Spatial shift and urban resilience:

A case study on the city of Rotterdam

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Floris Bottema
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Abstract

This research examines the multifaceted challenges posed by urbanization in the Netherlands, specifically focusing on the intricate relationships between modes of mobility and societal well-being. Central to this exploration is studying the modal split and understanding how shifts in this split can have profound implications for urban areas. The Dutch Ministry of Infrastructure and Water Management's (Min IenW) Well-being Monitor is the foundation for this study, aiming to chart the interplay of living environment, safety, health, and accessibility. It illuminates the potential consequences of changing transportation choices (modal split) on broader environmental concerns such as the Urban Heat Island effect, noise disturbance, air quality, and climate resilience. While cars due to their ubiquity, cars play a central role in the research. However, the importance of Non-Motorized Transport (NMT) and Public Transport (PT) is also highlighted, given their significant roles in urban mobility and their potential to redefine the modal split. Using Rotterdam as a case study, the research delves into the spatial constraints of one of the Netherlands' largest cities, emphasizing the need for effective urban planning that prioritizes sustainable transportation solutions and envisions future shifts in transportation preferences. The goal is to offer valuable insights that can influence urban strategies, ensuring sustainable and livable cities.

Table of context

Glossary

BGT,	Basisregistratie Grootschalige Topografie / Key Register Large-Scale Topography
BL,	Bike Lane
CBS,	Centraal Bureau Statistiek / Statistics Netherlands
DME team,	Data Monitoring and Evaluation team (part of Min IenW)
GIS,	Geographic Information System
KiM,	Kennisinstituut voor Mobiliteitsbeleid / Netherlands Institute for Transport Policy Analysis
Min IenW,	(Dutch) Ministry of Infrastructure and Water Management
MT,	Motorized Transport
NMT,	Non-Motorized Transport
NOx,	Nitrogen Oxide
ODiN,	Onderweg in Nederland / Large Dutch Mobility Research
OSM,	Open Street Map
PBL,	Planbureau Leefomgeving / Netherlands Environmental Assessment Agency
PM(2.5/10),	Particular Matter
PT,	Public Transport
ROER,	Rotterdamse Omgevingseffectrapport / Rotterdam Environmental Impact Report
RMA,	Rotterdamse Mobiliteits Aanpak / Rotterdam Mobility Approach
(S)RQ,	(Sub) Research Question
SUMP,	Sustainable Urban Mobility Plan
UHI,	Urban Heat Island (effect)
WBM,	Well-Being Monitor
WHO,	World Health Organization

Introduction

Motivation

Rapid urbanization has fundamentally reshaped the contours of modern life, especially in densely populated regions like the Netherlands. As urban centres grow and evolve, so does the mobility challenge, becoming not just a logistical concern but a determinant of the quality of urban life.

Exploring the spatial efficiency of various mobility modes sparked interest in this arena. Findings such as those by Apel (2000) and Gössling et al. (2016) underscored the significant spatial demands of car usage in urban contexts, often overshadowing more spatially efficient transport modes like public and non-motorized transport. Such transportation decisions have far-reaching ramifications, influencing a multitude of urban challenges. From manifestations like the Urban Heat Island effect, as detailed by Snellen et al. (2021), to pervasive noise pollution and air quality degradation, the transportation fabric of a city profoundly affects its environmental and social landscapes.

The potential of transportation also extends into realms of health and well-being. As Nijland & van Meerkerk (2017) assert, mobility modes encompassing physical activities such as walking and cycling can significantly boost mental and physical health. Furthermore, the space liberated from reduced car usage can be repurposed for green areas, as Gössling et al. (2016) and Sampson (2021) proposed, thereby combating challenges like the Urban Heat Island effect and improving the overall quality of life.

In an ever-urbanizing world, understanding the interplay between urban mobility and broader city dynamics is crucial. With global commitments like the United Nations Sustainable Development Goals and the Paris Agreement underscoring the need for sustainable trajectories, the choices made in urban transportation today will reverberate into the future, impacting everything from environmental health to societal well-being.

Through the lens of Rotterdam, this thesis aims to contribute a nuanced understanding of these choices, with the knowledge that insightful research can steer urban development towards more sustainable and livable futures.

Research objectives & questions

Rotterdam's urban environment is marked by car dominance. The shift to prioritize alternative transportation modes—biking, walking, and public transport—is complex, demanding insights into spatial implications, environmental impacts, and change strategies. This research targets the spatial footprints of transportation in Rotterdam and aligns with the Dutch Ministry of Infrastructure and Water Management's (Min IenW) initiative for a well-being monitor. The core objectives and guiding research questions are outlined as follows,

The primary research objectives are:

1. Investigating the spatial implications of the current modal split in Rotterdam and the infrastructure allocation.
2. Estimating the potential urban space that could be freed up if a certain percentage of car trips were transitioned to these alternative modes.
3. Evaluating the potential environmental and social impacts of such a shift.
4. Exploring potential strategies to encourage a shift from car usage to other modes of transport and identifying potential barriers to implementing these strategies.

The research questions that guide towards the objectives are:

Main Research Question:

"What are the potential impacts on spatial allocation and specific urban challenges in Rotterdam if there is a significant shift from car usage to other modes of transport such as biking, walking, or public transport?"

And the Sub-Research Questions:

1. "What is the current spatial footprint of car usage in Rotterdam, and how does it compare to the spatial footprints of biking, walking, and public transport?"
2. "How much urban space could potentially be freed up in Rotterdam if a certain percentage of car trips were switched to biking, walking, or public transport?"
3. "What are the potential environmental impacts of freeing up urban space by reducing car usage in Rotterdam?"
4. "How could the space freed up by reducing car usage be repurposed for urban greenery, and what would be the potential impact on air quality, the Urban Heat Island effect and noise levels?"
5. "What are the potential impacts on the distribution and accessibility of amenities and services in Rotterdam if car usage is reduced"
6. "What are the potential neighbourhood-specific impacts of changes in transportation allocation in Rotterdam, and how might these changes influence the urban environment?"

With those questions and goals, the research aims to contribute to the development of the well-being monitor and provide valuable insights for improving urban mobility and transportation planning in Rotterdam and potentially other similar urban environments.

Background & Scope

Background

Many cities in the Netherlands and globally find themselves grappling with urbanization's complex challenges, navigating between finite spatial resources and mounting environmental pressures. How we navigate these environments - our modes of mobility - plays a significant role in shaping our cities' spatial layout and ecological health. Recognizing the importance of understanding these relationships, the Dutch Ministry of Infrastructure and Water Management (Min IenW) has asked Master students like myself to contribute insights that might guide their strategies.

At the heart of this request lies the development of a well-being monitor initiated by Min IenW. This innovative instrument explores the intricate linkages between mobility, infrastructure, and four critical dimensions of societal well-being: living environment, safety, health, and accessibility (see Figure 1). By charting the interplay of these aspects, the Ministry hopes to foster urban environments that thrive on sustainability and livability.

The parameters of the well-being monitor were brought into sharp focus by TNO's 2021 research named *Indicatoren Brede voor Welvaart in het mobiliteitsdomein*, which laid out a matrix of potential indicators. It created a conceptual lens to connect well-being and mobility, illuminating how accessibility, safety, living environment, and health intersect in urban mobility (Vonk Noordergraaf Diana et al., 2021). These dimensions were then also featured in a report by the Planbureau Leefomgeving (PBL) titled "Brede Welvaart en Mobiliteit" (2021) (Snellen et al., 2021).

Currently, within Min IenW, the Data Monitoring and Evaluation (DME) team is working to enhance the well-being monitor based on the insights provided by TNO's research. The team is particularly interested in exploring spatial allocation of mobility, one of the potential indicators of well-being. My research project is aligned with this objective. The insights garnered from this research could enrich the well-being monitor, serving as a valuable tool for provinces and municipalities to enhance urban well-being.

The Scope

Given the broad framework of the well-being monitor, which integrates nearly 50 potential indicators across the four key topics, it becomes imperative to focus on the exploration. The DME team at Min IenW pinpointed certain areas within the Living Environment dimension that they would like for further investigation. Specifically, the need for an indicator to gauge the spatial use of mobility is underlined; the selected direction is shown in the left dotted sector in Figure 2.

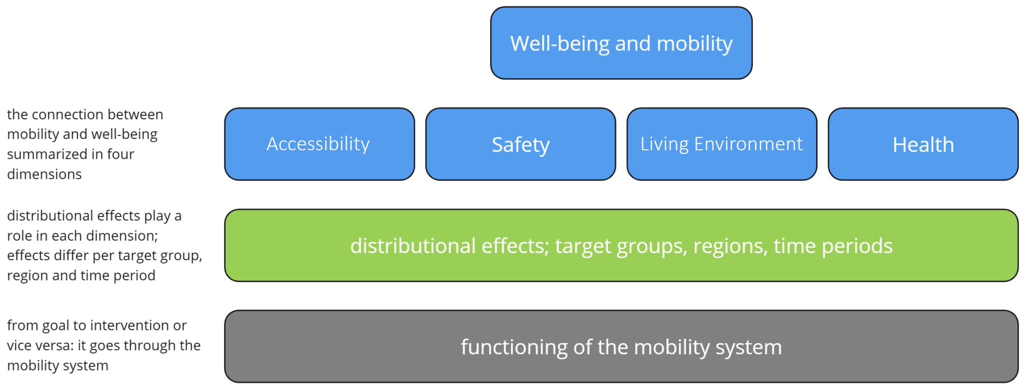


Figure 1 - The Four dimensions and layers of the Well-being Monitor (Vonk Noordergraaf Diana et al., 2021)

Figure 2 also illustrates that spatial usage is a critical facet of the Living Environment domain. It can be broken down further into three sub-categories: vehicles, public space, and infrastructure, with each potentially serving as an indicator (Vonk Noordergraaf Diana et al., 2021). The complete list of examples provided by TNO can be found in Appendix 1.

The focal point of this research is to investigate the infrastructure space used per mobility in cities. What makes this particularly intriguing is that cars, as a prevalent mode of transportation, are known for their substantial spatial footprint (Gössling et al., 2016). Secondly, cars are also of interest to the Ministry, as it aims to reduce car usage, given its significant environmental implications (Vonk Noordergraaf Diana et al., 2021).

However, the scope of this research is not confined to Motorized Transport alone. Given the multifaceted nature of urban mobility, it is crucial also to consider Non-Motorized Transport (NMT) (Walking and Cycling) and Public Transport (PT). These forms of mobility play significant roles in city transportation networks and influence how urban space is used.

This multi-modal view of transportation forms the base where spatial allocation intersects with environmental considerations. Specifically, space usage for different transportation modes can significantly affect emissions, air quality, and climate resilience. For instance, prioritizing NMT or PT over motorized transport can lead to lower emissions and improved air quality, contributing to climate resilience (Sampson, 2021).

Given the pressing issue of limited available space in urban Netherlands (Programma Mooi Nederland, 2022) and the inability to repurpose these areas for other public utilities, efficient spatial allocation for mobility becomes a vital topic. Thus, the city of Rotterdam, one of the largest urban areas in the Netherlands, has been chosen as a case study to explore these interconnected aspects.

Incorporating these considerations, the research will also integrate vital elements within the Living Environment domain, particularly those linked to the climate domain. Recognizing that spatial allocation directly impacts various climate aspects, the focus within the climate domain will specifically focus on Emissions, Air Quality, and Climate Resilience.

Figure 2 shows the 'path' to the research scope (scope is in the right dotted box) and which elements are included.

The diagram illustrates the transition from the wide-ranging context of the Well-being Monitor to a more specialized and integrative examination of space usage by various modes of transportation within Rotterdam, considering its climate implications. This focus has informed the design of a case study that seeks to provide actionable insights within these intersecting domains.

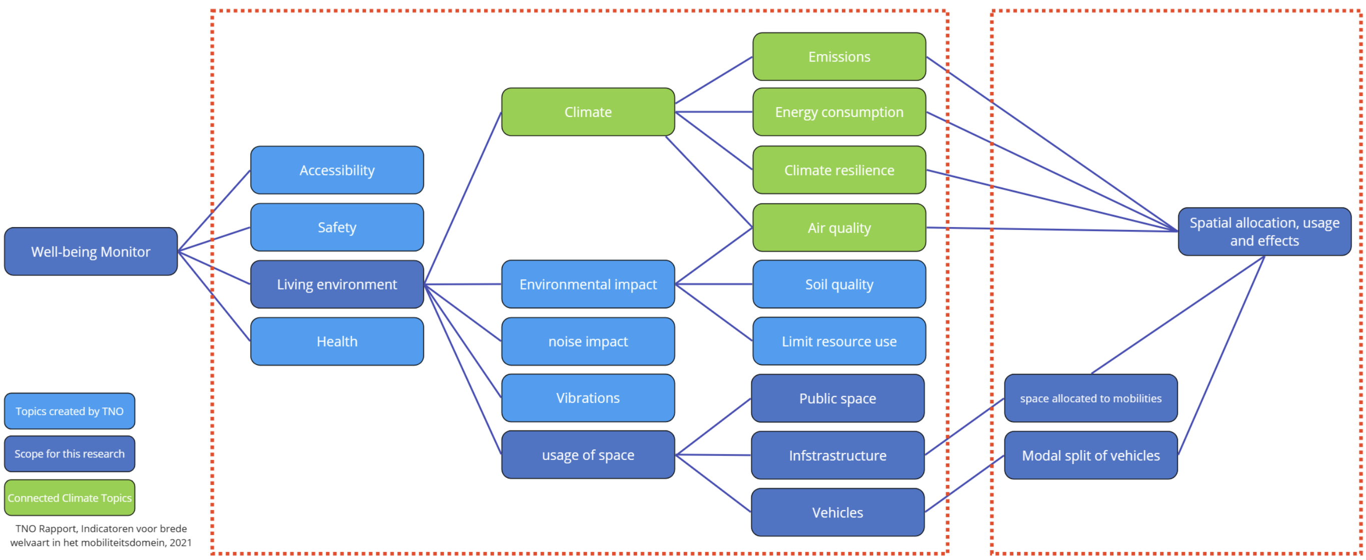


Figure 2 - Scope condensed from TNO's categories for the Well-being Monitor (Vonk Noordergraaf Diana et al., 2021)

Research approach and outline

Approach:

This research is based on a data-driven methodology seeking to grasp the multifaceted consequences of a significant shift from car usage to alternative modes of transport in Rotterdam. It analyses spatial reallocations and delves deeply into the larger narrative of urban development and well-being. As a city distinctive for its post-war, car-centric design, Rotterdam's exploration promises insights that are potentially useful for other similar urban environments.

The chosen methodology combines spatial analysis with policy- and literature review. This combination offers a comprehensive perspective. The case study approach on Rotterdam is central to this methodology. By focusing on a specific city, the research can derive deeper, contextualized, and nuanced insights, making the findings more actionable and relevant.

Outline:

The research begins with an Introduction where the study's motivations, objectives, and broader context are discussed. This leads to the Literature Review, which reviews existing urban mobility and development literature. Following this, the Methodology and Data Collection section breaks down the research process, providing details on how data was collected, selected and the limitations to be aware of.

Next, the Case Study: The Situation in Rotterdam section explores Rotterdam's urban and mobility landscape. This includes an analysis of policy documents and an overview of the city's spatial characteristics—environmental metrics and a correlation analysis help understand the city's dynamics. The Results section then outlines findings related to Rotterdam's current spatial configurations and potential future changes, especially with reduced car usage.

The Addressing Rotterdam's Urban Challenges through Spatial Reallocation section discusses urban challenges in Rotterdam and suggests how spatial reallocation might help. This leads to proposed policy recommendations. The focus narrows further in the Spatial Reallocation in Rotterdam's Neighbourhoods section, examining potential changes in specific Rotterdam neighbourhoods.

The Discussion section reflects on the findings in the broader context of the research objectives. The study wraps up with Conclusions and Recommendations summarizing key findings, offering suggestions for urban planners and policymakers, and pointing out potential areas for future research. The research document concludes with the Sources & for those interested in further details.

In summary, this document thoroughly examines urban dynamics in Rotterdam, focusing on mobility, urban challenges and well-being.

Image 1, Cyclists in Rotterdam

2 Literature Review

This chapter synthesizes the findings and insights from various studies, focusing on the spatial efficiency of different transportation modes and their impact on urban space in cities like Rotterdam. The investigation encompasses the repercussions of these modes on urban challenges such as heat, pollution, and noise, as well as the implications for health, well-being, and road safety. These analyses collectively contribute to a comprehensive understanding of the central research question: "What are the potential impacts on spatial allocation and specific urban challenges in Rotterdam if there is a significant shift from car usage to other modes of transport?" The exploration is grounded in existing literature and past studies to offer a holistic perspective.

2.1 Spatial efficiency of different Modes of Mobility

Multiple studies have focused on the spatial efficiency of various mobility modes in urban environments. A reason is that significant portion of urban space is consumed by mobility, particularly car usage, which is often spatially inefficient (Apel, 2000; Gössling et al., 2016). As cities become increasingly dense, the efficient use of space becomes a valuable commodity (Barton, 2009; Bertolini et al., 2005; Crozet, 2020).

According to Apel (2000), car usage in urban environments demands considerable space. This issue is further dissected by Gössling et al. (2016), who compared the spatial distribution of different modes of transport. They discovered that public and non-motorized transport could be up to 20 times more spatially efficient per passenger than a typical car (Figure 3) (Héran & E. Ravalet, 2008; Marie-Eve Will et al., 2020). As Crozet (2020) pointedly put it, having only one person in a car results in overconsumption of space.

Additional data provided by Studio Bereikbaar (2022) shows that residents' travel behaviour in high-density urban areas differs significantly from other residents. These residents frequently use the public transportation and bicycle system and less often the car system. In 2016, compared to residents in urban (but not high-density) areas, the difference was about 35% more kilometres per person by public transportation and bicycle and 35% fewer car kilometres per resident. Compared with residents in rural areas, the differences increased to 150% more public transportation and bicycle kilometres and 60% fewer car kilometres per resident. Those differences reflect the benefits of shifting from car-centric urban environments to ones that prioritize more spatially efficient modes of transportation.

Cities also play a crucial role in economic growth, generating as much as 85% of Europe's GDP (Crozet, 2020; Sustainable Urban Mobility: European Policy, Practice and Solutions, 2017). Despite this, cities are often plagued with challenges such as reducing congestion, pollution, and accidents. These issues are caused mainly by private motorized modes, which continue to dominate even though the average annual distance travelled by car may have peaked (Crozet, 2020; Goodwin & Van Dender, 2013). These trends underscore the need for sustainable transportation options, given the high societal and economic costs of congestion and pollution and the urgent need to reduce CO_2 and air pollutant emissions from road transport to meet the United Nations Sustainable Development Goals and the Paris Agreement (Paris Agreement, 2015; Sustainable Development Goals, 2015).

Addressing these challenges requires efficient use of road space and the promotion of sustainable modes of transport, such as active travel (walking and cycling) and public transport (Crozet, 2020; Sampson, 2021). The optimal use of road space also has become a critical issue, with city policies increasingly shifting their focus away from car-dominant transport models. But to move away from those models, as Nello-Deakin (2019) emphasizes, understanding the different spatial efficiency of mobility modes is vital.

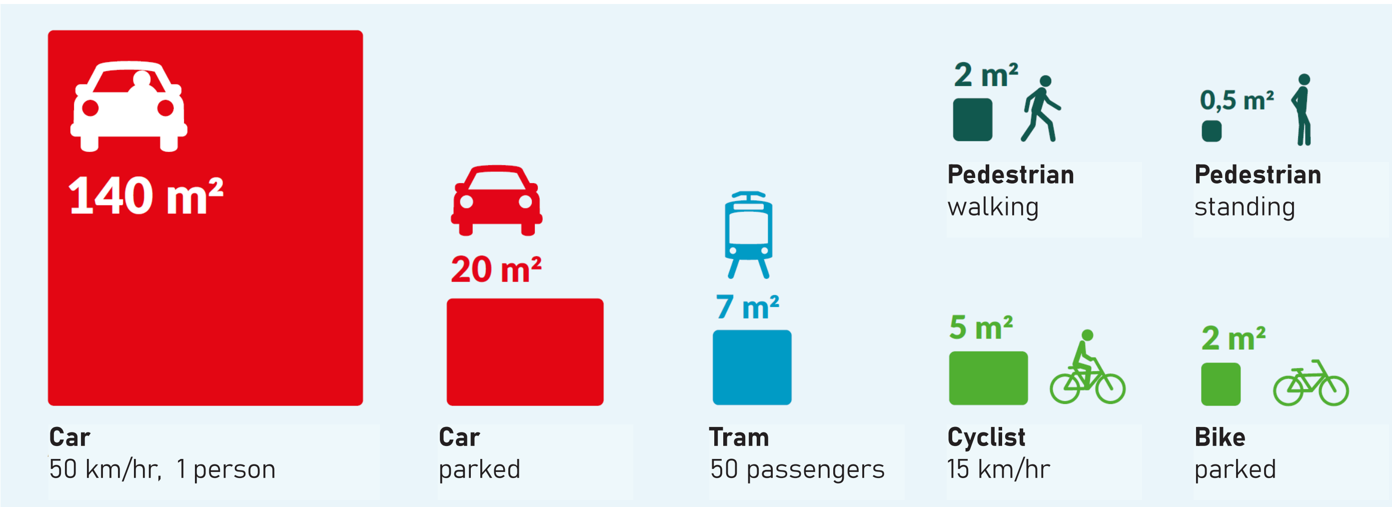


Figure 3 - Space acclaimed per mobility (Mobiliteitsverkenning Voor Een Groeiend Amsterdam, 2017)

The connection between transport and land use planning plays an integral role in sustainable accessibility (Bertolini et al., 2005). Additionally, there is a link between land use planning and health, indicating that effective spatial planning significantly influences societal well-being (Barton, 2009). A report by Liere Bram van et al. (2017) titled "Van wie is de stad?" discusses the allocation of public space in urban areas, mainly focusing on the space dedicated to cars versus other modes of transportation like walking and cycling. The report highlights that more than half of the street space, precisely 55% (Figure 4), is reserved for cars in the twenty largest municipalities in the Netherlands (Liere B. et al., 2017).

The report also discusses a scenario where sustainable modes of transport replace a quarter of car kilometres. It suggests that if 25% of car kilometres are distributed over other modes of transportation, city space could be freed up. The area for public transport is not considered in this analysis. The report concludes by advocating for a shift towards more sustainable modes of transportation. It argues that reducing the space dedicated to cars would not be a loss,

but rather a gain, it would free up space for walking, cycling, public transport, recreation, green spaces, and healthier air.

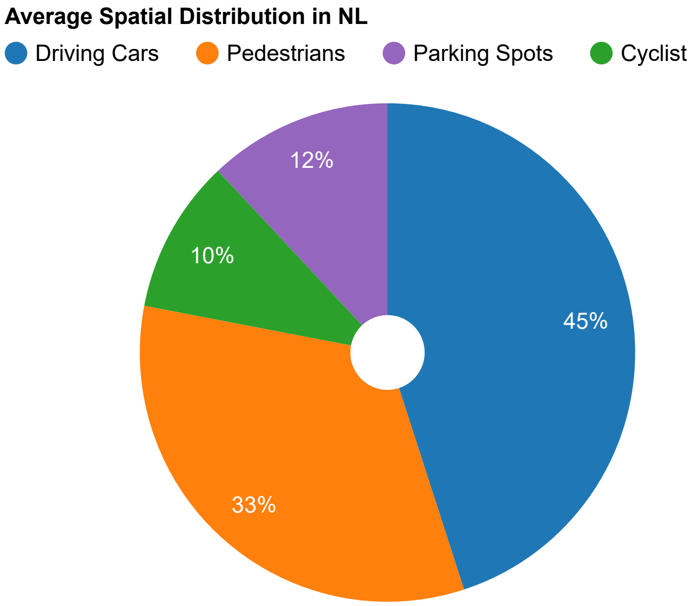


Figure 4 - Average Spatial distribution of the 20 largest municipalities of the Netherlands (Liere Bram van et al., 2017)

Theoretical link between spatial allocation and mobility

The interactions between spatial allocation and mobility are crucial for urban planning, and one of the most significant theories elaborating on these interactions was presented by Wegener and Fürst (Wegener & Fürst, 1999). They developed a circular model encapsulating the relationship between transportation and spatial planning, thereby highlighting these elements' interconnectedness and mutual influences (Figure 5).

This model comprises four primary elements that form a continuous loop: the transport system, accessibility, land use, and activities. It begins with the transportation system, which influences accessibility. Accessibility, in turn, affects land use decisions, defining which movements occur in different areas. This influence cycle underscores the need for an integral approach to urban planning.

Other scholars, like Clifton (2017) and Cheng et al. (2021), have also emphasized the importance of these interaction effects. They again stress the link between space and mobility, recommending a thorough explanation of spatial effects on travel behaviour.

Each element in this cycle plays a distinct role:

- **The transport system** facilitates the movement of people, connecting different activities and locations. Individual decisions such as vehicle availability, trip frequency, destination, mode of transport, and route choice determine the resulting traffic flows. For instance, Nijland and van Meerkerk (2017) provide empirical evidence of how significant the transport system can influence mobility behaviour. They noted that a well-implemented car-sharing system could cause 20%-30% of people to reconsider owning a car.

- **Accessibility** relates to travel times, costs, and duration, contributing to a location's attractiveness. Improved transportation infrastructure increases a location's accessibility, influencing construction decisions, which impact the spread of activities in an area.

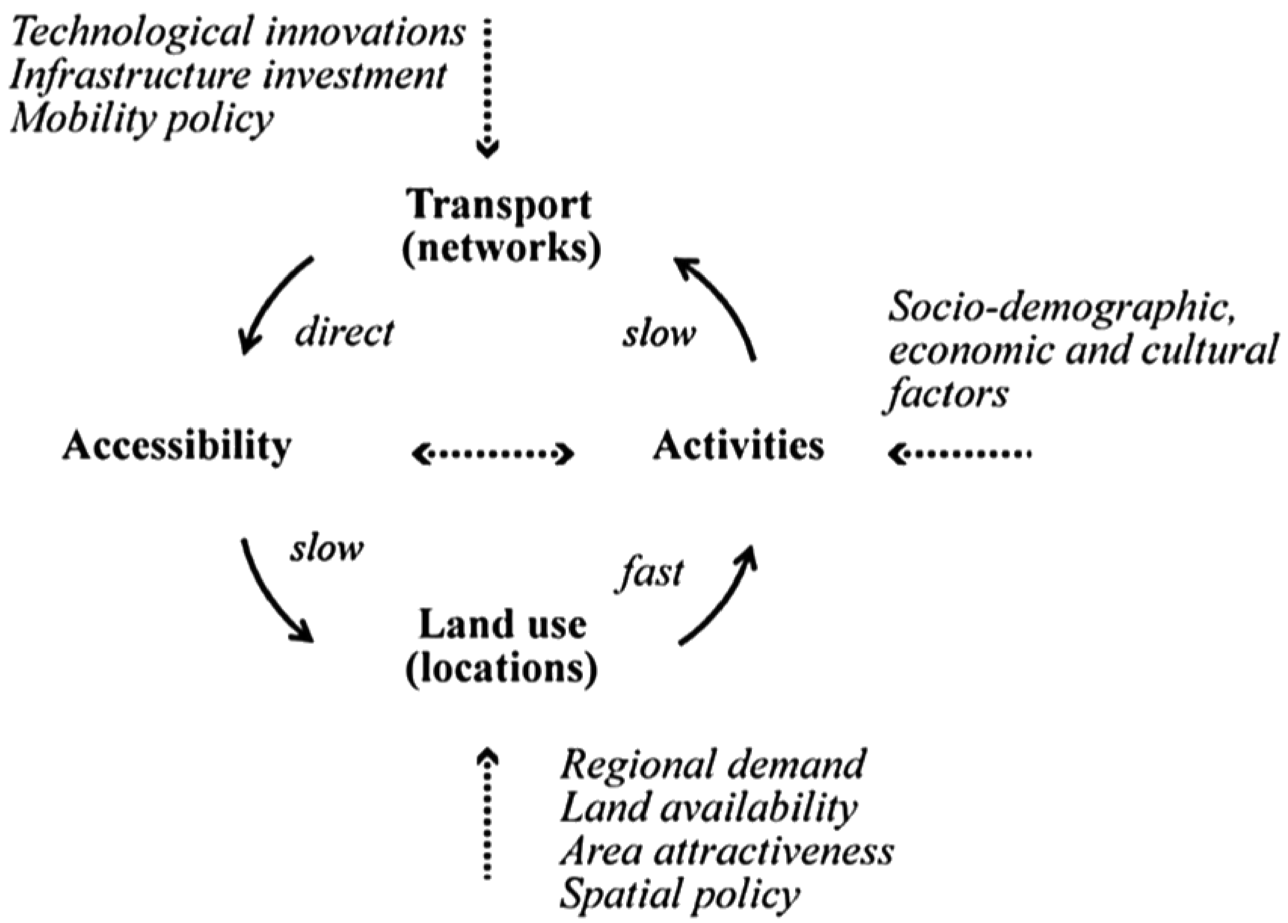


Figure 5 - Four elements in a loop: transport system – accessibility – land use – activities (Wegener & Fürst, 1999)

- **Land use** involves the distribution of housing, commerce, industry, and public amenities, which determines the locations of activities such as living, working, shopping, education, and recreation. Depending on the design and arrangement of an area, it may attract other residents, leading to “residential self-selection,” which can influence specific mobility patterns.

- **Activities** refer to the daily tasks that individuals engage in, such as work, education, shopping, and recreation. The nature and location of these activities significantly influence the demand for and use of different modes of transportation.

This interplay between the transport system, accessibility, land use, and activities underscores the intricate connections between spatial allocation and mobility. Understanding these dynamics can provide insights into addressing urban challenges derived from TNO’s report on wellbeing, like the Urban Heat Island effect, noise pollution, air quality, and CO2 emissions. Those will be discussed in the following sections.

Despite these findings, a gap persists in the literature. While there is ample research on the spatial footprint of cars, non-motorized transport (NMT), and public transport (PT), it is less common to find studies that integrate these different mobility modes within a single urban context (De Gruyter et al., 2022). The relationship between spatial footprint, modal split, and spatial allocation and its effects on the living environment remains underexplored.

The following section will dive further into the different urban challenges.

Image 2, Weena Rotterdam

2.2 The role of transportation in urban challenges

Urban areas are increasingly grappling with multiple challenges, such as the Urban Heat Island (UHI) effect, noise pollution, poor air quality, scarcity of green spaces, and high CO2 emissions.

These challenges manifest across the four dimensions of the WBM (Snellen et al., 2021) (touched upon in The Scope), as shown in Figure 6. Importantly, these urban challenges are closely linked to how space within cities is allocated, particularly about mobility infrastructure.

The selection of these specific challenges is based on a combination of factors. Firstly, they have been identified in the PBL report as significant contributors to the quality of urban life. In addition to this, they feature prominently in the 'Aanpak omgevingseffectrapportage's assessment framework (Figure 7). This framework distinguishes between aspects, indicators, and parameters. Indicators are utilized to describe effects. For instance, air is an indicator reflecting the degree of pollution experienced by people and a measure of the healthiness of an environment. Indicators can, in turn, be aggregated into aspects. For example, air and noise are part of the 'Safe, healthy, physical living environment.'

Several overlapping indicators include Noise, Air Quality, Ruimtebeslag (space occupation), and biodiversity. Interestingly, the UHI effect isn't directly listed as an indicator within the existing framework. Still, it's significant enough to include it in this study due to its profound influence on urban life. Notably, the UHI effect is a consequential effect of climate change. This positions it squarely within the category of 'Climate Resilience'.

Consequently, these factors led to selecting the following four aspects (UHI, Noise, Air Quality & greenery) that are elaborated upon in the coming subsections.

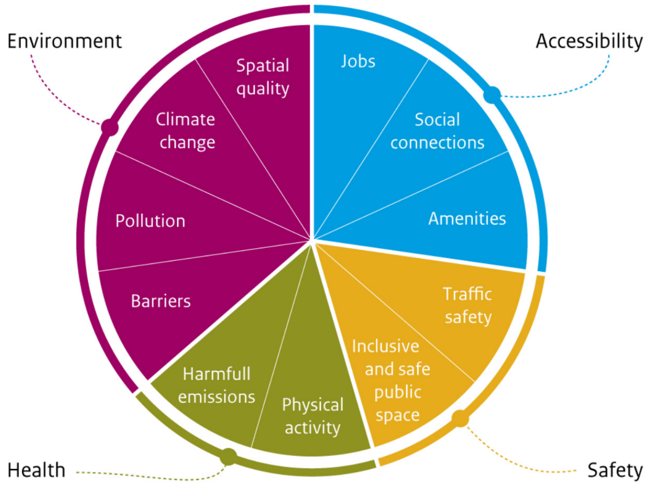
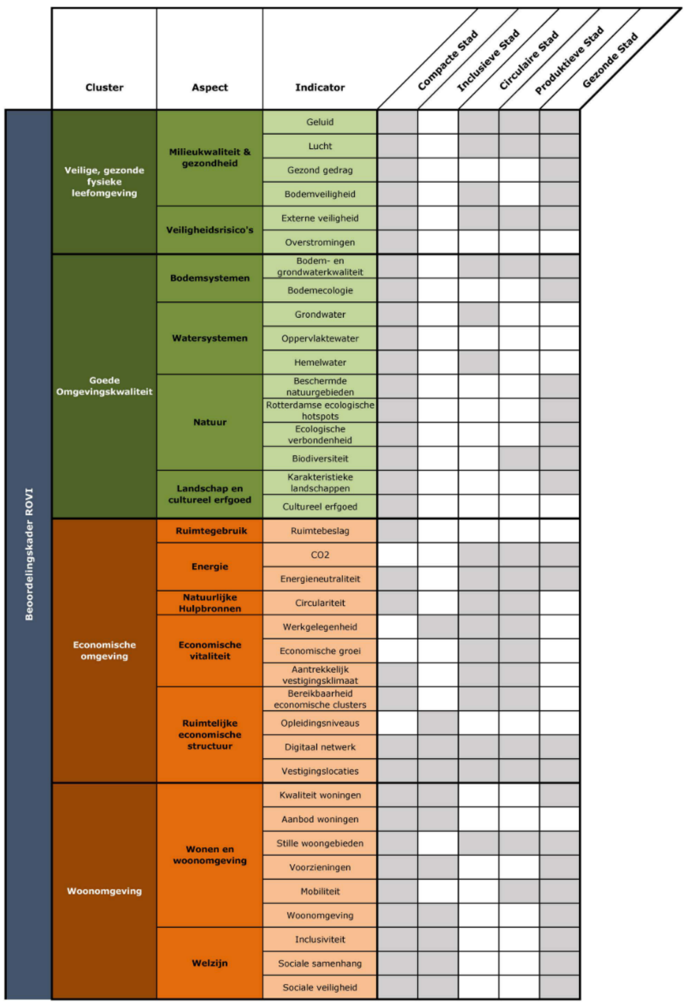


Figure 6 - four dimension of wellbeing related to mobility (Snellen et al., 2021)



Beoordelingskader ROVI	Cluster	Aspect	Indicator	Compacte Stad	Inclusieve Stad	Circulaire Stad	Produktieve Stad	Gezonde Stad
	Veilige, gezonde fysieke leefomgeving	Milieukwaliteit & gezondheid	Geluid					
			Lucht					
			Gezond gedrag					
			Bodemveiligheid					
		Veiligheidsrisico's	Externe veiligheid					
			Overstromingen					
	Goede Omgevingskwaliteit	Bodemsystemen	Bodem- en grondwaterkwaliteit					
			Bodemecologie					
		Watersystemen	Grondwater					
			Oppervlaktewater					
			Hemelwater					
		Natuur	Beschermde natuurgebieden					
			Rotterdamse ecologische hotspots					
			Ecologische verbondenheid					
			Biodiversiteit					
		Landschap en cultureel erfgoed	Karakteristieke landschappen					
			Cultureel erfgoed					
	Economische omgeving	Ruimtegebruik	Ruimtebeslag					
		Energie	CO2					
			Energieneutraliteit					
		Natuurlijke Hulpbronnen	Circulariteit					
		Economische vitaliteit	Werkgelegenheid					
			Economische groei					
			Aantrekkelijk vestigingsklimaat					
		Ruimtelijke economische structuur	Bereikbaarheid economische clusters					
			Opleidingsniveaus					
			Digitaal netwerk					
			Vestigingslocaties					
	Woonomgeving	Wonen en woonomgeving	Kwaliteit woningen					
			Aanbod woningen					
			Stille woongebieden					
			Voorzieningen					
			Mobiliteit					
			Woonomgeving					
		Welzijn	Inclusiviteit					
			Sociale samenhang					
			Sociale veiligheid					

Figure 7 - Assesment framework used by Municpilatiy Of Rotterdam (in dutch) (Aanpak Omgevings Effect Rapportage, 2020)

Urban Heat Island Effect

The UHI effect, for instance, arises primarily from spatial decisions within cities (Kurn et al., 1994). Large swaths of concrete and asphalt roads and buildings absorb and re-emit heat, while the scarcity of green spaces, which could provide cooling, is a direct outcome of city planning favouring car-based transport (Chen et al., 2022).

This phenomenon is vividly displayed in a map of the Netherlands (Figure 8) created by the National Institute for Public Health and the Environment (RIVM).

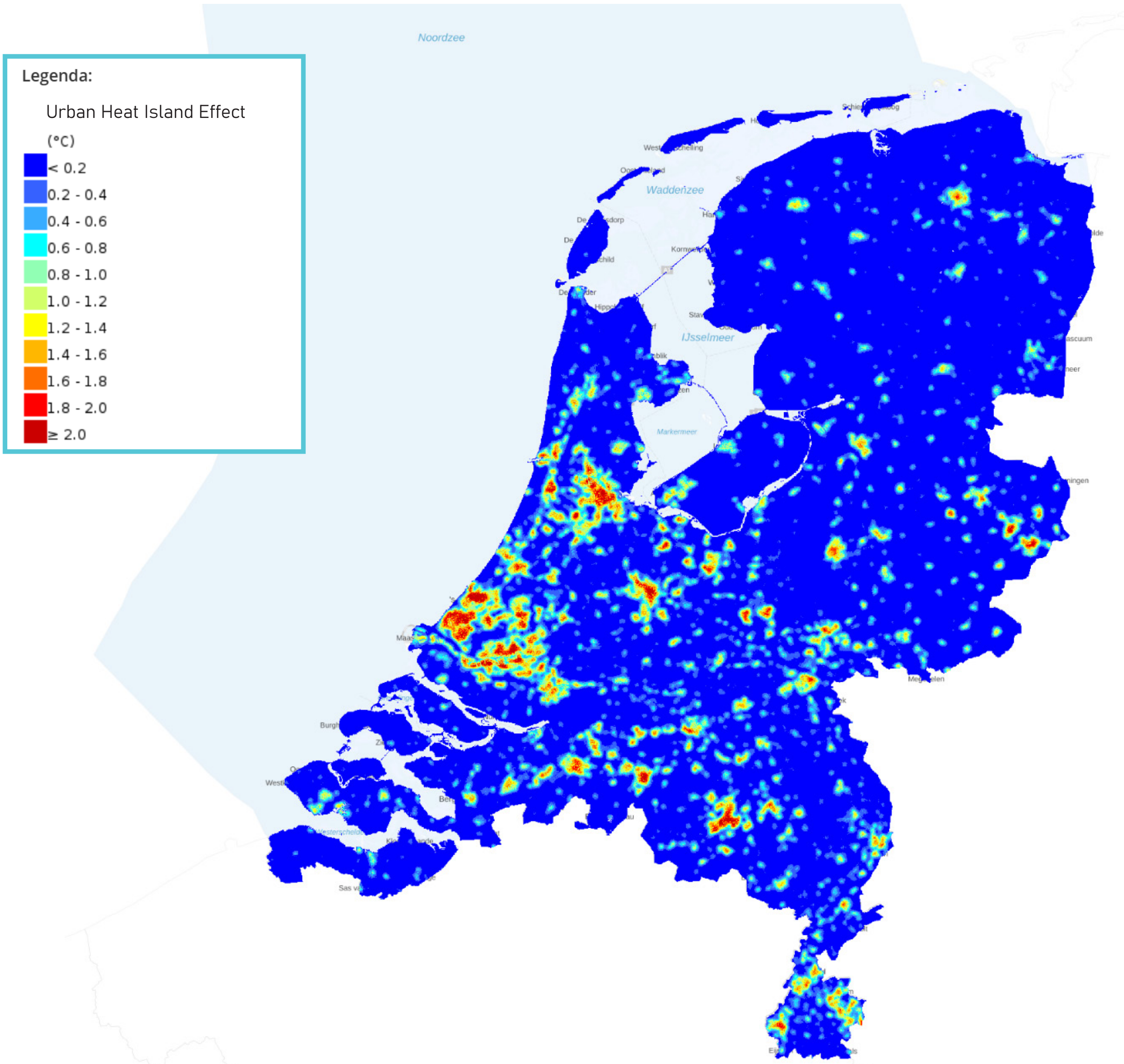


Figure 8 -UHI effect map (RIVM 2020a)

Impact of spatial allocation on noise pollution

Noise pollution in urban areas is another issue linked to (intra-city) spatial allocation. Cars, as the predominant mode of transport, contribute significantly to noise pollution (Sampson, 2021). Roads and highways near residential areas further amplify this issue (Rosén et al., 2011). This spatial correlation is evident in Figure 9, which shows that noise levels peak around these densely trafficked areas.

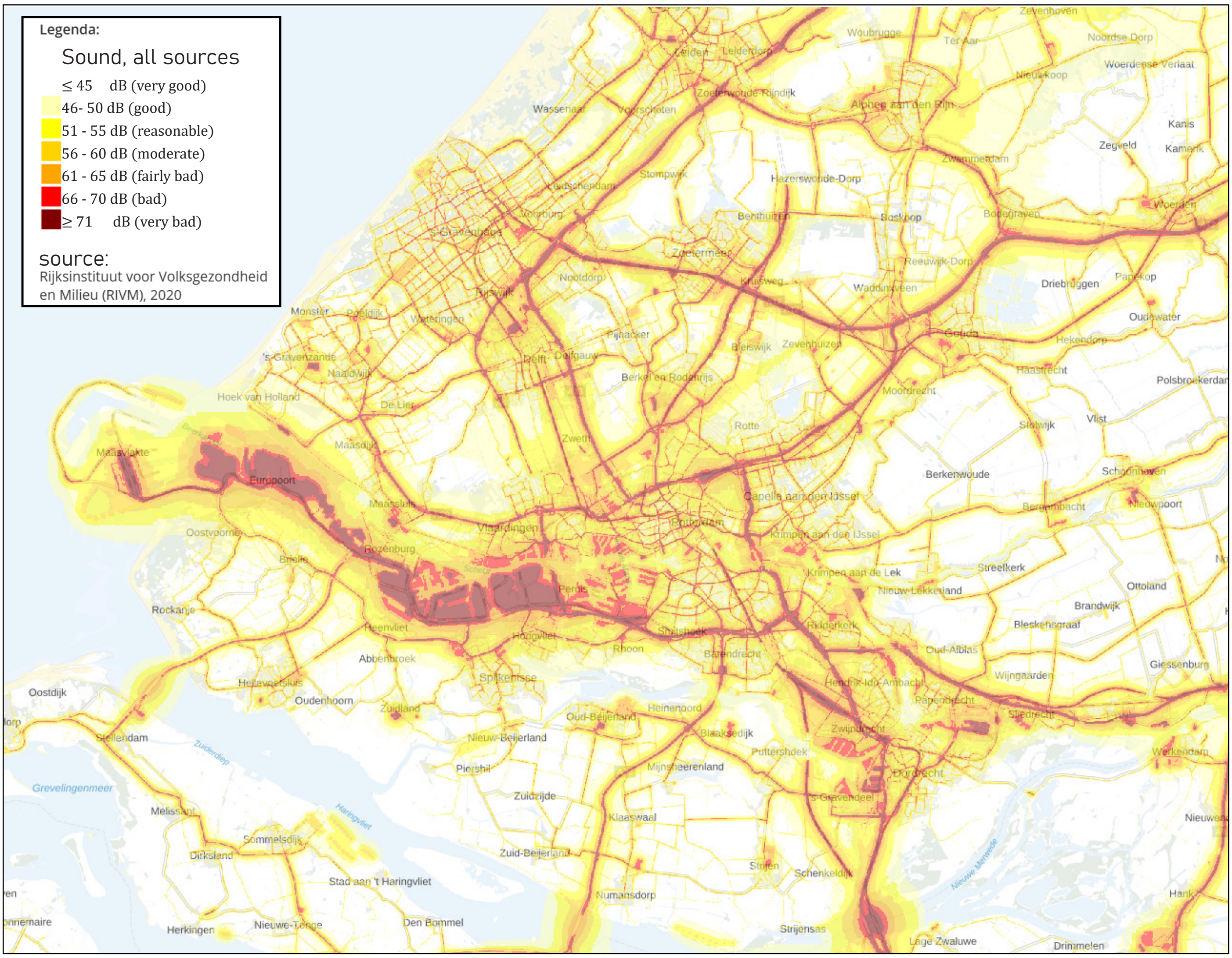


Figure 9 - Measured Noise Levels in the Netherlands (RIVM 2020b)

Impact of spatial allocation on air quality

Air quality in cities also suffers due to cars' (spatial) priority. The pollutants they emit, including particulate matter and nitrogen oxides, can cause serious health problems (Banister, 2008). Furthermore, their CO2 emissions contribute to climate change.

The spatially segregated impact of these emissions can be observed in the maps created by the DME team (available at emissieregistratie.nl), showing emissions scores per neighbourhood (Figure 10) and those emissions linked to infrastructure (Figure 11); both maps show that the more densely populated areas of the Netherlands (including Rotterdam) score higher.

Further enhancing understanding of air pollution across the country, the DME team has produced additional informative maps as part of the Min IenW' Well-being Monitor (WBM).

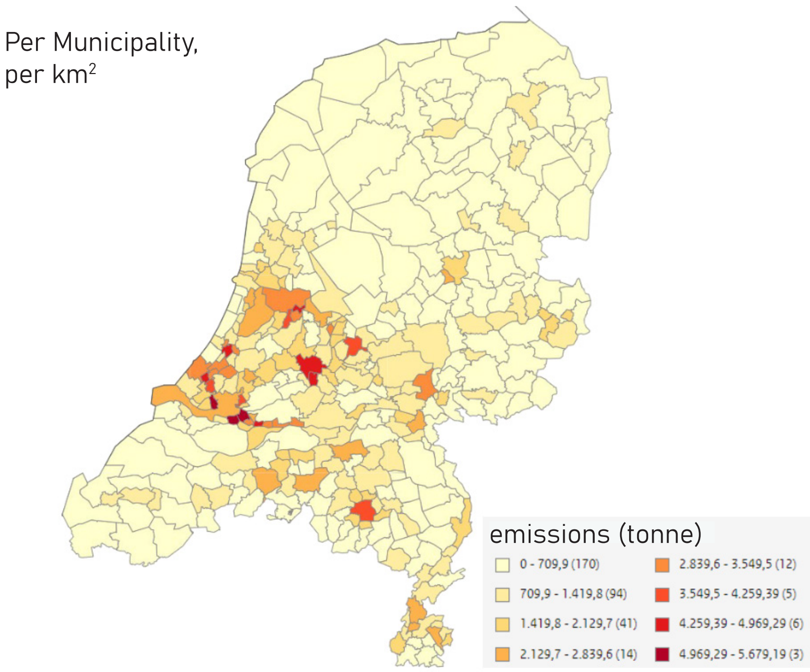


Figure 10 - Pollution map (CO_2) of the netherlands (Monitor Brede Welvaart en Mobiliteit, Eerste uitwerking van 16 indicatoren 2022)

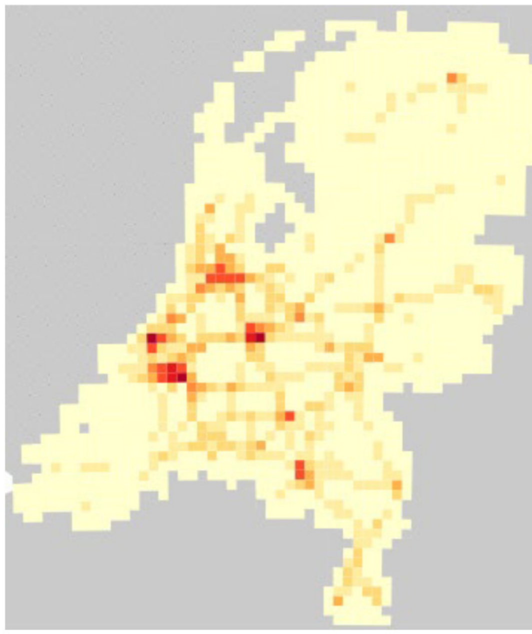


Figure 11 - CO2 map in relation to the roadnetwork (Monitor Brede Welvaart en Mobiliteit, Eerste uitwerking van 16 indicatoren 2022)

Figure 12, the first of these additional maps, presents the distribution of PM10 (fine dust) levels across different municipalities in the Netherlands. This map glaringly highlights that Rotterdam records the highest PM10 levels in the country. Notably, this ranking remains unchanged even when marine traffic contributions are excluded.

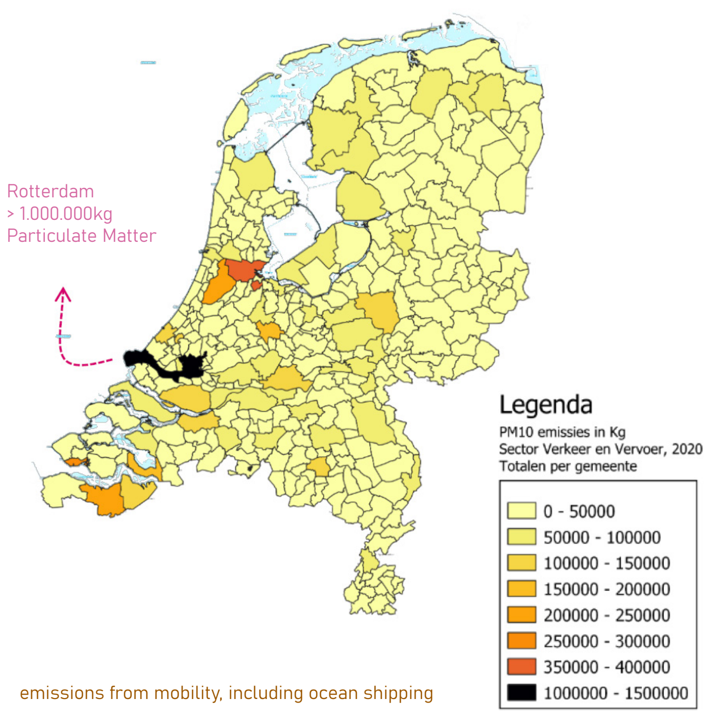
In Figure 13, the DME team presents the spread of nitrogen oxide (NOx) emissions across Dutch municipalities. As with PM10, the map reveals that Rotterdam leads with the highest NOx emissions. It's worth noting that this map focuses solely on traffic-generated NOx emissions, excluding those from marine sources.

Figure 14 delves deeper into the NOx emissions within the mobility sector. Presented as a treemap, it gives a clear visual breakdown of various emission sources. The map reveals that a significant proportion of NOx emissions in the sector stem from road traffic. For reference, the share of road traffic in the total national emission of nitrogen (NOx) is approximately 3% (Monitor Brede Welvaart En Mobiliteit Eerste Uitwerking van 16 Indicatoren, 2022)

These additional figures underline the severity of the air quality issue in densely populated areas like Rotterdam, emphasizing the urgent need for pollution management and clean mobility solutions.

Particulate matter PM10

Distribution of PM10 emissions across the Netherlands



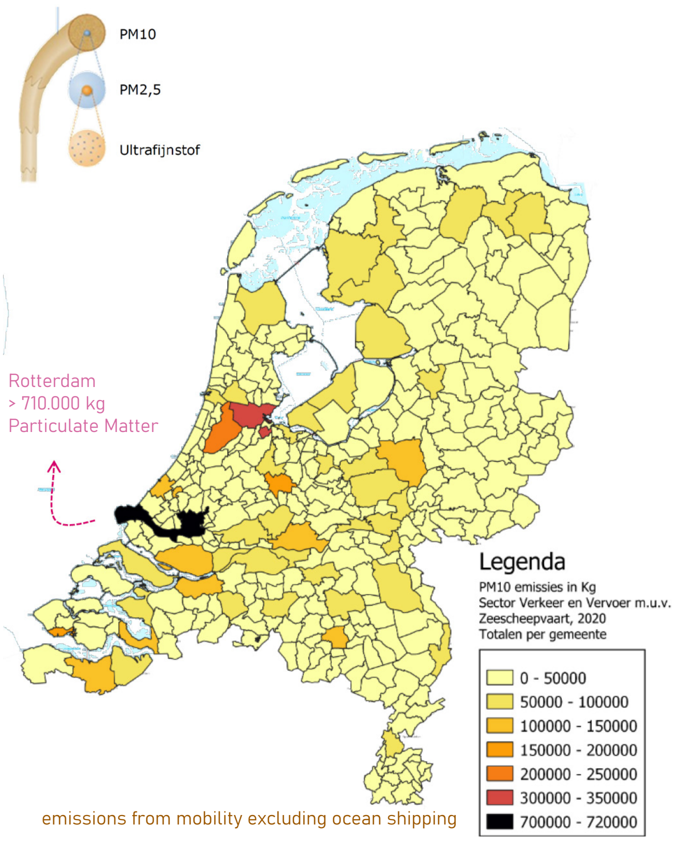


Figure 12 - PM10 concentrations in the Netherlands (Monitor Brede Welvaart en Mobiliteit, Eerste uitwerking van 16 indicatoren 2022)

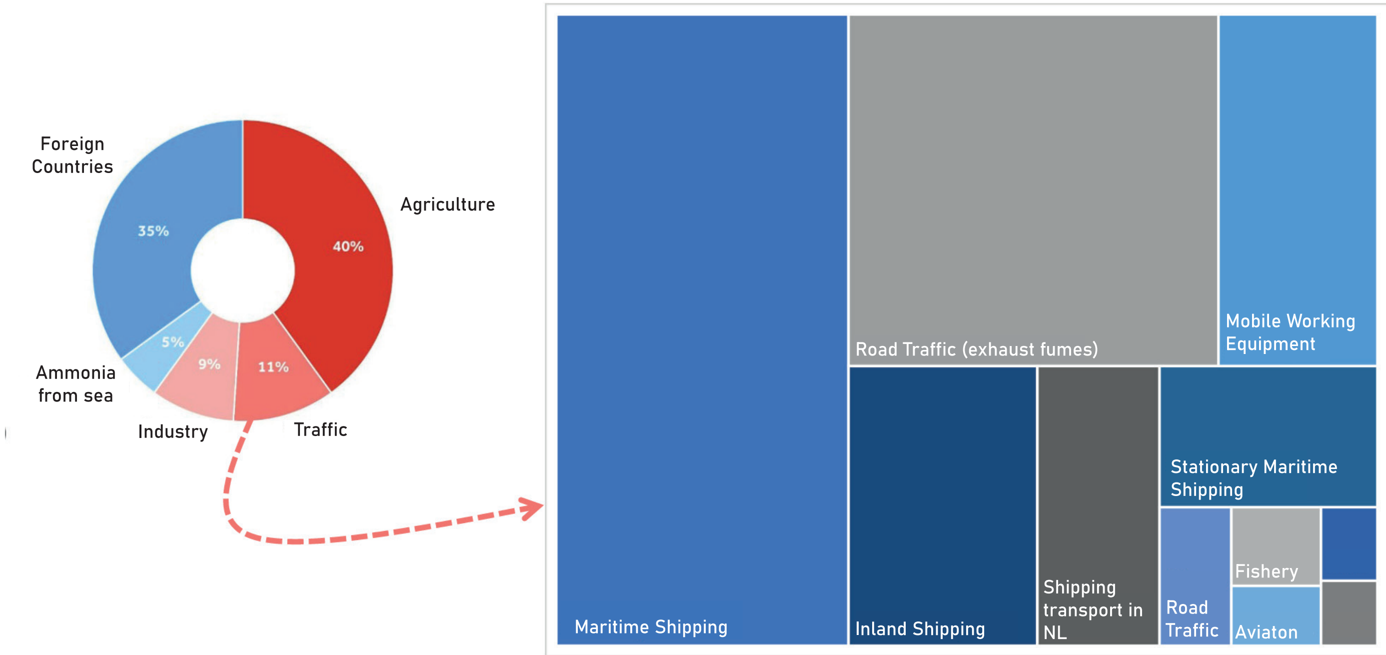


Figure 14 -Distrubtion of NOx emissions per mobility, (Monitor Brede Welvaart en Mobiliteit, Eerste uitwerking van 16 indicatoren 2022)

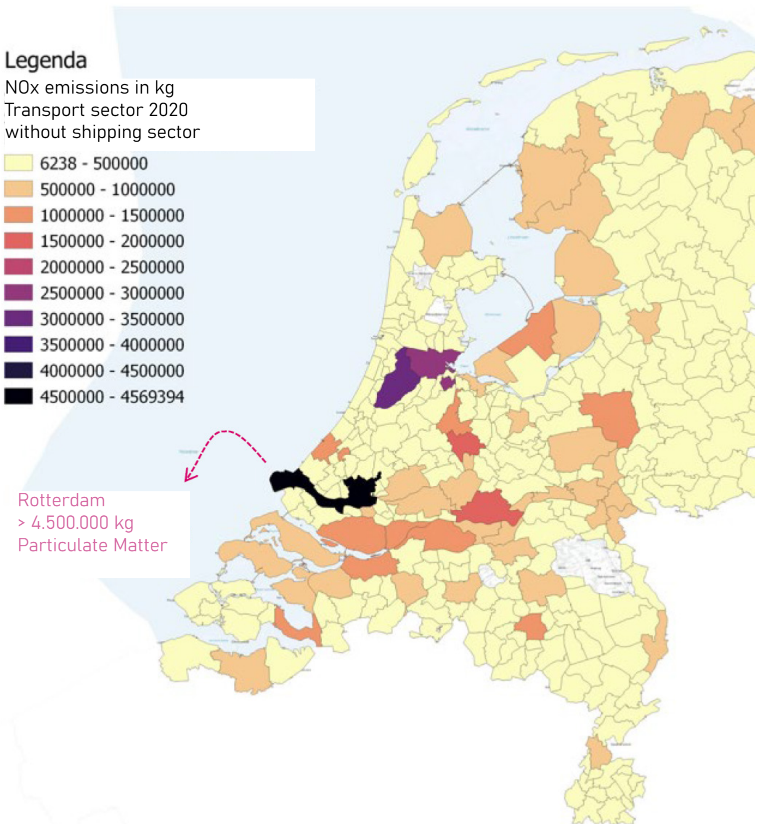


Figure 13 -NOx emissions within the Netherlands (Monitor Brede Welvaart en Mobiliteit, Eerste uitwerking van 16 indicatoren 2022)

2.3 Reallocation of space for green spaces

Spatial allocation within urban environments significantly influences public health and well-being—the current prominence of car-centric infrastructure limits opportunities for physical activities like walking and cycling. However, reports from Liere B. et al. (2017), Nello-Deakin (2019), Nijland & van Meerkerk (2017), Sampson (2021), and Snellen et al. (2021) argue that reallocating some of this urban space to more active, human-centred forms of transport, it can both encourage physical activity and enhance public health.

Furthermore, the scarcity of green spaces in urban settings, primarily due to spatial allocation favouring car-based infrastructure, poses another challenge: the UHI effect. Thus, those green spaces are essential for environmental and recreational benefits (Thompson et al., 2016). By reconsidering the approach to urban spatial allocation, room can be made for these much-needed green areas.

How space is allocated within cities is crucial in various urban challenges. The current predominance of car-centric areas contributes to problems such as noise and air pollution, CO2 emissions, and the UHI effect. However, by shifting spatial priorities, there could be an opportunity to alleviate these problems.

By reducing space for cars and promoting more spatially efficient modes of transport, such as cycling and walking, healthier and more vibrant cities can be created. Moreover, by forming green spaces with the space saved from reducing car usage, we can further enhance air quality, mitigate the UHI effect, and provide essential recreational areas for urban residents (Gössling et al., 2016; Sampson, 2021).

In essence, the urban spatial allocation should not be seen as a static construct but a flexible one, capable of being moulded better to suit the well-being of its residents and the environment.

2.4 Role of mobility in health and well-being

Mobility can also have positive health effects when it involves physical activities such as walking and cycling, increasing life expectancy and improving mental and physical health (Nijland & van Meerkerk, 2017). The lack of green spaces in urban areas is a further challenge. Green spaces provide recreational areas for residents and offer environmental benefits, including improving air quality, reducing the UHI effect, and providing habitats for urban wildlife. But the space dedicated to cars often limits space availability for green areas (Thompson et al., 2016).

By reducing the space dedicated to cars and reallocating it to more spatially efficient modes of transport, cities could mitigate these issues. For instance, reducing car usage can decrease noise, air pollution, and CO2 emissions. The freed-up space can create green spaces, mitigating the UHI effect, improving air quality, and providing recreational areas for residents (Gössling et al., 2016; Sampson, 2021).

2.5 Effects on & from the modal split

The modal split, or the share of daily trips made by each travel mode, is a valuable indicator of city functions (Pucher, 1988). It involves multiple variables and interactions within the city, reflecting city-specific features such as history, culture, land use, industries, and relationships with other towns or adjacent countries (Lee et al., 2022).

A study by Lee et al. (2022) found that the modal split is determined by a variety of factors, some of which are more critical than others. For instance, higher population density and mixed land use are associated with low automobile dependency. Public transit use tends to rise in dense areas with frequent services. On the other hand, extreme weather conditions (e.g., hot temperatures) can prevent bicycle usage.

The study Of Lee et al. also states that the socio-demographic factor has the highest impact on determining the cities' modal splits. High population density and employment rate are positively associated with low-emission travel modes. High gasoline tax and low public transit and taxi fares often make people reconsider possessing private vehicles.

In sum, the origin and effects of the modal split are complex and intertwined with various city-specific features and conditions. Understanding these relationships is vital for developing strategies or policies for a modal shift toward sustainable mobility infrastructure at the city level (Lee et al., 2022).

Image 3, Rotterdam's metro

2.6 Impact of urban planning and modal shift on road safety

Changes in mobility can also have effects on safety. To gain more insight into these effects, research was conducted on "How does a modal shift from short car trips to cycling affect road safety?" by Schepers & Heinen (2013) and "Urban Policies and Planning Approaches for a Safer and Climate Friendlier Mobility in Cities: Strategies, Initiatives and Some Analysis" by Tiboni et al. (2021).

Schepers and Heinen's study investigates the potential effects of a shift from car trips to cycling. The research indicates that while such a shift may not significantly impact the number of road deaths, it may lead to an increase in severe injuries due to an uptick in single-bicycle crashes. However, this risk can be mitigated with improved infrastructure safety. Moreover, while fatalities may increase among those aged 65 and above, the 18-64 age group may witness a decrease in deaths. Despite an expected increase in serious road injuries, the promotion of cycling may still be favourable given its health benefits and additional measures to reduce single-bicycle crashes.

On the other hand, Tiboni et al.'s document presents a detailed analysis of sustainable urban mobility. It stresses the necessity for an integrated land-use and transport system to sustain long-term economic growth, social cohesion, and environmental protection. The importance of Sustainable Urban Mobility Plans (SUMPs) in integrating long-term transport goals at all mobility levels is underscored. It proposes a shift from mobility-oriented to accessibility-based transport planning, facilitated by urban regeneration, as the key to sustainable and energy-efficient transport planning for all users.

A case study of the redevelopment of an abandoned area, the "Magazzini Generali" in Brescia, illustrates the successful implementation of these strategies. The redevelopment improved accessibility and promoted soft mobility despite location challenges. The document also emphasizes accessibility as a crucial concept in sustainable transport planning.

Both papers emphasize the importance of a holistic approach in urban planning and mobility management, where infrastructure changes, modal shifts, and integrated planning strategies are considered together to create a safer and more sustainable urban environment. Both papers suggest that these findings can form a valuable foundation for future research and policy planning, potentially extending to different case studies at the national and European levels.

2.7 Summery of the literature review

As cities undergo rapid expansion, densification, and environmental changes, the interplay of spatial allocation, modal split choices, and their respective efficiencies becomes an increasingly pressing concern. The studies highlighted several vital implications for future urban development, emphasizing the need for a holistic understanding of the intricate dance between urban planning, mobility, and public health.

Spatial efficiency and transport modes

Spatial efficiency in transportation modes is pivotal. From the data presented, it's evident that car-centric models, while prevalent, are far less efficient in terms of spatial utilization compared to more active, human-centric modes like walking and cycling. Such spatial disparities can significantly amplify urban challenges. For instance, by consuming vast tracts of land for roadways and parking, we inadvertently sideline the urgent need for green spaces, intensifying issues like the urban heat island effect. However, by integrating spatially efficient transportation modes, cities can reclaim land for greener, more recreational uses, directly enhancing the quality of life and addressing environmental concerns.

Urban challenges and the need for green spaces

Urban environments grapple with myriad challenges: from the tangible impacts of noise and air pollution to more abstract mental well-being and social connectivity issues. The continued emphasis on car-centric infrastructure exacerbates these challenges by inhibiting active modes of transportation and limiting green space allocation. As the studies underline, green spaces are more than just aesthetic elements; they play a crucial role in mitigating urban heat islands, enhancing air quality, providing habitats for urban wildlife, and acting as recreational zones that foster community interaction and mental rejuvenation.

Mobility, modal split, and safety

The modal split, reflective of a city's socio-economic and cultural fabric, acts as a bellwether for its priorities and challenges. With high population density areas showing preferences for low-emission modes of transportation, the implications are clear: cities need to facilitate and encourage shifts towards sustainable, efficient transport. However, as studies like Schepers & Heinen (2013) suggest, while promoting changes (like from cars to bicycles) can have multifaceted benefits, they also bring forth safety concerns that cities must preemptively address.

Integrated planning for the future

One significant takeaway from the "Magazzini Generali" case study in Brescia is the undeniable potential of adaptive reuse and innovative urban regeneration. Urban spaces need not be static; they can evolve, adapt, and transform to meet the shifting needs of their populace. This adaptability and a keen understanding of spatial efficiencies and urban challenges can guide cities towards more sustainable, health-centric futures.

Identifying the research gap

While these studies provide invaluable insights into the relationship between urban planning, transportation modes, and public health, a conspicuous research gap remains. Notably, there's a need for empirical assessments that directly juxtapose the spatial efficiencies of various transport modes in diverse urban environments. Additionally, while particular urban challenges are addressed, a holistic understanding of the socio-cultural implications of shifting transport modalities remains underexplored. Future research must delve into these gaps, using both quantitative metrics and qualitative explorations, to harness the potential of urban spatial reallocation in promoting public health and environmental well-being.

In essence, the future of urban development hinges on this delicate balance. By recognizing the spatial inefficiencies of current transport modes, understanding and addressing urban challenges, and adopting integrated, forward-thinking planning strategies, cities can forge a path toward holistic growth that prioritizes environmental and human health.

3 Methodology and data collection

This research aims to investigate the potential impacts on spatial allocation and specific aspects of urban development in Rotterdam in the event of a significant shift from car usage to other modes of transport, such as biking, walking, or public transport. To pursue this investigation, the research adopts a data-driven approach that integrates spatial analysis, policy review, and correlation analysis within a structured methodological framework. A vital component of this spatial analysis involves the utilization of Geographic Information System (GIS) files, with all data processing and analysis performed in the open-source program QGIS.

3.1 Methodology flowchart

As shown in Figure 15 - Flow chart of the methodology and research, the methodological process commences with the collection of publicly available (spatial) datasets. This data, predominantly sourced from the Ministry of Infrastructure & Water Management, undergoes a GIS spatial analysis specific to Rotterdam using QGIS. Subsequently, data is filtered based on insights from comparable research and expert interviews, creating a neighbourhood-specific dataset that forms the basis for addressing the first sub-research question (SRQ 1).

With this detailed dataset, further calculations and analyses are conducted, grounded in a comprehensive literature review and policy documents from the Municipality of Rotterdam. This stage allows for conceptualising potential spatial distribution within Rotterdam, addressing SRQ 2.

The subsequent stage contemplates the potential benefits of this spatial reallocation alongside the impacts of the current infrastructure. These considerations are augmented by a well-being monitor and a literature review, which collectively respond to SRQ 3.

The methodology then transitions into analysing the potential impacts of such reallocations, specifically concerning greenery, UHI, air quality, noise (SRQ4), and accessibility (SRQ 5). These impacts are evaluated through supplementary literature reviews, additional spatial and data analysis of Rotterdam using QGIS, and expert interviews.

Lastly, the methodology culminates in a detailed exploration of the potential impacts on a neighbourhood-specific scale (SRQ 6), offering a localised perspective of the effects of a modal shift in transport.

To estimate the potential spatial reallocations, a step-by-step approach has been employed. This approach involves establishing a baseline of the current space allocation, defining the scenario for the new modal split, estimating the space requirements for these new scenarios, calculating potential space savings, and considering other influential factors. This systematic approach comprehensively examines the spatial allocation of different modes of mobility in Rotterdam and its possible implications for urban well-being.

Central to this research's methodology is its case study approach, which focuses on Rotterdam. Case studies are particularly suitable for investigations of this nature as they furnish contextualised insights, lending depth and nuance to the findings. Rotterdam emerges as an ideal candidate for this case study, not just due to its stature as one of the Netherlands' largest cities and the availability of rich datasets but also because of its distinctive urban layout. Unlike many Dutch cities, Rotterdam boasts a post-war, car-centric design, setting it apart and amplifying this study's relevance and potential implications.

In essence, this methodology offers a data-driven framework for understanding the potential of shifts in transportation modes on spatial allocation, urban development, and well-being in Rotterdam.

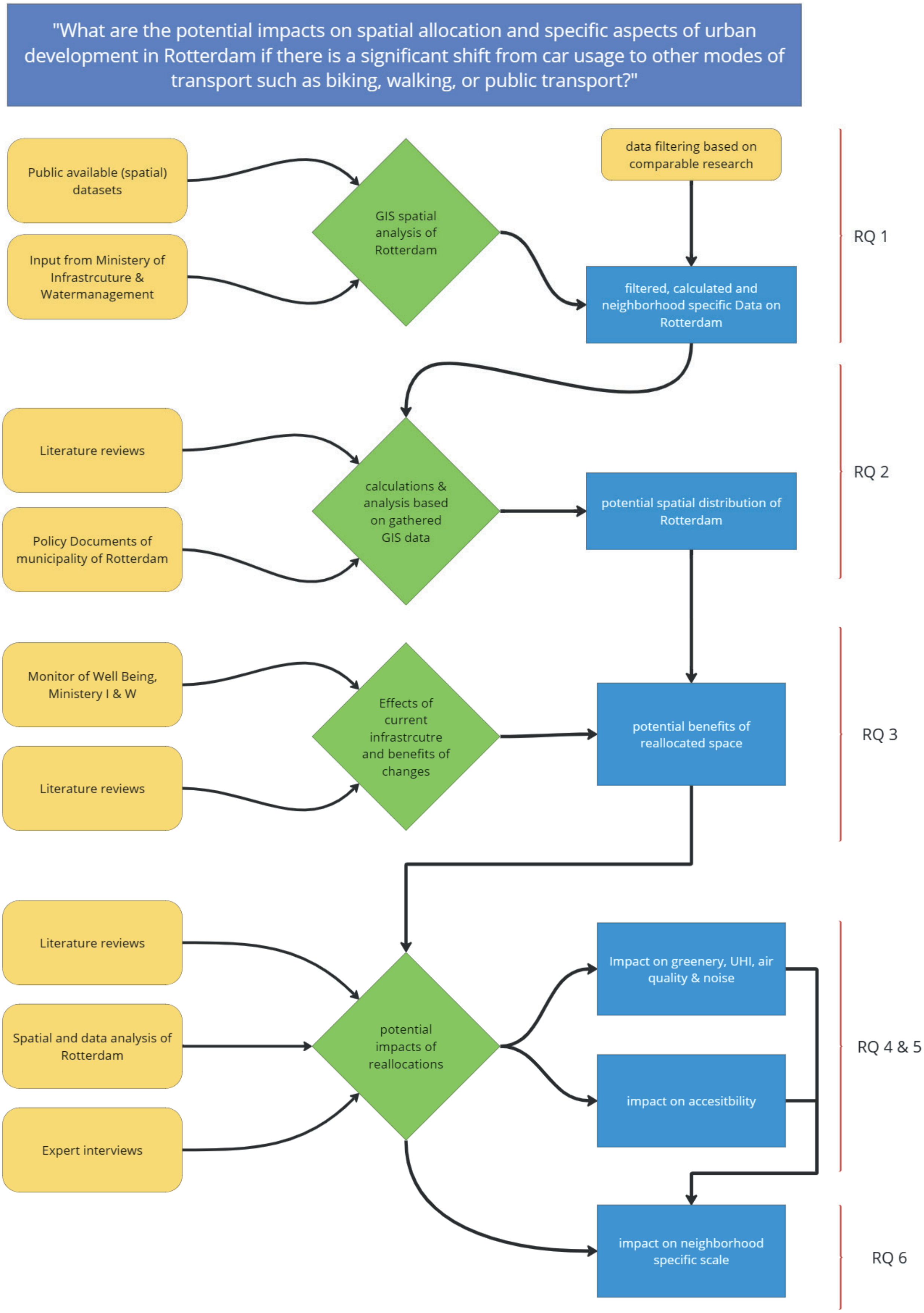


Figure 15 - Flow chart of the methodology and research

3.2 Data collection

This sector will briefly describe the stage of data collection and processing; it tells which datasets are used, their sources, and the reasons for their selection. Also, the limitations encountered during this process are described. In this research, multiple datasets were employed to provide comprehensive insights into the mobility distribution and urban well-being of Rotterdam. These datasets, sourced from government-hosted platforms, the municipality of Rotterdam, and primary research, include spatial data (vector and raster formats), demographic data, transportation data, environmental data, and others.

3.3 Primary data collection

Basic Topography Data: The topographical data was downloaded from PDOK.nl, a government-hosted website that offers publicly available datasets. The version used in this research was obtained on 1-5-2023, provided in shapefile format.

CBS Data: For delineating the neighbourhoods, the CBS classification on Wijken en Buurten (2022) was utilized, ensuring precise segmentation of Rotterdam's diverse areas.

Mobility Data: For data on modal split and other mobility information, the Municipality of Rotterdam provided a specially filtered and cleaned dataset. This dataset, which combines data from MON, OViN, & ODiN, has been updated up to 2021 and accounts for the impact of the COVID-19 pandemic on mobility.

3.4 Secondary data collection

Statline Data: A wide array of data, including information on income, age, address density, housing stock, and more, was obtained from CBS-Statline. These datasets were updated at different times, so only data from 2021 was used to maintain consistency, even though the start of that year still witnessed some effects from the COVID-19 pandemic.

Environmental datasets: For datasets on the Urban Heat Island effect, noise, greenery, and air quality, resources were retrieved from Atlasleefomgeving.nl, another government-hosted platform. While the most recent datasets available were from 2020, this timeframe was deemed suitable for the current research given the comprehensive and geographically-specific data provided. Those datasets were all supplied in raster format.

For a quick overview, Table 1 below summarizes the datasets used for the research:

Table 1 - Overview of the used datasets

Dataset	Source	Publisher	Year Used
Basic Topography (BGT)	PDOK.nl	Government of the Netherlands	2023
CBS Indeling on Wijken en Buurten	CBS	CBS	2022
Mobility (MON, OViN, & ODiN)	Municipality of Rotterdam	CBS	2021
CBS Statline (various data)	CBS Statline	CBS	2021
Environmental Metrics (Urban Heat Island Effect, Noise, Greenery, Air Quality)	Atlasleefomgeving.nl	Government of the Netherlands	2020

3.5 Data selection, rationalization, and limitations

The data utilized in this research was carefully selected and rationalized based on various criteria. Factors such as the data's relevance to the research objectives, the overlap with indicators from the municipality's mobility vision, and the directives from the TNO report on well-being (were considered during the selection process.

The data collection process experienced a few limitations. These ranged from the non-availability of the most recent environmental data to the challenges of using datasets with different update timelines. Potential issues with data accuracy or reliability, limitations imposed by using QGIS, and the impact of external circumstances like the COVID-19 pandemic on the collected data are discussed.

4 Case study: the situation in Rotterdam

Introduction

This chapter offers a comprehensive exploration of spatial allocation in Rotterdam, delving into the historical and current state of the city's urban space distribution and its connection to various modes of transport. Recognising Rotterdam's post-war layout and car dependency, the study draws on a systematic approach that begins with data extraction and navigates through multiple stages of data processing. This methodology ensures the accuracy and reliability of the findings, making the research replicable for other urban contexts.

Much of this chapter is dedicated to analysing the policy documents issued by the Municipality of Rotterdam. This analysis provides insights into the city's spatial allocation and mobility vision and contextualises the challenges and opportunities Rotterdam faces in adapting to modern urban planning needs. Readers can anticipate detailed insights from key policy documents, reflecting on the city's aspirations, strategies, and measures to transform its urban landscape.

Moreover, to provide comparative perspectives and highlight methodological intricacies, a sidebar on the 'What the Street?!' project (Szell & Bogner, 2017) is integrated into this chapter. Though operating on different datasets and methodologies, this case study shares a thematic resonance with the core objective of analysing urban space allocation. This part of the research provides a detailed explanation of the methodology adopted to examine the distribution of urban space in Rotterdam. The process is divided into multiple stages, each explained in detail in the subsequent sections. This systematic approach allows for the dissection of urban space distribution across different modes of transport.

This chapter has the following sections:

4.1 Policy document analysis: This section offers an in-depth review of Rotterdam's urban mobility and spatial allocation strategies, reflecting on the city's future aspirations.

4.2 Spatial analysis of Rotterdam: A systematic breakdown of Rotterdam's urban space distribution is presented, showing its unique spatial character.

Sidebar: what the Street?!: A comparative analysis of the 'What the Street?!' project, highlighting methodological differences.

4.3 Incorporation of environmental metrics: Emphasizes how the study considers environmental factors in its spatial analysis, recognizing their growing importance in urban planning.

4.4 Correlation analysis of spatial Allocations and other variables: This section delves deep into the interplay between spatial allocations and various urban elements, revealing potential insights and trends.

4.1 Policy documents analysis: vision and strategy for Rotterdam's mobility

The Municipality of Rotterdam has formulated its vision and strategy for future urban mobility through key policy documents. This section presents a review and analysis of several policy documents prepared by the municipality of Rotterdam. These documents reflect the city's vision and projections for the future, with a particular focus on the modal split - the distribution of various modes of transport used by the population.

For this review, three key policy documents are explored: the 'Rotterdam Mobility Approach' (Rotterdamse Mobiliteits Aanpak (2020)) the 'Approach Environmental Impact Report' (Aanpak Omgevings- Effect- Rapportage (2020)), and the 'Cycling Course 2025' (Fietskoers 2025 (2019)).

These reports provide invaluable insights into Rotterdam's planned trajectory for urban mobility and spatial allocation.

Key points and findings from those documents are listed, aiming to provide a comprehensive overview of Rotterdam's future as envisioned by its policymakers.

Image 4, Noordersingel Rotterdam

Aanpak omgevingseffect-rapportage (2020)

In the urban development strategy of the municipality of Rotterdam, a comprehensive approach is taken to create a compact, healthy, inclusive, circular, and productive city. The strategy is built around 12 key points, which are the foundation for in-depth discussions with stakeholders. These discussions focus on opportunities and risks and the management of conflicting space claims.

A significant emphasis is placed on the role of public transport as a catalyst for urbanization at both the city and regional levels. This is part of a broader initiative to enhance the city centre, promoting the use of bicycles, walking, and public transport while reducing the reliance on cars.

The strategy also underscores the importance of enhancing the city's green-blue structure. This involves integrating natural elements and water bodies into the urban environment, contributing to the city's resilience, biodiversity, and overall quality of life.

High-environmental-impact businesses must be concentrated and intensified in specific areas, providing room for economic transition. This approach is complemented by the development of city and district hubs for the logistics of goods and resources in the urban area, which could have significant implications for the city's mobility and infrastructure.

The strategy also includes measures to limit energy demand, reuse waste streams, and generate power sustainably, aligning with the city's ambition to become more circular. Furthermore, the strategy includes "softening and cooling" public spaces, particularly in older city districts. This could involve measures such as increasing green spaces and water bodies, which can help to mitigate the urban heat island effect and improve the city's resilience to climate change.

The Rotterdam Environmental Impact Report (ROER) is a crucial tool in this strategy, providing insight into the effects of critical decisions. The ROER also forms the basis for a Monitoring & Evaluation plan, which will assess the implementation of the urban development strategy based on the observed effects. This ongoing evaluation is essential, as some aspects of the strategy are still somewhat abstract and require further elaboration. Therefore, the Monitoring & Evaluation plan is necessary for regularly checking progress and determining whether additional measures or adjustments are needed.

Rotterdamse Mobiliteitsaanpak (2020)

In the plan, "Rotterdamse Mobiliteitsaanpak", the municipality of Rotterdam outlines its approach to mobility, infrastructure, and modal split. The document shows the city's commitment to creating a more sustainable, efficient, and user-friendly mobility infrastructure that caters to all residents and visitors.

The plan emphasizes the need for safe and healthy connections, advocating a shift from modal classification to speed and choice per modality. This shift includes gradually transforming boulevards, city streets, and residential streets into road profiles with speed classification. The document underscores the importance of shared use of the same infrastructure, which is not only space-saving but also suitable for zero-emission city distribution (loading/unloading). This approach leaves room for future forms of mobility and innovation, such as light electric vehicles and steps.

The city proposes a shift from crossing to staying, with measures to increase residential and 'stay' areas. The design around public transport nodes, schools, and sports facilities primarily aims at pedestrians and cyclists. Introducing car-free zones near schools during pick-up and drop-off times is also proposed.

The document also discusses the importance of infrastructure in the city centre, where pedestrians and cyclists will be given more priority. The plan is to gradually improve the quality of stay and provide more space for walking and cycling as a mode of transport. This means a different traffic network layout to accommodate walking, cycling and public transport use in the city centre.

The document provides specific numbers for the projected change in the modal split in Rotterdam by 2040. The share of car use for trips from, to, and within the city centre is expected to decrease from 42% to 32% in 2030 and eventually to 28% in 2040. Conversely, the share of bicycle use for these trips is expected to increase from 29% to 36% in 2030 and eventually to 38% in 2040. The percentage of public transport (including walking) for these trips is expected to increase from 29% to 32% in 2030 and eventually to 34% in 2040.

In absolute numbers, car traffic in the city centre is expected to decrease by 17,000 car trips over 20 years. Meanwhile, the number of bicycle trips is expected to increase by 67,000, and the number of public transport trips is expected to increase by 52,000. By 2040, the number of bicycle trips in the city centre is expected to be 50,000 more than the number of car trips. Public transport trips are also expected to be 30,000 more than car trips.

This indicates a significant shift towards more sustainable modes of transport, implying that infrastructure and facilities for cycling and public transport will need to be improved. The document also notes that the car will continue to play a significant role in trips to and from the city, but its share will be only 28%, compared to 38% for bicycles and 34% for public transport. This suggests that the space for infrastructure will need to be redistributed, with more space and priority given to bicycles, pedestrians, and public transportation.

In conclusion, the document provides a roadmap for achieving these goals, focusing on promoting healthier and more sustainable modes of transport.

Fietskoers 2025 (2019)

The 'Fietskoers 2025' tells that mobility is not merely about transportation from one point to another. Instead, it encompasses a broader range of factors, including the utilization of space, the creation of connections between places, the realization of economic opportunities, the facilitation of social interactions, the promotion of healthy movement, and the inclusion of all citizens in societal activities.

The city is currently developing the Rotterdam Mobility Approach (RMA). This strategic plan will inform spatial decisions and guide the city's transition toward a more sustainable and inclusive mobility system. A vital element of this transition is the promotion of active mobility, mainly walking and cycling, which aligns with the city's ambitions for a clean, space-efficient, healthy, and inclusive urban environment.

To support this transition, the city is prioritizing the update of its cycling network map. This tool is instrumental in decision-making processes related to traffic systems, maintenance planning, and traffic light strategies. Moreover, it provides valuable insights for regional and national discussions, urban development initiatives, and other spatial/urban planning issues.

Data plays a crucial role in this process. The city is working towards defining clear objectives for using data in developing policies and programs. This approach will enhance the effectiveness of interventions and provide valuable insights for developing design principles.

As a significant employer in the city, the municipality is committed to leading by example. It is actively encouraging its employees to cycle and avoid vehicles that run on fossil fuels. This initiative is part of a broader strategy to promote sustainable and active mobility.

The city is also acknowledging and responding to the emergence of new types of bicycles, collectively referred to as "Bike+". These include shared bicycles, e-bikes and speed pedelecs, sports bikes, (electric) mopeds, cargo bikes, (disabled) vehicles, and electric scooters. While these new forms of mobility offer many benefits, they also present challenges related to traffic safety and nuisance.

The city is developing a bicycle parking strategy and investment agenda to address these challenges. This strategy will define how to deal with situations where loosely parked bicycles cause nuisance and how to meet the growing demand for parking facilities for different types of bikes. The city is also exploring the concept of mobility hubs, which combine various forms of shared mobility and bicycle parking facilities.

In conclusion, Rotterdam's approach to urban mobility is characterized by a comprehensive and forward-looking strategy. This strategy recognizes the importance of active mobility, the potential of new forms of cycling, the value of data, and the municipality's role as a leading actor in promoting sustainable mobility practices. It also acknowledges the challenges associated with these developments and outlines concrete measures to address them.

Summary of the policy documents

The policy documents analyzed lay the foundation for understanding Rotterdam's envisioned trajectory in urban mobility, emphasizing a gradual transition towards greener, healthier, and more sustainable transportation methods. The 'Aanpak omgevings-effect-rapportage' encapsulates Rotterdam's ambition of moulding a compact, inclusive, and environmentally-attuned city with public transport playing a central role.

The 'Rotterdam Mobility Approach' paints a future with a marked decline in car usage, forecasting a dip from 42% to 28% by 2040. In contrast, the city expects a surge in bicycle usage from 29% to 38% and an uptick in public transport reliance from 29% to 34%. This transition isn't just about numbers; it hints at a more profound restructuring of urban environments, with pedestrians and cyclists occupying centre stage.

Delving more profoundly, 'Fietskoers 2025' is a testament to Rotterdam's dedication to active mobility. It considers the challenges and potential introduced by the influx of various "Bike+" categories, suggesting a broadening palette of transportation options for the city's residents.

The policies collectively herald Rotterdam's ambition: a movement towards more sustainable transport options, which has implications beyond mere transport. It touches upon the metamorphosis of urban spaces, safety norms, accessibility considerations, and environmental impacts.

In the upcoming sections of this chapter, it transitions from policy aspirations to concrete data. By unpacking the selected data from Rotterdam, further, explain the methodology that steers the analysis and explores the correlations within this data. This approach will offer insights into the current state of Rotterdam and its urban fabric.

Image 5, Train station Rotterdam

4.2 Spatial analysis of Rotterdam

To provide an in-depth perspective of the spatial distribution of different transport modalities in Rotterdam, this research has chosen to focus on several neighbourhoods within the city. These neighbourhoods, selected based on their urban characteristics and relevance to the study, are the following:

- Centrum
- Charlois
- Delfshaven
- Feyenoord
- Hillegersberg-Schiebroek
- Hoogvliet
- Ijsselmond
- Kralingen Crooswijk
- Nieuw Matthenesse
- Noord
- Overschie
- Pernis
- Prins Alexander
- Spaanse Polder

Each of these neighbourhoods, illustrated in Figure 16, is part of the Rotterdam municipality. And are chosen because of the direct connection to the city's central area or high level of urbanity or "stedelijkheid". The latter criterion is based on a classification provided by the Netherlands Institute for Transport Policy Analysis (KiM). This criterion ensures that the selected areas reflect the city's typical urban fabric and transport characteristics.
Note: The boundaries of the neighbourhoods are founded on the borders delineated and employed by the CBS data and are acknowledged as the official borders of the neighbourhoods. However, it's pivotal to recognize the inherent limitations that borders can introduce to such datasets.

For instance, while a significant segment of the highway marginally lies outside the boundaries of Charlois and Ijsselmonde, while a considerable stretch is encapsulated within the limits of Prins Alexander. While pursuing a 'perfect' border may be elusive, it's essential to recognize and acknowledge these shortcomings in interpretation and analysis.

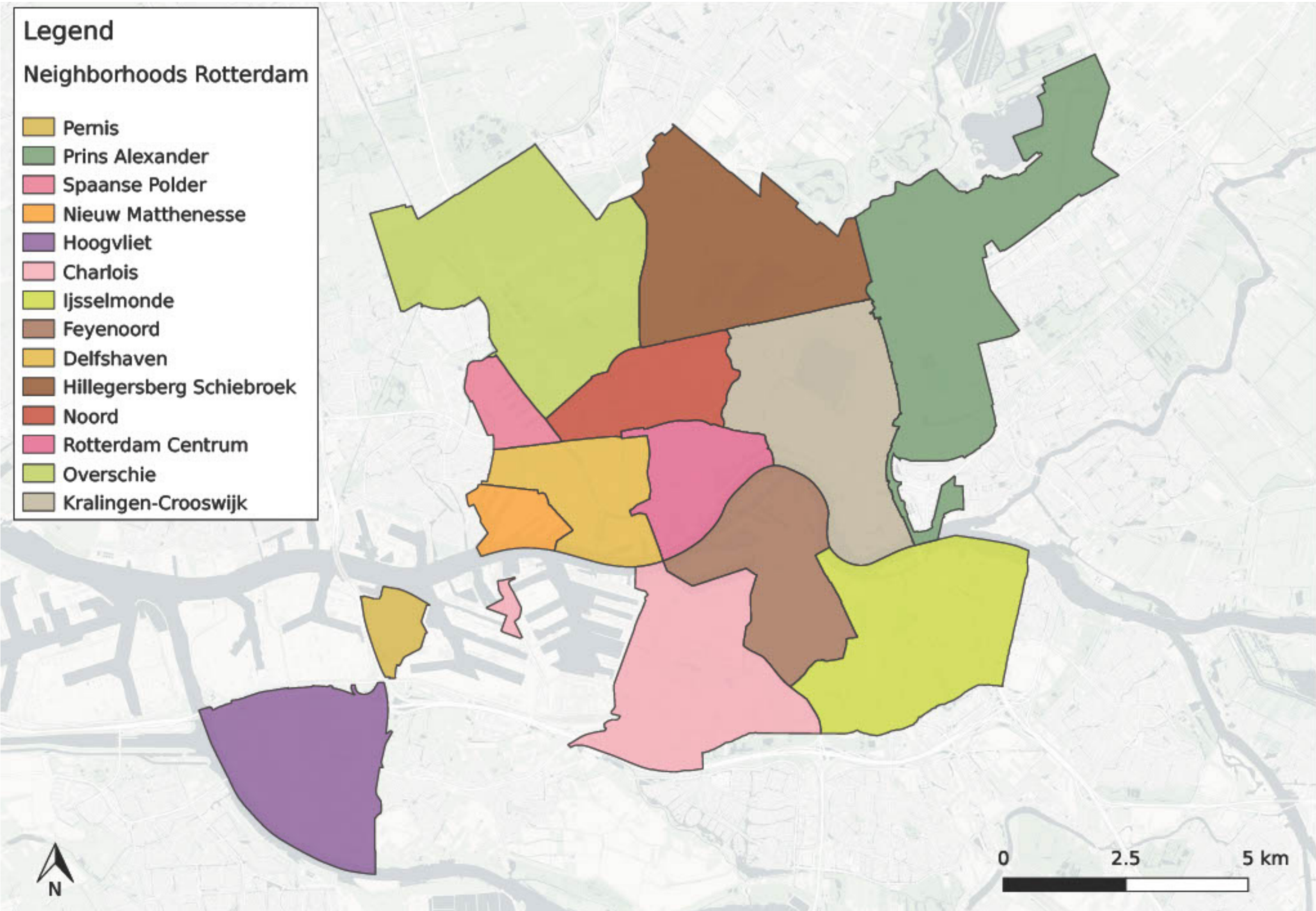


Figure 16 - The 14 selected neighbourhoods of Rotterdam

It's also noteworthy to mention the exclusion of specific neighbourhoods, like Hoek van Holland, despite being part of the Rotterdam municipality. Hoek van Holland does not directly connect to the city's centre and scores lower on the 'stedelijkheid' scale, as depicted in Figure 17. Therefore, including it would not provide a representative overview of the transport modalities in the core urban areas of Rotterdam, which is the primary focus of this study.

Having defined the spatial borders of the study, the research then proceeded with a systematic approach to dissect and analyze the urban space, incorporating elements of spatial data, categorization, and correlation analysis. This process is outlined in the subsequent sections.

Retrieving BGT data
The initial step involved procuring the BGT data specific to the Rotterdam area from the PDOK, a national geodata portal in the Netherlands. This dataset provided granular topographical data essential to the study's purpose

Spatial selection and clipping
The research focused on specific neighbourhoods of Rotterdam, defined by polygons in data from the Centraal Bureau Statistiek (CBS). The BGT data was therefore manipulated to fit these selected areas using QGIS' clipping functionality.

Data cleaning
This process removed redundant elements from the dataset, ensuring only relevant data was considered. Specifically, it excluded underground roads and spaces or those with a termination date before 31/12/2022.

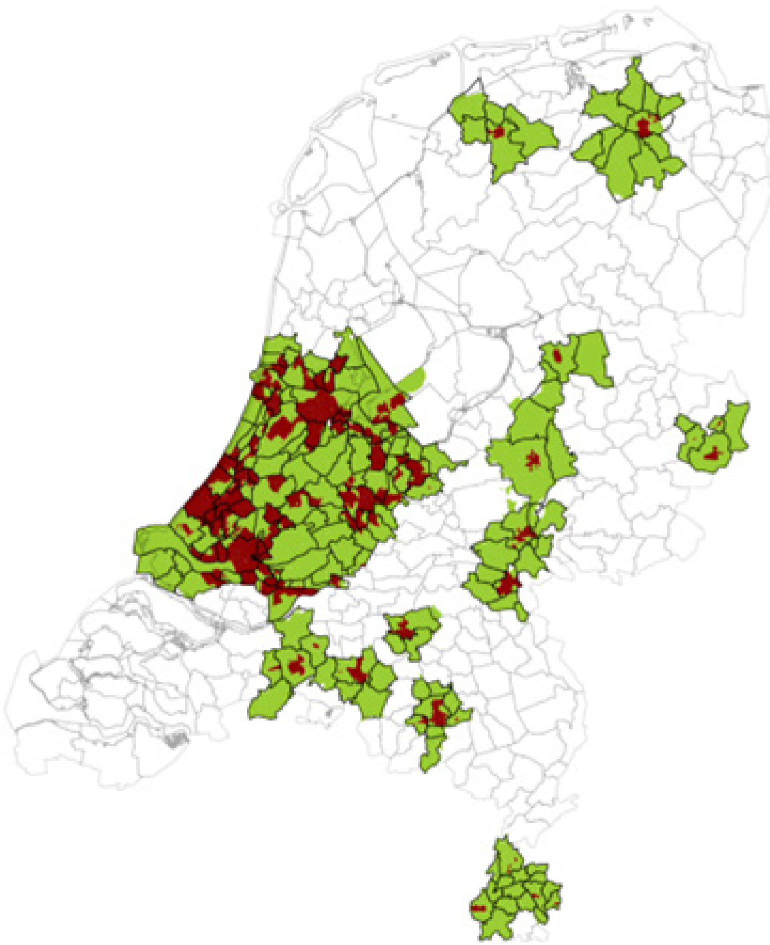


Figure 17 – Spatial demarcation of urban Netherlands. Red = highly urban, green = low urban, white = non-urban. The black lines are the borders of municipalities that belong to an urban region. The grey lines are the borders of municipalities that do not belong to an urban region. (Jonkeren et al., 2019)

Area Calculation and Categorization

QGIS was utilised to calculate the area of each space per neighbourhood to categorise space for different modes of transport. The many categorisations (see Appendix 2 for the complete list) from the BGT data itself were combined into the following four:

- Car Area (MT)
- Public Transport (PT)
- Walking Area (WA)
- Bicycle Lane (BL)

Subcategories such as; local road lanes, highway lanes, parking spaces, regional road lanes, sidewalks, staircases, footpaths, pedestrian zones, railway tracks, public transport lanes, and level crossings were then allocated to these broader categories. An example of how the provided map was categorised is visible in Figure 18.

Relative Height Position

After the categorisation, consideration was given to the 'relative height position' (in Dutch, 'relative hoogteligging') attribute within the BGT data. This attribute indicates the relative height of an object, with values ranging from -2 to +2. This enables a form of depth representation in a 2D map.

In the context of this research, the focus was on ground area. Thus, spaces with a 'relative height position' less than 0, such as underground metro lines, were excluded from the analysis as they do not occupy surface space. This decision is particularly significant for analysing public transport space due to Rotterdam's extensive metro network, which is underground, especially within the city centre.

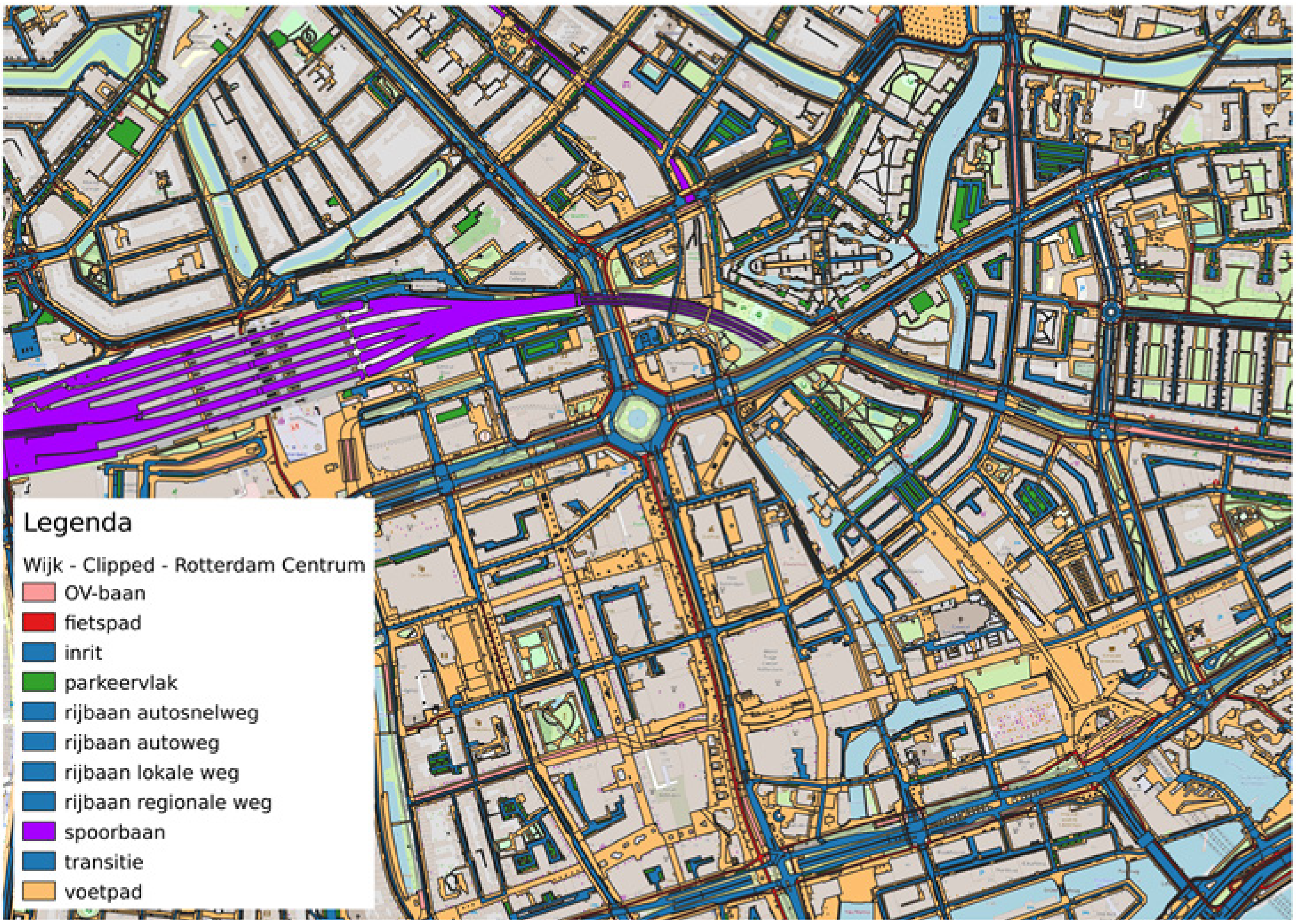


Figure 18 - BGT map, colorized per category

On the other hand, areas with a 'relative height position' greater than 0 were retained. Even though they are technically above ground level, they still interact with and affect the surface area. For example, a bridge over a park would inhibit the planting of tall trees in that area. Moreover, such features are visually present in the urban landscape, influencing perceptions of space.

The exclusion and inclusion of areas based on their 'relative height position' were crucial in ensuring a more accurate representation of surface-level space use in Rotterdam.

Note: *For roads, walking, and bicycle networks, the exclusion criterion for spaces with a 'relative height position' less than 0 has less of an effect because there are fewer tunnels or underground passages in Rotterdam. For example, the 'Tunneltraverse' (a deepened road through the city) in Rotterdam has a 'relative height position' of 0 for almost the whole trajectory because while it is recessed, it is not fully covered. Hence, it still counts as surface space in the analysis.*

Transformation of shared space

In classifying areas, a significant consideration was how to account for shared spaces. The dataset provided by the BGT does not distinguish between the space occupied by different transport modes on roads that are shared. For instance, most 30km/h roads don't have a specific area assigned to bicycle lanes but are used by both cars and bicycles. In some locations, walking areas are also partly used for cycling.

Several methods for addressing this issue were considered. An alternative approach was presented in the paper "Is there such a thing as a 'fair' distribution of road space?" by Samuel Nello-Deakin. Nello-Deakin's methodology acknowledges the shared nature of secondary roads but does not actively transfer road space from cars to bikes. The paper's approach is based on the dominant mode across each type of road space, even if they are occasionally shared with other transport modes.

After a careful review, the methodology from the 'Van Wie is de Stad' report was adopted. This report chose to assign 10% of all the regional and local road areas to the bicycle lane area. This method was selected for the following reasons:

- **Recognition of shared use:** The 'Van Wie is de Stad' method acknowledges the shared use of space on certain roads. It provides a more realistic reflection of the actual road space distribution.
- **Compensation for potential underrepresentation:** Without any transformation, the bicycle lane would be underrepresented as roads and walking areas are also (partly) used for cycling. Assigning a percentage of the shared (road) space to bicycle lanes compensates for this.
- **Ease of understanding:** Assigning a fixed proportion of the space on shared roads to each category simplifies the analysis and makes it easier to understand. It provides a straightforward approach to apportioning shared spaces that is easy for a broad audience to grasp.
- **Informed by expertise:** : The 'Van wie is de stad' report was carried out by *Geodan*, an advisory firm specializing in spatial issues, and commissioned by Milieudefensie, an environmental organization. Their expertise and knowledge influenced their choice of methodology, providing additional confidence in its validity.

To implement this transformation of shared space, 10% of the area of local and regional roads was added to the bicycle lane (BL) category. This step was accomplished by calculating the total area for these road types, reducing the Motorized Transport (MT) category, and increasing the Bicycle Lane (BL) category by the corresponding amount. This transformation ensures a more equitable representation of the space distribution among different transport modes in the city.

Relative space calculation

To provide a meaningful context for the categorization, the relative space occupied by each category was calculated in percentage terms. This allowed for a clear comparison between different modes of transport regarding their spatial allocations.

Modal split comparison and data visualization

The results were then compared with the modal split data from a municipal report, offering a comprehensive picture of the space allocation concerning the modal split in Rotterdam. It's important to note that there are various methods to calculate the modal split, each providing unique insights into transportation behaviour.

These methods can consider different aspects, such as only considering the movements of inhabitants or both inhabitants and visitors. Furthermore, you can examine trips from the centre, to the center, or a combination of both. Each method can yield a distinct modal split, which might paint a slightly different picture of transportation trends.

In deciding which modal split calculation to utilize for this research, advice was sought from W.C.G. Clerx, Senior Advisor of Traffic and Transport at the Municipality of Rotterdam City Development, Traffic and Transport department, and former researcher at TNO. During the interview, several modal split models were reviewed. The conclusion was that the modal split provided by the municipality of Rotterdam in the ODiN 2018 - 2021 report was the most representative for this analysis (Clerx, W.C.G., personal communication, July 13, 2023).

A full breakdown of the area calculations can be found in Appendix 3.

Sidebar: what the Street?!

What the Street?! is an intriguing project that offers data visualizations to compare and contrast how different cities worldwide allocate their urban spaces for various transport modes. (visit What the Street!?) It seeks to offer insights into street usage and the proportions of space dedicated to cars, bikes, and pedestrians.

This project uses OpenStreetMap data, an open-source, crowd-sourced mapping project. It extracts relevant data about roads, parking spaces, bike paths, and railways, categorizes and processes it, and creates visualizations. The area calculations involved in What the Street?! are intricate. They convert linear data, such as street lengths, into two-dimensional spaces, requiring assumptions about street, bike lanes, and pedestrian path widths. Assumptions might be based on typical city planning guidelines and can vary depending on the region and specific urban planning norms.

Parking space calculations might assume a typical size for a parking space and, by counting the number of parking spaces, estimate the total area dedicated to parking.

However, the calculations are approximations that offer a rough comparison between cities rather than exact measurements. The project aims to provoke thought and discussion about urban space usage and potential improvements.

Additionally, What the Street?! Urges future urban planners to consider the geometric efficiency of different transportation modes. Even if shared or autonomous, cars are less space-efficient than bikes or traditional mass transportation. They advocate prioritizing walking and proven forms of mobility. However, cars might still be valuable in specific scenarios, such as last-mile connections from train stations to homes.

One must avoid pitfalls like induced travel and over-prioritizing cars over bikes and trams, leading to increased traffic and space shortage. While eliminating all parking spaces might seem appealing, self-driving vehicles, for example, will still require hop-on/hop-off zones.

Despite its merits, What the Street?! has limitations due to data availability issues and geographical limits of OpenStreetMap coverage. Its coverage relies on user input, leading to inconsistent data quality across regions.

Why BGT over OSM?

While What the Street?! Uses OSM (Open Street Map, a free, globally available, and community-driven map of the world), the decision for this research still landed on the BGT data. Although limited to the Netherlands, BGT is more comprehensive and provides superior data for mobility areas.

The methodology for calculating the area from What the Street?! was considered but deemed infeasible for this research. Using BGT enabled a more precise evaluation of the mobility space distribution in Dutch urban settings. Despite its geographical limitation, the richness of the BGT data sets a solid foundation for this research's localized focus.

4.3 Incorporation of environmental metrics

As part of the data processing and assumptions, environmental metrics were also integrated into the spatial analysis. These metrics were added as an additional layer in QGIS, enabling a comprehensive examination of various ecological factors across the 14 neighbourhoods under study.

This process began by clipping the environmental metrics layer onto the 14 neighbourhoods. This allowed for a localized, focused analysis of each neighbourhood for different environmental conditions. After this, QGIS was used to calculate key statistical values for these metrics within each neighbourhood. This included the calculation of the mean, minimum, maximum, and median values. These computations gave an overview of the general and extreme conditions for each environmental factor within the neighbourhoods, thus providing a multifaceted view of the ecological context.

The resulting data from this operation was then added to the previously constructed dataset table. This expanded table combined the spatial data of Rotterdam (BL, MT, PT, etc.) with the environmental metrics, all organized on a per-neighbourhood basis.

A correlation analysis is done to see if there are specific correlations to find between the data of the different neighbourhoods.

The process of conducting the correlation analysis began by integrating secondary CBS Statline data into the dataset table. As with all other components of this research, these additional data were filtered on a per-neighbourhood basis, maintaining the localized focus of the investigation.

4.4 Correlation analysis of spatial allocations and other variables

The resulting expanded dataset table now incorporated spatial data, environmental metrics, and secondary CBS Statline data, providing a comprehensive source for subsequent correlation analysis. The table contained over 100 different rows, each representing a distinct category or metric (the entire dataset is in Appendix 4). To give an impression of the data, a small subset of this can is in Table 2.

To organize this vast amount of data, the categories were sorted into six main themes: Demographics, Density & Population, Environmental Quality, Housing, Land Use & Infrastructure, and Vehicles. Grouping these categories facilitated a more structured approach to the correlation analysis and assisted in highlighting patterns and interrelationships among categories.

The first step in the correlation analysis was the creation of a large correlation matrix encompassing all 100+ categories. However, due to its size, this matrix proved to be overwhelming and challenging to interpret. As such, it was necessary to refine the analysis to make the data more manageable and meaningful.

This led to the construction of a secondary correlation matrix that compared the six main categories as a whole. This intermediate step offered a way to identify which combinations of categories resulted in intriguing correlations without getting lost in the complexities of the larger matrix.

Info: *A correlation matrix is a table that displays the correlation coefficients between multiple variables. Each entry in the matrix represents the correlation between two variables. The coefficients range from -1 to +1, where -1 indicates a perfect negative correlation, +1 indicates a perfect positive correlation, and 0 suggests no correlation. It helps determine the strength and direction of relationships among variables.*

The most promising correlations identified in this category-based matrix were then selected for a more focused and interpretable correlation matrix. This final matrix presented the significant relationships in a clear and manageable format, which were then used for further discussion and interpretation in the study.

The calculations and visualizations were done in Python, the code for this can be found in Appendix 5.

Correlation data analysis

The correlation matrix comparison involving the six major categories (Figure 19) reveals some associations. Notable positive correlations include a 0.69 between Demographics and Density & Population, a 0.68 between Vehicles and Demographics, and a 0.67 between Land Use & Infrastructure and Housing. A substantial negative correlation is evident between Vehicles and Environmental Quality -0.81.

A separate, more focused correlation matrix for the Land Use & Infrastructure category was constructed due to its large size and a significant number of relevant indicators. This matrix is presented in Appendix 5.

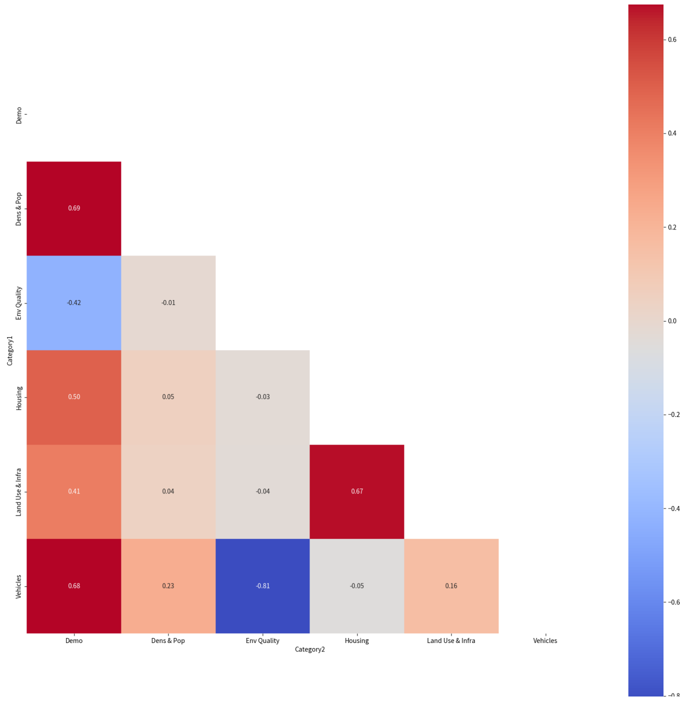


Figure 19 - Correlation Matrix between the six categories

Table 2 - Small subset of the created database for illustration

<table>
<tr><th>Neighbourhood</th><th>Centrum</th><th>Charlois</th><th>Delfshaven</th><th>Feyenoord</th><th>Hillegers-berg-Schie-broek</th><th>Hoogvliet</th><th>Ijsselmonde</th><th>Kralingen Crooswijk</th><th>Nieuw Mat-thenesse</th><th>Noord</th><th>Overschie</th><th>Pernis</th><th>Prins Alexander</th><th>Spaanse Polder</th></tr>
<tr><td>Env Quality|maximal NO2 (µg/m3)</td><td>34.30</td><td>36.85</td><td>35.04</td><td>36.24</td><td>34.73</td><td>35.00</td><td>28.25</td><td>34.61</td><td>38.14</td><td>36.28</td><td>38.03</td><td>34.46</td><td>33.38</td><td>41.79</td></tr>
<tr><td>Env Quality|Maximum Decibel Level (dB)</td><td>81.00</td><td>84.00</td><td>86.00</td><td>86.00</td><td>86.00</td><td>84.00</td><td>85.00</td><td>83.00</td><td>73.00</td><td>91.00</td><td>84.00</td><td>78.00</td><td>85.00</td><td>91.00</td></tr>
<tr><td>Env Quality|Mean Greenery Percentage (%)</td><td>40.61</td><td>55.06</td><td>39.86</td><td>37.38</td><td>57.25</td><td>56.73</td><td>50.63</td><td>63.65</td><td>22.86</td><td>45.42</td><td>69.75</td><td>57.69</td><td>50.34</td><td>33.53</td></tr>
<tr><td>Land Use & Infra|Neighborhood Walking Area (%)</td><td>0.23</td><td>0.13</td><td>0.19</td><td>0.18</td><td>0.08</td><td>0.10</td><td>0.11</td><td>0.11</td><td>0.03</td><td>0.16</td><td>0.04</td><td>0.10</td><td>0.11</td><td>0.05</td></tr>
<tr><td>Land Use & Infra|Neighborhood Public Transit Area (%)</td><td>0.04</td><td>0.01</td><td>0.01</td><td>0.04</td><td>0.01</td><td>0.01</td><td>0.02</td><td>0.02</td><td>0.00</td><td>0.04</td><td>0.00</td><td>0.01</td><td>0.01</td><td>0.02</td></tr>
<tr><td>Land Use & Infra|Neighborhood Greenery Area (%)</td><td>0.21</td><td>0.43</td><td>0.28</td><td>0.20</td><td>0.46</td><td>0.44</td><td>0.36</td><td>0.44</td><td>0.05</td><td>0.34</td><td>0.58</td><td>0.50</td><td>0.41</td><td>0.15</td></tr>
<tr><td>Land Use & Infra|Neighborhood Bike Area (%)</td><td>0.04</td><td>0.03</td><td>0.03</td><td>0.03</td><td>0.02</td><td>0.02</td><td>0.03</td><td>0.02</td><td>0.01</td><td>0.03</td><td>0.02</td><td>0.02</td><td>0.03</td><td>0.03</td></tr>
<tr><td>Housing|Average House Price Value (*1000€)</td><td>322.00</td><td>161.00</td><td>222.00</td><td>217.00</td><td>369.00</td><td>212.00</td><td>188.00</td><td>298.00</td><td>170.00</td><td>267.00</td><td>275.00</td><td>209.00</td><td>265.00</td><td>326.00</td></tr>
<tr><td>Housing|Ownership|Owned Houses</td><td>0.28</td><td>0.28</td><td>0.27</td><td>0.21</td><td>0.54</td><td>0.45</td><td>0.38</td><td>0.25</td><td>0.00</td><td>0.33</td><td>0.51</td><td>0.73</td><td>0.44</td><td>0.57</td></tr>
<tr><td>Dens & Pop|Address Density</td><td>6306.00</td><td>3805.00</td><td>5711.00</td><td>4896.00</td><td>2322.00</td><td>2060.00</td><td>2570.00</td><td>5261.00</td><td>3539.00</td><td>6657.00</td><td>1694.00</td><td>746.00</td><td>2707.00</td><td>1486.00</td></tr>
<tr><td>Dens & Pop|Population Density (Per km^2)</td><td>9365.00</td><td>6225.00</td><td>14861.00</td><td>11767.00</td><td>3826.00</td><td>3799.00</td><td>5190.00</td><td>5254.00</td><td>900.00</td><td>10257.00</td><td>1190.00</td><td>3079.00</td><td>5502.00</td><td>48.00</td></tr>
<tr><td>Dens & Pop|Total Households</td><td>23040.00</td><td>35520.00</td><td>39755.00</td><td>38350.00</td><td>20600.00</td><td>16350.00</td><td>29030.00</td><td>31680.00</td><td>805.00</td><td>29740.00</td><td>8720.00</td><td>2225.00</td><td>46545.00</td><td>45.00</td></tr>
<tr><td>Dens & Pop|Total Population</td><td>38710.00</td><td>69645.00</td><td>76605.00</td><td>77935.00</td><td>44485.00</td><td>35575.00</td><td>61180.00</td><td>54725.00</td><td>1110.00</td><td>52425.00</td><td>19535.00</td><td>4860.00</td><td>95625.00</td><td>90.00</td></tr>
<tr><td>Dens & Pop|Urban Address Density (Per km^2)</td><td>1.00</td><td>1.00</td><td>1.00</td><td>1.00</td><td>2.00</td><td>2.00</td><td>1.00</td><td>1.00</td><td>1.00</td><td>1.00</td><td>2.00</td><td>4.00</td><td>1.00</td><td>3.00</td></tr>
<tr><td>Demo|High Level Education</td><td>16980.00</td><td>10410.00</td><td>20240.00</td><td>15230.00</td><td>15080.00</td><td>4290.00</td><td>8840.00</td><td>18080.00</td><td>480.00</td><td>20700.00</td><td>4770.00</td><td>610.00</td><td>22040.00</td><td>null</td></tr>
<tr><td>Demo|House. Income|Avg. Standardized Household Income (*1000€)</td><td>34.20</td><td>25.10</td><td>26.60</td><td>26.90</td><td>39.00</td><td>29.80</td><td>27.70</td><td>30.60</td><td>null</td><td>30.00</td><td>32.80</td><td>null</td><td>31.90</td><td>null</td></tr>
<tr><td>Demo|Low Level Education</td><td>6690.00</td><td>20380.00</td><td>21040.00</td><td>22870.00</td><td>7310.00</td><td>9680.00</td><td>16880.00</td><td>10810.00</td><td>370.00</td><td>10220.00</td><td>4060.00</td><td>1200.00</td><td>19570.00</td><td>null</td></tr>
</table>

Continue of: Correlation data analysis

Based on these findings, the following hypotheses were generated:

1. Increasing the greenery in urban neighbourhoods reduces the Urban Heat Island (UHI) effect.
2. Reducing motor traffic and promoting alternative transportation modes increase urban greenery.
3. Reducing motor traffic in urban neighbourhoods decreases the UHI effect.
4. More greenery in urban neighbourhoods lowers mean decibel levels.
5. Higher motor traffic leads to higher decibel levels.
6. Urban areas with larger sections for walking and biking have lower mean decibel levels.
7. Increased car usage in urban neighbourhoods reduces address density.
8. Higher public transport usage increases address density in urban neighbourhoods.

These hypotheses were tested and shown in a new correlation matrix (Figure 20). The results are as follows:

1. UHI Effect and Greenery: -0.83, as also found in literature, (urban) greenery reduces the UHI effect.
2. Modal Split and Greenery: Inconclusive from the matrix, though increases in bike area correlate with increases in green area.
3. UHI Effect and Motor Traffic: 0.74
4. Decibel Levels and Greenery: -0.45
5. Decibel Levels and bike area: -0.84
6. Decibel Levels and Walking area: -0.83
7. Decibel Levels and Motor Traffic: Not a strong correlation from the matrix, though maps indicate higher noise near motorways. In this case, the reason for no clear correlation might be because the matrix uses the mean noise levels per neighbourhood, while the 'spikes' in noise are the issue.
8. Car Usage and Address Density: -0.77
9. Public Transport Usage and Address Density: 0.83
10. Walking and Address Density: 0.85

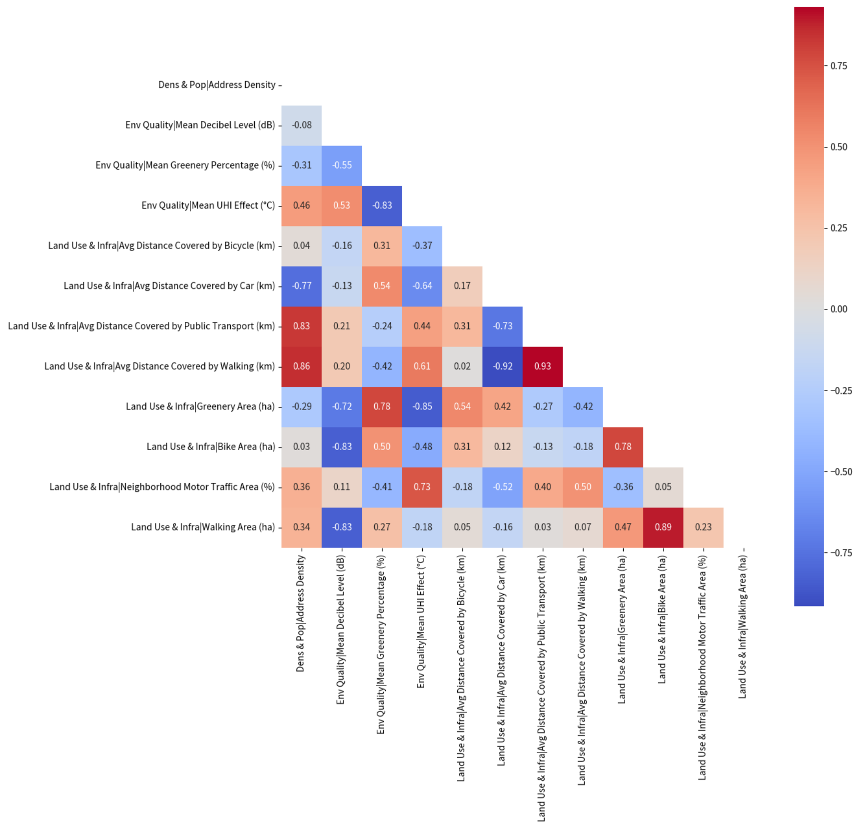


Figure 20 - Correlation Matrix between selected categories

While these correlations offer compelling insights into how different factors interact within Rotterdam's urban environments, it's essential to remember that they reflect more generalized relationships across various contexts. These patterns may not hold uniformly across all areas of a city, and this is where a spatial perspective comes into play. Furthermore, the fact that this analysis was based on a relatively small sample of just 14 neighbourhoods may somewhat limit the certainty of these results. Despite seeming statistically significant, these findings should be interpreted cautiously due to the limited group size.

The spatial allocation of cities plays a crucial role in manifesting these correlations. Each neighbourhood is unique, characterized by a distinct mix of demographic, environmental, and infrastructural factors. The context of each locale profoundly impacts these interactions. Consequently, diving deeper and examining these correlations from a more localized viewpoint is necessary. This will be done in Chapter 7, *Spatial Reallocation in Rotterdam Neighborhoods*. First, chapter 5 will dive into the spatial (infrastructure) analysis results and add the modal split into the picture.

Image 6, Bike in Rotterdam

5 Results – spatial allocation and urban dynamics in Rotterdam

Introduction

The urban landscape of Rotterdam reflects the effects of past and present priorities. This chapter dissects and discusses the spatial allocation of Rotterdam, highlighting the relationship between modal split and infrastructure. The chapter starts with an analysis of the current spatial distribution within the city, illustrating how different modes of mobility are distributed across various neighbourhoods. Delving into the Modal Split reveals discrepancies in the allocation of space for various modes of transportation, comparing existing realities against future expectations. The narrative then shifts focus to the implications of reduced car usage, illuminating the potential to reclaim urban space. This sets the stage for a discussion on proposed changes in the city's traffic management and their anticipated outcomes. The concluding sections of this chapter delve into the broader ramifications of spatial reallocation, capturing both environmental and societal perspectives. Through this exploration, a comprehensive view of Rotterdam's evolving urban dynamics and the pivotal decisions shaping its future emerges.

5.1 Current spatial allocation in Rotterdam

This chapter has a spatial dissection of the data to explore the distribution of various categories across different regions. These in-depth spatial analysis results are in Table 3, where a breakdown is provided of the different types of land use and infrastructure across 14 neighbourhoods in Rotterdam.

When delving deeper into the data, substantial variations in green space across different regions become apparent. For instance, such areas as Hillegersberg-Schiebroek, Overschie, and Prins Alexander are marked by a significantly larger share of greenery. This underscores the diverse nature of Rotterdam's cityscape, highlighting the need for region-specific urban development strategies.

Turning to infrastructure, we examine the allocation of road space, as illustrated in Figure 21. This stacked bar graph portrays the relative percentage of road space dedicated to four key categories: Motor Traffic (MT), Bike Lane (BL), Public Transit (PT), and Walking Area (WA). The numerical data from this graph are further detailed in Table 4.

Table 4 and Figure 21 expose patterns in the allocation of road space across Rotterdam. Notably, a significant portion of road space is dedicated to motor traffic in nearly all neighbourhoods. Despite area-specific differences, a substantial part of the road space is allocated to motor traffic, reinforcing the historical emphasis on car-centric urban design. Figure 22 shows the relative amount of infrastructure space per neighbourhood on a colour scale.

Table 3 - Area per neighbourhood calculated from BGT data (with 10% of area transferred from road to bike area)

Category (ha)	Centrum	Charlois	Delfshaven	Feyenoord	Hillegers-berg-Schiebroek	Hoogvliet	IJsselmonde	Kralingen Crooswijk	Nieuw Matthenesse	Noord	Overschie	Pernis	Prins Alexander	Spaanse Polder
Total Area	488	1190	596	855	1326	1036	1309	1277	207	535	1732	162	1860	204
Land Area	413	1119	515	662	1163	936	1179	1042	123	511	1642	158	1738	184
Water Area	75	71	81	192	163	99	130	235	84	24	90	4	122	20
Greenery Area	104	514	167	175	608	454	476	561	10	183	1004	80	755	30
Total Infrastructure Area	221	361	236	316	270	272	396	326	26	209	219	35	546	59
Road Area (no parking)	60	144	81	78	118	108	167	101	15	64	108	14	206	31
Parking Area	12	15	23	29	13	25	22	37	2	23	21	0	62	8
Walking Area	112	154	112	157	104	108	148	136	6	87	61	16	203	11
Bike Area	18	32	18	22	27	25	34	31	3	16	26	3	50	6
Public Transit Area	20	16	4	30	8	6	26	21	0	19	4	2	25	3

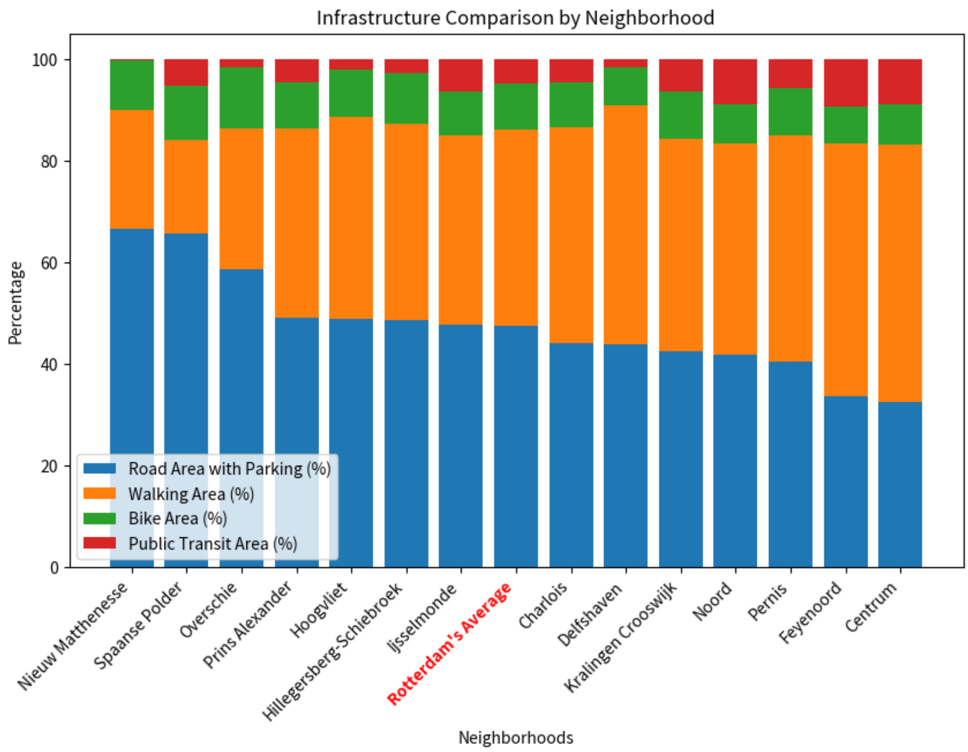


Figure 21 – Stacked bar graph with relative areas per mobility

Table 4 - relative areas per mobility

Neighbourhood	Roads for Cars (MT)	Walking Area (WA)	Bike Lanes (BL)	Public Transport (PT)
Nieuw Matthenesse	66%	23%	10%	0%
Spaanse Polder	66%	18%	11%	5%
Overschie	59%	28%	12%	2%
Prins Alexander	49%	37%	9%	5%
Hoogvliet	49%	40%	9%	2%
Hillegersberg-Schiebroek	49%	39%	10%	3%
Ijsselmonde	48%	37%	9%	6%
Rotterdam's Average	47%	39%	9%	5%
Charlois	44%	43%	9%	5%
Delfshaven	44%	47%	7%	2%
Kralingen Crooswijk	42%	42%	9%	6%
Noord	42%	42%	8%	9%
Pernis	40%	45%	9%	6%
Feyenoord	34%	50%	7%	9%
Centrum	32%	51%	8%	9%

Although generally substantial, walking areas occupy a slightly lower share than motor traffic across most neighbourhoods. However, a notable disparity emerges when we examine the share allocated to biking and public transport. The percentage of infrastructure space dedicated to public transport and bike lanes is remarkably low, indicative of an imbalance in the transportation infrastructure that does not favour these more efficient modes of transport and thus shows the spatial inefficiency of specific modes. Public transport's share is the lowest among the four categories.

This can be partly attributed to the fact that public transport, particularly buses, often shares road space with motor traffic, so they have little dedicated area. Additionally, a significant portion of Rotterdam's public transport infrastructure, such as the metro system, is underground, especially in the neighbourhoods included in this analysis. As this underground space is not accounted for in the area calculation, it contributes to a smaller share of road space allocated to public transport.

Figure 23 provides another perspective, showing the relative areas of each mode of transport as a pie chart for the Rotterdam average. It further separates parking as a distinct category. Intriguingly, this chart reveals that almost as much space is dedicated to parking (8.1%) as bike lanes (9.1%).

An additional Table 5 presents the total area dedicated to each mode of mobility in Rotterdam in hectares. The detailed breakdown further illuminates the stark disparities in spatial allocation across different modes of transport.

Through this analysis, there is a clearer understanding of how space is divided in Rotterdam and how these divisions differ by neighbourhood. These findings are a foundation for further exploring spatial allocation and mobility modal split in the following sections.

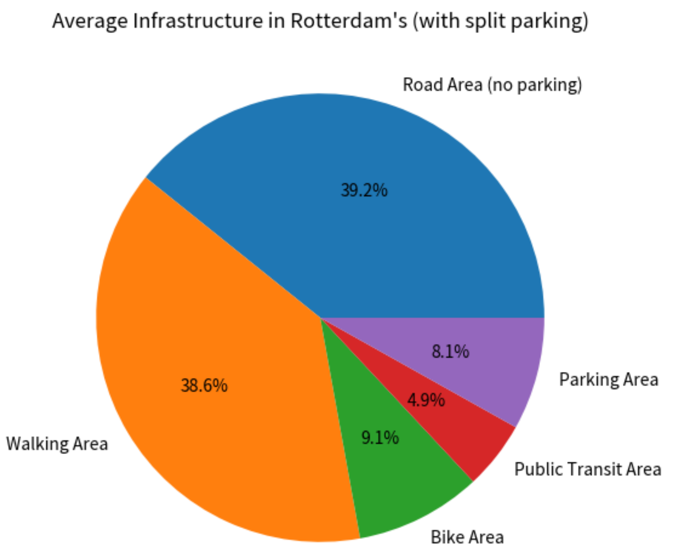


Figure 23 - Average infrastructure distribution of Rotterdam

Table 5 – Rotterdam's total infrastructure area

Total of Rotterdam's:	Total ha
Roads for vehicles (minus parking)	1292.41
Parking area	219.62
Walking area	1414.54
Bike lanes	311.30
Public Transport	182.16

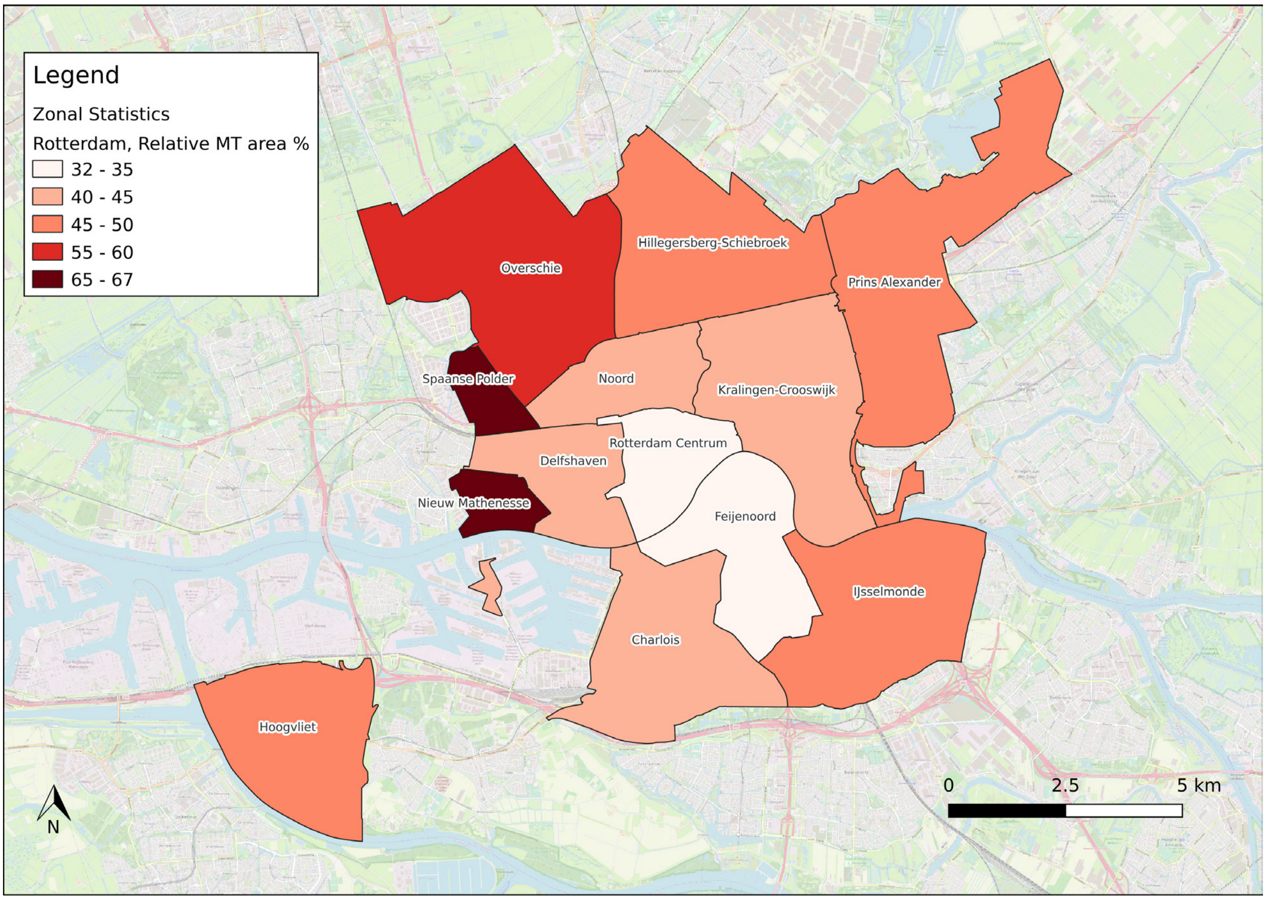


Figure 22 - Relative amount of MT area (%) per neighbourhood

5.2 Spatial layout for different modes of mobility in Rotterdam

The chosen modal split

As briefly mentioned in Modal Split Comparison and Data Visualization, there are multiple ways to calculate the modal split. The selection of the method can significantly impact the resulting data. As Clifton & Muhs (2012) underscores, modal split estimates can vary widely depending on the geographical scale and range of trips considered. They often overlook trip chains and undercount short trips. For instance, as W.C.G. Clerx pointed out, if a person walks to a train station or bus stop as part of their commute, only the public transport portion of the trip is typically counted in the modal split, while the walking part is overlooked. Therefore, these figures should be seen as an approximation, and the real disparities might be even greater than those presented. This variability highlights the need to interpret modal split data carefully and underlines the importance of considering multiple measurements when making urban planning decisions. To illustrate this, let's consider the data from the ODiN 2021 report provided by the Municipality of Rotterdam.

For example, Table 6 on the left displays the modal split for movements within the municipality in 2021. Contrastingly, the right-hand table presents the modal split for movements towards the municipality:

It can be observed that the modal split varies significantly between these two scenarios. The differing behaviours of residents and visitors in the municipality can explain this. W.C.G. Clerx clarified that people tend to walk within the city centre but do not usually walk toward the centre (Clerx, W.C.G., personal communication, July 13, 2023). This explains the drastic difference in the 'Walking' category. Similarly, residents prefer cycling or walking within the city, leading to lower public transport usage. However, those moving towards the city are more likely to use a car or public transport, hence the higher percentages for these modes. It's important to note that the figures for 2021 were somewhat influenced by COVID-19 effects, notably leading to lower public transport usage. For this analysis, an average of multiple measurements, also used by the Municipality of Rotterdam and advised by W.C.G. Clerx, will be used. The resulting modal split is as follows (Table 7):

Table 7 - Average Modal split for Rotterdam

Mode	Percentage
Car	38%
Public Transport	15%
Bicycle	20%
Walking	27%

This average provides a comprehensive representation, accommodating the varied mobility behaviours observed in different scenarios.

Table 6 - Modal Split Within (left) & Towards (right) the municipality of Rotterdam (ODiN, 2021)

Within municipality	Percentage
Car	25%
Public Transport	8%
Bicycle	24%
Walking	41%
Other	4%

Towards municipality	Percentage
Car	69%
Public Transport	10%
Bicycle	7%
Walking	1%
Other	6%

Modal split and spatial allocation

The spatial allocation for different modes of mobility in a city can drastically impact its environmental quality and livability (Sampson, 2021). Understanding the spatial distribution of transportation infrastructure in Rotterdam is crucial. Table 8 presents the space dedicated to cars, pedestrians, bikes, and public transport, with their modal split and the related implications.

Table 8 - Spatial Allocation vs Modal Split

	Spatial allocation	Modal split	difference
Cars	47%	38%	+9%
Pedestrians	39%	27%	+12%
Bikes	9%	20%	-11%
Public Transport	5%	15%	-10%

Despite representing 38% of the modal split, cars occupy 47% of the city's infrastructure space, pointing to an over-representation. Given their size and parking requirements, this spatial inefficiency of cars comes at a cost to the urban environment. The extensive land used for car infrastructure contributes to increased noise levels, the urban heat island effect, reduced green spaces, and diminished livability.

Meanwhile, the space dedicated to pedestrians takes up 39% of the city, surpassing its modal split by 12%. However, pedestrian zones often double as social spaces, contributing positively to urban life and community cohesion (Liere B. et al., 2017). Therefore, the overrepresentation of pedestrians can be seen as beneficial for urban life, contrary to the overrepresentation of cars.

Bikes and public transport are significantly under-represented, with only 9% and 5% of city space allocated. This under-representation, in contrast to the high spatial allocation for cars, impacts the city's ability to transition to more sustainable modes of transportation and reduce environmental challenges.

The over-representation of cars becomes even more pronounced when considering the average kilometres travelled per person per day (Table 9, from ODiN data). Cars dominate, averaging 15.62 km per person daily, representing 61% of travel. This exceeds their spatial allocation by 14%, further underscoring this car-heavy landscape's inefficiency and environmental implications. Gössling et al. (2016) argue that comparing road space distribution with total distances travelled per mode can provide more insight into the balance of infrastructure allocation and use.

Table 9 - Spatial allocation vs Average trip length

	Spatial allocation	Average km/person/day	difference
Cars	47%	15.62 km = 61%	-14%
Pedestrians	39%	1.25 km = 5%	+34%
Bikes	9%	1.91 km = 7.5 %	-1.5%
Public Transport	5%	5.42 km = 21%	-16%

Both modal share and total distances travelled by mode fail to consider an essential aspect: different transport modes require different physical spaces. This lack of spatial consideration forms the core of the argument against the current distribution of road space, which appears to favour the most spatially inefficient modes (Nello-Deakin, 2019). A moving car, for example, takes up 70 times more space than a pedestrian(Marie-Eve Will et al., 2020; Mobiliteitsverkenning Voor Een Groeiend Amsterdam, 2017)—this reality cannot be ignored when discussing equitable space distribution. (as shown in Figure 3).

Following this train of thought to an extreme, one might argue that each transport mode should occupy road space proportional to its modal share and relative physical size (Nello-Deakin, 2019). This concept creates a 'weighted' score, combining mode share and space requirements, as shown in Table 10.

Table 10 - Spatial allocation vs weighted score

	Spatial allocation	Modal split * space required	Weighted score	Difference
Cars	47%	38% * 140m^2	95%	-48%
Pedestri-ans	39%	27% * 2m^2	1%	+38%
Bikes	9%	20% * 5m^2	2%	-7%
Public Transport	5%	15% * 7m^2	2%	-3%

This calculation suggests that cars should be allocated 95% of road space due to their large size, leaving only 5% for pedestrians, cyclists, and Public transport. Of course, this is an extreme example that is hyperbolic and not practical. However, it illustrates the danger of viewing all transport modes through the same lens and ignoring their distinct spatial requirements.

The advantages of biking, for instance, lie in its spatial efficiency, flexibility, and ability to move a large number of people in a reduced space. Therefore, it's illogical to equate the space requirements of cyclists to those of cars or pedestrians. Similarly, the pedestrian realm is not just about movement; it includes other activities such as talking, observing, or sitting. Therefore, it arguably requires more generous space allocation than different transport modes.

The analysis underscores the complexity and challenges of achieving a balanced and sustainable urban mobility ecosystem. The current spatial allocation in Rotterdam may not appear disproportionate or un-logical when measured solely against modal split or distance. Still, it fails to consider the negative externalities associated with a car-dominated landscape, such as noise pollution, worse air quality, urban heat island effect, reduced green spaces, and diminished livability. Different modes of transport have other spatial requirements and environmental impacts, underscoring the need for a more nuanced understanding of 'fair' allocation.

Determining the 'right' or 'fair' allocation is complex, given the many ways to measure it. However, the current over-representation of car space in Rotterdam is environmentally detrimental and inconsistent with broader urban sustainability goals. These findings point to a need to reassess urban planning strategies, reduce the over-representation of cars, and promote more spatially efficient modes of transport like walking, cycling, and public transportation.

The subsequent sections of this chapter will delve into the municipality's future projections for modal splits.

5.3 Projected changes in modal plit in Rotterdam

The current modal split in Rotterdam reveals that cars account for 38% of all trips, pedestrians 27%, bicycles 20%, and public transport 15%. This distribution reflects an infrastructure heavily skewed towards car usage, which doesn't align with the city's sustainable mobility goals.

Research by CE Delft supports this need for change, stating that a 25% reduction in road traffic volume is necessary if CO2 emissions from air and sea transport do not decrease significantly from 2025 onwards (Hoen & Meerwaldt, 2017). This essentially means a shift in modal split is crucial to meet (the city's) climate goals.

In line with these considerations, the municipality of Rotterdam has outlined a progressive shift in the modal split in their comprehensive plan (Rotterdamse Mobiliteits Aanpak, 2020), projecting significant changes by 2040:

- Cars are expected to reduce their share from 38% to 28%, indicating a relative decrease of 26%.
- Bicycles are expected to increase their share from 20% to 38%, a considerable relative increase of 90%.
- Public Transport and walking are expected to go from a combined share of 42% to 34%, a relative decrease of 21%.

In absolute terms, car traffic in the city centre is expected to decrease by 17,000 car trips over 20 years. Meanwhile, the number of bicycle trips is expected to increase by 67,000 and the number of public transport trips by 52,000. Importantly, by 2040, the number of bicycle trips in the city centre is projected to be 50,000 more than the number of car trips, with public transport trips also surpassing car trips by 30,000 (Rotterdamse Mobiliteits Aanpak, 2020).

This results in the following expected modal split for 2040 (Figure 24), However, in this model, the PT is combined with walking. But as W.C.G. Clerx mentioned in the interview, the municipality expects that the percentage of walking will stay roughly the same as it is currently (around 25%).

This stark difference between the projected and current modal split suggests a future where infrastructure will be restructured to favour bicycles, pedestrians, and public transport.

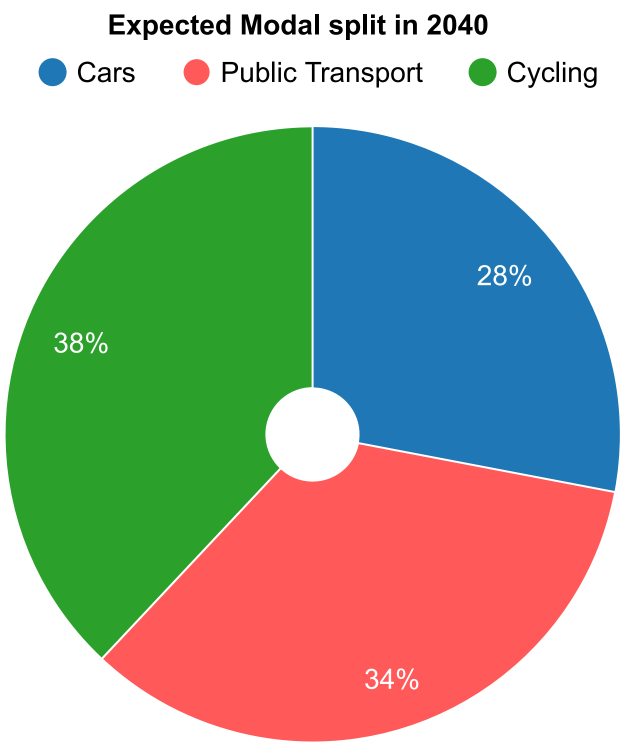


Figure 24 - Expected modal split for 2040 (Rotterdamse Mobiliteits Aanpak, 2020)

5.4 Potential space freed ip by decreased car usage in Rotterdam

A potential redistribution of the modal split in Rotterdam would have significant spatial implications. According to the BGT data for 2023, the current area allocated to different mobility types in Rotterdam can be broken down as follows (Table 11), combined with the present and the expected modal split (Figure 25).

Assuming a – hypothetical – 1:1 correlation between the increase or decrease in modal share and the space allocated to that mode, we could estimate the potential changes in infrastructure layout. Applying these percentages to the respective areas reveals an interesting possible transformation (Table 12):

The total theoretical difference would amount to almost 470 hectares of urban space city-wide being freed up. This considerable amount of space could be repurposed for various uses, from parks and green spaces to housing and public amenities.

However, it's worth noting that these changes won't be as straightforward in reality. Removing 1% of a road is not feasible just because 1% fewer cars are using it, or a 1% change in the modal split. What can be done is reducing the number of lanes on a road when car usage decreases significantly or decreasing the speed limit on a road, which could make it safe for mixed use and thereby indirectly create more space for bicycles.

Parking space is an area where reductions could be more directly achievable. As car usage decreases, the need for parking spaces will also diminish. This could potentially free up large amounts of urban space, given the significant area currently dedicated to parking.

Even if only car areas (so roads & parking) decrease by 26% and bike areas increase by 90% (so walking & public transport remain untouched) approximately 130 hectares of space could be freed up city-wide. This underscores the spatial efficiency of bikes versus cars and highlights the potential benefits of this modal shift.

A shift in modal split towards more sustainable forms of transport could have significant spatial benefits for the city, freeing up large amounts of space that could be utilized for other community needs.

Table 11 - Area distribution per Mobility

Mode of Transport	Area (ha)
Roads (excluding parking)	1364
Parking area	220
Walking area	1415
Bike lanes	311
Public transport	182
Total	3492

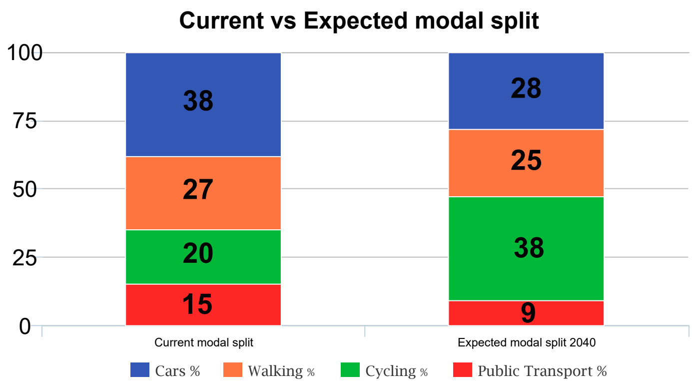


Figure 25 - Current vs Expected modal split

Table 12 - Calculated area distribution for new modal split

Mode of Transport	Current Area (ha)	% Change	New Area (ha)	Difference (ha)
Roads (excluding parking)	1364	-26%	1010	-355
Parking area	220	-26%	163	-57
Walking area	1415	-21%	1117	-297
Bike lanes	311	90%	591	280
Public transport	182	-21%	144	-38
Total	3492	-	3025	-467

Disappearing traffic

The phenomenon of ‘disappearing traffic’ offers a counter-intuitive perspective on the consequences of reallocating road space away from motor vehicles. The belief that reducing road space will inevitably lead to increased congestion in surrounding areas, often in Dutch referred to as the ‘waterbed effect’, is contested by the concept of disappearing traffic.

The University of Cambridge conducted extensive research, examining over 70 case studies from eleven countries and collating the opinions of over 200 transport professionals (Cairns et al., 2002). Their findings suggest that the concerns of traffic congestion spilling over into adjacent areas due to road space reallocation are frequently overestimated. Instead of an increase in traffic volume elsewhere, they observed a considerable reduction in overall traffic levels.

This is partly because people’s reactions to changes in road conditions are more complex than what traditional traffic models predict. For example, instead of merely shifting their route to an adjacent road, some drivers might decide to change their mode of transport, alter their travel times, or even reconsider the necessity of their trip altogether. This complex array of behavioural responses can lead to a surprising outcome: rather than redistributing, some traffic ‘disappears’.

The concept of disappearing traffic refutes the presumption of the waterbed effect and highlights the transformative potential of road space reallocation. The Cambridge research emphasizes that well-designed schemes to reallocate road space can contribute to multiple policy aims and objectives. This indicates that the implications of such interventions go beyond traffic management and can catalyze a range of beneficial urban transformations. As such, the phenomenon of disappearing traffic encourages a bold reimagining of urban space and underpins the feasibility of Rotterdam’s modal shift strategy.

5.5 Reducing the speed limits and New traffic management approach

Besides a change in modal split, implementing new strategies to manage vehicle usage is crucial. One such strategy is the reduction of speed limits across the city, an initiative that the Municipality of Rotterdam plans to commence in 2025 (Gemeente Rotterdam, 2021). This approach, referred to as the '30 km/h, unless...' strategy, aims to make the entire city a 30 km/h maximum speed zone, with a few exceptions (Clerx, W.C.G., personal communication, July 13, 2023).

According to the municipality, this approach carries multiple advantages. It ensures that the city's accessibility remains intact while improving the overall traffic flow, facilitating quicker journeys from point A to point B - even by car. Safety for all road users is notably enhanced due to slower vehicle speeds (Rosén et al., 2011). Furthermore, reducing speed limits contributes to a decrease in noise and emission levels, thereby improving the city's environmental health. An ancillary benefit is the aesthetic enhancement of the city, which results from a slower, calmer urban environment.

Rotterdam is not alone in this venture; it follows in the footsteps of several other European cities that have successfully implemented similar speed-reduction strategies. For instance, Helsinki has been implementing speed reduction policies since 1992 with remarkable results. In its 2015 road safety development program, Helsinki focused on four key areas: safe, eco-friendly transport for children and young people; better road safety for pedestrians and cyclists; clear principles for limiting speed; and cooperation with all stakeholders. The city's strategy has led to significant improvements in road safety, with the number of people killed or seriously injured on the roads falling from 150 in 1992 to 50 in 2015. In 2019, Helsinki imposed 30 km/h speed limits on all streets in residential neighbourhoods, and along with Oslo, it ended 2019 having zero pedestrian or cyclist deaths in traffic accidents (Murray, 2020).

Similar strategies are not only relevant to city centres but can also be applied to highways. An example from Rotterdam is the speed limit reduction to 80km/h on the A20, which improved air quality due to reduced traffic emissions. Traffic emissions of fine particles decreased by about 10%, and nitrogen oxide emissions decreased by 20-30% (Evaluatie 80 Km Zones Eindrapportage, 2007). The flow of traffic varied depending on the specific zones. While the travel time increased in some areas, the overall impact on safety was positive due to reduced average driving speeds and significantly improved accident figures for the A13 Overschie (Evaluatie 80 Km Zones Eindrapportage, 2007).

Notably, reducing the speed limits is not just about controlling the speed of traffic; it plays an essential role in urban planning. With the proposed speed reductions, roads previously dedicated to high-speed, high-volume traffic can be reassessed. As traffic flow becomes better managed and the amount of space necessary for vehicular movement decreases, opportunities for repurposing road space open up. This creates the potential for reallocation to other modes of transport or uses, aligning with the overarching goals of the city's mobility transition. This shift presents an exciting prospect for the city to optimize its infrastructure further and create more space for sustainable transport modes, public amenities, and green spaces.

The initiative to reduce speed limits, therefore, could act as a catalyst for the spatial transformation of the city, supporting the broader goals of enhancing livability, sustainability, and safety for Rotterdam's residents.

The S-road network, a potential starting point

As the previous section demonstrated, the anticipated shift in Rotterdam's modal split - with less car usage and more sustainable mobility - presents an exciting opportunity. By showing how much space could be freed up if a certain percentage of roads were removed, we introduced a hypothetical scenario that underlines the potential for large-scale urban landscape transformation. Within this context, the city's S-roads emerge as a compelling starting point for such a change (Figure 26).

These major city routes serve as primary arteries for vehicular traffic, typically characterized by multiple lanes. If car usage decreases significantly, the necessity for such wide roads would inevitably be reassessed. If traffic flow reduces accordingly, fewer lanes would be required. This change could open up opportunities for repurposing these areas to more space-efficient transport modes, thereby optimizing the city's infrastructure.

For instance, consider the S107, a six-lane road (three lanes on each side) that cuts across the city (Figure 26 & Figure 27). In a scenario of reduced traffic, it's conceivable that this road may not need all its lanes in the future. This could free up considerable space for alternative (more efficient) uses.

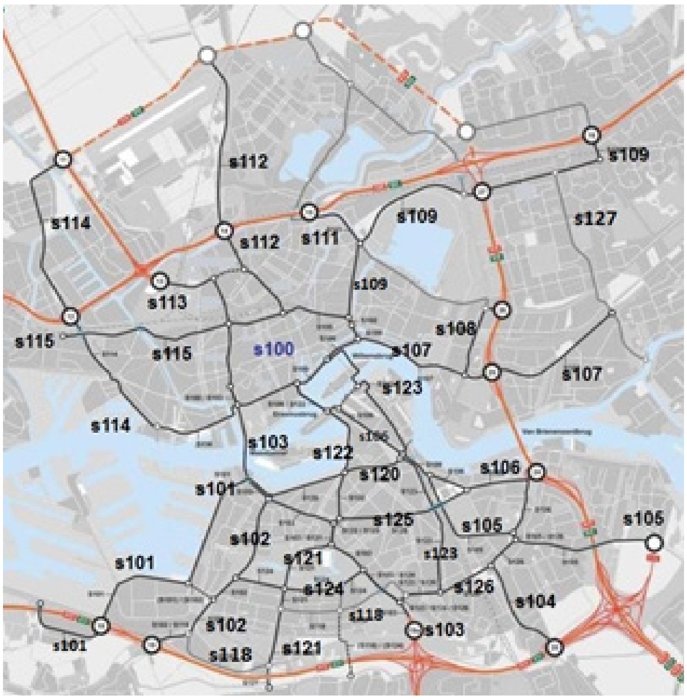


Figure 26 - S-route network of Rotterdam (Harry Fluks)

Figure 27 - S107 In Rotterdam, with 3 lanes each way (Adapted from Google Maps, 2023.

These transformations, however, won't be uniformly applicable across all S-roads or straightforward to implement. Yet, with their specific spatial characteristics and strategic locations across the city, the S-roads offer a valuable opportunity for spatial reallocation.

In the Rotterdam Mobility Vision 2020, a detailed analysis of these S-roads revealed that most of the trips on these roads were less than 15km, and many were even below 5km (Figure 28). The report found that a significant portion of auto traffic on these boulevards does not need to be there and could be shifted to alternative transport modes or routes, especially for these short and medium-length trips. It highlights the potential for reducing auto traffic on these boulevards by redirecting through traffic or offering alternatives. This could reduce 40 to 70% of the current auto traffic during evening peak times.

By decreasing the number of lanes on these roads, Rotterdam could accommodate the projected increase in bicycle usage and even introduce or expand other urban elements such as pedestrian zones, green spaces, or recreational areas. This would align with the city's mobility transition goals and contribute to a more sustainable, livable, and people-friendly urban environment.

There are over 116 km of S-routes in Rotterdam (Appendix 6). And with their spread, the potential for such transformation is city-wide. Future sections of this study will delve into the potential environmental and social implications of these spatial reallocations, illustrating how Rotterdam could use this spatial 'saving' to address its urban challenges and enhance its residents' quality of life.

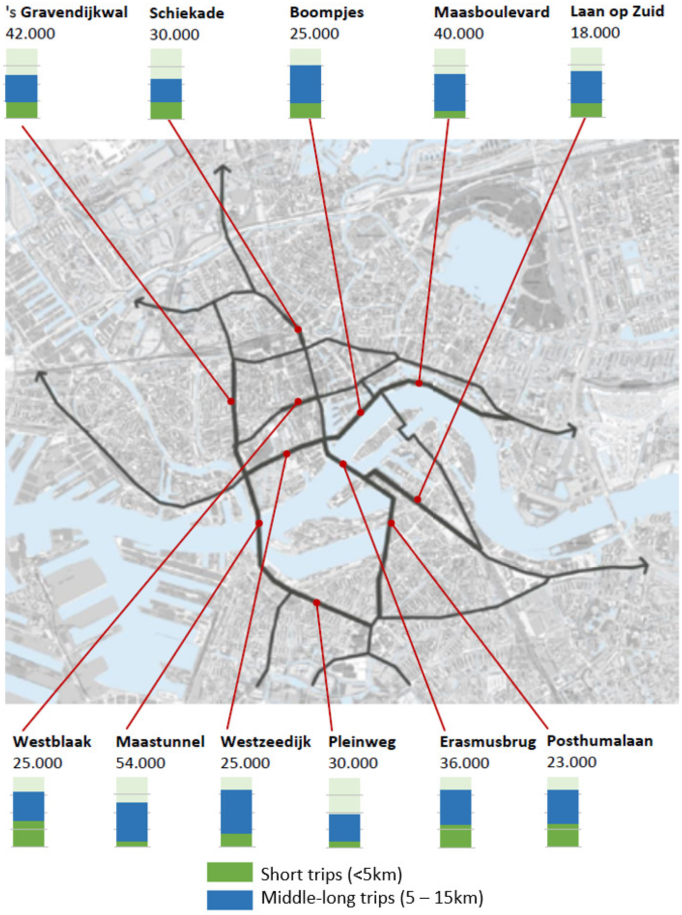


Figure 28 - Average trip length on main arteries in Rotterdam, numbers are amount of trips per day (Rotterdamse Mobiliteitsaanpak 2020)

New traffic management approach

Following the discussion on potential changes to the S-roads in section 5.5, to achieve those changes, it is equally crucial to consider another aspect of Rotterdam's traffic management: the focus on reducing traffic. Aiming to transform the city from being merely a transit point to a destination, the municipality has proposed several strategies to reconfigure traffic flows within the city.

While the city continues to accommodate car traffic destined for the city centre, it envisages a decrease in cars transiting through the city centre, intercepting them earlier. This facilitates better air quality and livability and paves the way for more attractive living environments.

The new traffic management approach, part of the Rotterdamse Mobiliteits Aanpak (2020), includes plans for city districts and suburbs (Figure 29). The intention is to create more space for cyclists and pedestrians, diverting non-essential car traffic to main routes to ensure optimum flow on the primary access routes.

Two relevant proposed measures are:

Space redistribution: The strategy is to make more space for pedestrians and cyclists. They tend to achieve this by concentrating through traffic to larger infrastructure corridors while enabling destination traffic to reach their destination.

Gradual speed reduction in the city center: : The city aims to enhance traffic safety and foster improved interactions between road users by reducing speed limits. Starting with city streets, the City Axis, and the *Knowledge Axis* (city centre to university), the aim is to create more 30 km/h streets and extend this to other boulevards and axes.

By strategically managing traffic flows and reducing traffic, Rotterdam wants to transition from being a city crossed by vehicles to a city where traffic mainly consists of people staying or living there. This results in a reduction in car traffic, thus enabling a reduction in car infrastructure.

Figure 29 - Plans from the Municipality of Rotterdam to Reduce through traffic. (Rotterdamse Mobiliteitsaanpak 2020)

5.6 Broader impacts of spatial reallocation

The envisaged spatial reallocation can have significant environmental and social implications. Understanding these potential impacts can aid in shaping a balanced and sustainable urban transformation.

Environmental impacts: The proposed alterations in urban space use might lead to changes in air quality, noise levels, urban heat island effects, and CO2 emissions. For example, a reduction in car usage can significantly improve air quality and reduce noise pollution, enhancing the city's overall livability. Furthermore, introducing more green spaces can offer multiple environmental benefits, such as mitigating the urban heat island effect, enhancing local biodiversity, and sequestering carbon.

Social impacts: The spatial reallocation can also cause changes in the city's social landscape. As urban spaces are repurposed, there could be shifts in the accessibility of amenities and services. It's important to consider how these changes would impact different demographic groups. For instance, how would older people, children, people with disabilities, and other vulnerable groups be affected by these changes? Moreover, alterations to the urban fabric could influence traffic safety and potentially affect community cohesion or local economies.

These potential impacts underscore the necessity of a comprehensive approach to managing urban transformation. The upcoming chapter will delve into specific strategies to tackle the identified urban challenges through spatial reallocation, providing a balanced perspective on making the most of the opportunities that the envisaged changes could bring.

6 Addressing Rotterdam's urban challenges through spatial reallocation

The findings presented in Chapter 6 indicate the potential to free up space within Rotterdam through a shift in the modal split and strategic infrastructure repurposing. This spatial shift offers a unique opportunity for the city, enabling it to address several pressing urban challenges.

6.1 Overview of urban challenges in Rotterdam:

Building on the understanding established in the literature review, this chapter will delve deeper into the challenges Rotterdam faces. Specifically, we focus on three main challenges: the combined UHI effect and lack of green spaces, noise pollution, and the interrelated problems of air quality and CO2 emissions. Each of these issues manifests differently across the city, as evidenced by the layered maps of Rotterdam (refer to Appendix 7 for full-scale maps). For clarity, the challenges are:

UHI effect and lack of green spaces: Rotterdam, like many urban areas, experiences the UHI effect, where the city's core is significantly warmer than its surrounding rural areas due to the predominance of concrete and asphalt surfaces and the lack of vegetation. The scarcity of green spaces exacerbates the UHI effect and deprives residents of recreational areas and natural habitats within the city.

Noise pollution: Noise pollution is a widespread issue, primarily arising from vehicular traffic on the city's extensive road network. The impact of this challenge varies across the city, with specific areas facing higher levels of noise pollution.

Air Quality and CO2 Emissions: Air quality in Rotterdam is influenced by various factors, including traffic emissions, industrial activity, and associated CO2 emissions. Areas with heavy traffic flow, in particular, face prominent air quality issues.

These challenges, though diverse, are interconnected and often exacerbated by the city's spatial configuration and dominant mobility modes. As such, the potential of spatial reallocation to mitigate these issues is worth exploring. The subsequent sections will delve deeper into the potential impacts and strategies of using freed space to address these urban challenges.

The Urban Heat Island Effect

The Urban Heat Island effect is a prevalent urban challenge where the temperature in city centres is often significantly higher than in the surrounding rural areas. This phenomenon can be attributed primarily to the urban landscape's characteristics, particularly the large amounts of concrete and asphalt, which absorb and re-emit heat, and the shortage of green spaces that could otherwise help cooling the environment.

Figure 30 provides a compelling illustration of the UHI effect in Rotterdam. With temperature differentials ranging from +0°C to +2.6°C, the city's heat map exhibits evident "hot spots". These hotspots generally coincide with areas marked by a high concentration of built environments and limited green spaces.

Conversely, the impact of green spaces in alleviating the UHI effect is remarkably noticeable. The areas surrounding the parks and green spaces manifest as cool zones on the UHI heat map. Figure 31 overlays the UHI map with Rotterdam's green spaces map, accentuating the stark contrast between warmer and cooler regions. Trees and vegetation can play a role by effectively reducing surface and air temperatures by providing shade and evapotranspiration. Shaded surfaces may be 11–25°C cooler than unshaded ones (Akbari et al., 1997). Evapotranspiration can further reduce peak summer temperatures by 1–5°C. These cooling effects could significantly mitigate urban heat challenges like the Urban Heat Island effect (Kurn et al., 1994; Ronot et al., 1983).

Upon closer examination, as shown in Figure 32, the cooling effect of significant green spaces such as *Kralingse Bos* and *Het Park* becomes even more pronounced. This cooling impact of green spaces is intuitive and quantitatively substantiated. The analysis reveals a strong negative correlation of -0.83 between the mean UHI effect and the amount of greenery per neighbourhood (see Figure 19 - *Correlation Matrix between the six categories*, in *4.4, Correlation Data Analysis*), reinforcing the inverse relationship between urban heat and green spaces.

The following section will delve into the second urban challenge - noise pollution - and its spatial implications within Rotterdam.

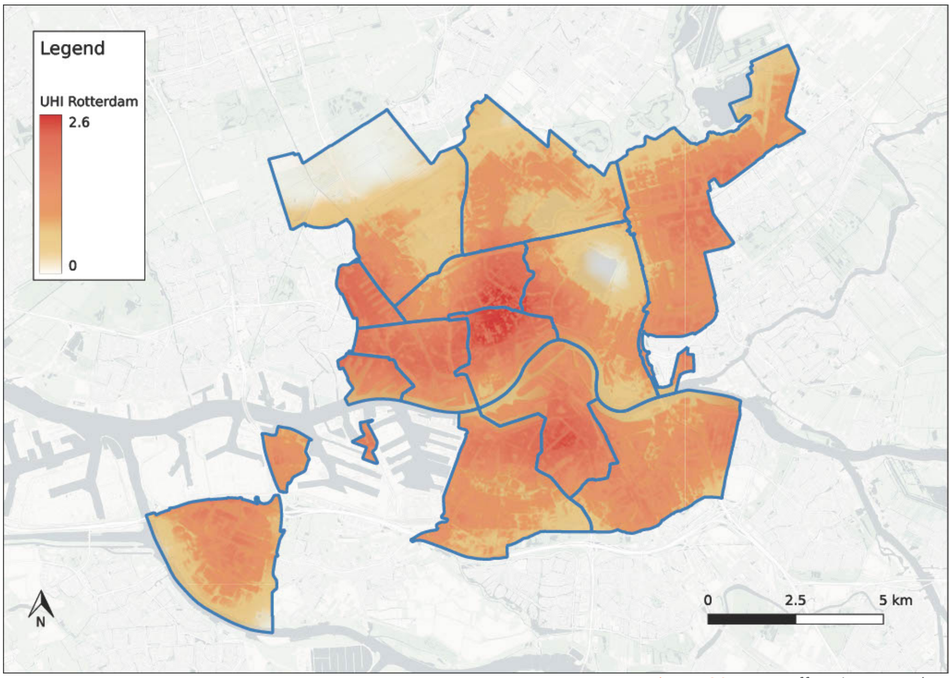


Figure 30 - UHI effect in Rotterdam

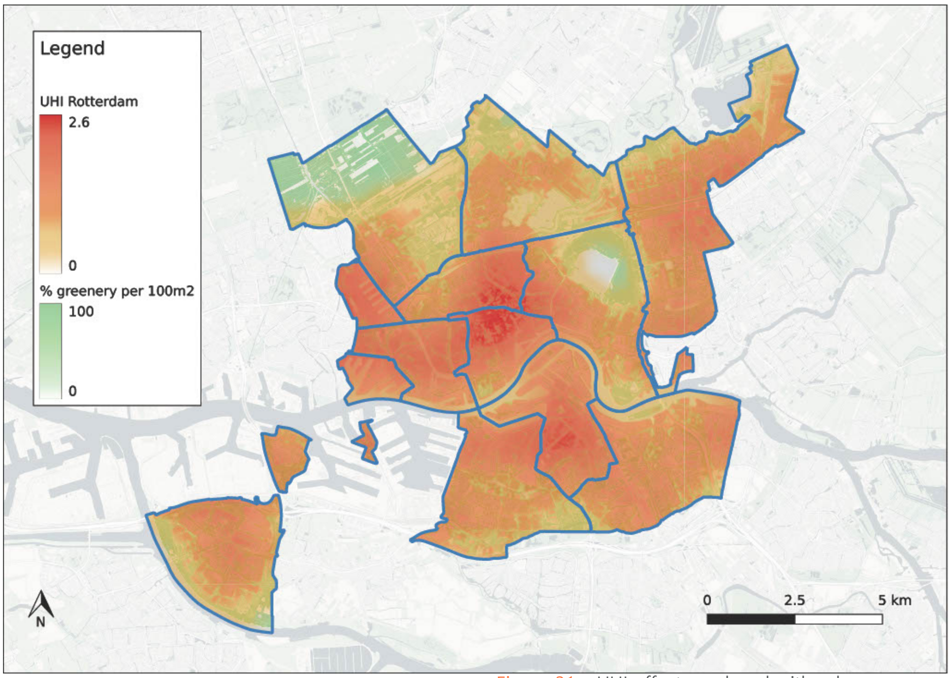


Figure 31 - UHI effect overlayed with urban greenery

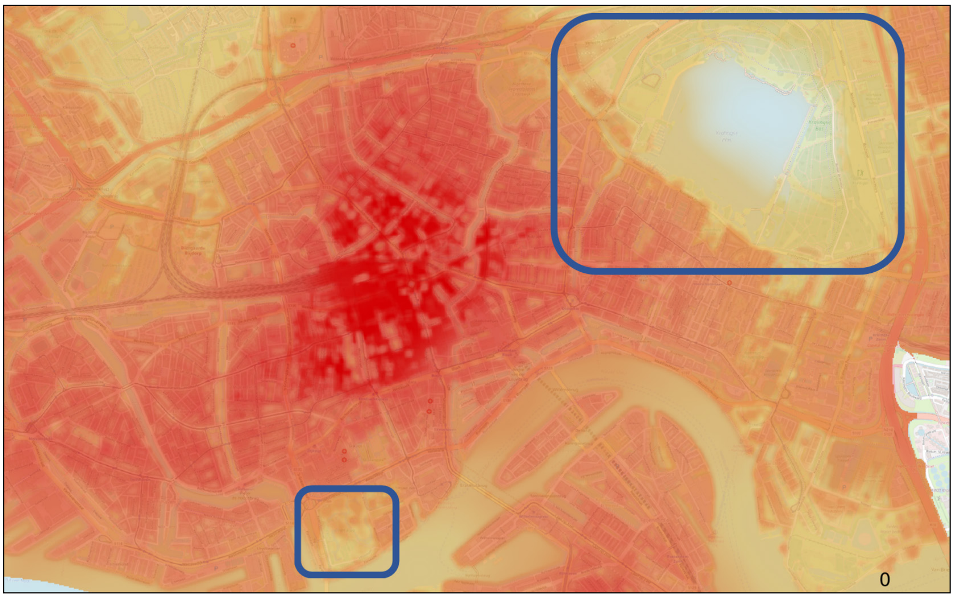


Figure 32 - Effects of park on UHI in Rotterdam, left 'het park' and right the 'Kralingse Bos'

Urban green spaces

Besides tackling the UHI effect, urban green spaces have more (social) benefits to the city. According to the EEA, the health benefits of urban green spaces, or "green and blue spaces," as they're also referred to, are notable. These benefits extend across various demographic groups but are particularly significant for children and older adults. Living, playing, and learning in green environments improves children's physical and mental development. Similarly, older adults benefit significantly from visiting these spaces through enhanced physical health and social well-being (EEA, 2022).

Within cities, the extent and quality of green space often differ across neighbourhoods, with lower-income communities typically having less access to high-quality green space (EEA, 2022). As a result, the EEA underscores the need for targeted action to reduce these disparities and maximize the health and well-being benefits of nature in cities. Involving local communities in the design and management of green spaces can promote a sense of ownership and encourage usage (EEA, 2022).

Several studies have shown that urban green spaces are particularly beneficial for people of lower socio-economic status, helping to reduce stress and improve mental health. In several European cities, urban gardens and allotments have been found to foster social integration, provide access to healthy food, and offer environmental learning opportunities for lower-income groups. This aspect has gained further relevance during the COVID-19 pandemic, where the importance of accessible recreational green spaces was underscored, especially for those lacking access to private green areas (Camps-Calvet et al., 2016; Korpilo et al., 2021; Marselle et al., 2020; Reinwald et al., 2021; Ugolini et al., 2020; Veen & Eiter, 2018; Ward Thompson et al., 2016).

The health benefits for children and young people living in greener environments include better physical and mental health, improved memory and attentiveness, learning ability enhancement, and stress reduction. Furthermore, parks and playgrounds encourage social activities, fostering social well-being and cohesion. In contrast, young people and children with less exposure to green spaces tend to have poorer eyesight, higher obesity rates and are exposed to oxidative stress (Andrusaityte et al., 2020; Dadvand et al., 2015, 2017; De Petris et al., 2021; Kabisch et al., 2016; Petraviciene et al., 2018; Ugolini et al., 2020; Vujcic & Tomicevic-Dubljevic, 2018).

For older adults, the benefits of using green spaces include increased physical activity levels, better cardiovascular health, lower risk of heat-related mortality, and reduced risk of depression. Accessible green spaces also provide places for social interactions, countering the dangers of social isolation among older adults (Artmann et al., 2017; Camps-Calvet et al., 2016; Dempsey et al., 2018; Kabisch et al., 2021; Machón et al., 2020).

Furthermore, urban green spaces have been found to promote the social inclusion of disadvantaged groups in various cities, acting as spaces for migrants and asylum seekers to connect with others (Rishbeth et al., 2019).

Prioritizing urban green spaces in infrastructure reallocations

The considerable environmental and societal benefits of urban green spaces have been established. However, city landscapes often suffer from space scarcity, threatening the maintenance and increase of these spaces. The opportunity presented by the areas freed through infrastructure reallocation may be consumed by new housing or commercial projects, which while important, do not directly counteract the UHI effect or offer the benefits of green spaces.

To reconcile this, a 'Green Norm' is proposed. This norm would mandate a minimum percentage of any freed area, or the neighbourhood area, to be developed into green spaces. By doing so, it ensures that reclaimed road space results in reduced traffic and increased green areas, improving the urban environment and residents' well-being.

This doesn't downplay the importance of housing or commercial developments but seeks a balance between urban growth and sustainability. Implementing a Green Norm enables cities to approach urban development strategically, acknowledging its environmental impacts, societal benefits, and future challenges. It ensures urban green spaces' preservation amidst city development dynamics, marking a step towards a sustainable urban future.

Image 7, Urban green spaces

Levels of noise

Noise pollution is another urban challenge, particularly in densely populated cities such as Rotterdam. Noise pollution arises from various sources, including transport, industry, and general urban activities. However, transportation, particularly road traffic, is often the most pervasive contributor.

The World Health Organization (WHO) has set guidelines recommending that noise exposure levels not exceed 70 decibels (dB) over 24 hours. Exceeding these levels can cause various health issues, from hearing impairment and sleep disturbances to more severe cardiovascular problems.

Figure 33 provides a detailed overview of noise levels across Rotterdam, with the noise levels colour-coded on a scale from light to dark red, representing noise levels from 65 to 85 dB. Notably, areas with high noise levels almost perfectly align with the city's road map, showcasing the substantial impact of road traffic on noise pollution.

The overlap is apparent when the noise map is placed side by side with the map of S - roads (Figure 34). It presents a compelling visual argument for the role of transportation, especially road traffic, in contributing to urban noise pollution.

Interestingly, the data analysis doesn't reveal a strong correlation between noise levels and Motorized Transport area, as seen in the correlation matrix. This can be attributed to the matrix using the mean dB noise levels per neighbourhood, and the high dB areas are often localized. This localized concentration might obscure the broader correlation at the neighbourhood level. However, the alignment of the noise and S - roads maps suggests a relationship between transportation infrastructure and noise pollution levels.

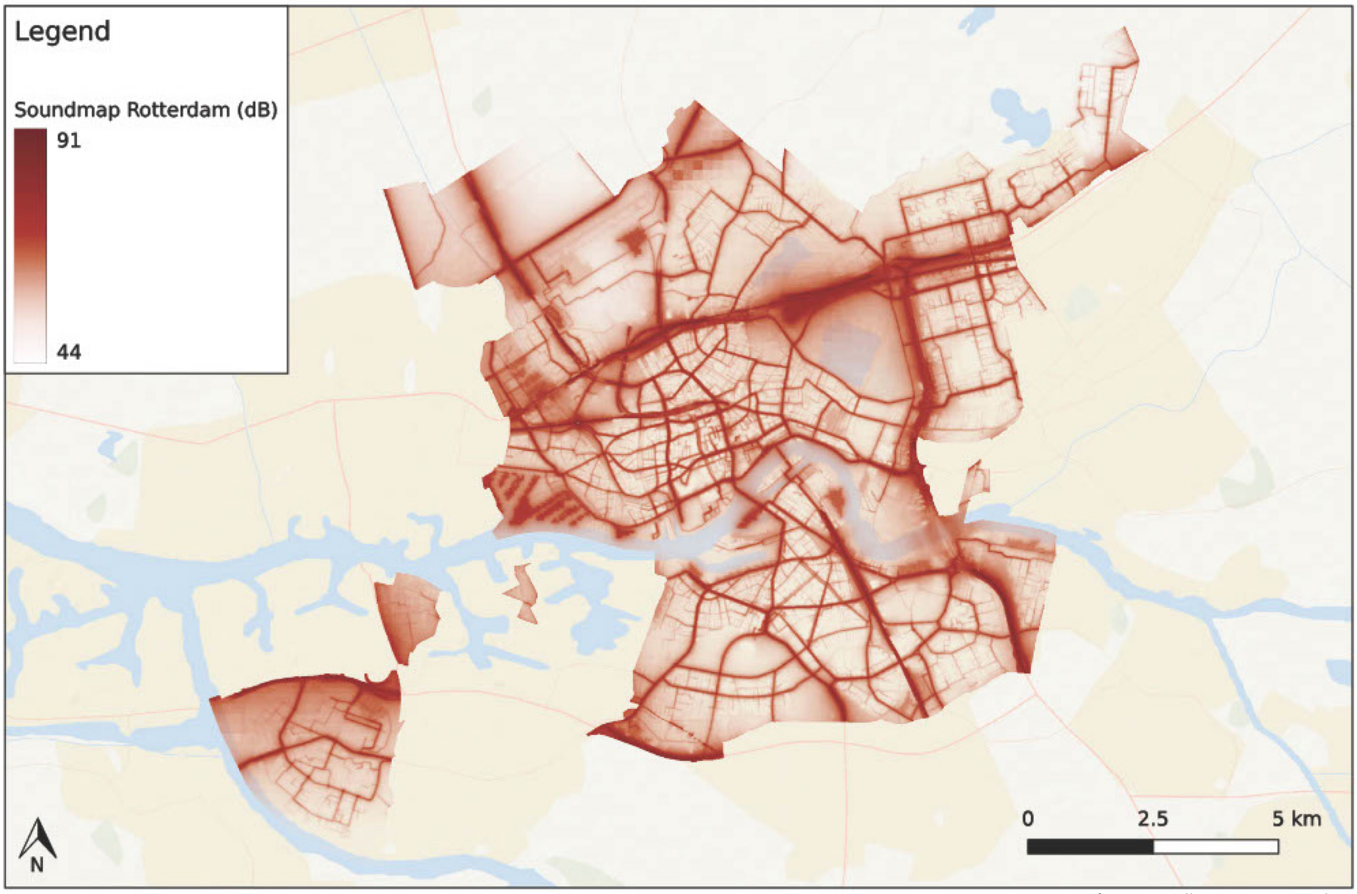


Figure 33 - Map of Noise pollution in Rotterdam

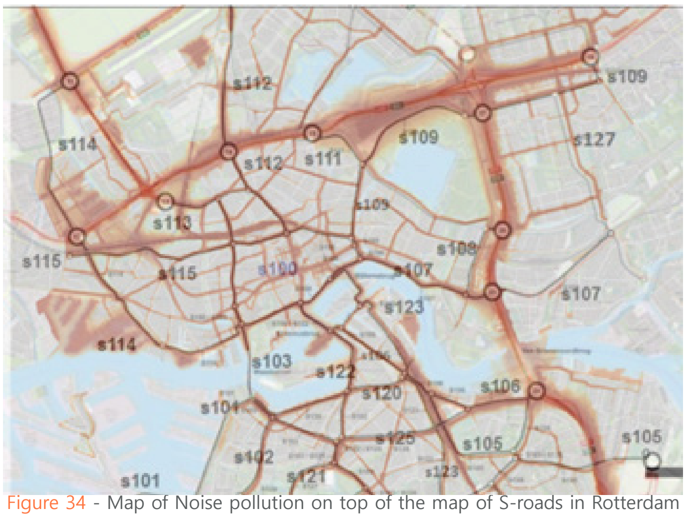


Figure 34 - Map of Noise pollution on top of the map of S-roads in Rotterdam

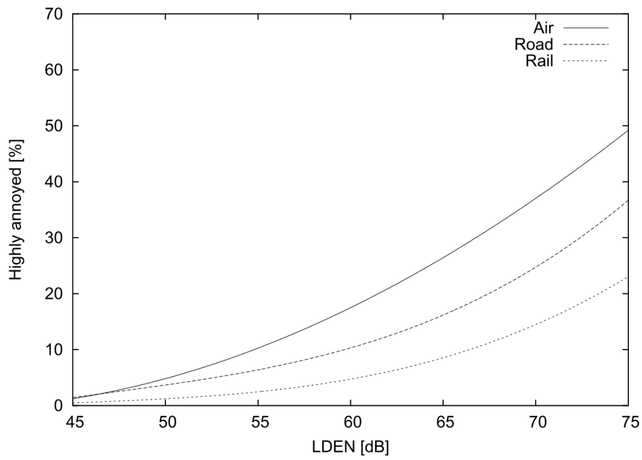


Figure 35 - Polynomial approximation of percentage of subjects highly annoyed (Ögren M, 2006)

Noise from trains

An equally important contributor to the urban noise profile, although to a lesser extent than roads, is train noise. As demonstrated in Figure 33, the train tracks in Rotterdam also generate significant noise levels. While the total noise production from trains is smaller due to fewer railways than roads, its impact should not be disregarded.

Research by the Swedish National Road and Transport Research Institute (VTI) sheds light on the different aspects of train noise, specifically its effects on annoyance, sleep disturbances, and cardiovascular health. The research categorizes the impact of railway noise on the public into three areas: general annoyance, sleep disturbance, and cardiovascular effects. General annoyance refers to the discomfort experienced by the public as reported in questionnaires, which, if sustained over a long period, alongside sleep disturbances, could lead to cardiovascular issues (Ögren, 2006).

Interestingly, studies have shown that general annoyance reported from railway noise is lower than that from road and air traffic. This is possible because of the less frequent and more predictable nature of railway noise than the constant and unpredictable noise from road traffic. As depicted in Figure 35, out of Ogren's research, a smaller percentage of subjects reported being "highly annoyed" by railway noise than by noise from road or air traffic.

These findings often influence noise pollution regulations, with railways typically receiving a 'bonus' or leniency due to the lower annoyance levels associated with their noise. However, as also noted by Ögren, some studies suggest that in specific cases, the annoyance from railway noise may equal or surpass that of road traffic (Takashi et al., 2002).

Regarding health impacts, cardiovascular effects linked to transportation noise, including railway noise, have been extensively studied. Meta-analyses of questionnaire data and laboratory experiments indicate an increased risk of myocardial infarction (lethal heart attack) and high blood pressure, particularly in male subjects, after prolonged exposure to high noise levels (Level Day Evening Night (Lden) > 65 dB) (Ögren, 2006).

In sum, while the noise from trains in Rotterdam contributes less significantly to the overall noise pollution than road traffic, it is still essential to consider these noise sources in the overall strategy for managing noise pollution.

Noise disturbance

The Uitvoerings Programma Mobiliteit (2022, p. 18) shows the percentage of Rotterdam's population experiencing noise disturbance from traffic from 2013 to 2021. Within this period, the overall nuisance remained relatively stable at around 60% of the population. However, the composition of this figure has shifted over the years.

Figure 36, sourced from the UPRM, reveals that the 'much disturbance' category has surged from 17% to 23% between 2018 and 2021. This increase represents a relative rise of 35%, suggesting a growing proportion of Rotterdam's population is experiencing significant noise annoyance. This trend underscores the need for attention to improving the city's acoustic environment.

This increase in 'much disturbance' is particularly worrying given the documented adverse effects of sustained high noise levels on human health. As Rotterdam's urbanization continues, tackling noise pollution becomes increasingly critical to safeguard the health and well-being of its residents.

The following section will delve into the third urban challenge: air quality.

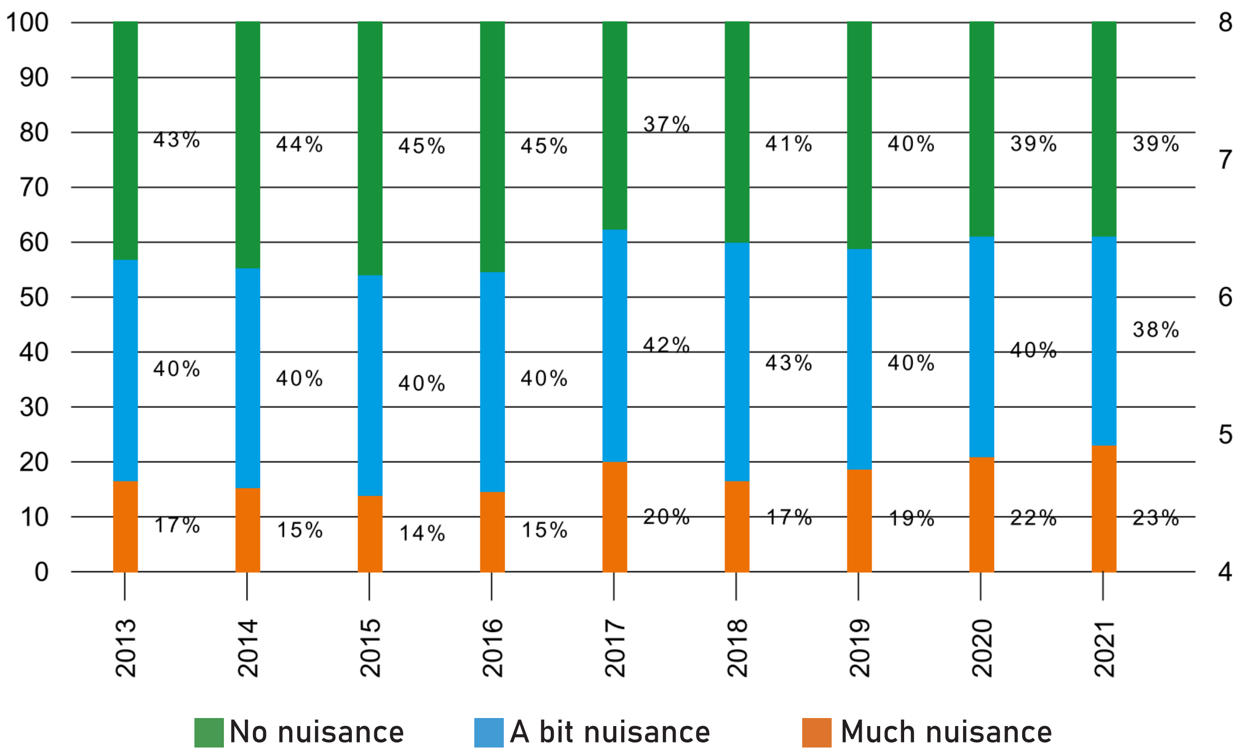


Figure 36 - Noise Distrubance from Traffic (Uitvoerings Programma Mobiliteit, 2022)

Image 8, Rotterdam Central Station

Air quality

Rotterdam's air quality is a significant concern affecting its environment and inhabitants' health. The figures in Impact of Spatial Allocation on Air Quality provide a stark visualization of this challenge. In these figures, Rotterdam stands out on the map of the Netherlands due to its high CO2 concentrations.

To further underscore this point, the figures in that section also show how Rotterdam has the highest levels of PM10 fine dust and NO2 in the country. The detrimental effects of such pollutants cannot be overstated, impacting not only air quality but also contributing to adverse health outcomes for the city's population (Monitor Brede Welvaart En Mobiliteit Eerste Uitwerking van 16 Indicatoren, 2022).

Zooming into the city level, the following three figures provide a more detailed picture of the situation in Rotterdam. The first map (Figure 37) shows PM2.5 fine dust levels, indicating that the entirety of Rotterdam exceeds the WHO recommended limit of 5 µg PM2.5/m³.

The second map (Figure 38) highlights the PM10 levels and paints a similar picture, with all parts of the city surpassing the WHO-advised limit of 15 µg PM10/m³.

The third map (Figure 39), focusing on NO2 levels, reveals the outlines of the city's roads in the heatmap. This visualization underscores the link between car usage and NO2 emissions. This correlation is further supported by the first two maps, which show that the city's downtown areas, which have the highest traffic levels, also have the worst air quality indicators.

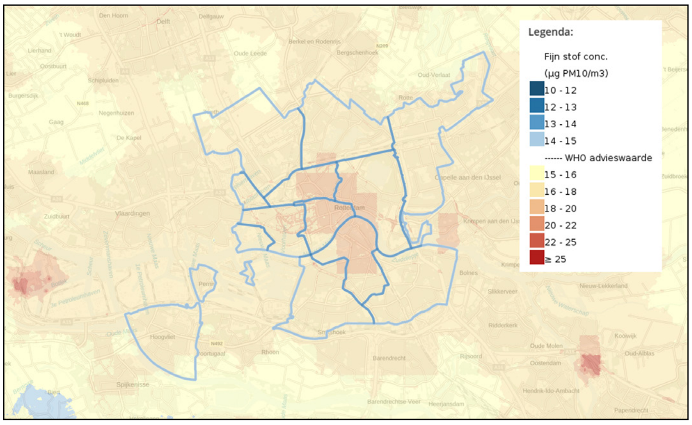


Figure 38 – PM10 concentrations in Rotterdam (RIVM, 2020c)

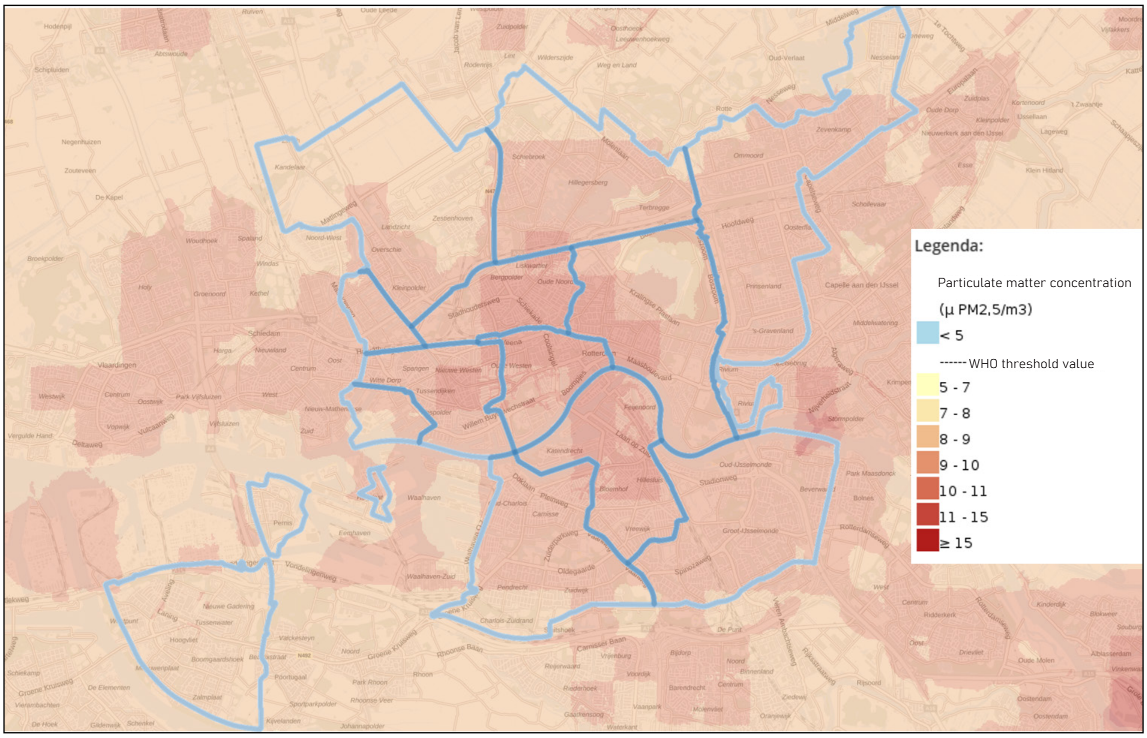


Figure 37 - PM2.5 concentrations in Rotterdam (RIVM, 2020c

The Rijksinstituut voor Volksgezondheid en Milieu (RIVM) has highlighted the potential health effects of short-term exposure to fine dust (fijnstof) pollutants. According to RIVM, even brief exposure to polluted air can cause significant health impacts (RIVM, 2023). Research has shown that heart attacks are more likely to occur after only a few hours of exposure to traffic (Peters, 2005; Pope & Dockery, 2006). A Dutch study found that exposure to particulate matter and soot among cyclists, car drivers, and bus passengers was associated with changes in lung function and airway resistance (Zuurbier et al., 2011). Another recent study reported changes in plasma indicating damage to the lungs, heart, kidneys, and brain within just 2 hours of exposure to traffic-related air pollution (Krauskopf et al., 2018).

Electric vehicles and air quality

One commonly proposed solution to combat deteriorating urban air quality is the transition to electric vehicles. While this sounds promising on the surface, the nuances of its efficacy are more complex than often perceived. In a study conducted by Calatayud et al. (2023), the impact of Vehicle Electrification (VE) on air quality in Valencia, Spain, was rigorously examined using machine learning. The findings provided a multifaceted perspective. With a massive 70% adoption of electric vehicles, Valencia would see a significant decline in nitrogen dioxide (NO2) pollution. The annual mean concentrations across the city's air quality stations would decrease by 34% to 55%; however, when it came to particulate matter, like PM2.5 and PM10, the effect of VE was minimal, reflecting a 1% to 4% reduction. The repercussions on ground-level ozone concentrations varied, showing a spectrum from a 2% reduction to a 12% increase. Notably, even with such a vast majority of electric vehicles on the roads, some air quality stations in Valencia would still breach the 2021 World Health Organization Air Quality Guidelines for specific pollutants.

This illustrates that although electric vehicles offer a meaningful solution to reduce NO2 pollution, their impact on particulate matter remains limited, and the effects on ozone can be erratic. Calatayud et al. (2023) emphasize that transitioning to electric vehicles can enhance urban air quality in specific domains like NO2 concentrations. Still, it's not a silver bullet. Other complementary strategies need to be rolled out in tandem to address urban pollution holistically. Given the severity and extent of air quality issues in Rotterdam, it's crucial to address this challenge as part of the city's spatial reallocation and urban mobility strategy.

The subsequent sections will explore potential strategies for mitigating these urban challenges through spatial reallocation.

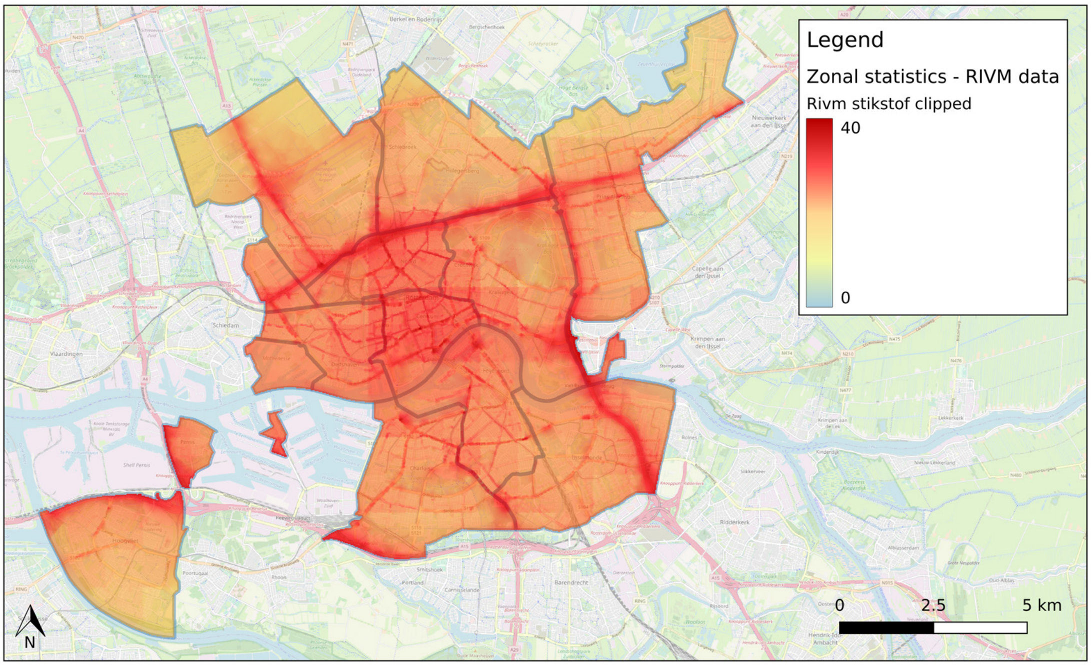


Figure 39 - NO2 Concentrations in Rotterdam (RIVM, 2020c)

6.2 Accessibility paradigm in urban Planning

The concept of 'accessibility' in urban planning and transportation has evolved significantly in recent years, a shift prominently discussed by Crozet (2020). The paper emphasizes that increasing car ownership and reliance, or "automobility", is not synonymous with improved accessibility. On the contrary, this approach often generates a set of negative externalities, such as pollution, congestion, and urban sprawl.

Crozet (2020) introduces the concept of an 'accessibility turn', a paradigm shift that focuses on improving accessibility rather than merely increasing transport supply. This approach includes redefining public policy to reduce car use and focusing more on public transport and active modes of transportation.

The travel and transport supply surge, coupled with the speed gains brought about by new transport infrastructure, has frequently led decision-makers to expand road capacity to increase accessibility. This decision has led to urban sprawl and aggravated congestion, increasing greenhouse gas emissions and pollution. This situation is present in Rotterdam, where car reliance has dominated transportation modes.

Consequently, Crozet (2020) advocates for a change in the focus of mobility policy, suggesting that the emphasis should not merely be on speed and individual time gains. Instead, improving accessibility should involve modifying land use and curbing urban sprawl - a vital part of the proposed 'accessibility turn'.

Crozet (2020) defines accessibility as a function of both the accessibility to amenities and the transport supply. This perspective highlights that improving accessibility is about increasing transport options and the strategic distribution of amenities and services across the city. This aligns with (Rotterdamse Mobiliteits Aanpak, 2020) 's vision of improving accessibility by decreasing travel distances.

The significance of Crozet (2020) 's insights into Rotterdam's urban challenges is considerable. As envisaged in the city's proposed changes in mobility patterns, the reduction in car use does not necessarily translate to a decrease in accessibility. Instead, with strategic spatial reallocation and the prioritization of public and active transport modes, accessibility can be enhanced.

Understanding accessibility in this light is particularly useful when considering the city's pressing issues, such as the Urban Heat Island effect, noise pollution, and poor air quality. These urban challenges can be exacerbated by car-dominated mobility modes and the city's spatial configuration. However, the spatial reallocation inspired by the 'accessibility turn' has the potential to mitigate these issues by reducing the reliance on cars and thus diminishing associated pollution, noise, and heat generation.

The new accessibility paradigm sets the stage for a profound transformation in Rotterdam. While this paradigm addresses key environmental and urban challenges, it's equally critical to consider its impact on the city's social fabric. The subsequent section delves into these social implications, emphasizing the importance of an inclusive and cohesive approach to urban planning.

6.3 Social implications of spatial reallocation

While the core focus of this research remains on the spatial reallocation of space from cars to more sustainable and resilient urban uses, it is also crucial to briefly acknowledge the social implications of such changes. To do this, a new correlation matrix for these demographics has been made and is in Appendix 11. Although the correlation matrix based on this data didn't yield any significant social indicators, there are important social aspects to consider when discussing the re-purposing of urban spaces.

As touched upon in 2.5 Effects on & from the Modal Split, the modal split is more than a mere indicator of transportation preferences; it reflects and influences the social fabric of the city, demonstrating its connections with various city-specific features, such as population density, land use, and socio-demographic factors (Lee et al., 2022). High population density and mixed land use are often associated with lower automobile dependence. Consequently, transit use tends to rise in dense areas with frequent public transit services. These shifts in travel modes can ripple effects on city social dynamics, influencing factors such as employment rates and social interaction patterns. For instance, higher population density and employment rates often go hand in hand with low-emission travel modes (Lee et al., 2022). Changes in the modal split could therefore have broader implications for social equity and cohesion.

In this regard, introducing urban green spaces in re-purposing urban areas can contribute to social well-being. The European Environment Agency (EEA) underscores urban green spaces' multifaceted health and social benefits. They serve as venues for physical activity and social interaction. They are especially beneficial to specific demographic groups, like children and older adults (EEA, 2022), as also touched upon Urban green spaces.

Green spaces support children's physical and mental development and provide older adults with opportunities for enhanced physical health and social connectivity. Moreover, they can promote social integration, particularly for lower socioeconomic groups and migrants, contributing to a more inclusive urban environment (Andrusaityte et al., 2020; Artmann et al., 2017; Dadvand et al., 2017; Rishbeth et al., 2019).

Furthermore, successful spatial reallocation heavily hinges on public consensus. Garnering support from citizens isn't an inherent aspect of these initiatives but rather an evolving process that needs careful nurturing. Clear communication, education, and participatory methods can positively influence public opinion over time. A city's residents are the primary stakeholders in any urban development, and thus their voices and concerns must be central to the decision-making process. This collective involvement ensures the successful implementation of spatial reallocation plans. It fosters a sense of shared responsibility, creating an environment of trust and cooperation that ultimately leads to a more sustainable, resilient, and socially harmonious city.

To summarize, spatial reallocation holds promise for a greener, more sustainable city and for fostering a sense of community and health among its residents. As Rotterdam embarks on this transformative journey, practical strategies will be essential. The following section introduces seven key strategies that align with the new accessibility paradigm, aiming to create a sustainable and socially inclusive urban environment.

6.4 Strategies for using reallocation to address urban challenges

This section identifies and proposes strategies to capitalise on the freed space resulting from the shift in the modal split in Rotterdam. The overarching goal is to address the urban challenges discussed earlier, emphasising creating a more sustainable and resilient city. Each strategy aligns with the concept of accessibility-based planning, intending to enhance urban life quality without sacrificing mobility. After detailing these strategies, the section will transition to practical examples highlighting urban green interventions.

1. **Traffic management:** A crucial aspect of reshaping urban mobility involves managing traffic flows. Prioritising traffic to ring roads and limiting traffic within the city, mainly to destination traffic, could significantly reduce traffic volume within Rotterdam's city centre. This reduction can further open up space and contribute to safer and more pleasant urban environments, as inner-city roads would primarily serve residents and visitors rather than transiting traffic.

2. **Parking space reduction and repurposing:** Parking spaces, especially surface lots, occupy vast urban space. By reducing the number of these spaces and repurposing them, a significant amount of urban land can be reclaimed. This step is crucial as it provides the space necessary to implement the subsequent strategies. Another beneficial step would be transforming the other parking spaces into green ones where possible.

3. **Road dieting:** With fewer cars on the road, the city can focus on 'road dieting,' a strategy involving the reduction of traffic lanes or lane width. Short trips dominate Rotterdam's traffic, and a significant share of these trips take place on S-roads so that these roads could be the starting point for road dieting. This action can create a safer and more pleasant environment for non-motorised road users while freeing up more space for alternative uses.

4. **Enhancement of active mobility infrastructure:** The space made available by road dieting and parking space reduction can be allocated to active mobility infrastructure, such as wider sidewalks, dedicated bike lanes, and pedestrian-only zones. This shift promotes active modes of transportation, including walking and cycling, which contributes to reduced noise pollution and CO2 emissions.

5. **Green infrastructure expansion and Implementation of the green norm:** Freed-up spaces can be transformed into green spaces to help counteract the Urban Heat Island effect, improving air quality, absorbing and filtering noise, and enhancing the aesthetic value of urban areas. Incorporating a Green Norm ensures a minimum percentage of any freed area, or the neighbourhood area, is developed into green spaces. This will help ensure that the urban growth resulting from reclaimed road space aligns with sustainability principles, effectively balancing the need for development and preserving urban green areas

6. **Public transit optimization:** The spaces previously dedicated to cars can now be reallocated to enhance public transit. This can be done by dedicating more lanes to buses, trams, or other forms of mass transit, making public transportation a more efficient and attractive option.

7. **Urban density management and local amenities enhancement:** The space reclaimed from cars can be used to manage urban density better, curtailing urban sprawl and bringing amenities closer to residents. Reducing travel distances can further decrease the reliance on motorised transport. Additionally, the newly available space can enhance local amenities like markets and playgrounds, improving the accessibility and quality of neighbourhoods.

Having detailed key strategies to implement the new accessibility paradigm and seeing them in action is beneficial.

The following section provides practical examples, specifically relevant to steps 2 and 5, illustrating how urban green interventions have been successfully integrated into other cities.

Image 9, Erasmusbrug by night

6.5 Real-world examples of urban green interventions

When exploring potential strategies for addressing urban challenges through spatial reallocation, numerous successful initiatives across the Netherlands inspire. These examples exemplify innovative urban planning and design solutions that mitigate environmental impacts, improve air quality, reduce noise pollution, counteract the Urban Heat Island effect, and enhance the well-being of residents. Some examples are:

- the Tree & Bicycle Parking platform in The Hague
- the ParkxPark Project in Amsterdam
- Green parking spaces

Tree & bicycle parking platform in The Hague

Facing crowded sidewalks and a lack of greenery, The Hague introduced the Bicycle Tree Parking Platform (Figure 40). Here's how it works:

- Residents join a car-sharing program, reducing personal vehicle usage.
- Vacant car parking spaces can be transformed into temporary bike racks with a tree, pending underground suitability checks.
- If residents approve and after a five-month evaluation, the temporary platform is made permanent with robust bike racks and a tree.

Starting in 2019, The Hague began this initiative, rotating platforms every three months. So far, 37 of 46 temporary platforms have become permanent, each accommodating four to six bicycles and enhancing greenery (Gemeente Beloont Autodelen Met Meer Ruimte Voor Groen En Fietsen, 2023).

Figure 40 - Bike / Tree Platform in the Hague, picture by Valarie Kuypers (Gemeente Beloont Autodelen Met Meer Ruimte Voor Groen En Fietsen, 2023)

ParkxPark Project in Amsterdam

A second example is the ParkxPark project at the Marineterrein in Amsterdam. As the municipality intends to remove 10,000 parking spaces in the city, they are also seeking ways to give more room to greenery, pedestrians, and recreation. This ParkxPark initiative opens up opportunities to reimagine the use of these freed spaces. To experiment with these opportunities, the first twenty parking spaces on the Marineterrein have been repurposed and returned to the city. Examples of the new uses include a mini forest, a herb garden, and an 'insect oasis,' serving as showcases for the transformative possibilities, as seen in Figure 41 (Park x Park Amsterdam, 2023).

Figure 41 - The ParkXPark project in Amsterdam (Park x Park Amsterdam 2023

Green parking spaces

Another innovative approach is the concept of green parking spaces. Instead of eliminating parking spaces, this concept makes them greener. These parking spaces are not 100% paved but have green and semi-hardened parts (Figure 42). This configuration allows rainwater to infiltrate the ground directly, reducing the load on the sewer system or preventing rapid drainage via ditches. The parking space remains user-friendly for the motorist due to partial paving.

Green parking spaces can be implemented on a small scale with a limited investment. Replacing concrete with greenery mitigates heat stress. Moreover, it is less necessary to water because green parking spaces counteract soil drought; the rainwater seeps directly into the ground. This also contributes to biodiversity (Duurzaam Gastvrij, 2022). More water in the ground and less pavement on top promotes a healthier soil life.

Figure 42 - Example of Green Parking spots (2D environment)

Those three examples show that repurposing parking spaces doesn't necessarily mean eliminating parking altogether but rather integrating more sustainable, green elements into their design. And show promising options for spatial reallocation. The subsequent section delves into the social implications, emphasizing the importance of understanding how spatial reallocation affects the city's physical layout, social fabric, and dynamics.

6.6 Policy recommendations for spatial reallocation implementation

With the formulated spatial reallocation strategy in place, the subsequent section provides actionable recommendations. These recommendations aim to enhance sustainable mobility, enrich urban green spaces, and ensure the practical realization of the strategy's objectives for both the Municipality of Rotterdam and the Dutch Ministry of Infrastructure and Water Management.

Shared recommendations (for both the municipality of Rotterdam and the Dutch Ministry of Infrastructure and Water Management)

Prioritize infrastructure: Emphasize pedestrian-friendly, cyclist-centric, and public transport-focused designs in infrastructure development and improvements.

Public awareness campaigns: Collaboratively promote the benefits of reduced car usage, highlighting broader environmental, health, and social benefits. As well as promoting the alternatives to reduce car usage, such as car sharing promotions or bike commuting and potentially support this with policies.

Enhanced public transport: Encourage frequency, reliability, and coverage improvements to make it a more attractive option.

Incentivize sustainable mobility: Support and incentivize the adoption of bicycles, electric vehicles, and other eco-friendly options. Explore innovative parking solutions, such as integrating adaptive parking with car-sharing systems, to further reduce car dependency.

Greenery, UHI, and air quality norms: Emphasize and actively promote the establishment of benchmarks for urban greenery, urban heat islands (UHI), and air quality.

Recommendations for the Municipality of Rotterdam

Incremental reduction: Advocate for a phased approach in reducing car usage within city limits, progressively replacing vehicular spaces with alternative modes of transport.

Urban greening initiatives: Utilize any available space from reduced car usage for urban greening, countering environmental challenges and offering community spaces.

Neighbourhood-specific approaches: Implement strategies tailored to different neighbourhoods' specific needs and dynamics.

Regular monitoring & feedback: Employ local-level indicators to assess progress and adapt strategies as necessary continuously.

Involve communities: Ensure active participation in decision-making to garner public support and insight.

Establish parking norms and modal split goals: Formulate parking norms conducive to the overarching objectives. Additionally, set clear modal split distribution goals to ensure a balanced and sustainable transportation system.

6.6.3 Recommendations for the Dutch Ministry of Infrastructure and Water Management

Introduce regulatory norms: Establish regulatory standards not only for vehicle usage but also for green space, UHI mitigation, and air quality, thereby providing a roadmap for urban transformation across the Netherlands.

Collaborate with other Cities: Create platforms for Dutch cities to share experiences, information, challenges, and data. Encourage and assist municipalities to share data and strategies to approach urban restructuring.

Financial & technical support: Provide resources and expertise to cities and municipalities undertaking efforts to reduce car usage and promote alternative transport modes.

Research & innovation: Support research and innovative transportation and spatial planning practices to uncover new and effective strategies.

Following the overarching policy recommendations, the next chapter delves deeper into the intricacies of neighbourhood-specific reallocations by applying the broader strategy to selected neighbourhoods in Rotterdam.

Image 10, Rijnhavenbrug Rotterdam

7 Spatial reallocation in Rotterdam neighbourhoods

Building on the broad strategies proposed in the previous section, this chapter narrows the scope to examine spatial reallocation possibilities in specific neighbourhoods of Rotterdam. Leveraging the formed datasets, it aims to provide a better understanding of how these strategies could be implemented on a neighbourhood-by-neighbourhood basis.

7.1 Identification of potential neighbourhoods for spatial reallocation

Before continuing this process, it should be noted that neighbourhoods 'Pernis', 'Nieuw Matthenesse', and 'Spaanse Polder' were excluded from the analysis. Because those neighbourhoods are very small in both size as inhabitant numbers and primarily exist of businesses and industry.

The process involved developing a liveability metric that encompassed all other neighbourhoods. This assessment relied on key environmental and infrastructural factors significantly affecting the quality of life. These factors include the Urban Heat Island effect, walking area, public transit, parking area, motor traffic, bike area, NO2 levels, noise levels, the number of cars per surface area, greenery percentage, and the total greenery area.

Initially, these factors were isolated into a subset of the larger dataset, simplifying the analysis process. This subset was subsequently structured with the neighbourhood names as columns and the factors as rows. This arrangement allowed a more visually intuitive comparison of each neighbourhood's performance across varying areas.

These values were inverted because some factors like noise and NO2 levels negatively impact liveability. To facilitate a direct comparison among these factors, originally featuring different units and scales, all values were normalized to a scale from 0 to 1, thus preserving the relative differences between neighbourhoods for each factor.

The livability index for each neighbourhood was calculated as the mean value across all factors, assuming equal weightage for each. This approach provided a single livability score for each neighbourhood, which was then utilized to rank the neighbourhoods. The ranking can be seen in Table 13. The entire table is in Appendix 8.

This ranking allows for identifying neighbourhoods potentially more suited for spatial reallocation strategies. Given their lower livability scores, neighbourhoods with lower ranks may benefit more from such a strategy. On the other hand, neighbourhoods with higher rankings could serve as successful models for spatial allocation.

However, it's essential to acknowledge the limitations of the livability index and the need for additional aspects to the complex topic of livability. In response to these limitations, the focus shifted towards identifying which neighbourhoods have the most room for improvement, in a way, the reverse of the livability index.

Table 13 - Livability Index

Neighbourhood	Liveability Index	Liveability Rank
Hillegersberg-Schiebroek	0.63	1
Ijsselmonde	0.61	2
Hoogvliet	0.61	3
Charlois	0.59	4
Prins Alexander	0.53	5
Overschie	0.51	6
Centrum	0.51	7
Kralingen Crooswijk	0.48	8
Feyenoord	0.44	9
Delfshaven	0.37	10
Noord	0.28	11

This led to the creation of an improvement index. The index reversed the previous one on some elements where a higher value now indicates a greater need/opportunity for improvement. Also, this time some factors are weighted as part of the index's development; road space, for example, received a higher weightage due to its central role in addressing other urban challenges. An improvement index allows for easier justifications for neighbourhoods that require more attention instead of making more general statements about overall livability. The improvability ranking can be seen in Table 14. The entire table and the weights are in Appendix 9.

This initial, high-level analysis is a reference point, providing a way to gauge which neighbourhood(s) would be the best starting point for spatial reallocation strategies. According to the improvement scores, the top three candidates for such strategy would be Noord, Delfshaven, and Feyenoord. This analysis aims to shed light on which neighbourhoods could benefit the most from spatial changes.

Expanding the analysis, each neighbourhood's scores on individual urban challenges were also examined. The results are as follows (Table 15):

Table 14 - Improvability Index

Neighbourhood	Improvement Index	Improvement Rank
Noord	9.51	1
Delfshaven	8.29	2
Feyenoord	7.54	3
Kralingen Crooswijk	7.23	4
Overschie	6.77	5
Prins Alexander	6.72	6
Centrum	6.58	7
Charlois	5.68	8
Hoogvliet	5.49	9
Ijsselmonde	5.04	10
Hillegersberg-Schiebroek	4.95	11

The following section dives deeper into the primary driver of this analysis: to reallocate road space to mitigate other challenges by looking at the effects for specific neighbourhoods.

Table 15 - Neighbourhood score per category

Challenge/Factor	Neighbourhood
Most relative Motor Traffic Infrastructure	Overschie
Most relative Parking Space	Noord
Most area of Motor Traffic Area (Roads + Parking)	Prins Alexander
Highest Urban Heat Island effect	Noord
Highest NO2 Levels	Overschie
Highest PM2.5 concentration	Centrum
Highest PM10 concentration	Centrum
Highest Majority Noise Level	Centrum
Most Parking Area	Prins Alexander
Least Greenery Area	Centrum
Least Bike Area	Noord

7.2 Analysis of potential impacts and benefits in selected neighbourhoods

This section will thoroughly examine four neighbourhoods – Noord, Delfshaven, Feyenoord, and Prins Alexander (figure 43). These neighbourhoods, each with distinct urban challenges, represent significant opportunities for implementing the spatial reallocation strategies outlined in 6.4 Strategies for Using Freed Space to Address Urban Challenges. Rather than taking a blanket approach, the analysis of each neighbourhood will proceed in alignment with the strategic steps, as suggested in 6.3, to generate a clear and feasible roadmap towards their spatial transformation.

Noord, Delfshaven, and Feyenoord were selected based on their top rankings in the Improvability Index. Each neighbourhood presents unique challenges ripe for improvement through targeted interventions.

Besides those three, Prins Alexander has been selected because it has the most significant area dedicated to parking within the city. As the first step of the proposed strategy centres around reducing parking spots, an in-depth exploration of Prins Alexander will offer insights into the potential impact and benefits of this initial intervention. Next to the extended analysis of those four neighbourhoods, in Appendix 10, the analysis can be found of all 14 individual neighbourhoods.

It's also important to note that in analysing these neighbourhoods and calculating reclaimable space, the area of highways is excluded for the time being. Although highways often represent a significant amount of space and impact urban environments, they are also costly to alter. As such, they are realistically less likely to undergo substantial changes in the near term. However, their role and impact should not be overlooked in long-term planning and visioning for the city.

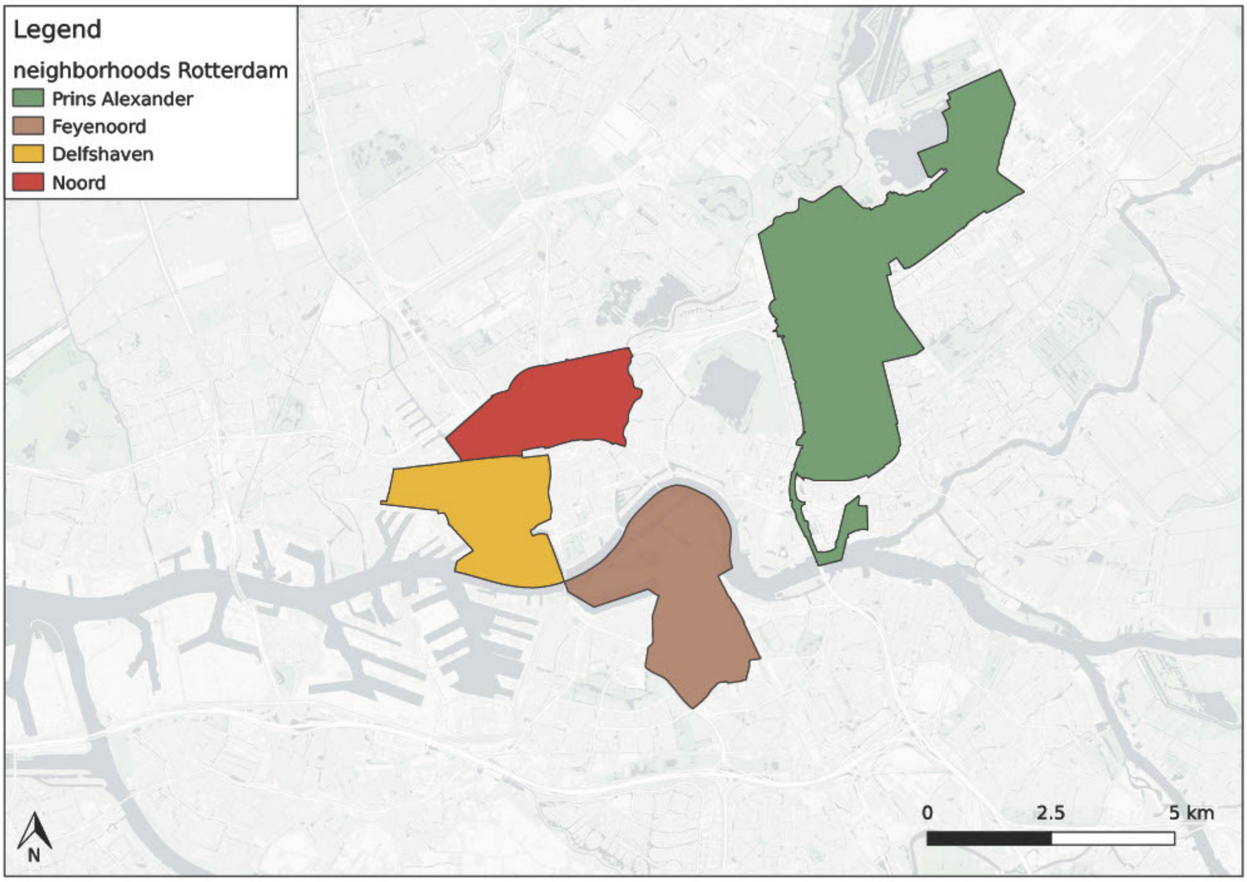


Figure 43 - The selected Neighbourhoods

Noord

Noord spans a total area of 535 ha, of which 208.59 ha is allocated to infrastructure.

A neighbourhood marked by high Urban Heat Island (UHI) (2.65 °C) effects and an elevated percentage of parking spaces (representing 11% of its infrastructure), can benefit from spatial reallocation and improvements. If well managed, these changes could significantly enhance the liveability of this neighbourhood, offering its inhabitants a better quality of life regarding the urban challenges. Here's an in-depth exploration of potential enhancements:

Parking space reduction and repurposing: Noord currently hosts 23.02 ha of parking space, equating to 18,500 parking spots. A 26% reduction strategy could liberate approximately 6.0 ha of space, downsizing the total parking area to 17.0 ha. In turn, this would result in removing about 4,800 parking spots. The space reclaimed through this strategy holds significant potential for transformation into pedestrian zones, bike lanes, or green areas, cultivating a more pedestrian-centric urban landscape. Also, transforming the remaining parking spots into green parking spaces can improve the urban resilience of Noord.

Road dieting: The total road area in Noord is 63.95 ha, including 10.86 ha of highways. Reclaiming space from highways is more complex and expensive, but a 26% reduction on the other roads could save up to 13.8 ha. The S-roads, particularly those with higher usage, could be the focus of road dieting strategies. For Noord, the S111, S112 and & S113 have potential. Even a modest reduction could liberate significant space for other uses, enhancing the overall urban mobility experience.

Enhancement of active mobility infrastructure: Noord currently features 15.95 ha of bike lanes. With the reclaimed spaces from road dieting and parking reduction, the area allocated to bike lanes could see a substantial increase. A 90% increase could provide Noord with approximately 30.3 ha of bike lanes, further promoting active mobility. This hypothetically could be achieved by the space from reduced parking and road dieting, but for Noord reducing road speeds to 30 km/h and transforming those roads to shared spaces could also help provide more room for bicycles.

Green Infrastructure expansion & norm: Noord currently hosts approximately 183.26 ha of greenery, about 34% of the neighbourhood area. However, its notable UHI effect (maxing out at 2.65 °C) signifies a need for additional green spaces. A substantial portion of reclaimed areas from parking reduction and road dieting should be transformed into green spaces. Moreover, it is essential to encourage green practices in both public and private realms, such as promoting residential gardens, vertical greenery, and greener sidewalks. Incorporating a Green Norm is also essential to ensure that the relative greenery, currently at 34%, does not decrease during spatial reallocation. Ideally, it should increase to mitigate the UHI effect further, promote biodiversity and enhance air quality.

Public Transit Optimization: Noord has an extensive public transit network, including an underground metro stop, multiple tram routes, and a train station, which spans 18.87 ha. However, the significant portion (17ha) of the railway track traversing the neighbourhood does not necessarily contribute to local accessibility. With careful planning, there may be opportunities to optimize the current network, possibly expanding tram routes or bus lanes to improve access using reclaimed space from road and parking reductions.

Given these potential strategies, Noord presents a compelling opportunity for urban transformation. The suggested changes could create a more sustainable, resilient, and livable neighbourhood, making Noord a valuable example for Rotterdam's broader modal split shift strategy.

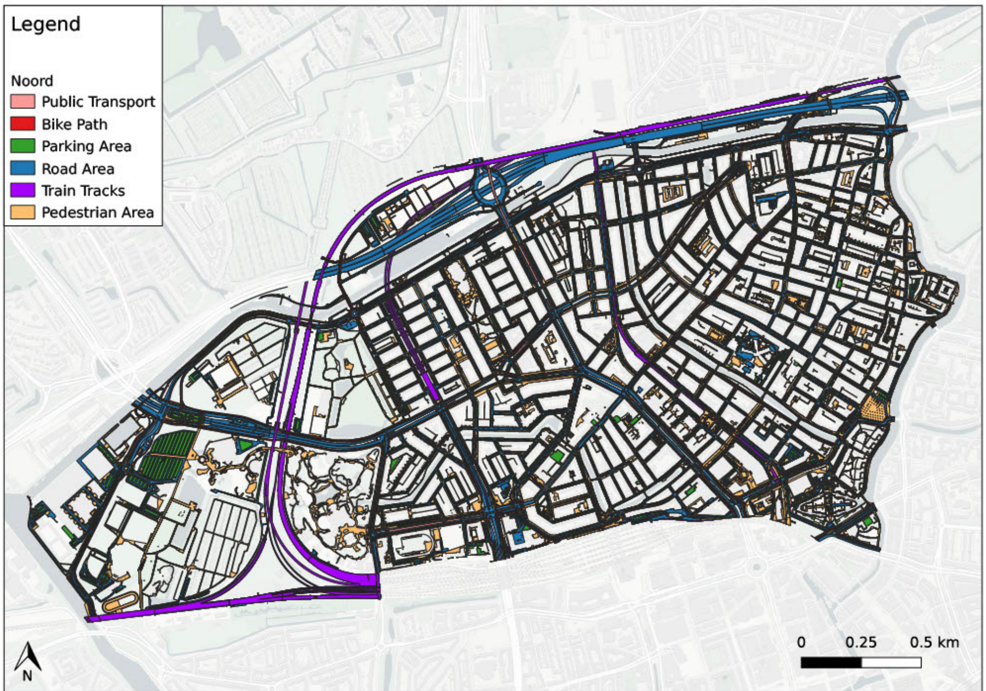


Figure 44 - Spatial Layout of Noord

Delfshaven

Delfshaven has a total area of: 596.0 ha, of which 236.3 ha is infrastructure.

This neighbourhood is marked by a large amount of infrastructural space, particularly road area, and a comparatively lower proportion of green spaces relative to its overall size. The area has significant potential for spatial reallocation, which could address the urban challenges and create an enhanced, more livable Delfshaven.

Parking space reduction and repurposing: Delfshaven currently has a considerable parking area of 22.7 ha, equating to approximately 18,200 parking spots. Enacting a strategic 26% reduction in this parking space would reclaim an estimated 5.9 ha, leading to a downsized parking area of about 16.8 ha. This significant reduction would mean the removal of around 4,800 parking spots. The newly liberated area offers a golden opportunity for transformation into more pedestrian-friendly zones, additional cycling lanes, or green spaces.

Road dieting: Delfshaven has a road area of 80.6 ha, of which 22.7 ha is highways. If we consider the road area excluding highways (57.9 ha) and apply a 26% reduction, it would mean a reduction of 15.1 ha, leaving 42.9 ha of road area (excluding highways). For Delfshaven, a starting point could be the S114. This would allow for repurposing spaces into green spaces, pedestrian pathways, or extended bicycle lanes.

Enhancement of active mobility infrastructure: Currently, Delfshaven has 17.5 ha dedicated to bike lanes. With the proposed 90% increase in cycling infrastructure, an additional 15.8 ha could be added, resulting in 33.2 ha of bike lanes. This expansion could encourage. Active mobility, decreased car usage, and improved the overall environmental health of the neighbourhood.

Green infrastructure expansion & norm: Delfshaven has approximately 167.3 ha of greenery, 28% of the neighbourhood's area. The recorded Urban Heat Island (UHI) effect of 2.36 °C confirms this relatively low percentage. The neighbourhood's urban challenges and the potential to expand green spaces through reclaimed parking and road areas call for a substantial expansion of green infrastructure. Implementing the Green Norm here would ensure that the greenery's proportion should not decrease but ideally increase beyond 28% during spatial reallocation. This would aid in alleviating the UHI effect, enhancing air quality, fostering biodiversity, and contributing to a healthier, more sustainable urban environment.

Public Transit Optimization: Delfshaven dedicates 3.9 ha to public transit, including 2.7 ha for railway tracks. While this might seem low in terms of area, it's worth noting that Delfshaven lies between two major train stations, Rotterdam Centraal and Schiedam Centrum. It is also served by three different metro lines, multiple metro stations, and various tram and bus routes, indicating a robust existing public transit infrastructure. However, there is always room for optimization and expansion.

Implementing these spatial reallocation strategies could transform Delfshaven into a neighbourhood that is more sustainable and resilient and more vibrant, livable, and socially cohesive.

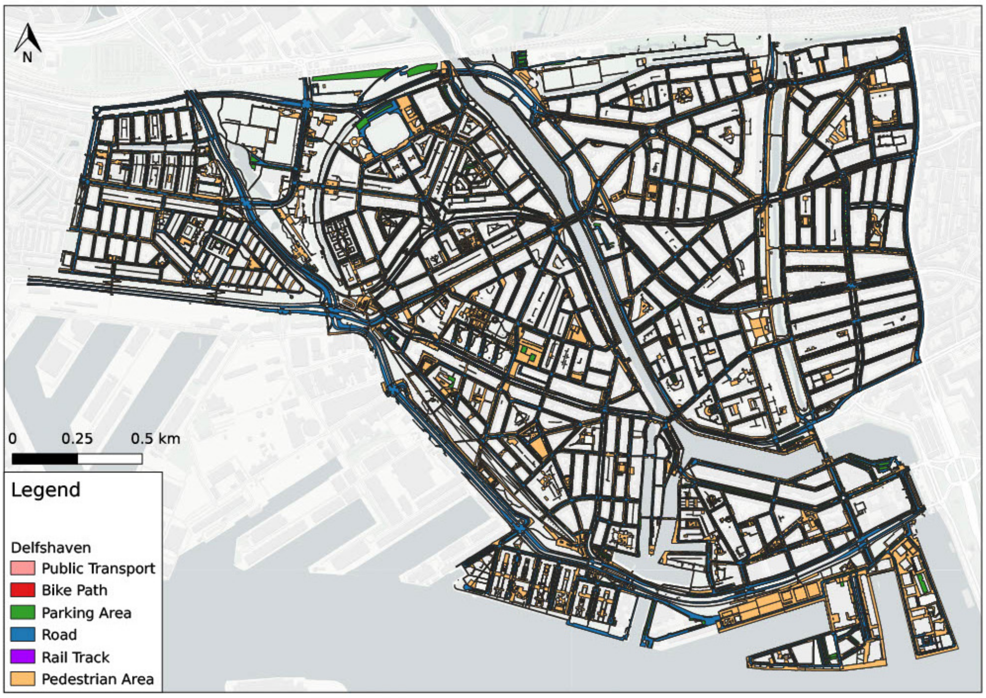


Figure 45 - Spatial Layout of Delfshaven

Feyenoord

Feyenoord has a total area of: 855.0 ha, of which 316.1 ha is for infrastructure.

Positioned third in the improvability index, Feyenoord spans a substantial area of 855.0 ha, with a significant 316.1 ha dedicated to infrastructure. Its current layout, however, reveals the lowest proportion of greenery among the analyzed neighbourhoods. Thus, the opportunity for improvements via strategic spatial reallocation in Feyenoord is immense and multifaceted.

Parking space reduction and repurposing: Currently, Feyenoord has a total parking area of 28.8 ha, equivalent to approximately 23,100 parking spots. A 26% reduction would liberate an estimated 7.5 ha of space. This would reduce the total parking area to around 21.3 ha, correlating with the removal of approximately 6,000 parking spots. The remaining 17,000 spots offer a great chance to be transformed into greener parking spots. The reclaimed area can be repurposed into more community-centred uses such as green spaces or active mobility infrastructure, thereby contributing to the neighbourhood's overall sustainability and livability.

Road dieting: The total road area in Feyenoord, excluding the highways, stands at 77.6 ha. By applying a 26% reduction, we could free up around 20.2 ha of space, leaving 57.4 ha of road area. A starting point could be one of the many S roads in Feyenoord, such as the S106, S120, S122, S123, and S125. This freed-up space presents an opportunity for repurposing further to bolster the neighbourhood's environmental resilience and livability.

Enhancement of active mobility infrastructure: Feyenoord currently has a biking area of 22.4 ha. This figure could increase significantly if we consider the potential for repurposing space from road dieting and parking space reduction. Implementing a 90% increase would expand the biking area to 42.6 ha, offering improved biking accessibility and promoting active mobility.

Green infrastructure expansion & norm: With the current greenery occupying only 174.8 ha, Feyenoord's greenery percentage stands at a mere 20%. Coupled with the noted UHI effect of 2.48°C, there is a pressing need for a substantial increase in green infrastructure. The enforcement of the Green Norm here would help ensure that during spatial reallocation, the relative greenery not only maintains but ideally surpasses its current percentage. As parking and road areas are reduced, the freed space can be transformed into new green spaces. This expansion could significantly mitigate the UHI effect, enhance air quality, promote biodiversity, and foster a healthier, more sustainable urban environment.

Public transit optimization: Feyenoord already has an extensive public transit (PT) network, with the total area dedicated to PT being 29.9 ha, of which 26.9 ha is for railway tracks. Despite the considerable existing network, there could be expansion opportunities, particularly leveraging the areas reclaimed from road and parking space reductions. This optimization can promote public transit over cars, decreasing car dominance and fostering a more sustainable neighbourhood.

With these potential improvements, Feyenoord could transition into a more sustainable, resilient, and livable neighbourhood, in line with Rotterdam's broader modal split shift strategy.

Figure 46 - Spatial Layout of Feyenoord

Prins Alexander

Prins Alexander has a total area of: 1860.0 ha, of which 546.1 ha is for infrastructure.

As one of the more expansive neighbourhoods in Rotterdam, Prins Alexander spans an impressive 1860.0 ha. A significant portion of this total area, 546.1 ha, is dedicated to infrastructure, indicating a (heavy) reliance on car usage.

This is further underscored by the fact that the neighbourhood has the highest allocation of Motor Traffic Area and Parking Areas among the 14 neighbourhoods examined. Through a strategic shift in modal split, the neighbourhood has the potential to liberate a substantial amount of space for more sustainable and socially beneficial uses.

Parking space reduction and repurposing: The current infrastructure indicates that Prins Alexander has the highest parking space of the 14 neighbourhoods, amounting to 62.1 ha, which translates to approximately 49,700 parking spots. Implementing a 26% reduction strategy could free up about 16.1 ha of space, reducing the total parking area to 45.9 ha. This process would necessitate the removal of around 13,000 parking spots. The spaces gained through this process could be used to create additional green spaces, bike lanes, pedestrian zones, or other socially beneficial uses, whilst the remaining spots could transform into green areas, enhancing Prins Alexander's livability.

Road dieting: Prins Alexander, with the most extensive road area (205.8 ha) of the 14 neighbourhoods, has significant potential for strategic road dieting. Out of this total, 43.1 ha are highways, leaving a remainder of 162.7 ha as regular road infrastructure. The area hosts several high-capacity roads, including S107, S109, and S127, with S107, a four-lane road with a parallel route, presenting a prime opportunity for lane reduction. By implementing a 26% reduction in the non-highway road area, we can free up approximately 42.3 ha of space, reducing the non-highway road area to 120.4 ha. This reclaimed space offers a sizeable resource for enhancing Prins Alexander's sustainability and livability.

Enhancement of active mobility infrastructure: Prins Alexander has a biking area of 50.1 ha. However, this figure could significantly increase, given the potential for repurposing space from road dieting and parking space reduction. If the biking area received a 90% increase, as suggested by the modal split shift, it would expand to a substantial 95.3 ha, improving biking accessibility and encouraging active mobility.

Green infrastructure expansion & norm: Prins Alexander, with 755.0 ha of greenery or about 41.0% of the total area, still experiences a noticeable Urban Heat Island effect of 2.06°C. Expanding the green infrastructure using space reclaimed from parking and road dieting could help mitigate this. By maintaining a Green Norm of at least 41%, the relative greenery remains stable or may even increase. This supports biodiversity, improves air quality, and creates a healthier, more livable neighbourhood.

Public Transit Optimization: Prins Alexander already has an extensive public transit (PT) network, including Metro, buses, and a train station, spanning 24.8 ha. Although the current network is substantial, there could be expansion opportunities, particularly leveraging the areas reclaimed from road and parking space reductions. This optimization can further encourage the use of public transit, contributing to a decrease in car dominance.

With these potential improvements in mind, Prins Alexander could transition into a more sustainable, resilient, and livable neighbourhood, making it a compelling case study for Rotterdam's broader modal split shift strategy.

Figure 47 - Spatial Layout of Prins Alexander

7.3 Contribution to the Well-Being Monitor

Given this backdrop, it's time to explore what this research can offer the well-being monitor. The monitor revolves around four core dimensions: living environment, safety, health, and accessibility. In this context, this research's findings could contribute to the monitor. Here's how:

Living Environment: The research's focus on aspects like Urban Heat Island effect, noise mitigation, and improved air quality aligns with the well-being monitor's 'living environment' facet. Monitoring these parameters over time can illustrate the tangible benefits of spatial reallocation.

Safety: By proposing a recalibrated modal split, coupled with interventions such as reduced speed limits, there's potential to elevate safety standards across Rotterdam. These changes can be monitored to see reductions in accidents and pedestrian incidents.

Health: Beyond just environmental factors, the inherent health advantage of promoting active mobility exists. As residents lean more towards walking or cycling, there are direct benefits in cardiovascular health, reduced obesity rates, and overall well-being.

Accessibility: This research provides insights into the spatial distribution and the impact of alternative modes of transport. Such information can help understand accessibility in terms of both physical reach and the availability of diverse transport modes.

Indicators from this research could be extracted to further contribute to the well-being monitor. Elements from the improvability index, such as the green norms, area distributions, and modal split, are good candidates. However, it's imperative to establish baselines or standards. So that the current indexes, which are relative to each other, can then be calibrated against these baselines, allowing individual areas to be assessed. Moreover, these baselines will enable a temporal measurement, helping to see trends over time and adjust strategies accordingly.

Image 11, Market in Rotterdam

8. Discussion

Introduction

This discussion is set up to enlighten some complex findings and the interpretation of the results. Here's how it's organised: First is a recap of the research objectives. Following this, there's an examination of the research's validity and important acknowledgements of this. After validating, the results are put into context, aligning them with existing knowledge and interpreting their significance. These segments are written down per topic. Next, a segment recognises the study's limitations, ensuring a well-rounded perspective. The chapter concludes by delving into the broader implications of the research, contemplating its potential impact and relevance—first, a recap of the objectives.

The research objectives:

1. Investigating the spatial implications of the current modal split in Rotterdam and the infrastructure allocation.

2. Estimating the potential urban space that could be freed up if a certain percentage of car trips were transitioned to these alternative modes.

3. Evaluating the potential environmental and social impacts of such a shift.

4. Exploring potential strategies to encourage a shift from car usage to other modes of transport and identifying potential barriers to implementing these strategies.

The findings underscore the signs that Rotterdam's urban fabric seems car-oriented. This infrastructure setup, resulting from historical events and decisions that emphasise car mobility, is increasingly spatially inefficient in today's context. With urban populations growing and increasing environmental changes, there's a call for reimagining the city's spatial priorities. This discussion seeks to elaborate on the implications of these findings and evaluate the research.

8.1 Assessment of research Validity:

Measurement accuracy: The quality and precision of data in research influence the robustness and validity of its findings. In the present study, a concerted effort was made to source data from reputable and trustworthy sources, ensuring high accuracy and detail. This provides a solid foundation for the interpretations and conclusions drawn.

However, there are layers of complexity to consider:

Classification challenges: While the study offers a detailed assessment at the neighbourhood level, the act of classification, by its very nature, can be constraining. Although grounded in previous research, the classifications used may not encapsulate every nuance, mainly when analysed down to the street. Thus, any interpretation based on these classifications must acknowledge potential nuances that might have been overlooked.

Modal split variances: The data on modal split presents its challenges. Given the diverse methodologies available for measuring modal split, there's potential for varied outcomes. This research used one such method, but it's worth noting that alternative measurements might yield different results.

Spatial reallocation calculations: Estimating the impact of spatial reallocation on space reduction is complex and nuanced. While the methods employed in this research are supported by existing literature, it's essential to understand that there isn't a singular definitive method to calculate the potential spatial savings resulting from a reduction. Different methodologies or interpretations could potentially produce varied outcomes.

Generalizability of conclusions: The findings can be generalised to an extent. They align with what's expected from the literature and can apply to other cities in the Netherlands.

Reliability of sources and methods: The sources and methodologies are reliable and publicly accessible, ensuring transparency. Relying on public datasets allows other researchers or organisations to validate and utilise the study quickly.

8.2 Interpretation and contextualization of findings:

Interpretation of results and alignment with expectations: The research's outcomes resonate with the initial hypothesizes and insights gained from the existing literature. A few critical reflections emerge from the findings:

Spatial inefficiency of cars: The data underscores the spatial inefficiency associated with cars in the urban landscape. The current urban layout indicates a car-centric design philosophy, which has inadvertently shaped many of the city's present challenges while catering to mobility needs.

Urban challenges tied to layout and modal split: The array of urban challenges – ranging from compromised air quality to noise pollution and the pronounced Urban Heat Island (UHI) effects – can be attributed, at least in part, to the prevailing spatial planning and modal split. As the city evolves and transport preferences shift, spatial allocations must reflect these changing realities.

The necessity for spatial reallocation: With the municipality's projections on modal split changes, there's an urge for spatial reallocation. Such reallocation isn't just about accommodating emerging transport preferences but also about creating spaces that mitigate the existing urban challenges.

Evidence of mitigation: The tangible benefits of spatial reallocation are already visible in certain pockets of the city. For example, the noticeably cooler temperatures in larger parks underscore the potential for mitigating UHI effects. Such examples showcase the possibilities of urban transformation.

Integration with theoretical framework: The results emphasize the academic context, underpinning the significance of urban spatial planning in addressing urban challenges.

New insights gained: The study provides a clearer understanding of how space is allocated in the city, emphasizing the significant influence of car infrastructure. It also offers insights into the city's current state concerning urban challenges.

Results demonstration: The study underscores the potential to improve the city's current layout, leaning heavily on car usage. It reveals how the present situation exacerbates urban challenges and illuminates the potential changes and how they can better accommodate the predicted modal split.

8.3 Limitations and challenges encountered:

Data reliability concerns:

Neighbourhood boundaries: The utilized CBS data for neighbourhood boundaries might distort the proper representation. Determining correct boundaries is challenging and subjective, but the potential influence of the boundaries on the data can't be ignored.

Temporal limitations: By focusing on a singular 'snapshot' of data and environmental effects, the study may have overlooked the nuanced effects of time. A more dynamic temporal analysis could yield more insights.

Comparative limitations: The absence of parallel studies from other cities constrains the study's contextual breadth. Also, looking at examples or neighbourhoods within the city that give the 'right' example and are already successful in the strategy could be beneficial.

Research bias and subjectivity: Stemming from a background in sustainable studies, there's a possibility that the viewpoint towards sustainable urban designs, such as car-free zones, could have nudged the research direction. While objective public data was employed to counterbalance this influence, the inherent bias and its potential impact on the study's findings should be acknowledged and considered.

Matrix limitations: With only 14 neighbourhoods making up the correlational matrix, the sample size poses potential concerns regarding representation and generalization for the entire city.

Indexes limitations: The newly introduced improvability and livability indexes have scope for further refinement. The selected topics and their respective weightage within the improvability index remain subjects of discussion, indicating opportunities for iterative enhancement. Another inherent limitation is the index's relative nature. Instead of measuring from a consistent baseline, it compares neighbourhoods, potentially overlooking absolute measures of improvability and livability.

Technical limitations: A limited prior skillset in managing extensive datasets and leveraging GIS tools might have impacted the depth of the study within its timeframe.

Data recommendations for future research: Future research should prioritize data source selection and organization. Verifying modal split data with regional traffic specialists and tapping into diverse expertise for determining reclaimable space would significantly bolster research robustness.

8.4 Broader implications and relevance:

Consequences of the research: The findings help Rotterdam's municipality with deeper insights into the city's spatial organization and the differential space allocation to each mode of mobility. This could also provide a roadmap for other cities to conduct similar assessments.

Potential outcomes if the status quo persists: Achieving the projected modal split becomes challenging if the city fails to evolve in line with these findings/suggestions. The city's climate resilience would wane, intensifying urban challenges and deteriorating living conditions due to noise, increased temperatures, and declining air quality.

Alignment with theoretical implications: The implications underscore the literature's consistent message: the current city layout is unsustainable. Changes are imperative for cities to combat urban challenges and ensure residents' well-being.

To summarize, this research delved deep into the multifaceted nature of urban planning in the context of Rotterdam, exploring its spatial distribution, the prevailing car-centric layout, and the intertwined relationship between infrastructure allocation and urban challenges. The questions posed at the start served as guideposts, enabling to probe the validity of the research, interpret the findings in the light of previous literature, and recognize the constraints that might influence the authenticity of the results.

The thorough assessment reveals support for change. The present infrastructure heavily relies on automobiles, perpetuating urban challenges that, if left unchecked, could deteriorate the city's livability. If Rotterdam intends to meet its ambitious modal split and climate targets and emerge against mounting urban challenges, its urban infrastructure requires recalibration. This research offers a diagnostic snapshot and underscores the potential for transformation and reallocation, emphasizing the role of public data and transparent methodologies.

The imperfections and limitations identified don't diminish the study's value but rather outline avenues for future research—more nuanced spatial analyses, time-series evaluations, and comparisons with other cities. They highlight urban studies' dynamic and evolving nature and the importance of constant learning and adaptation.

Furthermore, the implications of this research stretch beyond the boundaries of Rotterdam. It acts as an example for other cities facing similar challenges, demonstrating the profound impact of infrastructure on urban well-being and sustainability.

In closing, while Rotterdam stands at a pivotal juncture, it is equipped with insights, data, and the potential for transformation. With the right efforts, a vision towards sustainable urban living, and lessons learned from this study, the city can follow a resilient, inclusive path that reflects its aspirations.

der implications and relevance:

Image 12, Kop van Zuid

9 Conclusions and recommendations

Introduction

This chapter summarizes the key findings, insights, and implications derived from the study. By examining the relationship between infrastructure allocation and urban challenges in Rotterdam, the research provides a comprehensive understanding of the city's spatial dynamics. The primary outcomes, alongside the study's limitations and future research directions, are synthesized here to offer a clear picture of the current situation and potential future trajectories.

9.1 Conclusions

This research aimed to address the main research question: "What are the potential impacts on spatial allocation and specific urban challenges in Rotterdam if there is a significant shift from car usage to other modes of transport such as biking, walking, or public transport?" The research was further structured around specific objectives and sub-questions as stated in Research Objectives and Questions. Following is a recap of the six sub-research questions, categorized per research objective, followed by the main research question.

1. Investigating the spatial implications of the current modal split:

Sub-Question 1: "What is the current spatial footprint of car usage in Rotterdam, and how does it compare to the spatial footprints of biking, walking, and public transport?"

Findings: The data shows an inclination towards a car-centric infrastructure design in Rotterdam, which takes up nearly half of the city's infrastructure space. Also, walking infrastructure has a large share of the distribution. In comparison, provisions for cycling, despite its tangible presence in the modal split, appear limited.

2. Estimating the potential urban space benefits:

Sub-Question 2: "How much urban space could potentially be freed up in Rotterdam if a certain percentage of car trips were switched to biking, walking, or public transport?"

Findings: Quantifying the exact correlation is complex; however, even minor reductions in car infrastructure can lead to substantial spatial advantages, given the current amount of area dedicated to cars.

3. Evaluating the potential environmental and social impacts of the modal split:

Sub-Question 3: "What are the potential environmental impacts of freeing up urban space by reducing car usage in Rotterdam?"

Findings: A transition from car dependency can significantly decrease vehicular emissions, reduce noise pollution, and provide potential areas for urban green spaces, promoting a healthier urban environment.

Sub-Question 4: "How could the space freed up by reducing car usage be re-purposed for urban greenery, and what would be the potential impact on air quality, the Urban Heat Island effect and noise levels?"

Findings: Strategic integration of green spaces can effectively counter the Urban Heat Island effect. Coupled with diminished car dependency, a reduction in noise pollution and increased air quality is anticipated.

Sub-Question 5: "What are the potential impacts on the distribution and accessibility of amenities and services in Rotterdam if car usage is reduced?"

Findings: A less car-oriented urban design does not necessarily compromise accessibility. On the contrary, a well-integrated approach might improve overall accessibility and inclusivity across the city. But, it remains essential to ensure that places are reachable with different transport modes so that people who need to use a car because of a disability, for example, can reach their destinations.

Sub-Question 6: "What are the potential neighbourhood-specific impacts of changes in transportation allocation in Rotterdam, and how might these changes influence the urban environment?"

Findings: Though impacts might differ by neighbourhood, general trends indicate possibilities for quieter, cleaner, and more resilient environments.

4. Exploring potential strategies for a modal shift:

Findings: For a successful transition, infrastructural modifications that align with and promote the intended modal split are helpful. Also, besides data, examples from other countries show the potential benefits of such changes, looking at Helsinki and Olso, who have cut their traffic deaths to zero by reevaluating their urban fabric. This entails understanding and overcoming potential barriers in the implementation phase.

Main research question:

"What are the potential impacts on spatial allocation and specific urban challenges in Rotterdam if there is a significant shift from car usage to other modes of transport such as biking, walking, or public transport?"

In addressing the main research question, the potential impacts span both spatial allocation and urban challenges:

Spatial allocation impacts: The potential shift in the modal split, transitioning from car dominance to more spatially efficient transport modes, provides an opportunity to reallocate significant portions of urban land in Rotterdam. Such reallocation allows areas that once were saturated by car infrastructure to transform, better aligning with the evolving modal split and environmental challenges. This change makes the city layout fit better with the new modal dynamics and offers opportunities for these spaces to pivot toward more sustainable places.

Impact on urban challenges: Mitigate car reliance has the dual advantage of reducing vehicular emissions and noise pollution. This shift paves the way for the city to weave in more urban green zones, presenting multifaceted benefits. This includes combating the Urban Heat Island effect, enhancing air quality, and fostering a healthier living environment for its residents.

Methodological replicability & broader application:

The methodology employed in this research, especially BGT data, presents a blueprint that can be projected to other Dutch cities. The BGT data, complemented by the various datasets adopted in this study, is nationally covered and accessible. Although modal split data might manifest variations in granularity across municipalities, the fundamental approach elucidated in this research remains pertinent. This positions other Dutch cities to harness similar strategies, addressing urban challenges and optimizing spatial allocations with sustainability and well-being aspirations.

Well-being monitor & potential indicators:

The link between mobility and spatial allocation underscores the need for an integrated range of indicators for the well-being monitor. This research's proposed indicators include the modal split, infrastructure area, greenery area or percentages, and metrics related to Noise, Air quality, and the Urban Heat Island effect. Furthermore, monitoring elements like the absolute and relative quantity of parking spaces can furnish insights into the prevailing state and establish benchmarks for envisioned scenarios. In light of the ministry's inquiry about well-being monitor indicators, this research advocates assimilating several metrics. These should encapsulate the dynamics between mobility frameworks and spatial layouts, reflecting the realities and potentials of urban environments.

In conclusion, this research provides actionable insights for Rotterdam and outlines a scalable strategy for reshaping urban mobility and spatial planning across the Netherlands. The urban spatial allocation is dynamic and adaptable, emphasizing its potential to evolve in ways that prioritize the well-being of residents and the environment. It's crucial to view this allocation not as a fixed entity but as a flexible framework that can significantly enhance urban landscapes with thoughtful planning and dedication. With careful planning and commitment, the potential benefits of restructuring urban environments are significant and well within reach.

9.2 Recommendations for policy makers

The transition toward a sustainable urban environment is a complex task that requires intricate planning, thorough understanding, and decisive action. The research presented in this thesis has aimed to provide insights and a foundation upon which these actions can be predicted. In so doing, it is essential to realize that a holistic approach, engaging various stakeholders and agencies, can be the most effective. Consequently, the recommendations have been tailored for different governing bodies to ensure specificity, relevance, and feasibility. Realizing these recommendations rests equally on the governance structures and the community they represent. Presented below are the findings and recommendations from the research, categorized to better align with the responsibilities and capabilities of the respective governing bodies.

For both the Municipality of Rotterdam and the Dutch Ministry of Infrastructure and Water Management:

Infrastructure re-design: Prioritize pedestrian, cyclist, and public transport-friendly infrastructure.

Public Awareness: Launch campaigns to promote reduced car dependency's environmental, health, and societal benefits. Also, encourage the alternatives to cars, potentially via policy regulations

Promote sustainable mobility: Incentivise adopting bicycles, electric vehicles, and adaptive parking solutions to decrease car reliance.

Enhanced public transport: Improve frequency, reliability, and coverage to make public transport the preferred choice.

Establish green and air quality norms: Set benchmarks for urban greenery, UHI mitigation, and air quality.

Recommendations for the Municipality of Rotterdam:

Phased car usage reduction: Advocate for a gradual decrease in car usage, transitioning towards alternative transport modes.

Urban greening: Allocate reduced car spaces for urban greening, addressing environmental concerns and creating community hubs.

Neighbourhood-specific strategies: Implement initiatives tailored to different neighbourhood dynamics.

Continuous monitoring: Use local-level indicators for regular progress checks and adapt strategies as necessary.

Community engagement: Encourage active community participation in policy-making for broader acceptance and valuable insights.

Parking and modal split goals: Define parking norms and modal split distribution objectives for a sustainable transport system.

Recommendations for the Dutch Ministry of Infrastructure and Water Management:

Regulatory standards: Set standards for vehicle usage, green space, UHI mitigation, and air quality for a national urban transformation guideline. Also, suggest policies to ensure that those standards can be reached and enforced.

City collaborations: Facilitate platforms for Dutch cities to exchange experiences, challenges, and strategies in urban restructuring.

Support cities: Offer financial and technical assistance to cities and municipalities focusing on reducing car usage and enhancing alternative transport.

Research & innovation: Back research initiatives in transportation and spatial planning to discover new strategies. In essence, achieving Rotterdam's vision of a sustainable urban fabric necessitates joint endeavours from multiple levels of policymakers, urban planners, and the community. This endeavour encompasses infrastructural changes and shifts in perceptions towards a greener urban future.

9.3 Future research

This research has helped with understanding the intricate balance between urban mobility and spatial allocation. However, several avenues remain available for exploration in the scope of sustainable urban development. Such as:

Extension and expansion of current research:
This study provides a foundational framework based on current data and spatial dynamics of Rotterdam. Yet, the cityscape is complex, and extending the current research further can have multiple benefits. Some options are:

Longitudinal studies: Future research initiatives could capitalize on the existing dataset, adding new data layers as the city transforms. This would allow for longitudinal analyses, tracking the shifts, and assessing the real-time implications of urban policy decisions over extended periods.

Geographical expansion: While this research was primarily focused on specific parts of Rotterdam, there's potential to expand the spatial boundaries. Incorporating more neighbourhoods can provide a more coarse understanding. Moreover, considering the inter-connectedness of cities and towns, extending the research to encompass the entire Rotterdam-The Hague metropolitan region could offer insights into the broader urban-suburban interplay and its implications for spatial and transport dynamics.

Deep Dive into specific areas: Researchers could delve deeper into specific neighbourhoods or areas of interest with the dataset in place. Such focused studies can identify localized challenges and opportunities, tailoring urban solutions catering to each zone's unique characteristics.

Urban design and architecture: As cities look towards sustainable transportation modes, the architectural implications of these shifts become significant. Future research could explore how buildings and urban layouts can be designed or retrofitted to accommodate and promote sustainable transport.

Economic impacts: Understanding the financial ramifications of a shift in urban transport modalities is crucial. This includes potential changes in property values, implications on local businesses, and job opportunities in sustainable transport sectors.

Health outcomes: The correlation between transportation modes, urban green spaces, and public health is an area that deserves more in-depth study. Understanding how shifts in transport modalities can impact health outcomes such as respiratory conditions, cardiovascular health, and overall wellness can provide a comprehensive view of the benefits.

Equity and social implications: Ensuring that shifts in urban transport modalities cater to all strata of society is imperative. Research into how these changes affect various socio-economic groups and ensuring that policies do not inadvertently marginalize specific populations is vital.

Comparative international studies: Drawing comparisons between cities globally, especially between those that have successfully transitioned to sustainable transport modes and those still in the early phases, can offer rich insights. Understanding strategies, pitfalls, and success stories from a global context can inform local strategy better.

Interdisciplinary approaches: Urban mobility and spatial allocation aren't just technical issues. They intersect with sociology, psychology, economics, and even art. Embracing interdisciplinary studies can offer holistic insights, drawing from varied fields of knowledge.

Integration with technological innovations: The future of urban mobility might be shaped by technological innovations like autonomous vehicles, smart roads, and advanced public transport systems. Understanding how these innovations can be harmoniously integrated with city planning is another promising area for research.

Regenerative urban planning: Beyond sustainability, the concept of regenerative—where urban designs not only sustain but enhance the environment and well-being—could be an area of exploration. This would involve designing cities that give back to the environment more than they take.

The journey towards reshaping urban environments is intricate and multifaceted. While this research has shed light on significant aspects, the field remains dynamic, with many areas awaiting deeper exploration. Continued commitment to research and understanding will be pivotal in steering cities toward a sustainable, inclusive, and thriving future.

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Image 10, Photo by Micheile Henderson. "Rijnhavenbrug Rotterdam". Unsplash, 2023. Accessed on August 2023. https://unsplash.com/photos/CURk-c2NdLY

Image 11, Photo by Barcellosalice "Market in Rotterdam". Pixabay, 2023. Accessed on August 2023. https://pixabay.com/nl/photos/bloemen-tulpen-winter-rotterdam-2696737/

Image 12, Photo by Henk Mohabier. "Kop van Zuid". Pexels, 2023. Accessed on August 2023. https://www.pexels.com/nl-nl/foto/grijstinten-van-hoogbouw-440162/

Appendix

Extra data and information

Some files, due to their large size or incompatible formats, could not be included in the appendix of this thesis. Consequently, an online repository has been created, which provides access to the QGIS files, Python code, CSV files, Interview Transcripts and Excel datasheets.

The repository can be reached trough this link:
https://drive.google.com/drive/folders/1tEAyrtNtdYPf8sZJe4qD_WX0w8GYkis5?usp=drive_link

Appendix 1

List of potential indicators for the well being monitor from TNO, translated from dutch (Vonk Noordergraaf Diana et al., 2021)

Category	Indicator	Possible formulations and breakdowns
Emissions	CO2 emissions (g)	In kg or tons, possibly g/km, per vehicle or vehicle type, per individual trip or all trips in a network. Can also be broken down into groups of people, if their travel behavior is known. Example: Avoided CO2 emissions due to avoided trips, modal shift (as a result of the introduction of MaaS or improvement of infrastructure for micromodalities), more efficient routing or avoided traffic jams. Or CO2 emissions from different groups of people.
Emissions	Greenhouse gas emissions (g)	In CO2 equivalents (based on Global Warming Potential (GWP)). Example: See CO2 emissions.
Energy use	Required propulsion energy (Joule)	Breakdown of fossil and renewable, per km, or per vehicle type, per passenger/ton of goods, per unit of time, per individual trip or all trips in a network. Example: See CO2 emissions.
Energy use	Required energy for construction and maintenance of infrastructure and vehicles (Joule)	For example, per year or per object over its lifespan. Alternative scenarios can be compared. Example: required energy for the construction and maintenance of infrastructure: Hyperloop vs. High-Speed Line vs. (regional) airport.
Climate resilience	Number or share of vulnerable locations in transport network	Map with locations (with an explanation of what makes the location vulnerable, e.g., important low-lying road).
Air quality	Emissions of NOx, PM, etc. (g)	Per vehicle, or vehicle type, or traffic flow; total or per km or time unit (e.g., hour or year).
Air quality	(Contribution of mobility to) concentrations of NOx, PM, etc. (µ/m3)	According to the 2007 Air Quality Assessment Regulation - SRM1 and SRM2. It can be assessed how many residents are exposed to (considered) poor air quality. To then determine health effects (see chapter 6) from this (e.g., 'number of premature deaths due to particulate matter'), dose-effect relationships are needed.
Soil quality	(Contribution of mobility to) nitrogen deposition (mol/ha/year)	Calculation with AERIUS tool, for example for traffic on a road, or to and from a location, activities in a port, or for infrastructure construction projects.
Water quality	(Contribution of mobility to) water quality (no indicator determined yet)	(Mainly the impact of the construction and use of infrastructure in/above/next to water; think of disturbing the natural flow, nitrogen load of surface waters, or leaching of pollution from used materials).
Resource use	Total material use OR Saved materials - avoided use (g)	Per material type, total quantity, or reduction in kg or tons.
Resource use	Saved materials - recycling (g)	Per material type, reduction in kg or tons, or share of renewable materials.
Noise emissions (dB)		As prescribed in legislation and regulations (Standard Calculation Method 2 (SRM2) and Manual for measuring and calculating industrial noise (HMRI)). It can be assessed how many residents experience noise pollution from traffic or mobile sources ('number of people affected'), based on established relationships between noise levels and experienced nuisance.
Noise exposure (Lden, Lnight)		As prescribed in legislation and regulations. Noise levels at the facade or noise contours on a map. It can be assessed how many residents experience noise pollution ('number of people affected'), based on established relationships between noise levels and experienced nuisance.

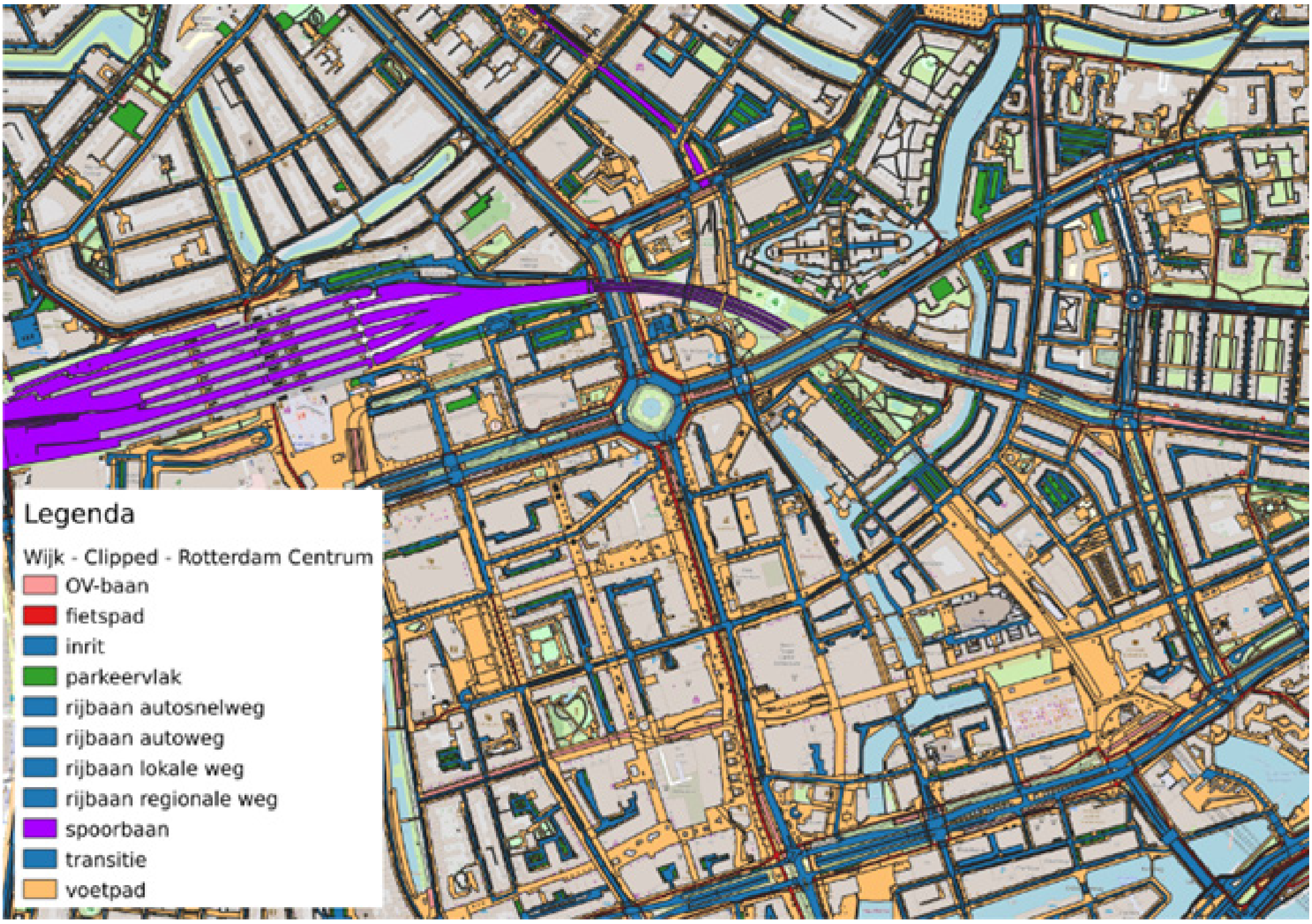
Nuisance to residents of roads, railways, and waterways		For example, to be viewed for different groups of residents, close to and further away from the source of the vibrations. Measurement or modeling of vibrations and comparison with requirements from guidelines or building regulations.
Roads, Railways, Waterways	Infrastructure space use per modality (m2) - for moving vehicles	Now: in (lane) km's of motorway. More attention needed for modalities other than the (freight) car: cycle paths, sidewalks, shared space, etc.
Parking/ storage/ shunting	Space use parking or mooring places (m2) - for stationary vehicles or vessels (storage)	Number of parking spaces/storage/shunting yards or tracks. Visualize for regular (private) vehicles and (free-floating or fixed base) (shared) vehicles. Car, bicycle, scooters, etc. Also shared vessels, should they be introduced. With or without charging infrastructure, for specific target groups (e.g., shared cars, taxis, disabled, for bicycles/scooters), whether or not for permit holders, by tariff group, etc.
Quality of space	Experience parking different modalities	Cars, bicycles, scooters/motorcycles, cargo bikes, delivery services, etc.
Green	Ratio of green and gray space (shares in %)	Green: Parks, gardens, water, nature/recreation areas. Gray: buildings, infrastructure, parking/storage/shunting. Optionally specify space specifically for mobility. Per neighborhood or zone/region/ country. Display in % and/or on a map.
Green	Fragmentation of green space (-)	Yet to be determined.
Public space	Quality of public (mobility) space	For example, something similar to the Urban functional diversity indicator (inventory per square km which of 9 functions are present, such as schools, shops, parks, businesses). To be applied, for example, to mobility hubs (functions to be inventoried yet to be determined). In addition, the experience of users of the space.
Public space	Commercial use of public space (m2, €	For example, on a square or street, for mobile and stationary activities, such as terraces, mobile shops, market stalls.
Investments	Costs of construction and maintenance of infrastructure and vehicles (€	To compare modalities, for example, a hyperloop, high-speed line, airport, etc.
Investments	Costs of operations (€	For example, to be compared for different mobility services (e.g., public transport, ride-sharing, car sharing).
Multifunctional space use	-	Example: Tunnel or parking lot with a park on top, railway tunnel with market on it, combination of sea defense and parking garage.
Accidents	Number of accidents	Number per billion km, by road type, time unit, modality, area, residents, etc.
Casualties	Number of deaths, seriously injured, and minor injuries	Number per billion km, by road type, time unit, modality, area, residents, etc. Also, the number of people who fully recover vs. those who experience lasting impairments.
Material damage	Costs due to material damage (Euros)	Costs per person/household/business, per time unit, by type of accident or category of damage.
Site-specific risk	Site-specific risk (chance per year)	The site-specific risk is the site-specific probability of death per year, due to an accident with a certain activity (e.g., the transport of hazardous materials on the road). The risk is shown in risk contours. Specific standards exist for this risk.
Group risk	Group risk (chance per year)	The official definition relates to the cumulative chance per year that at least 10, 100, or 1,000 people die due to their presence in an area affected by an unusual event involving hazardous substances. The group risk is displayed in a graph.
Understandability of mobility option	Percentage of users who find it difficult to use this option (#)	To be elaborated on modalities (various parts of the journey, such as planning the trip, paying for the journey, transferring, finding the way), user groups, possibly regions. Both physical and digital aspects should be considered.
Understandability of mobility option	Number of actions required to make a trip (#)	Yet to be determined.
Understandability of mobility option	Complexity required	To be elaborated on modalities (various parts of the journey, such as planning the trip, paying for the journey, transferring, finding the way).

Appendix 2

Categories from BGT data:

OV-baan
baan voor vliegverkeer
fietspad
inrit
overweg
parkeervlak
rijbaan autosnelweg
rijbaan autosnelweg
rijbaan autosnelweg
calamiteitendoorsteek
rijbaan autoweg
rijbaan autoweg
rijbaan autoweg
calamiteitendoorsteek
rijbaan regionale weg
rijbaan regionale weg
rijbaan regionale weg
verkeersdrempel
lokale weg
rijbaan lokale weg verkeersdrempel
ruiterpad
spoorbaan
voetgangersgebied
voetpad
voetpad op trap
woonerf
transitie

visual example of the catagories



Appendix 3

Dissection of all the area's per neighbhorhood, also as excel in the data files

Name Wijk	Transport Mode	Categorie	Opp. In m^2	opp. in Ha	opp. in km^2
Overschie					
		totaal oppervlakte infrastrcutuur	2188197	218.820	2.188
		totaal oppervlakte wijk	17324281	1732.428	17.324
	MT	oppervlak MT totaal	1374879	137.488	1.375
		rijbaan lokale weg	880356	88.036	0.880
		rijbaan autosnelweg	250619	25.062	0.251
		parkeervlak	206366	20.637	0.206
		rijbaan regionale weg	37538	3.754	0.038
	NMT	oppervlak NMT totaal	776968	77.697	0.777
		voetpad	605492	60.549	0.605
		fietspad	170109	17.011	0.170
		voetpad op trap	1367	0.137	0.001
		voetgangersgebied	0	0.000	0.000
	PT	oppervlakt PT totaal	36350	3.635	0.036
		spoorbaan	34378	3.438	0.034
		OV-baan	1972	0.197	0.002
		overweg	0	0.000	0.000
Delfshaven					
		totaal oppervlakte infrastrcutuur	2362676	236.268	2.363
		totaal oppervlakte wijk	5965442.000	596.544	5.965
	MT	oppervlak MT totaal	1097086	109.709	1.097
		rijbaan lokale weg	643816	64.382	0.644
		rijbaan autosnelweg	226635	22.664	0.227
		parkeervlak	226635	22.664	0.227
		rijbaan regionale weg	0	0.000	0.000
	NMT	oppervlak NMT totaal	1226315	122.632	1.226
		voetpad	1110741	111.074	1.111
		fietspad	110589	11.059	0.111
		voetpad op trap	4985	0.499	0.005
		voetgangersgebied	0	0.000	0.000
	PT	oppervlakt PT totaal	39275	3.928	0.039
		spoorbaan	27123	2.712	0.027
		OV-baan	12152	1.215	0.012
		overweg	0	0.000	0.000
Noord					
		totaal oppervlakte infrastrcutuur	2085862	208.586	2.086
		totaal oppervlakte wijk	5353212.000	535.321	5.353
	MT	oppervlak MT totaal	928729	92.873	0.929
		rijbaan lokale weg	589960	58.996	0.590
		rijbaan autosnelweg	108572	10.857	0.109
		parkeervlak	230197	23.020	0.230
		rijbaan regionale weg	0	0.000	0.000
	NMT	oppervlak NMT totaal	968471	96.847	0.968
		voetpad	864830	86.483	0.865
		fietspad	100492	10.049	0.100
		voetpad op trap	3149	0.315	0.003
		voetgangersgebied	0	0.000	0.000
	PT	oppervlakt PT totaal	188662	18.866	0.189
		spoorbaan	170205	17.021	0.170
		OV-baan	18339	1.834	0.018
		overweg	118	0.012	0.000
Centrum					
		totaal oppervlakte infrastrcutuur	2212554.17	221.255	2.213
		totaal oppervlakte wijk	4882446.000	488.245	4.882
	MT	oppervlak MT totaal	783924.6705	78.392	0.784
		rijbaan lokale weg	665669.3133	66.567	0.666
		rijbaan autosnelweg	0	0.000	0.000
		parkeervlak	118255.3572	11.826	0.118
		rijbaan regionale weg	0	0.000	0.000
	NMT	oppervlak NMT totaal	1232140.063	123.214	1.232
		voetpad	1106383.617	110.638	1.106
		fietspad	113025.0248	11.303	0.113
		voetpad op trap	11571.66128	1.157	0.012
		voetgangersgebied	1159.76006	0.116	0.001
	PT	oppervlakt PT totaal	196489.4366	19.649	0.196
		spoorbaan	168836.2767	16.884	0.169
		OV-baan	26822.17937	2.682	0.027
		overweg	830.9805587	0.083	0.001

Kralingen Crooswijk					
		totaal oppervlakte infrastrcutuur	3259623	325.962	3.260
		totaal oppervlakte wijk	12769162.000	1276.916	12.769
	MT	oppervlak MT totaal	1491983	149.198	1.492
		rijbaan lokale weg	1105319	110.532	1.105
		rijbaan autosnelweg	15430	1.543	0.015
		parkeervlak	371234	37.123	0.371
		rijbaan regionale weg	0	0.000	0.000
	NMT	oppervlak NMT totaal	1559378	155.938	1.559
		voetpad	1355918	135.592	1.356
		fietspad	196651	19.665	0.197
		voetpad op trap	6202	0.620	0.006
		voetgangersgebied	607	0.061	0.001
	PT	oppervlakt PT totaal	208262	20.826	0.208
		spoorbaan	171800	17.180	0.172
		OV-baan	36159	3.616	0.036
		overweg	303	0.030	0.000
Hillegersberg					
		totaal oppervlakte infrastrcutuur	2698273	269.827	2.698
		totaal oppervlakte wijk	13260590	1326.059	13.261
	MT	oppervlak MT totaal	1417697	141.770	1.418
		rijbaan lokale weg	1015692	101.569	1.016
		rijbaan autosnelweg	219058	21.906	0.219
		parkeervlak	130784	13.078	0.131
		rijbaan regionale weg	52163	5.216	0.052
	NMT	oppervlak NMT totaal	1205544	120.554	1.206
		voetpad	1041344	104.134	1.041
		fietspad	161419	16.142	0.161
		voetpad op trap	2781	0.278	0.003
		voetgangersgebied	0	0.000	0.000
	PT	oppervlakt PT totaal	75032	7.503	0.075
		spoorbaan	58449	5.845	0.058
		OV-baan	16583	1.658	0.017
		overweg	0	0.000	0.000
Ijsselmonde					
		totaal oppervlakte infrastrcutuur	3964521	396.452	3.965
		totaal oppervlakte wijk	13092235	1309.224	13.092
	MT	oppervlak MT totaal	2020463	202.046	2.020
		rijbaan lokale weg	1311590	131.159	1.312
		rijbaan autosnelweg	487487	48.749	0.487
		parkeervlak	221386	22.139	0.221
		rijbaan regionale weg	0	0.000	0.000
	NMT	oppervlak NMT totaal	1688803	168.880	1.689
		voetpad	1474257	147.426	1.474
		fietspad	209320	20.932	0.209
		voetpad op trap	5226	0.523	0.005
		voetgangersgebied	0	0.000	0.000
	PT	oppervlakt PT totaal	255255	25.526	0.255
		spoorbaan	207783	20.778	0.208
		OV-baan	47472	4.747	0.047
		overweg	0	0.000	0.000
Feyenoord					
		totaal oppervlakte infrastrcutuur	3161289	316.129	3.161
		totaal oppervlakte wijk	8548311	854.831	8.548
	MT	oppervlak MT totaal	1150231	115.023	1.150
		rijbaan lokale weg	862320	86.232	0.862
		rijbaan autosnelweg	0	0.000	0.000
		parkeervlak	287911	28.791	0.288
		rijbaan regionale weg	0	0.000	0.000
	NMT	oppervlak NMT totaal	1711678	171.168	1.712
		voetpad	1565682	156.568	1.566
		fietspad	137866	13.787	0.138
		voetpad op trap	7920	0.792	0.008
		voetgangersgebied	210	0.021	0.000
	PT	oppervlakt PT totaal	299380	29.938	0.299
		spoorbaan	268648	26.865	0.269
		OV-baan	30704	3.070	0.031
		overweg	28	0.003	0.000
Charlois					
		totaal oppervlakte infrastrcutuur	3605268	360.527	3.605
		totaal oppervlakte wijk	11903017	1190.302	11.903
	MT	oppervlak MT totaal	1703286	170.329	1.703
		rijbaan lokale weg	1181916	118.192	1.182
		rijbaan autosnelweg	358737	35.874	0.359
		parkeervlak	146844	14.684	0.147
		rijbaan regionale weg	15789	1.579	0.016
	NMT	oppervlak NMT totaal	1737670	173.767	1.738
		voetpad	1533545	153.355	1.534

		fietspad	200283	20.028	0.200
		voetpad op trap	3842	0.384	0.004
		voetgangersgebied	0	0.000	0.000
	PT	oppervlakt PT totaal	164312	16.431	0.164
		spoorbaan	135523	13.552	0.136
		OV-baan	28708	2.871	0.029
		overweg	81	0.008	0.000
Hoogvliet					
		totaal oppervlakte infrastrcutuur	2719078	271.908	2.719
		totaal oppervlakte wijk	11903017	1190.302	11.903
	MT	oppervlak MT totaal	1417962	141.796	1.418
		rijbaan lokale weg	884023	88.402	0.884
		rijbaan autosnelweg	259380	25.938	0.259
		parkeervlak	251099	25.110	0.251
		rijbaan regionale weg	23460	2.346	0.023
	NMT	oppervlak NMT totaal	1242968	124.297	1.243
		voetpad	1076747	107.675	1.077
		fietspad	163364	16.336	0.163
		voetpad op trap	2857	0.286	0.003
		voetgangersgebied	0	0.000	0.000
	PT	oppervlakt PT totaal	58148	5.815	0.058
		spoorbaan	51058	5.106	0.051
		OV-baan	7090	0.709	0.007
		overweg	0	0.000	0.000
Nieuw Matthenesse					
		totaal oppervlakte infrastrcutuur	258315	25.832	0.258
		totaal oppervlakte wijk	2072164	207.216	2.072
	MT	oppervlak MT totaal	188116	18.812	0.188
		rijbaan lokale weg	165044	16.504	0.165
		rijbaan autosnelweg	0	0.000	0.000
		parkeervlak	23072	2.307	0.023
		rijbaan regionale weg	0	0.000	0.000
	NMT	oppervlak NMT totaal	69585	6.959	0.070
		voetpad	60096	6.010	0.060
		fietspad	9142	0.914	0.009
		voetpad op trap	347	0.035	0.000
		voetgangersgebied	0	0.000	0.000
	PT	oppervlakt PT totaal	614	0.061	0.001
		spoorbaan	614	0.061	0.001
		OV-baan	0	0.000	0.000
		overweg	0	0.000	0.000
Spaanse Polder					
		totaal oppervlakte infrastrcutuur	594071	59.407	0.594
		totaal oppervlakte wijk	2036565	203.657	2.037
	MT	oppervlak MT totaal	419841	41.984	0.420
		rijbaan lokale weg	302068	30.207	0.302
		rijbaan autosnelweg	36335	3.634	0.036
		parkeervlak	81438	8.144	0.081
		rijbaan regionale weg	0	0.000	0.000
	NMT	oppervlak NMT totaal	142594	14.259	0.143
		voetpad	109563	10.956	0.110
		fietspad	32886	3.289	0.033
		voetpad op trap	145	0.015	0.000
		voetgangersgebied	0	0.000	0.000
	PT	oppervlakt PT totaal	31636	3.164	0.032
		spoorbaan	31268	3.127	0.031
		OV-baan	368	0.037	0.000
		overweg	0	0.000	0.000
Prins Alexander					
		totaal oppervlakte infrastrcutuur	5460951	546.095	5.461
		totaal oppervlakte wijk	18604946	1860.495	18.605
	MT	oppervlak MT totaal	2859413	285.941	2.859
		rijbaan lokale weg	1807252	180.725	1.807
		rijbaan autosnelweg	431230	43.123	0.431
		parkeervlak	620931	62.093	0.621
		rijbaan regionale weg	0	0.000	0.000
	NMT	oppervlak NMT totaal	2353503	235.350	2.354
		voetpad	2027322	202.732	2.027
		fietspad	320719	32.072	0.321
		voetpad op trap	5462	0.546	0.005
		voetgangersgebied	0	0.000	0.000
	PT	oppervlakt PT totaal	248035	24.804	0.248
		spoorbaan	230682	23.068	0.231
		OV-baan	17353	1.735	0.017
		overweg	0	0.000	0.000

Pernis					
		totaal oppervlakte infrastrcutuur	349631.6697	34.963	0.350
		totaal oppervlakte wijk	1615977.079	161.598	1.616
	MT	oppervlak MT totaal	154482.3184	15.448	0.154
		rijbaan lokale weg	133775.4862	13.378	0.134
		rijbaan autosnelweg	20645.37676	2.065	0.021
		parkeervlak	59.698161	0.006	0.000
		rijbaan regionale weg	1.757240961	0.000	0.000
	NMT	oppervlak NMT totaal	175016.0847	17.502	0.175
		voetpad	155084.227	15.508	0.155
		fietspad	19290.62008	1.929	0.019
		voetpad op trap	641.2375986	0.064	0.001
		voetgangersgebied	0	0.000	0.000
	PT	oppervlakt PT totaal	20133.26669	2.013	0.020
		spoorbaan	20133.26669	2.013	0.020
		OV-baan	0	0.000	0.000
		overweg	0	0.000	0.000

Appendix 4

Full data table, including al lthe catagories that are used for the correlation matrix, also available as excel and csv in the data files.

Catagory	Centrum	Charlois	Delfshaven	Feyenoord	Hillegersberg-Schiebroek	Hoogvliet	Ijsselmonde	Kralingen Crooswijk	Nieuw Matthenesse	Noord	Overschie	Pernis	Prins Alexander	Spaanse Polder
Land Use & Infra|Avg Distance Covered by Bicycle (km)	1.97	1.63	1.97	1.63	2.57	1.70	1.63	2.34	1.98	2.34	2.57	1.70	2.57	1.98
Land Use & Infra|Avg Distance Covered by Car (km)	10.80	14.14	10.80	14.14	18.43	20.86	14.14	14.31	14.59	14.31	18.43	20.86	18.43	14.59
Land Use & Infra|Avg Distance Covered by Public Transport (km)	7.93	4.22	7.93	4.22	4.52	3.31	4.22	8.05	5.37	8.05	4.52	3.31	4.52	5.37
Land Use & Infra|Avg Distance Covered by Walking (km)	1.53	1.23	1.53	1.23	1.13	1.06	1.23	1.41	1.28	1.41	1.13	1.06	1.13	1.28
Land Use & Infra|Bike Area (ha)	17.96	32.01	17.50	22.41	26.82	25.41	34.05	30.72	2.56	15.95	26.19	3.27	50.14	6.31
Land Use & Infra|Distance Covered by Biking (%)	0.09	0.08	0.09	0.08	0.10	0.06	0.08	0.09	0.01	0.09	0.10	0.06	0.10	0.00
Land Use & Infra|Distance Covered by Motor Traffic (%)	0.46	0.63	0.46	0.63	0.65	0.73	0.63	0.53	0.60	0.53	0.65	0.73	0.65	0.60
Land Use & Infra|Distance Covered by Public Transit (%)	0.34	0.19	0.34	0.19	0.16	0.11	0.19	0.30	0.22	0.30	0.16	0.11	0.16	0.22
Land Use & Infra|Distance Covered by Walking (%)	0.06	0.05	0.06	0.05	0.04	0.04	0.05	0.05	0.05	0.05	0.04	0.04	0.04	0.05
Land Use & Infra|Greenery Area (ha)	103.95	513.77	167.32	174.78	608.14	454.26	475.58	560.89	9.72	183.26	1003.80	80.20	755.03	30.43
Land Use & Infra|highway (ha)	0.00	35.87	22.66	0.00	21.91	25.94	48.75	1.54	0.00	10.86	25.06	2.06	43.12	3.63
Land Use & Infra|Infrastructure Area Total	221.26	360.53	236.27	316.13	269.83	271.91	396.45	325.96	25.83	208.59	218.82	34.96	546.10	59.41
Land Use & Infra|Infrastructure Bike Area (%)	0.08	0.09	0.07	0.07	0.10	0.09	0.09	0.09	0.10	0.08	0.12	0.09	0.09	0.11
Land Use & Infra|Infrastructure Motor Traffic (Roads & Parking) (%)	0.32	0.44	0.44	0.34	0.49	0.49	0.48	0.42	0.66	0.42	0.59	0.40	0.49	0.66
Land Use & Infra|Infrastructure Non-Motor Traffic (Walking & Bike) (%)	0.59	0.52	0.54	0.57	0.49	0.49	0.46	0.51	0.33	0.50	0.40	0.54	0.46	0.29
Land Use & Infra|Infrastructure Parking Area (%)	0.05	0.04	0.10	0.09	0.05	0.09	0.06	0.11	0.09	0.11	0.09	0.00	0.11	0.14
Land Use & Infra|Infrastructure Public Transit (%)	0.09	0.05	0.02	0.09	0.03	0.02	0.06	0.06	0.00	0.09	0.02	0.06	0.05	0.05
Land Use & Infra|Infrastructure Walking Area (%)	0.51	0.43	0.47	0.50	0.39	0.40	0.37	0.42	0.23	0.42	0.28	0.45	0.37	0.18
Land Use & Infra|Land Area (ha)	413.00	1119.00	515.00	662.00	1163.00	936.00	1179.00	1042.00	123.00	511.00	1642.00	158.00	1738.00	184.00
Land Use & Infra|Modal Split Biking (%)	0.22	0.15	0.22	0.15	0.23	0.14	0.15	0.26	0.22	0.26	0.23	0.14	0.23	0.23
Land Use & Infra|Modal Split Motor Traffic (%)	0.20	0.32	0.20	0.32	0.36	0.50	0.32	0.21	0.20	0.21	0.36	0.50	0.36	0.35
Land Use & Infra|Modal Split Other (%)	0.02	0.04	0.02	0.04	0.03	0.04	0.04	0.02	0.02	0.02	0.03	0.04	0.03	0.03
Land Use & Infra|Modal Split Public Transit (%)	0.16	0.15	0.16	0.15	0.10	0.09	0.15	0.14	0.16	0.14	0.10	0.09	0.10	0.12
Land Use & Infra|Modal Split Total (%)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Land Use & Infra|Modal Split Walking (%)	0.39	0.34	0.39	0.34	0.27	0.23	0.34	0.37	0.39	0.37	0.27	0.23	0.27	0.27

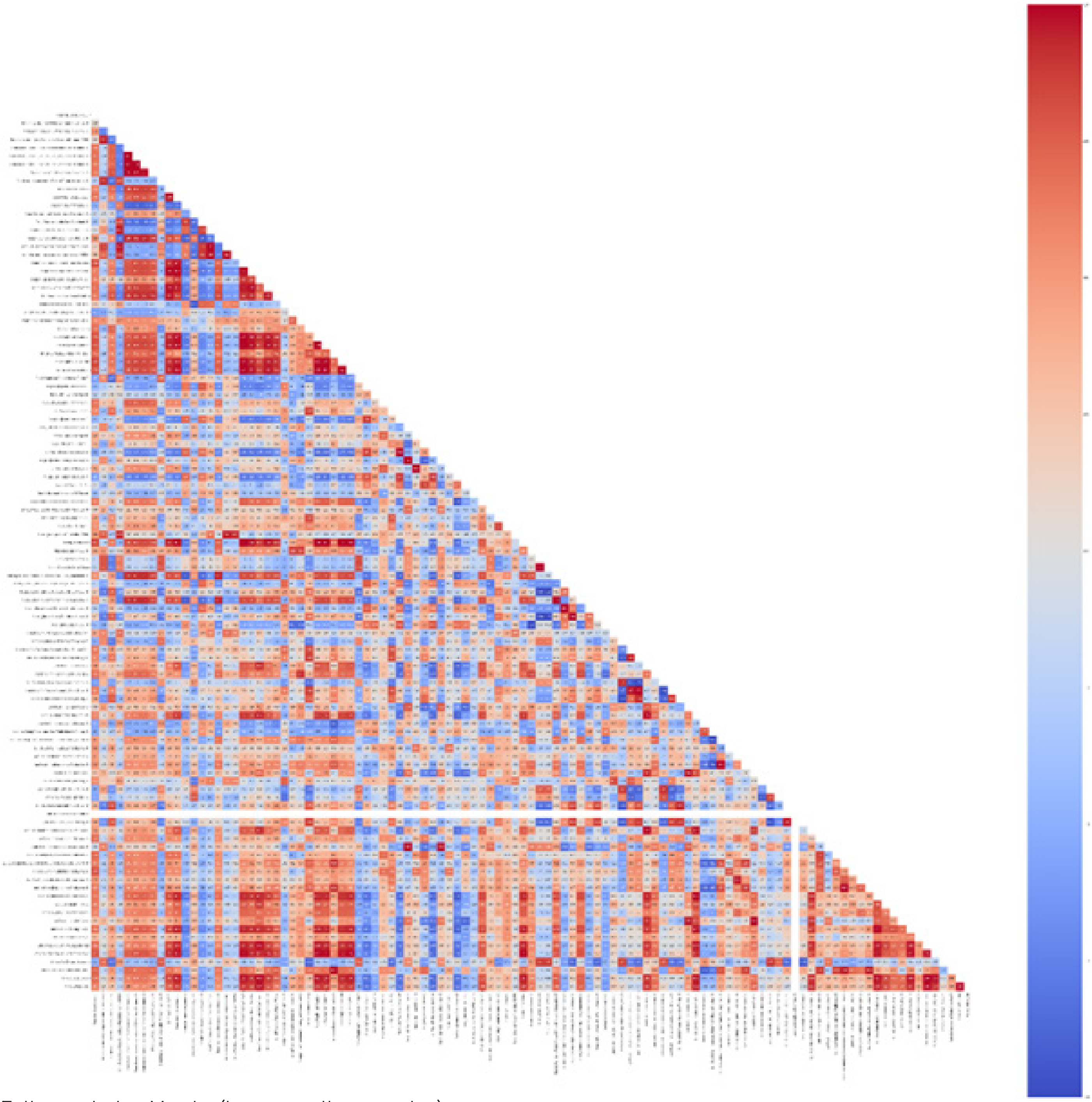
Land Use & Infra|Motor Traffic Area (Roads + Parking) (ha)	71.74	158.35	103.27	106.40	131.09	132.72	188.93	138.15	17.16	86.97	128.31	14.11	267.87	38.96
Land Use & Infra|Neighbourhood Bike Area (%)	0.04	0.03	0.03	0.03	0.02	0.02	0.03	0.02	0.01	0.03	0.02	0.02	0.03	0.03
Land Use & Infra|Neighborhood Greenery Area (%)	0.21	0.43	0.28	0.20	0.46	0.44	0.36	0.44	0.05	0.34	0.58	0.50	0.41	0.15
Land Use & Infra|Neighborhood Motor Traffic Area (%)	0.15	0.13	0.17	0.12	0.10	0.13	0.14	0.11	0.08	0.16	0.07	0.09	0.14	0.19
Land Use & Infra|Neighborhood Non-Motor Traffic Area (Walking + Bike) (%)	0.27	0.16	0.22	0.21	0.10	0.13	0.14	0.13	0.04	0.19	0.05	0.12	0.14	0.08
Land Use & Infra|Neighborhood Parking Area (%)	0.02	0.01	0.04	0.03	0.01	0.02	0.02	0.03	0.01	0.04	0.01	0.00	0.03	0.04
Land Use & Infra|Neighborhood Public Transit Area (%)	0.04	0.01	0.01	0.04	0.01	0.01	0.02	0.02	0.00	0.04	0.00	0.01	0.01	0.02
Land Use & Infra|Neighborhood Walking Area (%)	0.23	0.13	0.19	0.18	0.08	0.10	0.11	0.11	0.03	0.16	0.04	0.10	0.11	0.05
Land Use & Infra|Non-Motor Traffic Area (ha)	129.87	185.75	129.07	179.79	131.23	133.37	182.00	166.99	8.60	102.75	86.88	18.84	253.42	17.28
Land Use & Infra|Parking Area	11.83	14.68	22.66	28.79	13.08	25.11	22.14	37.12	2.31	23.02	20.64	0.01	62.09	8.14
Land Use & Infra|Public Transit Area (ha)	19.65	16.43	3.93	29.94	7.50	5.81	25.53	20.83	0.06	18.87	3.64	2.01	24.80	3.16
Land Use & Infra|railway track	16.88	13.55	2.71	26.86	5.84	5.11	20.78	17.18	0.06	17.02	3.44	2.01	23.07	3.13
Land Use & Infra|road area no park no highway (ha)	59.91	107.79	57.94	77.61	96.11	81.67	118.04	99.48	14.85	53.10	82.61	12.04	162.65	27.19
Land Use & Infra|road area no parking (ha)	59.91	143.67	80.61	77.61	118.01	107.61	166.79	101.02	14.85	63.95	107.67	14.10	205.78	30.82
Land Use & Infra|Total Area (ha)	488.00	1190.00	596.00	855.00	1326.00	1036.00	1309.00	1277.00	207.00	535.00	1732.00	162.00	1860.00	204.00
Land Use & Infra|Walking Area (ha)	111.91	153.74	111.57	157.38	104.41	107.96	147.95	136.27	6.04	86.80	60.69	15.57	203.28	10.97
Land Use & Infra|Water Area (ha)	75.00	71.00	81.00	192.00	163.00	99.00	130.00	235.00	84.00	24.00	90.00	4.00	122.00	20.00
Demo|High Level Education	16980.00	10410.00	20240.00	15230.00	15080.00	4290.00	8840.00	18080.00	480.00	20700.00	4770.00	610.00	22040.00	null
Demo|House. Income|20% Highest Income Households (%)	0.16	0.07	0.11	0.11	0.28	0.15	0.11	0.13	0.06	0.14	0.22	0.20	0.18	null
Demo|House. Income|40% Lowest Income Households (%)	0.50	0.61	0.59	0.59	0.41	0.44	0.52	0.58	0.50	0.53	0.43	0.33	0.47	null
Demo|House. Income|Avg. Standardized Household Income (*1000€)	34.20	25.10	26.60	26.90	39.00	29.80	27.70	30.60	null	30.00	32.80		31.90	null
Demo|House. Income|Households At or Around Social Minimum (%)	0.11	0.16	0.18	0.19	0.10	0.10	0.13	0.15	0.01	0.13	0.11	0.04	0.11	null
Demo|House. Income|Households Up to 110% of Social Minimum (%)	0.14	0.21	0.23	0.25	0.14	0.13	0.18	0.20	0.03	0.17	0.15	0.06	0.16	null
Demo|House. Income|Households Up to 120% of Social Minimum (%)	0.17	0.25	0.27	0.29	0.16	0.16	0.22	0.23	0.03	0.20	0.18	0.08	0.19	null
Demo|House. Income|Low Income Households (%)	0.11	0.16	0.17	0.18	0.10	0.09	0.13	0.14	0.03	0.13	0.10	0.04	0.10	null
Demo|House. Income|Median Wealth of Private Households (%)	0.10	0.03	0.03	0.02	1.15	0.28	0.12	0.05	0.03	0.09	0.59	0.81	0.37	null
Demo|Low Level Education	6690.00	20380.00	21040.00	22870.00	7310.00	9680.00	16880.00	10810.00	370.00	10220.00	4060.00	1200.00	19570.00	null
Demo|Medium Level Education	9250.00	23120.00	20570.00	22450.00	9450.00	12420.00	19420.00	15380.00	190.00	12640.00	5190.00	1870.00	28990.00	null
Demo|Net Labor Participation (%)	0.70	0.62	0.63	0.59	0.68	0.66	0.62	0.60	0.76	0.70	0.69	0.72	0.65	null
Demo|Overweight and Obesity (Severe Overweight) (%)	0.12	0.21	0.17	0.21	0.14	0.22	0.21	0.14	0.09	0.14	0.17	0.19	0.17	0.17

Demo|Perceived Health (Good/Very Good) (%)	0.79	0.72	0.73	0.69	0.79	0.73	0.72	0.76	0.87	0.77	0.77	0.78	0.75	0.79
Demo|Pers. Income|20% Highest Income Persons (%)	0.29	0.10	0.15	0.14	0.31	0.17	0.13	0.21	0.29	0.23	0.24	0.20	0.21	null
Demo|Pers. Income|40% Lowest Income Persons (%)	0.38	0.49	0.50	0.52	0.37	0.41	0.46	0.47	0.21	0.40	0.39	0.37	0.41	null
Demo|Pers. Income|Average Income per Recipient (*1000€)	42.40	27.50	30.10	29.70	45.90	32.20	29.60	35.90	null	35.80	38.50	34.70	35.90	null
Demo|Pers. Income|Average Income per Resident (*1000€)	36.80	21.60	24.10	23.20	35.30	26.00	23.30	29.40	null	30.00	29.10	28.50	29.10	null
Demo|Pers. Income|Number of Income Recipients	29500.00	52900.00	60100.00	59000.00	33600.00	27900.00	46600.00	42000.00	800.00	43100.00	14400.00	4000.00	75900.00	100.00
Demo|Persons by Type of Benefit; Disability,	990.00	3390.00	3060.00	3560.00	1200.00	1590.00	2820.00	1800.00	0.00	1840.00	670.00	160.00	3780.00	null
Demo|Persons by Type of Benefit; Old Age Pension	4230.00	7560.00	7110.00	9210.00	7730.00	6530.00	9820.00	7140.00	0.00	5260.00	2880.00	900.00	19600.00	20.00
Demo|Persons by Type of Benefit; Unemployment	410.00	1120.00	980.00	1020.00	460.00	420.00	730.00	540.00	10.00	640.00	230.00	50.00	1000.00	null
Demo|Persons by Type of Benefit; Welfare	1730.00	4620.00	5720.00	6140.00	1480.00	1370.00	3760.00	3070.00	10.00	2860.00	710.00	60.00	3710.00	null
Demo|Physical Activity (Meets Guidelines) (%)	0.51	0.43	0.49	0.42	0.49	0.40	0.38	0.48	0.55	0.51	0.45	0.42	0.42	0.46
Demo|Workers Distribution|Percentage of Employees (%)	0.84	0.84	0.83	0.84	0.79	0.89	0.86	0.84	0.91	0.84	0.82	0.88	0.85	null
Demo|Workers Distribution|Percentage of Self-employed (%)	0.16	0.16	0.17	0.16	0.21	0.11	0.14	0.16	0.09	0.16	0.18	0.12	0.15	null
Dens & Pop|Address Density	6306.00	3805.00	5711.00	4896.00	2322.00	2060.00	2570.00	5261.00	3539.00	6657.00	1694.00	746.00	2707.00	1486.00
Dens & Pop|Female Population	18535.00	33740.00	37885.00	39350.00	23190.00	18195.00	31225.00	28560.00	445.00	26415.00	9730.00	2440.00	49750.00	45.00
Dens & Pop|Male Population	20175.00	35900.00	38725.00	38585.00	21295.00	17380.00	29960.00	26170.00	665.00	26005.00	9805.00	2420.00	45870.00	45.00
Dens & Pop|Population Density (Per km^2)	9365.00	6225.00	14861.00	11767.00	3826.00	3799.00	5190.00	5254.00	900.00	10257.00	1190.00	3079.00	5502.00	48.00
Dens & Pop|Total Households	23040.00	35520.00	39755.00	38350.00	20600.00	16350.00	29030.00	31680.00	805.00	29740.00	8720.00	2225.00	46545.00	45.00
Dens & Pop|Total Population	38710.00	69645.00	76605.00	77935.00	44485.00	35575.00	61180.00	54725.00	1110.00	52425.00	19535.00	4860.00	95625.00	90.00
Dens & Pop|Urban Address Density (Per km^2)	1.00	1.00	1.00	1.00	2.00	2.00	1.00	1.00	1.00	1.00	2.00	4.00	1.00	3.00
Env Quality|Majority Decibel Level (dB)	58.00	53.00	55.00	51.00	53.00	48.00	56.00	57.00	69.00	58.00	57.00	60.00	48.00	63.00
Env Quality|maximal NO2 (µg/m3)	34.30	36.85	35.04	36.24	34.73	35.00	28.25	34.61	38.14	36.28	38.03	34.46	33.38	41.79
Env Quality|Maximum Decibel Level (dB)	81.00	84.00	86.00	86.00	86.00	84.00	85.00	83.00	73.00	91.00	84.00	78.00	85.00	91.00
Env Quality|Maximum UHI (C)	2.63	2.27	2.36	2.48	1.87	1.98	1.87	2.57	2.18	2.65	2.07	1.84	2.06	2.38
Env Quality|Mean Decibel Level (dB)	60.55	58.31	58.91	57.70	58.62	59.14	58.93	60.15	64.69	61.81	57.85	62.32	56.65	65.34
Env Quality|Mean Greenery Percentage (%)	40.61	55.06	39.86	37.38	57.25	56.73	50.63	63.65	22.86	45.42	69.75	57.69	50.34	33.53
Env Quality|mean NO2 (µg/m3)	23.39	23.55	26.79	28.19	26.01	27.17	25.27	25.31	23.62	26.14	25.40	23.82	26.25	28.93
Env Quality|Mean UHI Effect (C)	1.72	1.18	1.62	1.48	0.83	0.99	1.15	0.90	1.43	1.62	0.51	1.16	1.15	1.87
Env Quality|Median Decibel Level (dB)	60.00	57.00	58.00	56.00	57.00	59.00	58.00	59.00	64.00	60.00	57.00	62.00	55.00	65.00
Env Quality|Median Greenery Percentage (%)	30.00	58.00	30.00	27.00	60.00	61.00	48.00	76.00	7.00	40.00	88.00	65.00	48.00	21.00
Env Quality|median NO2 (µg/m3)	23.03	23.30	26.50	27.57	25.85	26.19	25.20	24.61	23.64	26.00	24.91	23.07	25.45	28.55
Env Quality|Minimum Decibel Level (dB)	47.00	46.00	48.00	46.00	49.00	47.00	46.00	47.00	56.00	49.00	46.00	56.00	44.00	56.00

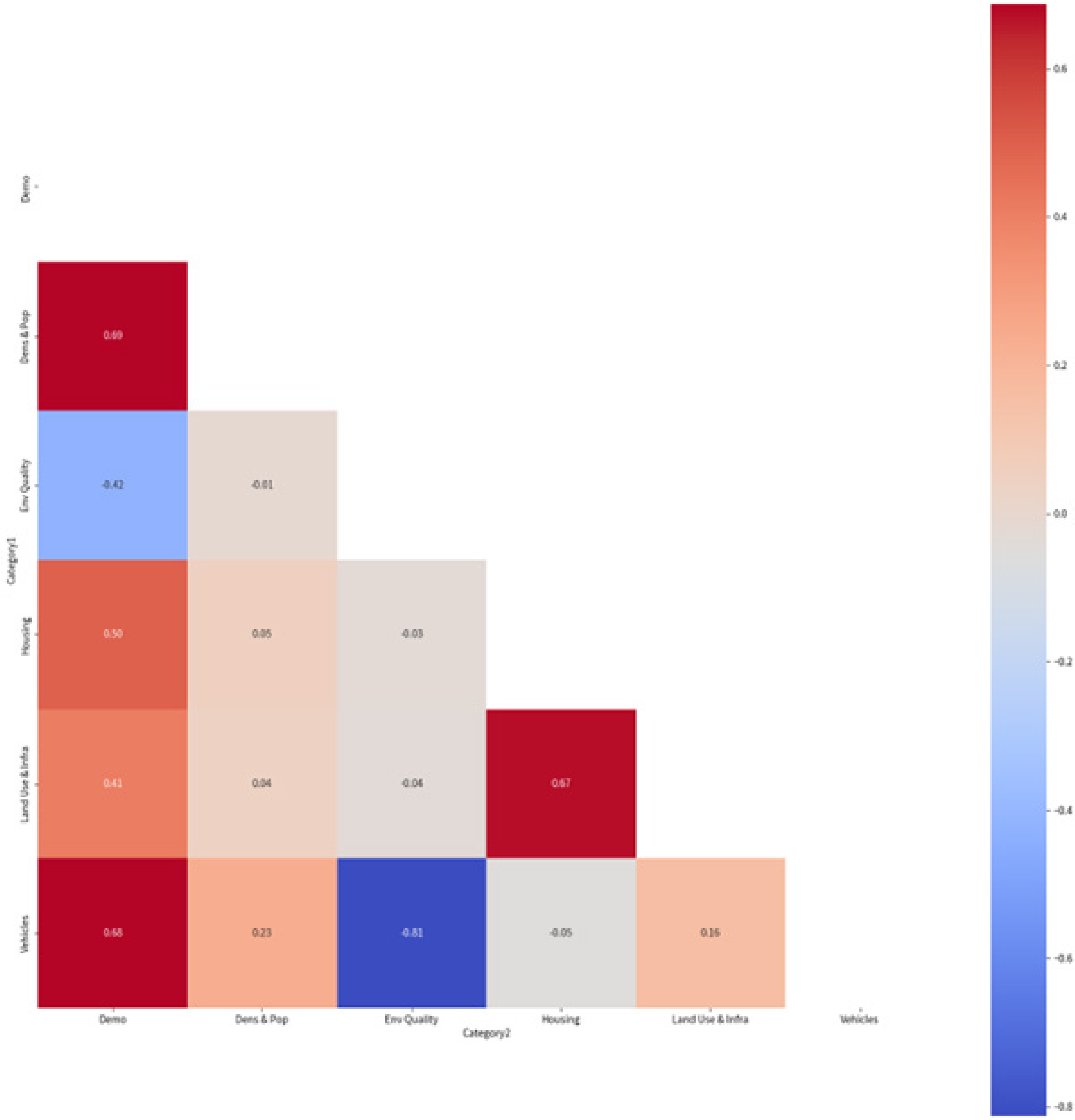
Env Quality|Minimum UHI (C)	0.56	0.39	0.67	0.55	0.24	0.08	0.47	0.05	0.69	0.64	0.03	0.71	0.17	1.02
Env Quality|relative greenery (%)	0.21	0.43	0.28	0.20	0.46	0.44	0.36	0.44	0.05	0.34	0.58	0.50	0.41	0.15
Env Quality|standard deviation NO2 (g/m3)	2.62	2.68	1.50	2.15	2.02	2.63	0.49	2.06	3.03	1.64	2.05	2.48	1.98	1.76
Env Quality|Standard Deviation of Decibel Level (dB)	7.11	6.76	5.91	7.16	6.41	7.34	7.15	6.52	4.04	7.66	6.61	3.92	7.73	4.29
Env Quality|Standard Deviation of Greenery Percentage (%)	36.26	36.16	35.29	33.65	35.47	37.01	36.65	36.44	30.54	35.81	35.16	38.03	35.13	34.59
Env Quality|Standard Deviation of UHI (C)	0.57	0.40	0.39	0.47	0.28	0.41	0.29	0.50	0.43	0.52	0.41	0.20	0.39	0.28
Env Quality|UHI Range (C)	2.07	1.88	1.69	1.93	1.63	1.89	1.40	2.52	1.49	2.02	2.04	1.13	1.88	1.36
Housing|Average House Price Value (*1000€)	322.00	161.00	222.00	217.00	369.00	212.00	188.00	298.00	170.00	267.00	275.00	209.00	265.00	326.00
Housing|Housing Stock	20142.00	34299.00	35440.00	36778.00	20842.00	16126.00	28858.00	28273.00	866.00	27514.00	8792.00	2269.00	46046.00	30.00
Housing|Occupied Houses (%)	0.91	0.93	0.95	0.93	0.95	0.96	0.95	0.93	0.78	0.94	0.94	0.95	0.97	0.60
Housing|Owned Houses (%)	0.28	0.28	0.27	0.21	0.54	0.45	0.38	0.25	0.00	0.33	0.51	0.73	0.44	0.57
Housing|Ownership|Owned Houses	0.28	0.28	0.27	0.21	0.54	0.45	0.38	0.25	0.00	0.33	0.51	0.73	0.44	0.57
Housing|Ownership|Rented Houses|Owned by Housing Corporation (%)	0.31	0.43	0.48	0.60	0.31	0.45	0.48	0.48	0.00	0.37	0.39	0.21	0.45	0.00
Housing|Ownership|Rented Houses|Owned by Other Landlords (%)	0.40	0.29	0.25	0.19	0.15	0.10	0.14	0.26	1.00	0.30	0.10	0.05	0.11	0.43
Housing|Ownership|Rented Houses|Total Rented Houses (%)	0.72	0.71	0.73	0.79	0.46	0.55	0.62	0.73	1.00	0.67	0.49	0.27	0.56	0.43
Housing|Rented Houses|Owned by Housing Corporation (%)	0.31	0.43	0.48	0.60	0.31	0.45	0.48	0.48	0.00	0.37	0.39	0.21	0.45	0.00
Housing|Rented Houses|Owned by Other Landlords (%)	0.40	0.29	0.25	0.19	0.15	0.10	0.14	0.26	1.00	0.30	0.10	0.05	0.11	0.43
Housing|Rented Houses|Total Rented Houses (%)	0.72	0.71	0.73	0.79	0.46	0.55	0.62	0.73	1.00	0.67	0.49	0.27	0.56	0.43
Housing|Unoccupied Houses (%)	0.09	0.07	0.05	0.07	0.05	0.04	0.05	0.07	0.22	0.06	0.06	0.05	0.03	0.40
Vehicles|Cars|Cars by Fuel Type|Gasoline Cars	10305.00	17935.00	16025.00	17975.00	14705.00	13060.00	18545.00	13270.00	245.00	12235.00	6355.00	2035.00	32530.00	410.00
Vehicles|Cars|Cars by Fuel Type|Other Fuel Cars	2495.00	3665.00	3670.00	4120.00	2800.00	1935.00	3395.00	2840.00	105.00	2285.00	1275.00	225.00	5325.00	395.00
Vehicles|Cars|Cars per Household	0.60	0.60	0.50	0.60	0.90	0.90	0.80	0.50	0.50	0.50	0.90	1.00	0.80	null
Vehicles|Cars|Cars per Surface Area (km^2)	3096.00	1931.00	3820.00	3337.00	1503.00	1601.00	1861.00	1545.00	287.00	2837.00	511.00	1430.00	2178.00	null
Vehicles|Cars|Total Cars	12800.00	21605.00	19695.00	22095.00	17505.00	14995.00	21940.00	16110.00	355.00	14525.00	7625.00	2255.00	37860.00	805.00
Vehicles|Motorcycles	585.00	1100.00	880.00	1055.00	955.00	1000.00	1290.00	740.00	15.00	995.00	550.00	255.00	2030.00	40.00

Appendix 5

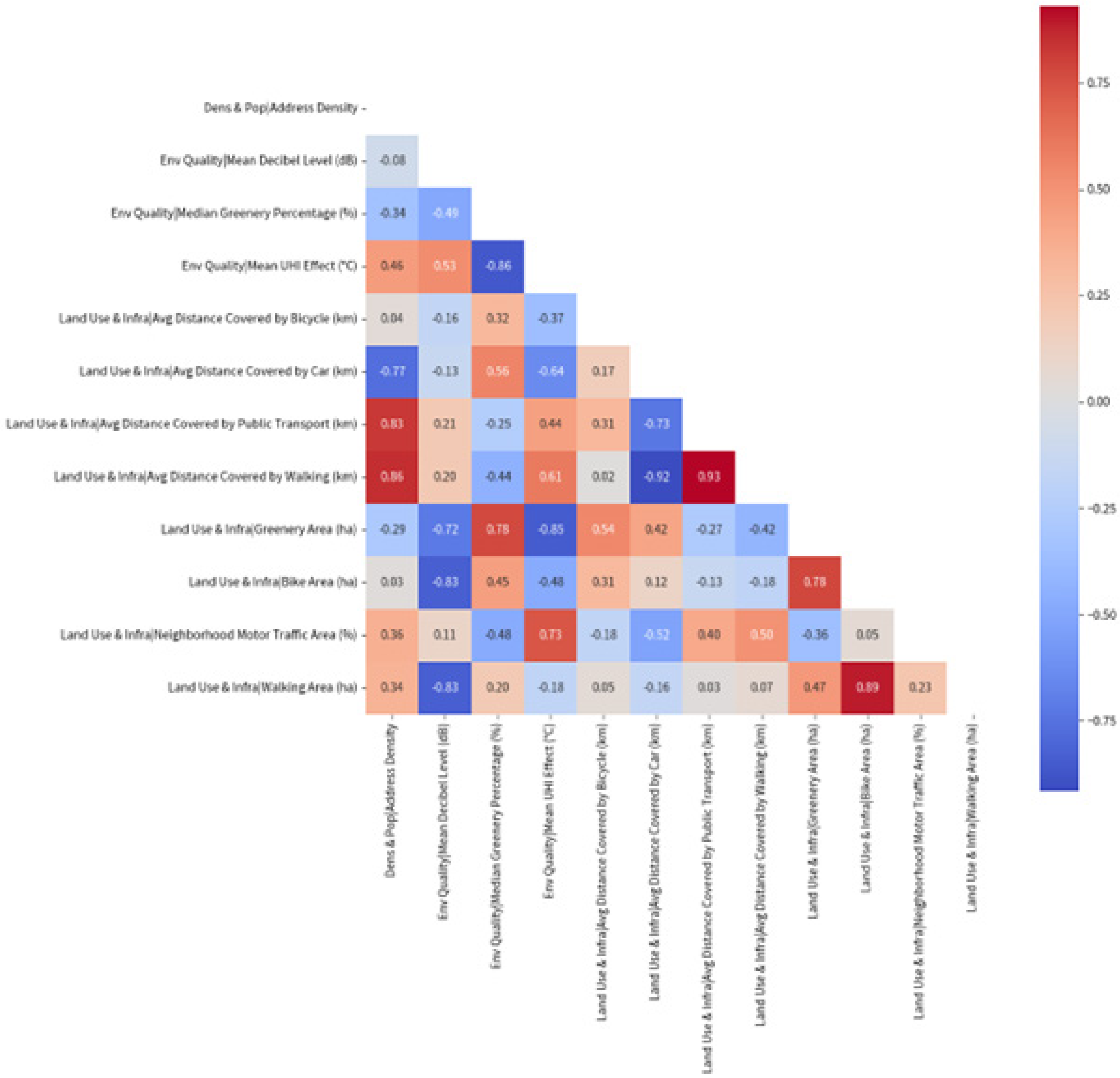
Different Correlation Matrix, the code for the calculation of the matrix's can be found in the data files as a Jupiter Notebook.



Full correlation Matrix, (between all catagories)



Catagorized correlation Matrix



Selected catagories correlation Matrix

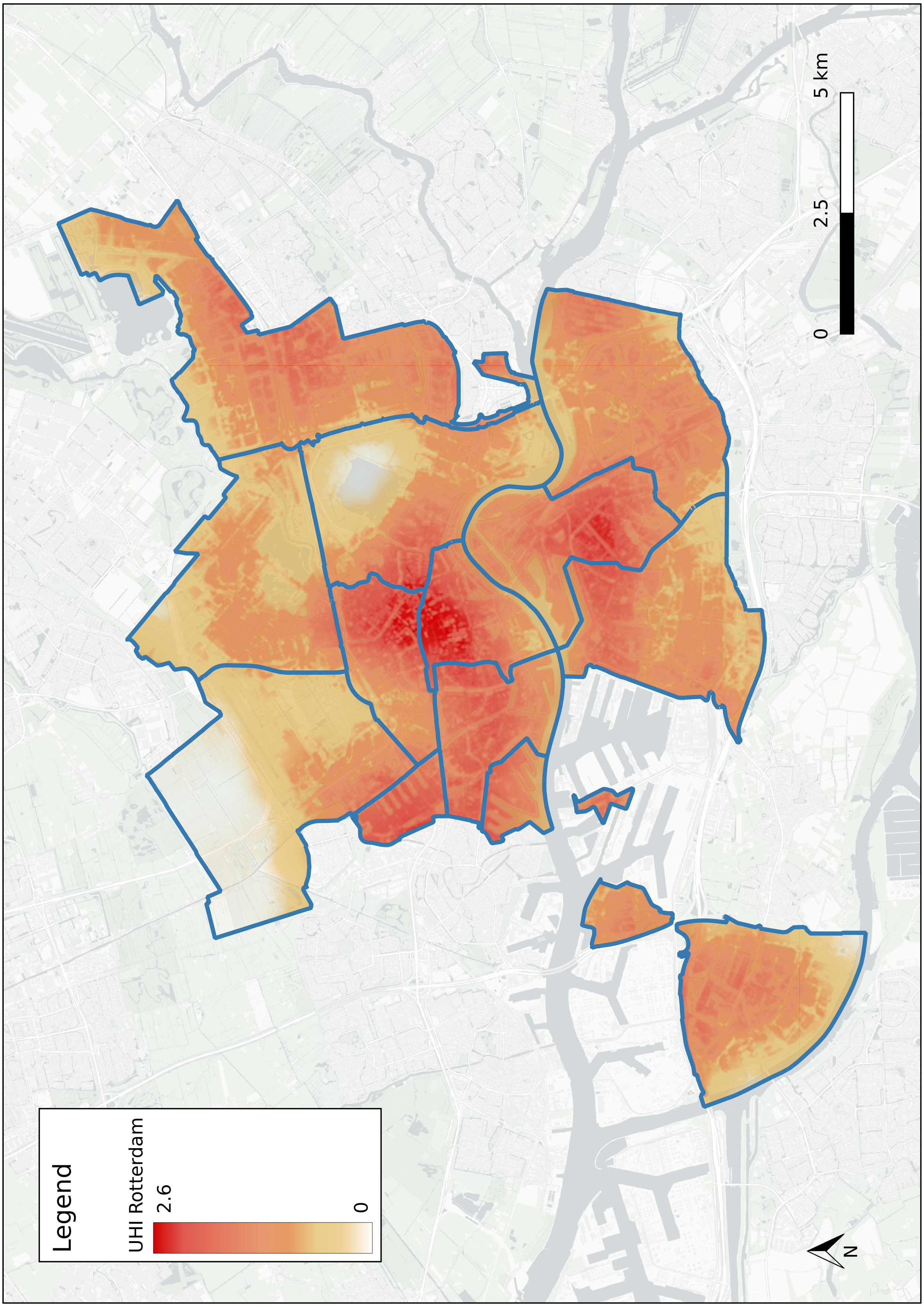
Appendix 6

S routes in Rotterdam with known lengths

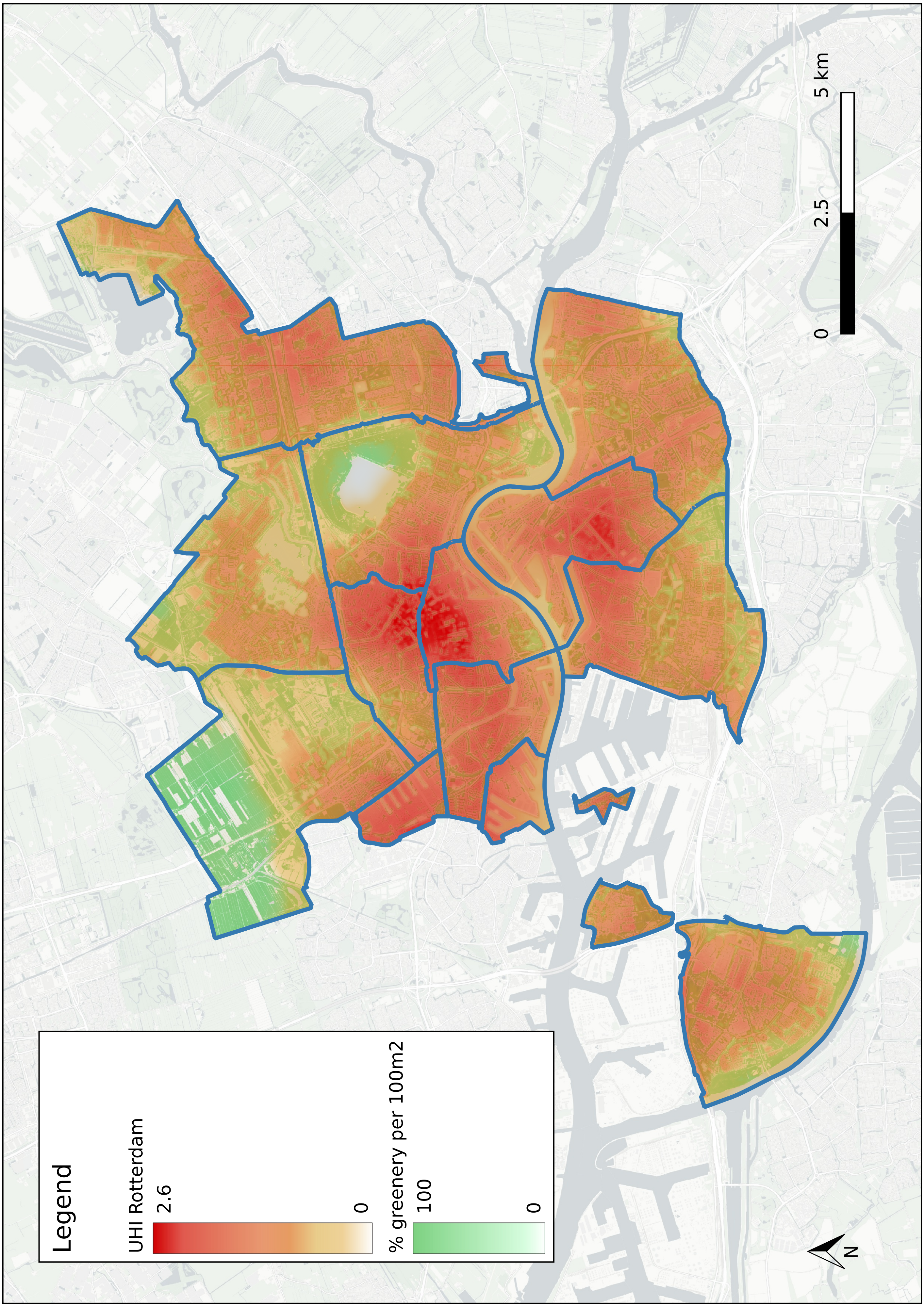
S road	Lenght (km)
s100	7
s101	9
s102	10
s103	5
s104	2
s105	5
s106	5
s107	6
s108	3
s109	10
s110	
s111	1
s112	6
s113	3
s114	8
s115	2
s116	
s117	
s118	6
s119	
s120	3
s121	4
s122	3
s123	5
s124	3
s125	2
s126	4
s127	4

Appendix 7

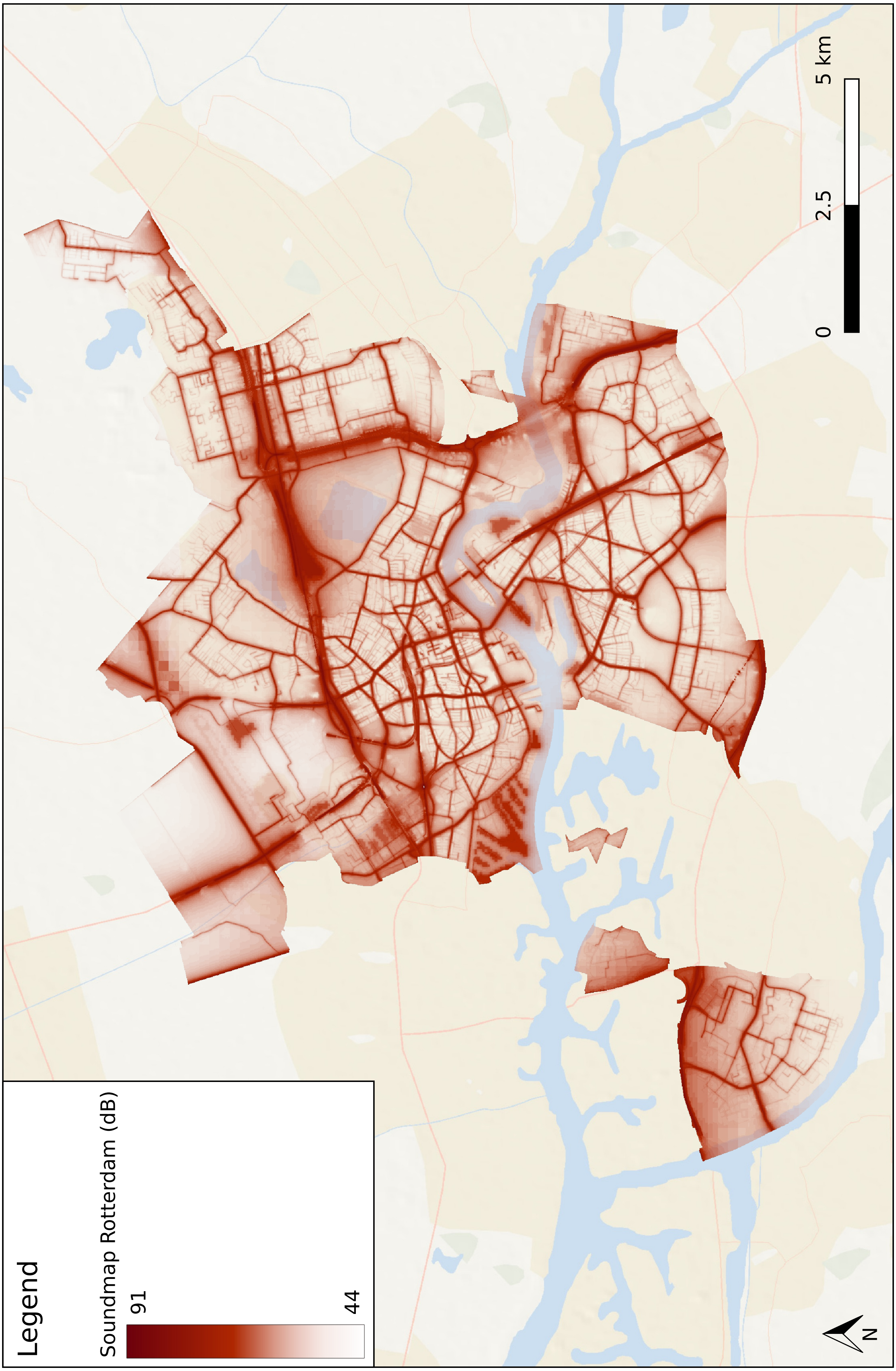
Full size maps, in the order: UHI effect map, UHI with greenery map, measured noise map and NOx concentration.



The UHI effect in Rotterdam



The UHI Effect with the current greenery %



Map with N

Appendix 8

Livability Ranking

Neighborhood	Env Quality|Maximum UHI (C)	Land Use & Infra|Infrastructure Walking Area (%)	Land Use & Infra|Infrastructure Motor Traffic (Roads & Parking) (%)	Land Use & Infra|Infrastructure Bike Area (%)	Env Quality|maximal NO2 (u g/m3)	Env Quality|Maximum Decibel Level (dB)	Env Quality|Majority Decibel Level (dB)	Vehicles|Cars|Cars per Surface Area (km^2)	Land Use & Infra|Parking Area	Relative Greenery Area (%)	Relative Parking Area (%)	Liveability Index	Liveability Rank
Hillegersberg-Schiebroek	1	0.48	0.37	0.6	0.34	0.5	0.5	0.7	0.98	0.68	0.82	0.63	1
Ijsselmonde	1	0.39	0.41	0.4	1	0.6	0.2	0.59	0.79	0.42	0.9	0.61	2
Hoogvliet	0.86	0.52	0.37	0.4	0.31	0.7	1	0.67	0.74	0.62	0.47	0.61	3
Charlois	0.49	0.65	0.56	0.4	0.12	0.7	0.5	0.57	0.94	0.61	1	0.59	4
Prins Alexander	0.76	0.39	0.37	0.4	0.48	0.6	1	0.5	0	0.54	0.78	0.53	5
Overschie	0.74	0	0	1	0	0.7	0.1	1	0.82	1	0.28	0.51	6
Centrum	0.03	1	1	0.2	0.38	1	0	0.22	1	0.02	0.72	0.51	7
Kralingen Crooswijk	0.1	0.61	0.63	0.4	0.35	0.8	0.1	0.69	0.5	0.63	0.46	0.48	8
Feyenoord	0.22	0.96	0.93	0	0.18	0.5	0.7	0.15	0.66	0	0.58	0.44	9
Delfshaven	0.37	0.83	0.56	0	0.31	0.5	0.3	0	0.78	0.2	0.25	0.37	10
Noord	0	0.61	0.63	0.2	0.18	0	0	0.3	0.78	0.37	0	0.28	11

Appendix 9

Weighted improvement Ranking

Neighborhood	Env Quality|Maximum UHI (C)	Land Use & Infra|Infrastructure Walking Area (%)	Land Use & Infra|Infrastructure Motor Traffic (Roads & Parking) (%)	Land Use & Infra|Infrastructure Bike Area (%)	Env Quality|maximal NO2 (u g/m3)	Env Quality|Maximum Decibel Level (dB)	Env Quality|Majority Decibel Level (dB)	Vehicles|Cars|Cars per Surface Area (km^2)	Land Use & Infra|Parking Area	Relative Greenery Area (%)	Relative Parking Area (%)	Improvement Index	Improvement Rank
Noord	1.5	0.47	0.56	0.96	1.23	1	1	0.7	0.33	0.76	1	9.51	1
Delfshaven	0.94	0.21	0.67	1.2	1.04	0.5	0.7	1	0.32	0.96	0.75	8.29	2
Feyenoord	1.17	0.05	0.11	1.2	1.23	0.5	0.3	0.85	0.51	1.2	0.42	7.54	3
Kralingen Crooswijk	1.35	0.47	0.56	0.72	0.98	0.2	0.9	0.31	0.75	0.45	0.54	7.23	4
Overschie	0.38	1.2	1.5	0	1.5	0.3	0.9	0	0.26	0	0.72	6.77	5
Prins Alexander	0.37	0.73	0.94	0.72	0.79	0.4	0	0.5	1.5	0.56	0.22	6.72	6
Centrum	1.46	0	0	0.96	0.93	0	1	0.78	0	1.17	0.28	6.58	7
Charlois	0.77	0.42	0.67	0.72	1.32	0.3	0.5	0.43	0.09	0.47	0	5.68	8
Hoogvliet	0.21	0.57	0.94	0.72	1.04	0.3	0	0.33	0.4	0.45	0.53	5.49	9
Ijsselmonde	0	0.73	0.89	0.72	0	0.4	0.8	0.41	0.31	0.69	0.1	5.04	10
Hillegersberg-Schiebroek	0	0.63	0.94	0.48	0.99	0.5	0.5	0.3	0.04	0.39	0.18	4.95	11

catagory	Weight given:
Env Quality|Maximum UHI (C)	1.5
Land Use & Infra|Infrastructure Walking Area (%)	1.2
Land Use & Infra|Infrastructure Motor Traffic (Roads & Parking) (%)	1.5
Land Use & Infra|Infrastructure Bike Area (%)	1.2
Env Quality|maximal NO2 (ug/m3)	1.5
Env Quality|Maximum Decibel Level (dB)	1
Env Quality|Majority Decibel Level (dB)	1
Vehicles|Cars|Cars per Surface Area (km^2)	1
Relative Greenery Area (%)	1.2
Relative Parking Area (%)	1
Land Use & Infra|Parking Area	1.5

Appendix 10

Spatial reallocation calculations per neighborhood

Neighborhood Characteristics for Centrum:
Total area: 488.0 ha Infrastructure area: 221.3 ha Max UHI: 2.63 Degrees C
Parking Space: Total parking area: 11.8 ha (Approximately 9500 parking spots) Reducing parking area by 26% would free up 3.1 ha, reducing the parking area to 8.8 ha This would result in the removal of approximately 2500 parking spots.
Road Dieting: Total road area: 59.9 ha (including highways), of which 0.0 ha is highways Reducing road area by 26% would result in a road area of 44.3 ha (excluding highways)
Enhancement of Active Mobility Infrastructure: Current bike lanes area: 18.0 ha Increasing bike lanes by 90% would result in a bike lanes area of 34.1 ha
Greenery: Neighborhood currently has 104.0 ha of greenery, which is about 21.0% of the neighbor-hood
Public Transport: Neighborhood currently has 19.6 ha of public transit area Within this, 16.9 ha is from railway tracks

Neighborhood Characteristics for Charlois:
Total area: 1190.0 ha Infrastructure area: 360.5 ha Max UHI: 2.27 Degrees C
Parking Space: Total parking area: 14.7 ha (Approximately 11800 parking spots) Reducing parking area by 26% would free up 3.8 ha, reducing the parking area to 10.9 ha This would result in the removal of approximately 3100 parking spots.
Road Dieting: Total road area: 143.7 ha (including highways), of which 35.9 ha is highways Reducing road area by 26% would result in a road area of 79.8 ha (excluding highways)
Enhancement of Active Mobility Infrastructure: Current bike lanes area: 32.0 ha Increasing bike lanes by 90% would result in a bike lanes area of 60.8 ha
Greenery: Neighborhood currently has 513.8 ha of greenery, which is about 43.0% of the neighborhood
Public Transport: Neighborhood currently has 16.4 ha of public transit area Within this, 13.6 ha is from railway tracks

Neighborhood Characteristics for Delfshaven:
Total area: 596.0 ha Infrastructure area: 236.3 ha Max UHI: 2.36 Degrees C
Parking Space: Total parking area: 22.7 ha (Approximately 18200 parking spots) Reducing parking area by 26% would free up 5.9 ha, reducing the parking area to 16.8 ha This would result in the removal of approximately 4800 parking spots
Road Dieting: Total road area: 80.6 ha (including highways), of which 22.7 ha is highways Reducing road area by 26% would result in a road area of 42.9 ha (excluding highways)
Enhancement of Active Mobility Infrastructure: Current bike lanes area: 17.5 ha Increasing bike lanes by 90% would result in a bike lanes area of 33.2 ha
Greenery: Neighborhood currently has 167.3 ha of greenery, which is about 28.0% of the neighborhood
Public Transport: Neighborhood currently has 3.9 ha of public transit area Within this, 2.7 ha is from railway tracks

Neighborhood Characteristics for Feyenoord:
Total area: 855.0 ha Infrastructure area: 316.1 ha Max UHI: 2.48 Degrees C
Parking Space: Total parking area: 28.8 ha (Approximately 23100 parking spots) Reducing parking area by 26% would free up 7.5 ha, reducing the parking area to 21.3 ha This would result in the removal of approximately 6000 parking spots.
Road Dieting: Total road area: 77.6 ha (including highways), of which 0.0 ha is highways Reducing road area by 26% would result in a road area of 57.4 ha (excluding highways)
Enhancement of Active Mobility Infrastructure: Current bike lanes area: 22.4 ha. Increasing bike lanes by 90% would result in a bike lanes area of 42.6 ha
Greenery: Neighborhood currently has 174.8 ha of greenery, which is about 20.0% of the neighborhood
Public Transport: Neighborhood currently has 29.9 ha of public transit area Within this, 26.9 ha is from railway tracks

Neighborhood Characteristics for Hillegersberg-schiebroek:
Total area: 1326.0 ha Infrastructure area: 269.0 ha Max UHI: 1.87 Degrees C
Parking Space: Total parking area: 13.1 ha (Approximately 10500 parking spots) Reducing parking area by 26% would free up 3.4 ha, reducing the parking area to 9.7 ha This would result in the removal of approximately 2800 parking spots.
Road Dieting: Total road area: 118.0 ha (including highways), of which 21.9 ha is highways Reducing road area by 26% would result in a road area of 71.1 ha (excluding highways)
Enhancement of Active Mobility Infrastructure: Current bike lanes area: 26.8 ha Increasing bike lanes by 90% would result in a bike lanes area of 51.0 ha
Greenery: Neighborhood currently has 608.1 ha of greenery, which is about 46.0% of the neighborhood
Public Transport: Neighborhood currently has 7.5 ha of public transit area Within this, 5.8 ha is from railway tracks

Neighborhood Characteristics for Hoogvliet:
Total area: 1036.0 ha Infrastructure area: 271.9 ha Max UHI: 1.98 Degrees C
Parking Space: Total parking area: 25.1 ha (Approximately 20100 parking spots) Reducing parking area by 26% would free up 6.5 ha, reducing the parking area to 18.6 ha This would result in the removal of approximately 5300 parking spots.
Road Dieting: Total road area: 107.6 ha (including highways), of which 25.9 ha is highways Reducing road area by 26% would result in a road area of 60.4 ha (excluding highways)
Enhancement of Active Mobility Infrastructure: Current bike lanes area: 25.4 ha Increasing bike lanes by 90% would result in a bike lanes area of 48.3 ha
Greenery: Neighborhood currently has 454.3 ha of greenery, which is about 44.0% of the neighborhood
Public Transport: Neighborhood currently has 5.8 ha of public transit area Within this, 5.1 ha is from railway tracks

Neighborhood Characteristics for Ijsselmonde:
Total area: 1309.0 ha Infrastructure area: 396.4 ha Max UHI: 1.87 Degrees C
Parking Space: Total parking area: 22.1 ha (Approximately 17800 parking spots) Reducing parking area by 26% would free up 5.8 ha, reducing the parking area to 16.4 ha This would result in the removal of approximately 4700 parking spots.
Road Dieting: Total road area: 166.8 ha (including highways), of which 48.7 ha is highways Reducing road area by 26% would result in a road area of 87.4 ha (excluding highways)
Enhancement of Active Mobility Infrastructure: Current bike lanes area: 34.0 ha Increasing bike lanes by 90% would result in a bike lanes area of 64.7 ha
Greenery: Neighborhood currently has 475.6 ha of greenery, which is about 36.0% of the neighborhood
Public Transport: Neighborhood currently has 25.5 ha of public transit area Within this, 20.8 ha is from railway tracks

Neighborhood Characteristics for Kralingen Crooswijk:
Total area: 1277.0 ha Infrastructure area: 326.0 ha Max UHI: 2.57 Degrees C
Parking Space: Total parking area: 37.1 ha (Approximately 29700 parking spots) Reducing parking area by 26% would free up 9.7 ha, reducing the parking area to 27.5 ha This would result in the removal of approximately 7800 parking spots.
Road Dieting: Total road area: 101.0 ha (including highways), of which 1.5 ha is highways Reducing road area by 26% would result in a road area of 73.6 ha (excluding highways)
Enhancement of Active Mobility Infrastructure: Current bike lanes area: 30.7 ha Increasing bike lanes by 90% would result in a bike lanes area of 58.4 ha
Greenery: Neighborhood currently has 560.9 ha of greenery, which is about 44.0% of the neighborhood
Public Transport: Neighborhood currently has 20.8 ha of public transit area Within this, 17.2 ha is from railway tracks

Neighborhood Characteristics for Nieuw Matthenesse:
Total area: 207.0 ha Infrastructure area: 25.8 ha Max UHI: 2.18 Degrees C
Parking Space: Total parking area: 2.3 ha (Approximately 1900 parking spots) Reducing parking area by 26% would free up 0.6 ha, reducing the parking area to 1.7 ha This would result in the removal of approximately 500 parking spots.
Road Dieting: Total road area: 14.9 ha (including highways), of which 0.0 ha is highways Reducing road area by 26% would result in a road area of 11.0 ha (excluding highways)
Enhancement of Active Mobility Infrastructure: Current bike lanes area: 2.6 ha Increasing bike lanes by 90% would result in a bike lanes area of 4.9 ha
Greenery: Neighborhood currently has 9.7 ha of greenery, which is about 5.0% of the neighborhood
Public Transport: Neighborhood currently has 0.1 ha of public transit area Within this, 0.1 ha is from railway tracks

Neighborhood Characteristics for Noord:
Total area: 535.0 ha Infrastructure area: 208.6 ha Max UHI: 2.65 Degrees C
Parking Space: Total parking area: 23.0 ha (Approximately 18500 parking spots) Reducing parking area by 26% would free up 6.0 ha, reducing the parking area to 17.0 ha This would result in the removal of approximately 4800 parking spots.
Road Dieting: Total road area: 64.0 ha (including highways), of which 10.9 ha is highways Reducing road area by 26% would result in a road area of 39.3 ha (excluding highways)
Enhancement of Active Mobility Infrastructure: Current bike lanes area: 15.9 ha Increasing bike lanes by 90% would result in a bike lanes area of 30.3 ha
Greenery: Neighborhood currently has 183.3 ha of greenery, which is about 34.0% of the neighborhood
Public Transport: Neighborhood currently has 18.9 ha of public transit area Within this, 17.0 ha is from railway tracks

Neighborhood Characteristics for Overschie:
Total area: 1732.0 ha Infrastructure area: 218.8 ha Max UHI: 2.07 Degrees C
Parking Space: Total parking area: 20.6 ha (Approximately 16600 parking spots) Reducing parking area by 26% would free up 5.4 ha, reducing the parking area to 15.3 ha This would result in the removal of approximately 4300 parking spots.
Road Dieting: Total road area: 107.7 ha (including highways), of which 25.1 ha is highways Reducing road area by 26% would result in a road area of 61.1 ha (excluding highways)
Enhancement of Active Mobility Infrastructure: Current bike lanes area: 26.2 ha Increasing bike lanes by 90% would result in a bike lanes area of 49.8 ha
Greenery: Neighborhood currently has 1003.8 ha of greenery, which is about 58.0% of the neighborhood
Public Transport: Neighborhood currently has 3.6 ha of public transit area Within this, 3.4 ha is from railway tracks

Neighborhood Characteristics for Pernis:
Total area: 162.0 ha Infrastructure area: 35.0 ha Max UHI: 1.84 Degrees C
Parking Space: Total parking area: 0.01 ha (Approximately 100 parking spots) Reducing parking area by 26% would free up 0.0 ha, reducing the parking area to 0.0 ha This would result in the removal of approximately 100 parking spots.
Road Dieting: Total road area: 14.1 ha (including highways), of which 2.1 ha is highways Reducing road area by 26% would result in a road area of 8.9 ha (excluding highways)
Enhancement of Active Mobility Infrastructure: Neighborhood currently has 80.2 ha of greenery, which is about 50.0% of the neighborhood
Greenery: Neighborhood currently has 80.2 ha of greenery, which is about 50.0% of the neighborhood
Public Transport: Neighborhood currently has 2.0 ha of public transit area Within this, 2.0 ha is from railway tracks

Neighborhood Characteristics for Prins alexander:
Total area: 1860.0 ha Infrastructure area: 546.1 ha Max UHI: 2.06 Degrees C
Parking Space: Total parking area: 62.1 ha (Approximately 49700 parking spots) Reducing parking area by 26% would free up 16.1 ha, reducing the parking area to 45.9 ha This would result in the removal of approximately 13000 parking spots.
Road Dieting: Total road area: 205.8 ha (including highways), of which 43.1 ha is highways Reducing road area by 26% would result in a road area of 120.4 ha (excluding highways)
Enhancement of Active Mobility Infrastructure: Current bike lanes area: 50.1 ha Increasing bike lanes by 90% would result in a bike lanes area of 95.3 ha
Greenery: Neighborhood currently has 755.0 ha of greenery, which is about 41.0% of the neighborhood
Public Transport: Neighborhood currently has 24.8 ha of public transit area Within this, 23.1 ha is from railway tracks

Neighborhood Characteristics for Spaanse Polder:
Total area: 204.0 ha Infrastructure area: 59.4 ha Max UHI: 2.38 Degrees C
Parking Space: Total parking area: 8.1 ha (Approximately 6600 parking spots) Reducing parking area by 26% would free up 2.1 ha, reducing the parking area to 6.0 ha This would result in the removal of approximately 1700 parking spots.
Road Dieting: Total road area: 30.8 ha (including highways), of which 3.6 ha is highways Reducing road area by 26% would result in a road area of 20.1 ha (excluding highways)
Enhancement of Active Mobility Infrastructure: Current bike lanes area: 6.3 ha Increasing bike lanes by 90% would result in a bike lanes area of 12.0 ha
Greenery: Total road area: 30.8 ha (including highways), of which 3.6 ha is highways Reducing road area by 26% would result in a road area of 20.1 ha (excluding highways)
Public Transport: Neighborhood currently has 3.2 ha of public transit area Within this, 3.1 ha is from railway tracks

Appendix 11

Correlation Matrix between the Demographic categories and the specific selected categories

	Dens & Pop|Address Density	Env Quality|Mean Decibel Level (dB)	Env Quality|Median Greenery Percentage (%)	Env Quality|Mean UHI Effect (°C)	Land Use & Infra|Avg Distance Covered by Bicycle (km)	Land Use & Infra|Avg Distance Covered by Car (km)	Land Use & Infra|Avg Distance Covered by Public Transport (km)	Land Use & Infra|Avg Distance Covered by Walking (km)	Land Use & Infra|Greenery Area (ha)	Land Use & Infra|Bike Area (ha)	Land Use & Infra|Neighborhood Motor Traffic Area (%)	Land Use & Infra|Walking Area (ha)	Demo|Pers. Income|40% Lowest Income Persons (%)	Demo|Pers. Income|20% Highest Income Persons (%)	Demo|Perceived Health (Good/Very Good) (%)	Demo|House. Income|Households At or Around Social Minimum (%)	Demo|Low Level Education	Demo|High Level Education
Demo|Pers. Income|40% Lowest Income Persons (%)	0.27	-0.70	0.25	0.03	-0.25	-0.27	0.08	0.19	0.20	0.49	0.53	0.71	1.00	-0.76	-0.94	0.93	0.82	0.50
Demo|Pers. Income|20% Highest Income Persons (%)	0.02	0.42	-0.09	-0.07	0.63	0.11	0.27	0.08	-0.04	-0.30	-0.41	-0.47	-0.76	1.00	0.84	-0.60	-0.74	-0.02
Demo|Perceived Health (Good/Very Good) (%)	-0.13	0.71	-0.28	0.10	0.35	0.05	0.19	0.07	-0.28	-0.55	-0.32	-0.71	-0.94	0.84	1.00	-0.83	-0.82	-0.33
Demo|House. Income|Households At or Around Social Minimum (%)	0.52	-0.67	0.08	0.14	-0.09	-0.48	0.30	0.40	0.19	0.48	0.60	0.73	0.93	-0.60	-0.83	1.00	0.84	0.66
Demo|Low Level Education	0.33	-0.69	-0.16	0.25	-0.24	-0.38	0.03	0.19	0.12	0.60	0.68	0.85	0.82	-0.74	-0.82	0.84	1.00	0.59
Demo|High Level Education	0.69	-0.42	-0.14	0.36	0.41	-0.49	0.63	0.57	0.08	0.48	0.70	0.68	0.50	-0.02	-0.33	0.66	0.59	1.00