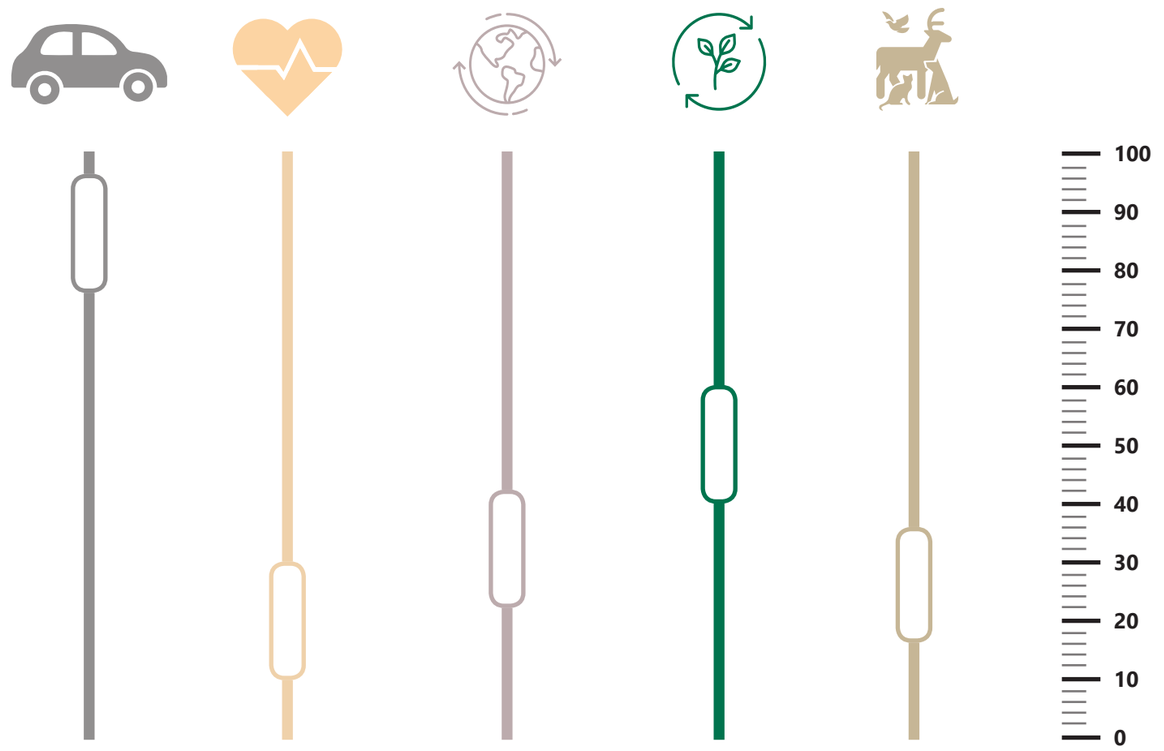
5m | 4m | 4.5m | 7m | 5m | 7m | 4.5m | 4.5m | 3.5m

The second scenario is an approximate 50% improvement from the current situation.
In this case the flora diversity is even more improved related to the previous scenario. Especially in the middle verge more diversity is created in order to create an extra lively middle verge.

Furthermore, on both side street, a complete lane is removed to create more space for the side verges. This way more flora can be created which in turn will improve wildlife numbers, climatic components and the overall quality of life. Incorporating plant diversity through parks, gardens, and street trees offers opportunities for relaxation, recreation, and connection with nature.

While the flora is more thriving in this scenario, the car is still very dominant. This is because the Willem de Zwijgerlaan is an important vein in the street network of Leiden. Therefore it is less efficient to get rid of the road in the middle.



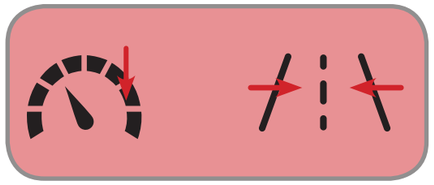




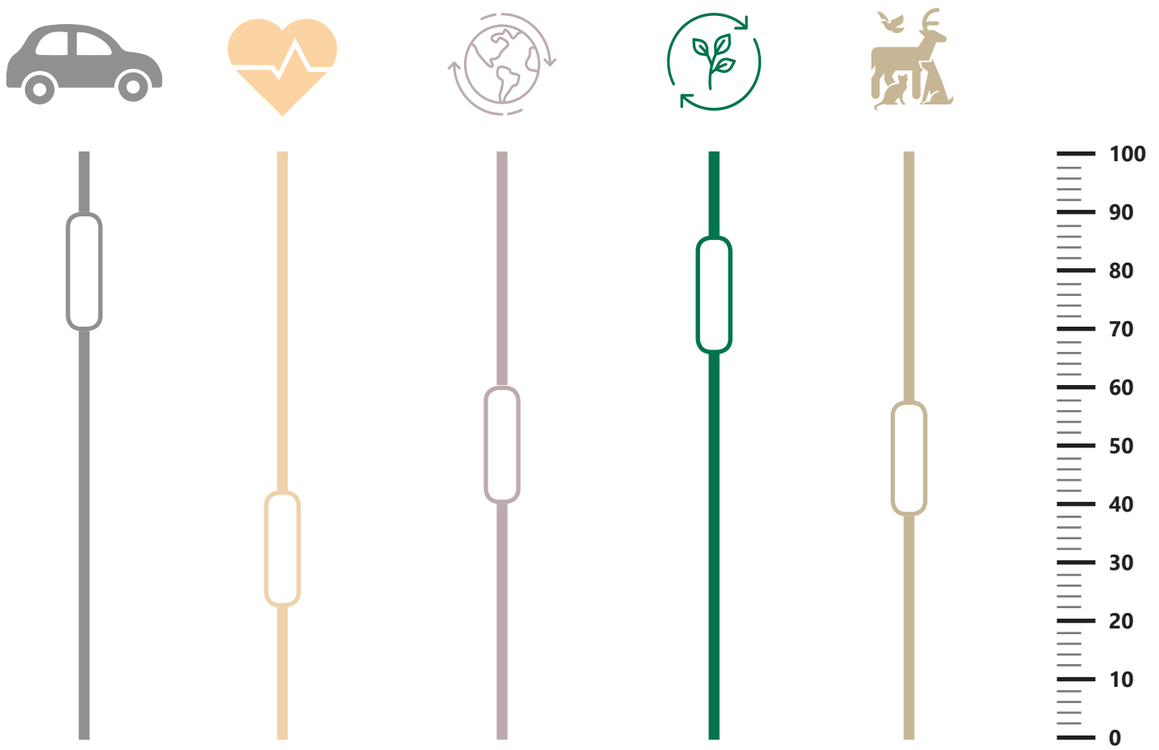
This scenario is an approximate improvement of 75% from the current situation. This is where the flora starts to really thrive in the street profile. Since plant diversity is already quite high, this needs not a lot of improvement from the previous situation.

What is important in this scenario is maximizing the surface that can be used to create space for flora. The middle verge in the current situation is five meters wide, which, in the case of the flora theme, has no function, except to create a safe distance between the four lanes in the middle. However, there are no minimal width that should be in between lanes. By narrowing down this middle verge to one meter, (to at least have some sort of safety between the lanes) an extra four meters can be created to add to the side verges. Since the middle verge is now only one meter wide, large trees can not grow there. Therefore a row of smaller trees is implemented to create a continuous corridor. In addition, the sidewalks are narrowed down, and all these extra meters will be added to the side verges, to create a robust and thriving ecosystem alongside the busy road.

In this scenario, the car's dominance is reduced to half compared to the current situation. This is because there is only one lane on either side, and people tend to drive slower when vegetation is close to the edge of the road.







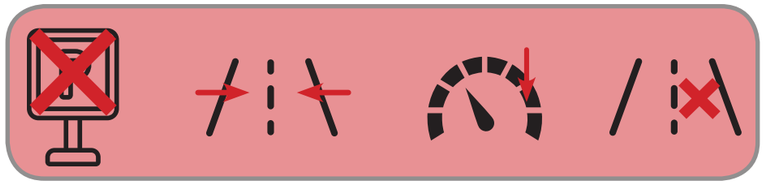


Maximized flora

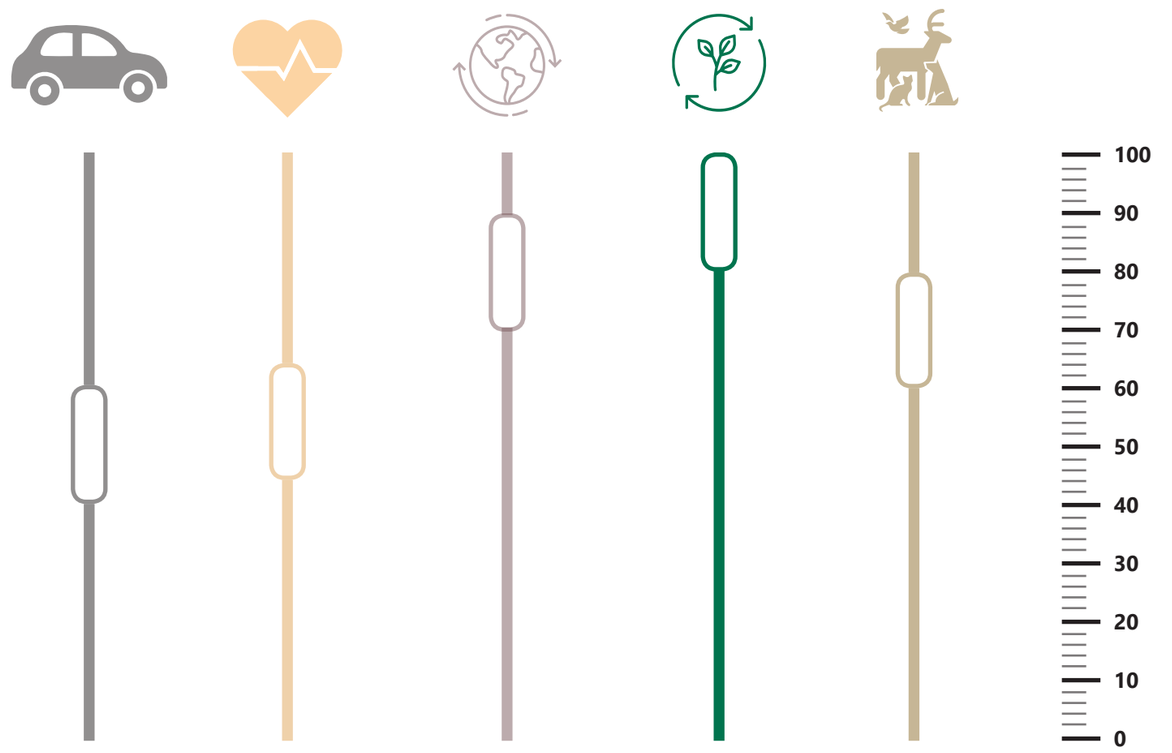
This is the final scenario in maximizing the flora theme in the street profile. Here the flora is put to its maximum of 100 points. All the previous mentioned design principles related to the flora are combined to get this scenario. This is the biggest step since the previous scenario.

The four lanes in the middle have been reduced to two, and traffic will be allowed to travel at a maximum speed of 30 km/h. This was chosen to reduce the impact of the cars without removing them entirely from the street scene. In addition, the parking spaces on the left have been removed to make room for the intermediate verges. The extra space created by removing the parking spaces and middle lanes allows the verges to be as wide as possible without making the street completely inaccessible by car. The health theme is still quite low, because in this scenario, all of the remaining space is dedicated to nature rather than people. In addition, the middle verge has more flora diversity, so this small space of green will not be forgotten.

This final and extreme scenario lets nature thrive, where the other themes also benefit from. The climate slider and the wildlife slider both are very much improved when just improving the flora, because they strongly influence each other.









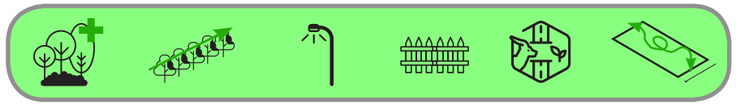
Maximized fauna

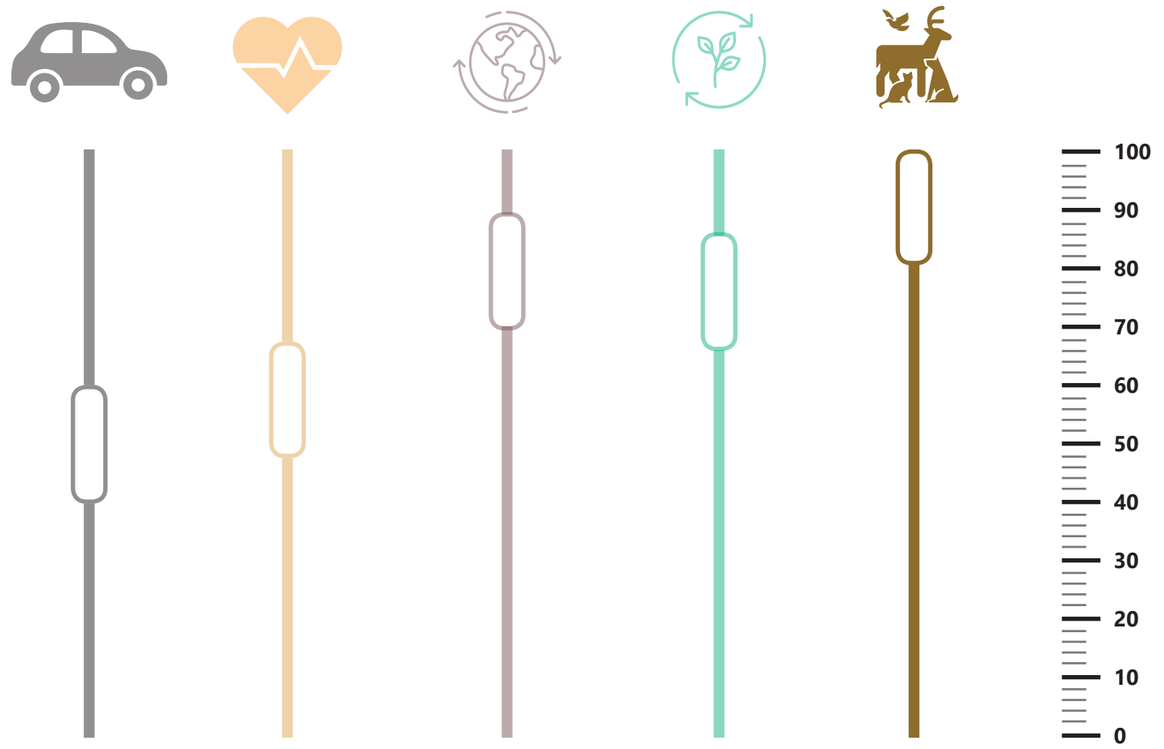
This is the scenario where instead of flora being maximized, the fauna theme is maximized. When considering designing for wildlife in a street profile, the most important problem is the large amount of road kill. Therefore a good protection layer between the verge and the street should be provided. In this case a solid wall is being chosen. However this could also be a dense hedge or a fence. As long as it ensures that wildlife can not easily walk on the road. Wildlife that accidentally find a way over the wall, also have a greater change of survival due to reduced speed limits.

Secondly, it is important for wildlife to move alongside the roads and to use the road network as an actual movement corridor. To make this happen, some of the same design principles, as stated in thee maximized flora scenario, are being implemented. This way the width of the verges are being maximized, which makes it possible for wildlife to move alongside the road. Also, the verges are wide enough for wildlife to use the verge as an habitat on their own. The underpass makes it also possible to cross the road without interference from cars or other heavy traffic. Using smart use of the landscape will lead wildlife to these underpasses. This way, the habitats are larger than just a single stroke.

Besides the conditions on ground level for a robust wildlife habitat, the habitats for birds in this scenario are also being maximized. By making the middle verge slightly larger, bigger trees can be planted here, and birds can safely cross the busy road.









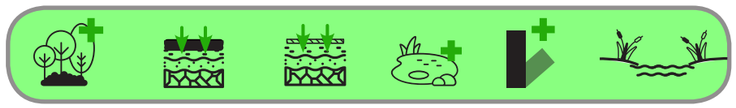
Maximized climate

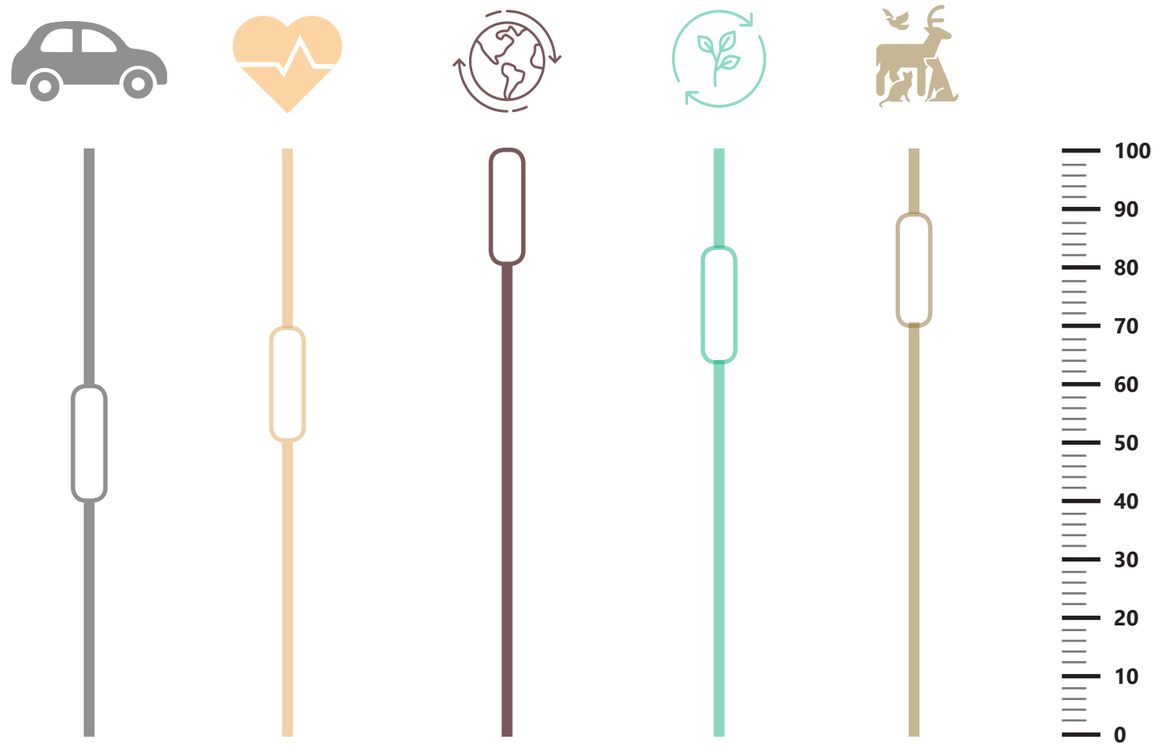
This scenario shows what could happen if the street profile is 100% adapted to cope with the effects of climate change. Again, the lanes in the middle are being brought down to two lanes, as well as the lanes on either side. Additionally, speed is being reduced, to minimize the car emissions.

The verges in this scenario are again being maximized, but this time they will be used to create wadi's. Urban wadis provide numerous advantages for addressing climate issues. These green spaces function as natural air purifiers, absorbing pollutants and releasing oxygen to improve air quality. They also help to reduce the urban heat island effect by providing shade, lowering surface temperatures, and lowering cooling energy consumption. Urban wadis act as carbon sinks, absorbing CO2 and helping to mitigate climate change. They also contribute to water management by capturing and filtering rainwater, reducing stormwater runoff, preventing flooding, and replenishing groundwater. In addition, permeable pavement and porous asphalt is being implemented to mitigate the impacts of a flooding even more.

Furthermore, there is not a lot of space left for human interactions. This is why the score on the health theme is not that high. However, it is still a great improvement from the current situation, because people that cross this street are still surrounded by green and water, which has positive effects on peoples well-being.









2m 3m 14m 3.5m 1m 3.5m 11.5m 3m 3.5m

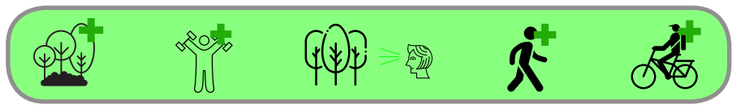
Maximized health

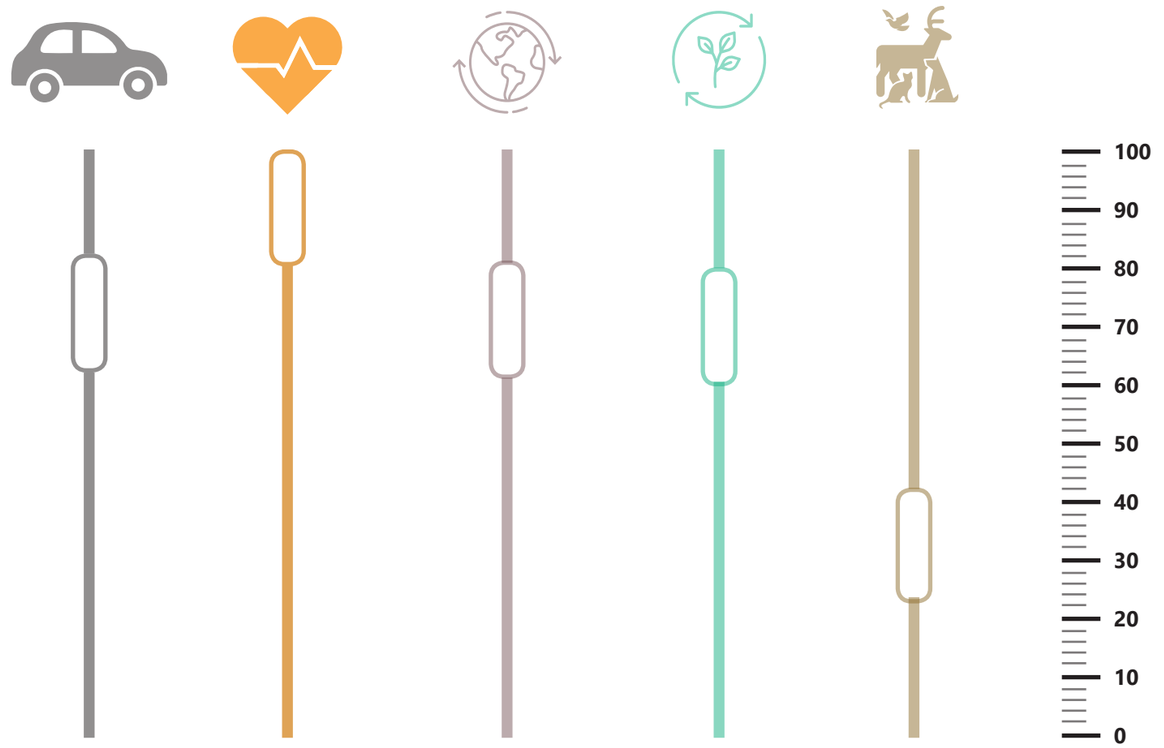
In this scenario the health theme is maximized to its full potential. Physical activity levels, air quality, noise pollution, pedestrian safety, and social interaction are all influenced by street design and layout.

This scenario also is about decreasing the influence of the car. However in this case, it is much more focused on the safety of pedestrians and cyclists. With the thought of pedestrian/ cyclists safety in mind, it has been chosen to keep the middle verge the same as in the existing situation. This way, there is optimal safety for pedestrians and cyclists if they want to cross the street, but for some reason can not make it in time. The middle path is there to ensure a safe waiting area for later crossing of the road.

The streets on either side are smaller, and again the extra space is reserved for a wider verge. However, in this scenario the verge is not as vegetated as in earlier scenarios. In the case of the health theme, more space should be reserved for human activities. This way the mental and physical well-being is optimized with a path through the improved nature in the wider verges. The downsize of this scenario is the impact human activities have on wildlife. People walking their pets, running by, or talking loudly disturb the behavior of any animals present. As a result, the fauna score in this scenario is quite low.









5m | 3.5m | 9m | 3.5m | 5m | 3.5m | 9m | 3m | 3.5m

Conclusion

To get a balanced design for the new street profile, careful consideration of the applied design principles in each theme is required. Each principle. Each theme is critical to achieving an integrated and sustainable approach to street design that benefits both people and the environment. The Willem de Zwijgerlaan in its current form focuses on ensuring safe and efficient movement for all modes of transportation. The car and public transport are the dominant factor in this situation. Each theme has its own strengths to change this car dominated street.

Green spaces, designated walking paths, and exercise facilities along streets can all help to promote physical activity and create a healthy environment. Access to nature and opportunities for physical activity help to improve mental health and lower chronic disease rates. Furthermore, incorporating measures to reduce air and noise pollution, such as tree planting, sound barriers, and emission controls, improves air quality and protects residents' well-being.

It is critical to consider the climate when designing sustainable street profiles. Climate-responsive design elements can assist in mitigating the urban heat island effect and adapting to changing weather patterns. To provide shade and reduce temperatures, streets can be designed with tree canopies and green infrastructure. Permeable surfaces and rainwater harvesting systems encourage effective water management by reducing runoff and replenishing groundwater resources. Furthermore, the use of environmentally friendly materials and energy-efficient lighting helps to reduce the carbon footprint and improve the overall sustainability of street profiles.

Flora and fauna principles aim to create a harmonious relationship between urban development and the natural environment. Streets can act as biodiversity corridors, allowing flora and fauna to move across urban areas. Native plantings, green walls, and wildlife-friendly features such as birdhouses and bee-friendly gardens all help to support local ecosystems. Street designs that take into account the ecological needs of various species and their habitats can help conserve biodiversity and create urban environments that coexist with nature.

The principles of flora and fauna seek to create a harmonious relationship between urban development and the natural environment. Streets can serve as biodiversity corridors, allowing plants and animals to move across urban areas. Native plantings, green walls, and wildlife-friendly features like birdhouses and bee-friendly gardens all contribute to the well-being of local ecosystems. Street designs that consider the ecological needs of various species and their habitats can aid in biodiversity conservation and the creation of urban environments that coexist with nature.

Finally, a well-balanced design for street profiles necessitates the incorporation of design principles that address mobility, health, climate, flora, and fauna. Street profiles can become vibrant and sustainable spaces by incorporating these principles.



Fig. 127: Maximized climatic design principles



Fig. 128: Maximized health design principles



Fig. 129: Maximized fauna design principles



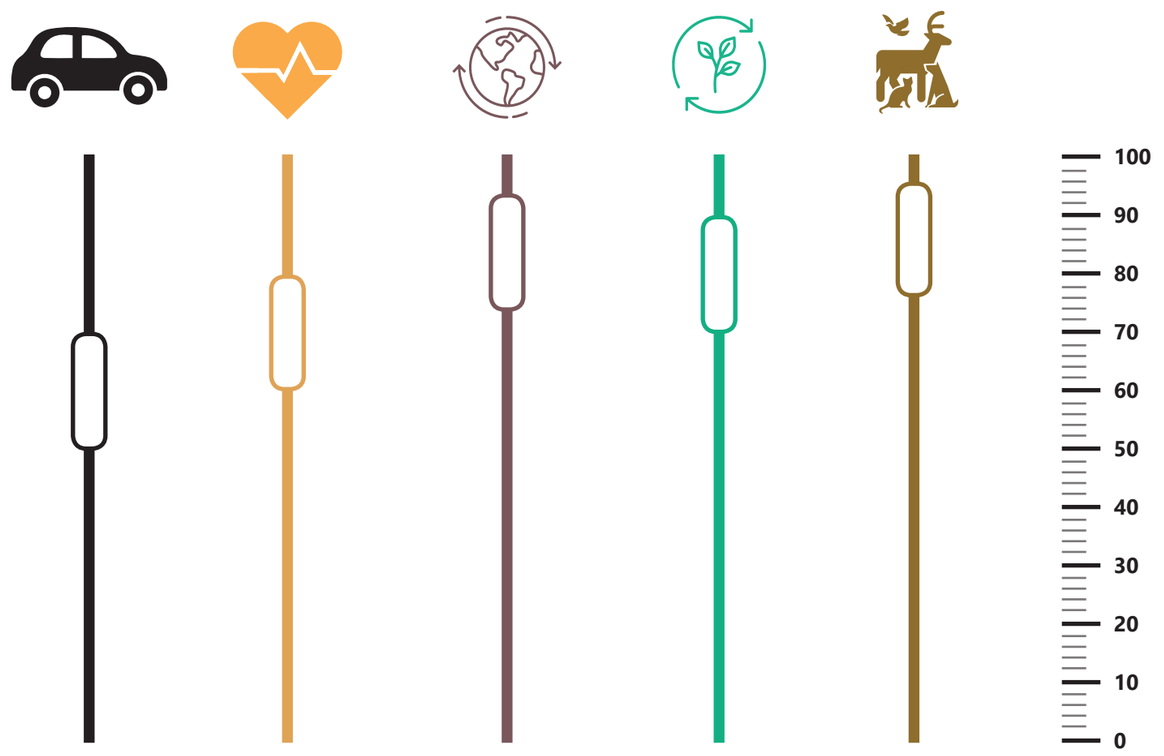
Fig. 130: Maximized flora design principles

The following scenario is the result of considered decisions and choices and how a combination of the different design principles can lead to the best possible result. By taking in consideration that not all design principles are possible at the same time, some principles are more obvious than others. A balance needs to be found between all the principles to come up with this result.

The most drastic interventions is the decreasing car-dependency. The lanes on either side of the main road are being brought down from two to a one-way street. The four lanes of the main road are brought down to two lanes. However, vehicle users are still allowed to drive 50km/h to keep the flow of the cars going. The choice set the middle verge on two meters, is because this firstly gives a form of safety for pedestrians that want to cross the street (as a safe waiting area) and secondly because this way larger trees can be planted that improve green continuity for birds alongside the street as well as across the street. The verges on the sides are improved to 10 meters each, so they can serve as a movement corridor, as well as an habitat on their own. Diverse flora is being planted which attracts wildlife, and for wildlife an underpass is implemented so that the barrier effect of this street is minimized.

Furthermore, people love to walk through nature. However, this greatly disturbs wildlife. In order to still have a fair walking path through nature, a path alongside the large verge is being implemented, so that people can still run and walk their dog here, without much interfering the wildlife. The hedges on the side provide shelter for smaller mammals, as well as safe passages to nearby green patches. In addition to the health theme, playgrounds should be implemented alongside the road, where space is now not being used to its fully potential.

Finally, parking is not completely removed, but in the future this is surely possible. The bricks are replaced by permeable pavement so climate issues do not occur in these areas.





4m | 3m | 2m | 10m | 3.5m | 2m | 3.5m | 10m | 2m | 3m | 2m



Fig. 131: Current situation



Fig. 132: New situation

To get back to the research question, a link is being made between the themes and the road-related ecosystem services. This way, a conclusion can be made if indeed the applied design principles can improve road-related ecosystem services.

Based on the analysis of the current situation of the Willem de Zwijgerlaan, a score can be given on the earlier mentioned spider chart (page 131). The scores on each service are based on the current situation. These are connected to the sliders of the current situation, where every service scores fairly low on scale one to five.

Design principles that prioritize health, climate, flora, and fauna can make a significant difference in the quality of road-related ecosystem services. We can create a more sustainable and environmentally friendly environment by incorporating these principles into road infrastructure.

Health: Providing pedestrian and cycling infrastructure on roads encourages active transportation, which has numerous health benefits. Sidewalks, bike lanes, and pedestrian-friendly crossings promote physical activity, reduce air pollution from vehicle emissions, and improve residents' overall well-being. In addition, incorporating green spaces and urban parks alongside roadways allows for recreation, relaxation, and stress reduction.

Climate: Climate-responsive design principles can help reduce the environmental impact of roads. Rainwater can infiltrate the soil through permeable pavements, replenishing groundwater and reducing stormwater runoff. Green roofs and walls can help to regulate temperature, improve air quality, and mitigate the urban heat island effect. Passive cooling can be achieved by optimizing road orientations and incorporating shading elements, reducing energy consumption for cooling purposes.

Flora and Fauna: Using native plant species to plant along roadsides promotes local biodiversity. Native plants provide food and habitat for insects, birds, and other wildlife, helping to maintain ecological balance. Creating wildlife corridors or underpasses across roads allows animals to travel safely, reducing fragmentation and increasing genetic diversity. Green infrastructure features such as bioswales and rain gardens can improve water quality, encourage habitat creation, and help pollinators.

Furthermore, innovative road design can prioritize wildlife-friendly crossings, such as eco-ducts or vegetated bridges, which aid in maintaining ecosystem connectivity. Such crossings allow species to move freely, lowering the risk of wildlife-vehicle collisions and ensuring the survival of diverse populations.





Fig. 133: Road-related ecosystem services score for the new design of the Willem de Zwijgerlaan


N7-714-T


N8-528-S
N7-714-T

08
Conclusion & Reflection

8.1. Conclusion

The global population is growing in an exponential rate which comes with a lot of urban challenges related to well-being, climate and biodiversity. An urban road network has a severe effect on these aspects. Creating a road network that will benefit ecosystem services will help with mitigating the aforementioned effects. The main research question of this thesis is: **What is a possible approach to use the road network of Leiden to improve road-related ecosystem services.** This question is divided in 4 parts, which all give a part of an answer. Combining these answers will give a full answer to the research question. A road is defined as: 'Any spatial or non-spatial component that is in-between the two outer buildings, streams, or meadows (or a combination of these).'

Since not all ecosystem services have a relation to roads it is important to pick the ones that do relate to a road network. These services are:

- Air quality regulation
- Climate regulation
- Water regulation
- Erosion regulation
- Moderation of extreme events
- Soil formation
- Wildlife corridor
- Wildlife habitat
- Aesthetic values
- Recreation and ecotourism
- Mental and physical health.

The theory of landscape ecology provides a theoretical background for the whole thesis. Applying the theory of the patch-corridor-matrix and of biogeography to Leiden helped with answering the question. In addition to this, several studies were consulted about how to improve road-related cultural services. By giving priority to walking and biking and giving the opportunity to exercise in green environment can greatly help with improving the physical well-being of inhabitants. On the other hand, by just seeing a lot of green and using green surfaces as an education tool can help with the mental well-being.



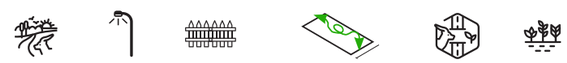
The current situation in Leiden was spatially analyzed to see where improvements need to be made and where problems occur. This gives answer to subquestion 2a. By understanding the current ecological function of the road network, better design choices can be made. Applying the patch-corridor-matrix to Leiden design principles could be made to cover some regulating services. Providing an continuous green structure as well as adding trees to a road network can help with improving this regulating services.



In addition to the ecological spatial analysis a climatic analysis was also necessary to understand the improvements that can be made for the regulating services. The urban heat island effect and flooding were analyzed resulting in the following design principles.



Flora and fauna also relates to road-related ecosystem services. Six target species were selected; starling, dwarfbat, bumblebee, brown frog, the Atalanta butterfly and the west-European hedgehog. These are the most common animals in Leiden and give a good picture of the biodiversity. The most important outcome is that in order for wildlife to use a road network as an habitat or as an movement corridor, enough width and cover should be provided. Furthermore, protection from the actual road is very important to mitigate roadkill and impact on the verges. The following design principles came out of this research.



These design principles were applied to the Noorderkwartier, a neighborhood in Leiden. The design principles were applied to different locations in the neighborhood giving an overall view of how and what a neighborhood can look like if we design with the given design principles. Furthermore two important streets were chosen as a test case.

Demonstrated in the strategy for the neighborhood and thereafter in the two streets, it has been proved that a road network is able to help with improving road-related ecosystem services. Applying different design principles can greatly improve the inhabitants mental and physical well-being, help with dealing with the effect on climate change, and will help with improving urban biodiversity in terms of the selected target species and the urban flora.

8.2. Reflection

Being on the road a lot, I came to notice how much space is actually dedicated to the car. When I started paying attention to the street profiles, I noticed that the road has a disproportionate part of the road compared to the green structure in the same profile. All we hear nowadays is that we need to greenify the city, but it never occurred to me that this could also be realized within the borders of a road network. A road system is often strongly embedded in the urban fabric. Today, we can still find streets that originated centuries ago. However, in almost every case, roads are mostly designed for mobility and safe passage, but the ecological effects on urban ecosystem is has not yet been extensively researched. By exploring what the ecological role of a city's road network can play, both on urban level as well as street level is being researched what could be adapted to improve the ecological structure of the city using the existing road network. At the same time, this is the direct link between the graduation topic, the master track and the master programme.

Project process

The project started of quite slow, since I did not have a idea about an topic to choose. When I looked at personal interests I came to my current topic, which is looking at what ecological role the road network can play in improving ecosystem services. Talking with my first mentor about it was always interesting, but it was mostly a little bit superficial, since I didn't know a lot yet about the topic, but also because of the way I was working on my project. Since the beginning I was very focused on producing a perfect report in the end, and since I knew this would take a lot of time, I wanted to start as soon as possible with this. However, this restricted me in my exploration, because I would only produce materials that would fit right in the report. Also, I had a clear view in mind on how the process would look like. This was a very straightforward way of working, which is often not the case in a project. There are always times of reflection, but I sometimes completely neglected the reflection, because I had to continue with the project. This was the case until the P2 presentation. Discussing with my mentor about the following steps, he helped me greatly with not only looking at making a report, but really explore and experiment during a project. So, I started sketching and visualizing what I had in mind, and this led to way more interesting meetings with my mentor. Where it was almost only about theory at first, we now had conversation about how I can now make a more complete project. This greatly helped me with looking at other aspects of the project and gave me a clearer view of the whole project.

Methods

In this thesis both research and design methods are used to give body to the project. Using desk research for the first chapter was very useful, since this gave a deeper understanding of the theory behind the problem, and greatly helped with bordering the magnitude of this project. Also, this helped with backing up the results, since now the results are theoretical underpinned. However, the disadvantage of this method is that it is rather general information, so a framework for Leiden was hard to make. Mapping the existing situation of Leiden, helped greatly with understanding the situation and where interventions are most needed. The municipality chose the spatial data that needed to be mapped based on an analysis of both scientific literature and policy documents. At the same time, this was a limitation within the project because the municipality has not mapped out everything and therefore no data is available. This had to be solved by making our own maps where this data was visible. Using the theoretical background and the spatial analysis made it way easier to come up with the design principles. These methods gave me an easier tasks of applying the design principles to a specific in Leiden and all that was left was applying them to the location.

Societal relevance

The start of the graduation year started off with choosing a topic for the graduation project. This was a hard task, not only because we only had one week to choose, but also what is the reason for choosing that topic. In the beginning it was hard to see why my topic would have any societal relevance, since then I only looked at the ecology of the road. However, as the project progressed the societal relevance became more and more clear, since other themes within the project were also researched. Ecosystem services are an important part of our daily life. Roads are diminishing these services, and therefore by improving the road network, an improvement can be made for the ecosystem services. By creating ecological corridors, and adapting the street scape to deal with climate change, will improve flora and fauna, but will also greatly improve people's mental and physical well-being. Being around green make people happier, but the green surfaces are also an inviting way to let people walk or bike more often, which has a direct effect on the overall health of the inhabitants. In addition to the mental and physical well-being, the economic damage that often occurs with climate-related problems be much lower than if we continue to petrify the cities in this way. So in the end, this project can be good for the society's overall health, give long-term economical benefits and will greatly improve the urban flora and fauna.

Ethical considerations

Since I've started doing the masters 5 years ago I've come to realize how bad the state of earth's biodiversity is. Green areas are not only very important for us human beings, but even more for flora and fauna, since they depend on green areas. When driving through Leiden, I started to notice in most cases how little space is dedicated for actual quality green surfaces, and how the car still gets all the attention. Although the discussion nowadays is about if the car needs that much space, little is still visible in the city. Most of the time I think about how much green we can add to the cities road system. And this is not just putting some trees and bushes in open spaces, but it is about the whole green urban structure of the city. For me its interesting to look at how we can take greenifying to the next level and actually create spaces where biodiversity can thrive, which can also have its economic and societal benefits. This project is a perfect opportunity to investigate how we can use the extended and most often underexposed street network to our advantage, and use street design to strengthen the urban biodiversity.

Transferability

Improving road-related ecosystem services is a has not yet been extensively researched. Most research on ecosystem services focuses on the outskirts of the city. However, several elements can be included in the urban fabric, but I have to make it clear that the project is located in an urban setting. Although the design principles are based on theory and spatial analysis, they have eventually become somewhat more generic elements. First of all, this helps with understanding them, but also this makes them applicable for other situations, and are not site-specific.

Financial feasibility

Improving road-related ecosystem services can have both financial and long-term benefits. Infrastructure investments that prioritize sustainable practices can result in cost savings and improved economic outcomes. Implementing green infrastructure, such as vegetated roadside buffers and storm water management systems, for example, can help mitigate the environmental impacts of roads by lowering the need for costly maintenance and repair work caused by erosion, flooding, and water pollution. Incorporating nature-based solutions, such as tree planting along roadsides, can also improve air quality, reduce noise pollution, and provide shade, thereby improving the overall quality of life for nearby communities and increasing property values. Furthermore, improving roads to promote biodiversity and restore ecosystems can contribute to eco-tourism and recreational opportunities, generating revenue and boosting local economies. Policymakers and stakeholders can make informed decisions that benefit both the environment and future generations by considering the financial implications of road-related ecosystem services.

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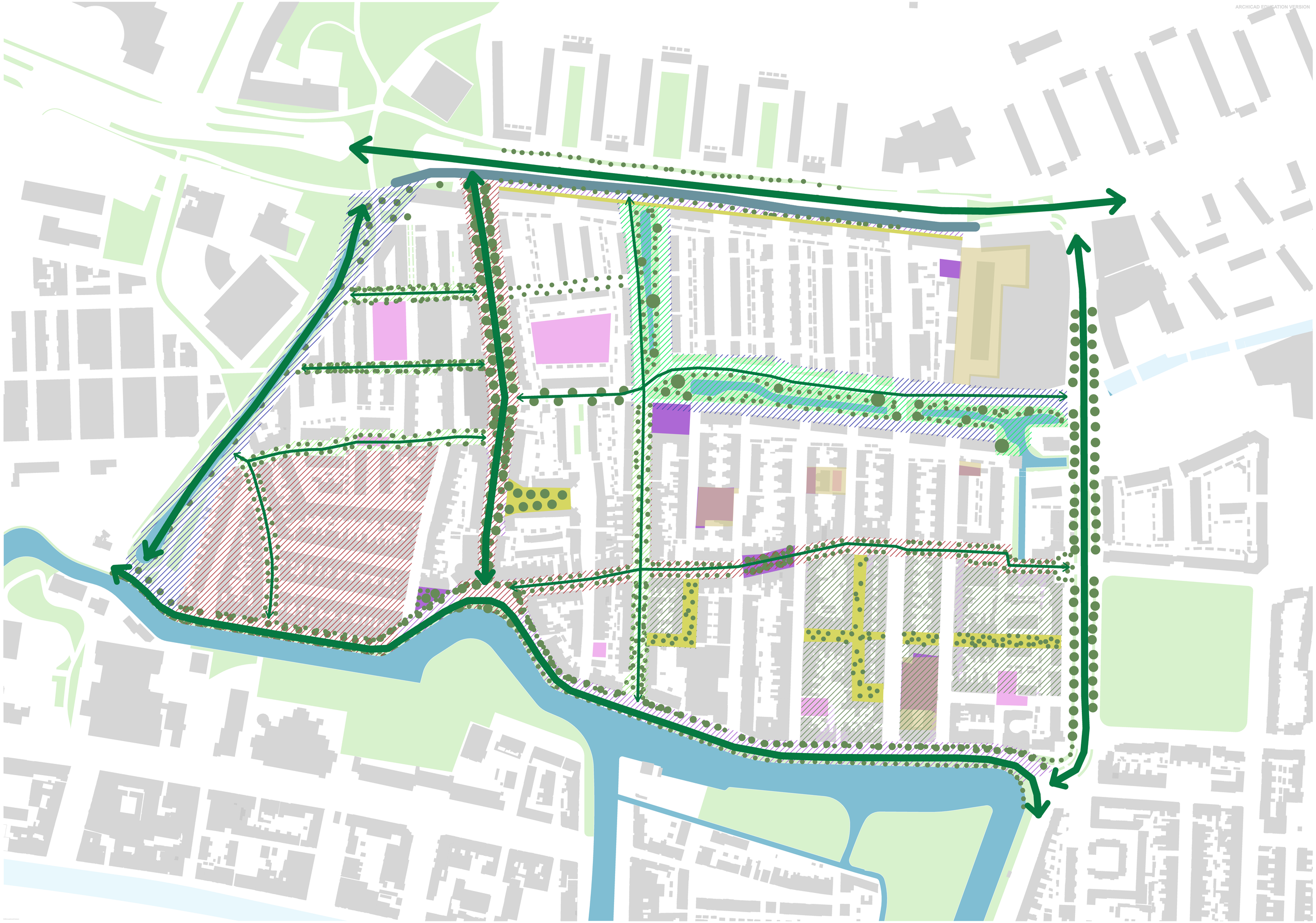
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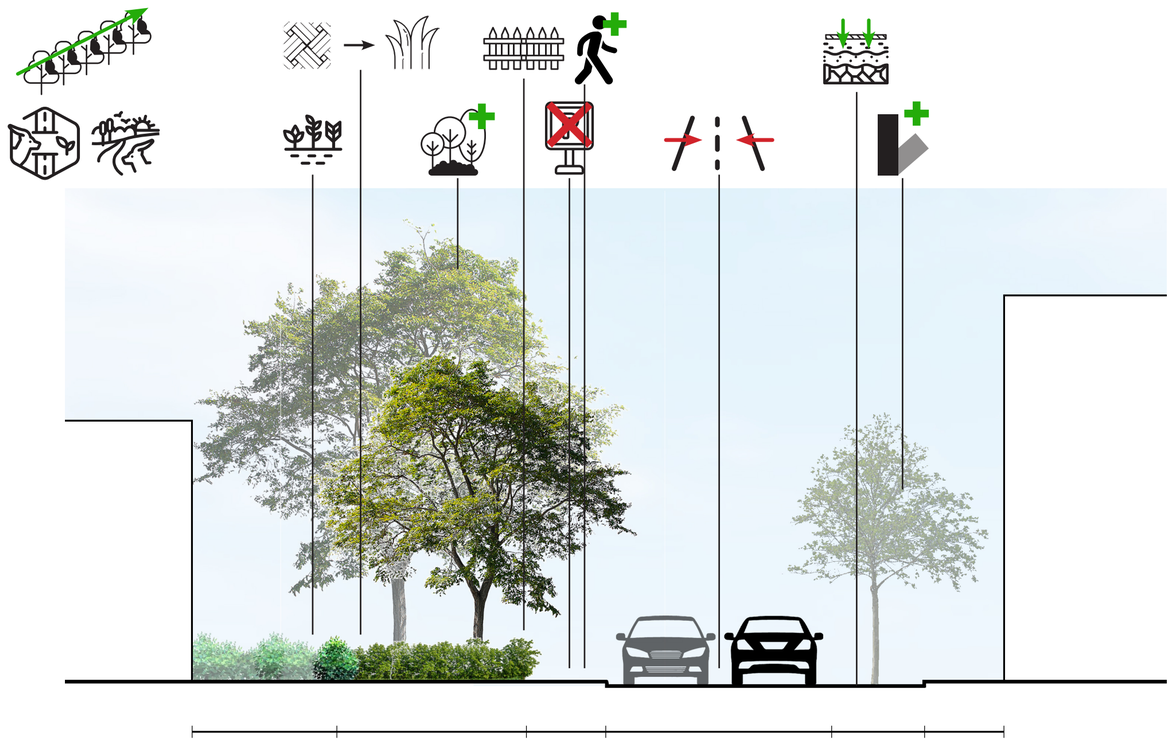
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Appendix 2 - Design principles applied to Marnixstraat

Current situation

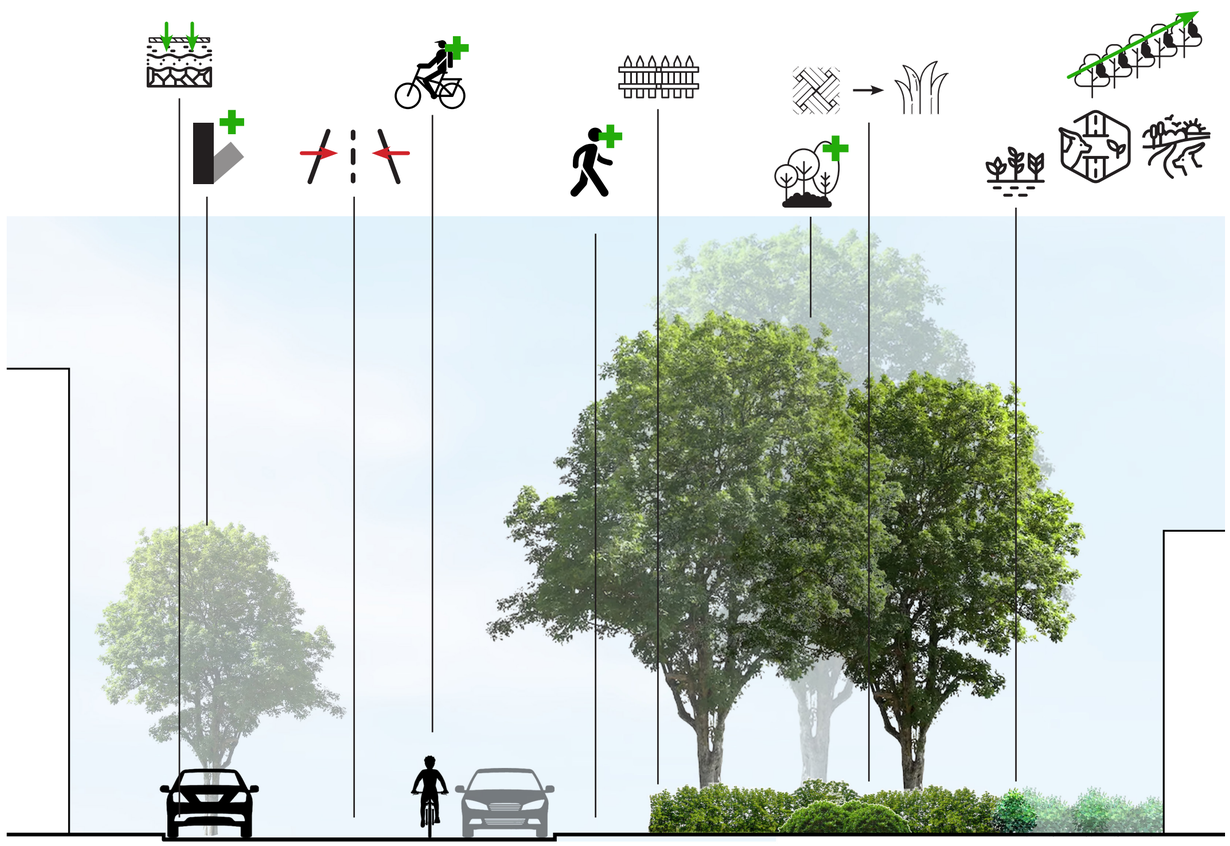




New situation

Current situation





New situation

Appendix 3 - Design principles applied to Willem de Zwijgerlaan



