The Ideal Crossing

Urban microclimate impacts of a renovated traffic intersection: The Case of Hugo de Vrieslaan in Amsterdam-Oost.

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The Ideal Crossing. Urban microclimate impacts of a renovated traffic intersection: The Case of Hugo de Vrieslaan in Amsterdam-Oost

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EXECUTIVE SUMMARY

Urban environments must be prepared to address the impacts of climate change and mitigate its repercussions. The rapidly surging rate of urbanization is expected to instigate significant land use and land cover changes, through expansion and densification of the built environment, on top of urban population growth. The Netherlands, a highly urbanized delta and densely populated country, is a prime example experiencing significant urban growth and climate-related events causing distress. This country has increasingly witnessed extreme weather events resulting in record-breaking heatwaves, drought, and precipitation leading to the disruption of public and transport infrastructures. The Netherland's authorities have established new strategic spatial plans aimed at ensuring climate-proof infrastructure and climate resilience for the coming years. However, the extensive goals and targets at national and international levels complicate the situation. Key changes are being initiated at the local level, with results yet to be fully realized.

This research conducts a single case study on a renovated road intersection in Amsterdam Oost in collaboration with the Ideal(s) City project from the Amsterdam Institute for advanced metropolitan solutions. The primary aim is to investigate Amsterdam's impacts on climate resilience and adaptation strategies. To assess the progress towards the program's fifth ideal state of "sustainability", a conceptual indicator list is derived from a literature review. This indicator list serves as a tool to evaluate the program's inventory and study the sustainability outcomes of the case study. The examined indicator parameters include: (1) temperature & urban morphology, (2) surface materials, and (3) vegetation in the microclimate.

Through a combination of qualitative and quantitative secondary data, the case study is compared to the literary indicator list. This process results in a refined indicators set to support the development of The Ideal(s) City's framework. The findings reveal a notable absence of all indicators in the inventory of the Ideal(s) City and the municipality of Amsterdam. To address this gap, recommendations are laid out to: First, the scientific community to further explore the application of indicators on traffic intersections in the city. Second, the Ideal(s) City programme to review and evaluate the existing indicators to fill the gaps and minimize the mismatch between the indicators. Third, the municipality of Amsterdam to increase the planting of trees and their variety on the median at Hugo de Vrieslaan to increase climate resilience and enhance the microclimatic conditions of traffic intersection.

Keywords: Case study • Climate resilience • Adaptation strategy • Urban road infrastructure • Urban microclimate • Urban morphology • Urban greening • Sustainability • Environmental assessment

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1. Introduction

1.1 General Introduction

To moderate the repercussions of climate hazards, urban environments must be prepared to respond to and address current and future impacts of climate change (IPCC, 2022). Despite only covering 3% of the world's surface, urban systems are recognized as major contributors to global climate change (United Nations, 2019). Globally, over 70% of CO_2 emissions and 60% of energy demand are attributed to metropolitan areas due to anthropogenic and socio-economic activities (World Bank, 2020). Urban regions' sustainability and quality of life are additionally endangered by climate change. In other words, residents' livelihoods, health, and well-being are jeopardized (IPCC, 2021). By 2050, urban areas are projected to accommodate over two-thirds of the global population, resulting in an increase to around 6.5 billion urban residents (Sharifi, 2019). The rapidly surging rate of urbanization is expected to instigate substantial land use and land cover changes, through expansion and densification of the built environment (Wang & Upreti, 2019).

The Netherlands, a highly urbanized delta and densely populated country, is a prime example of experiencing significant urban growth and climate-related events causing distress (Mees et al., 2018). In recent years, this country has increasingly witnessed more extreme weather phenomena resulting in record-breaking heatwaves, drought, and precipitation leading to the disruption of public and transport infrastructures (De Telegraaf, 2022; BBC, 2022). According to the Royal Dutch Meteorological Institute (KNMI, 2019), the country can expect an average summer day in 2050 to be as warm as the summer of 2018, which was the hottest summer since 1901 with an average temperature of 20.7°C. In 2018, a task force consisting of local, regional, and national authorities was established to implement the Delta Plan on Spatial Adaptation. This strategic spatial plan is aimed at ensuring climate-proof infrastructure and water resilience in the Netherlands by 2050 (Ten Brinke et al., 2022).

Despite these efforts, Dutch scholars, including Van den Broeke, have expressed concerns about the perceived ineffectiveness of collaborations aimed at addressing climate change. While most options for climate resilience are analysed at a technical level, the hesitancy of politicians to discuss these measures has resulted in a potential gap in public understanding. As a consequence, a lack of support for climate-resilient approaches has emerged, highlighting the need to study the impacts of implemented climate measures and conveying them to the public (Hernández-Morales & Coi, 2023). The complex nature of urban systems further adds an incredible difficulty and challenge in addressing climate change in cities, most prominently observed in Amsterdam (Carter, 2018). The Netherlands' capital is grappling with a multiplicity of environmental, social, and economic urban challenges, which are often interrelated and require collective action (AMS Institute, 2021).

There is a consensus that cities are the primary domain in which key changes must be implemented for sustainable human development (Klopp & Petretta, 2017). Consequently, urban areas have an increasing urgency to prioritise the necessary changes and enforce effective measures (Teixeira et al., 2022). The situation is further complicated by the extensive lists of goals and targets on the national and European levels. Urban areas are important centres of economic and political power, so they provide an ideal environment for testing and implementing innovative solutions (Carter et al., 2017; Rosenzweig et al., 2010). In Amsterdam, a water management program called 'Amsterdam Rainproof' has been developed to explore the city's susceptibility and risks of flooding. The program's aim is to strengthen Amsterdam's resilience against extreme precipitation events by improving the streets' capacities for water retention in vulnerable areas of the city (Het Parool, 2021). This approach is often realized through the integration of additional green spaces (Amsterdam Rainproof, n.a.; NH Nieuws, 2021). To further expand the effectiveness of this strategy, however, the city council has chosen to target and incorporate it into the design of streets undergoing maintenance and repair in the upcoming years.

In practice, this strategy was recently implemented in the transformations of a concrete-paved traffic intersection located on the arterial road of Hugo de Vrieslaan in Amsterdam Oost. The primary objective of the renovation was to address the need for concrete renewal along a significant segment of that street. However, at the request of citizens and the municipality, this renewal offered the possibility for a safer and greener street. The final redesign then focused on adding green surfaces through implementing five green spaces of 399 m^2 total in the redevelopment of the intersection. Furthermore, it addressed people's safety concerns by delineating the road's usage between vehicles, pedestrians, and cyclists along with raising curbs to enhance safety perceptions (Gemeente Amsterdam, 2022).

There has been increasing recognition and efforts to address climate resilience and promote sustainable urban developments in Amsterdam. However, despite these efforts, the impacts of local, physical and transformative implementation measures for climate resilience in Amsterdam's urban areas have not been extensively studied (AMS, 2022, p.76). As a result, there is currently a lack of understanding regarding these initiatives implemented at a local scale. This research aims to bridge this knowledge gap and study the impact of the measures taken with a focus on the above-mentioned intersection on Hugo de Vrieslaan. While the safety and social developments of Hugo de Vrieslaan are important, this thesis will investigate the development from an environmental lens. This study aims to provide insights into the challenges and the potential effectiveness of urban and environmental strategies. Ultimately, the findings will contribute to the development of informed and evidence-based strategies for sustainable urban development in the face of climate resilience. Further details will be provided in the subsequent chapters.

1.2 Societal and Industrial Ecology Relevance

Amsterdam has pledged to tackle the climate crisis through participation in collaborative initiatives and international agreements at the local level to achieve increased sustainability, enhance mitigation efforts, and reach climate neutrality (Abubakar et al., 2020; Climate KIC, 2021). The City is committed to, amongst others, the United Nations' 17 Sustainable Development Goals (SDGs), C40, the Paris Agreement under the UN Framework Convention on Climate Change, and the Global Covenant of Mayors for Climate Change.

The city of Amsterdam uses several frameworks and monitoring systems to track progress on reaching its ambitious targets, such as the City Donut, Brede Welvaart, and the State of the City Monitor (Gemeente Amsterdam, n.a.). These monitoring systems and frameworks hold significant societal relevance in providing an understanding of the sustainability dimensions, as they aim to facilitate informed and effective decision-making through policy development (Dizdaroglu, 2017). Such frameworks and studies are crucial for ensuring that the city's growth and development are sustainable, liveable, and inclusive across the environment, economy, and society (The Amsterdam City Doughnut, n.a.). Thus, further identifying and promoting areas in need of improvement for the well-being of urban residents.

It has been emphasized by the Intergovernmental Panel on Climate Change (2021) that cities' adaptiveness and responsiveness to the changing climate must be prioritized; sincere efforts must be made by the public administration as well as the scientific community. Given the urgency of changes to be made in cities to advance climate resilience, the significance of industrial ecology (IE) in this context cannot be overstated (Andrews, 2001). IE, as a discipline, considers industrial systems in a symbiotic relationship with their surrounding environment. Integrating IE principles with The Netherlands and specifically Amsterdam's' efforts to mitigate the impacts of climate change, is central to the discipline's multi-disciplinary and integrated approach to problem-solving (Isenmann, 2003). As emphasized by Kennedy (2016), blending the fields of spatial planning and IE have led to first, understanding the vital connections between urban patterns and cities' environmental performance, and second, highlighting the significant impact of designs on the built environment's eco-efficiency. However, Kennedy (2016) points outtwo deficiencies when intersecting the fields of IE and spatial planning, both of which revolve around urban metabolism – a concept defined as 'the sum total of the technical and socio-economic processes that occur in cities, resulting in growth, production of energy, and elimination of waste' (Newell & Cousins, 2014, p. 708). First, while urban metabolism has been acknowledged within IE, it has largely remained a separate discipline with its own literature, despite IE's focus on the three types of metabolism: industrial, socio-economic, and urban. Second, a literary review of 212 publications on the prominence and the relationship of cities and IE revealedthat the majority of these works primarily focused on energy, material flows, and waste management at regional or national scales, with little attention paid to the urban scale.

As a result, conducting a study on the redesign of an urban development project, such as the traffic intersection at the Hugo de Vrieslaan at a local scale, holds the potential to not only complement existing research but also contribute valuable insight into both fields of IE and urbanism. Thereby, it can bridge the gap between these two disciplines by enhancing the understanding of urban metabolism and spatial planning.

1.3 The Ideal(s) City: Overview and Scope

To comprehend the objectives and research inquiries that this thesis aims to tackle, it is necessary to first introduce the research institute, the specific research programme, and the fundamental frameworks and case study in question. This thesis project is a component of The Ideal(s) City project, carried out by the Amsterdam Institute for Advanced Metropolitan Solutions (AMS Institute).

The Amsterdam-based research institute was founded by Wageningen University, Delft University of Technology, and Massachusetts Institute of Technology. Its central focus point lies in generating metropolitan solutions through research, education, and cooperations with public and private institutions. Their research portfolio encompasses six urban challenges, executed via over 125 projects with interdisciplinary consortia (AMS Institute, n.a.).

In 2022, the AMS Institute launched the research program "The Ideal(s) City" seeking to develop a framework for monitoring and measuring 'what matters'. The program's primary objective is to assess. the state of the art and the progress of Amsterdam's ecological, social and welfare ideals via existing indicators and datasets. Important aspects include a focus on integral relations and interdependencies of different ideals and issues.

To realize the stated objectives, the research program investigates four questions.

1. What kind of city does Amsterdam want to be and what are the ideals of Amsterdam?
2. How can we measure these ideals?
    a) What indicators, what data and how are the indicators related?

    b) What information does the city already have and what is needed?
3. How do projects in the city contribute to reaching these ideals?
4. What tools can we develop to measure progress?

The Ideal(s) City has already conducted investigations into research questions 1 and 2. Firstly, through a text analysis of political coalition agreements in Amsterdam spanning 30 years (1990-2020), seven ideals of the city of Amsterdam were identified. The ideals are listed in Table 1.

Table 1 : Identified ideals for the city of Amsterdam based on a text analysis (The Ideal(s) City, 2022)

	Ideals
1.	Collective city. Together we make the city
2.	Equal opportunities for everyone
3.	Good governance
4.	Freedom and openminded
5.	Sustainability: a city within planetary boundaries
6.	Growth and progress: a creative and entrepreneurial city
7.	A safe and healthy city

Secondly, an inventory of indicators was compiled from eight existing monitoring systems employed by the municipality of Amsterdam. These eight different monitors include over 500 indicators (see Appendix fig. 3). Further explanations concerning the program can be found in Appendix A, "**A review of the previous efforts in the Ideal(s) City Program**.".

1.4 Research Questions and Objectives

With The Ideal(s) City having already investigated research questions 1 and 2, this thesis project will scrutinize the program's third research question outlined in Section 1.3: " How do projects in the city contribute to reaching these ideals?". The aim is to evaluate and apply in practice the findings from the previous research questions. To this end, its first case study will be employed in Amsterdam Oost focused on the redeveloped traffic intersection introduced in Section 1.1. The case study was selected in collaboration with the Future Proof Assets department (FPA) that is part of the Engineering Office (nl. Ingenieursbureau) of the City of Amsterdam. FPA is specifically focused on implementing (climate proof) innovations into the maintenance and development of public space. Further information on the FPA can be found in Appendix A: **The Future-Proof Assets department (FPA)**.

The redevelopment of the traffic intersection involved altering the urban design and increasing green surfaces. Given the existing lack in understanding the environmental impacts of physical alterations to the built environment at a local scale, this thesis will centre on the Ideal(s) City program's fifth ideal: "Sustainability: a city within planetary boundaries" (see Table 1). More specifically, this thesis project aims to investigate the impacts related to climate resilience and adaptation through a case study.

The significance of this study is underscored by its potential to assist the municipality of Amsterdam, particularly the FPA department, in its efforts to tackle impending climate challenges in urban environments in their daily projects in public space. In addition, this study provides insights to bridge the existing literary gap between the fields of industrial ecology and urban planning. Hence, the central research question is formulated as follows:

'How do spatial and environmental measures on the Hugo de Vrieslaan traffic intersection in Amsterdam-Oost contribute to the city's sustainable ideal?'

To address the main research question, the following sub-research questions will be examined:

1. How do extreme climate events impact urban road infrastructure?
2. How can spatial designs of road intersections affect cities' climate resilience, and how are they measured?
3. Which sustainability indicators that are applicable to the case study are suitable for The Ideal(s) City framework?
4. Which spatial and environmental guidelines can improve the designing of road intersections for the municipality of Amsterdam?

1.5 Reading Guide

This thesis is structured as follows. In Chapter 2, the theoretical framework and relevant theories and concepts for the research are presented. Chapter 3 introduces the case study at Hugo De Vrieslaan and outlines the methodology to assess the impact of the redevelopment of the crossing. In Chapter 4, the case study's redevelopment is analysed by applying relevant indicators and datasets derived from the literature review and the data collection. Next, Chapter 5 discusses the results and the limitations of this study. In Chapter 6, the conclusions for this thesis project are drawn. Lastly, Chapter 7 closes with policy recommendations for the redevelopment of the traffic intersections at Hugo de Vrieslaan, which are directed towards the scientific community for future research, the development of the Ideal(s) City program (AMS Institute), and the municipality of Amsterdam.

2. Theoretical framework

This chapter presents a literature review to establish the fundamental concepts relevant to this research. The literature review will be structured into three parts, with the first two parts addressing the first and second sub-research questions outlined in Section 1.4:

1. How do extreme climate events impact urban road infrastructure?
2. How can spatial designs of road intersections affect cities' climate resilience, and how are they measured?

The first research question seeks to identify and examine the environmental impacts of climate change that pose significant challenges to urban road infrastructure, along with their measurement methods.

Meanwhile, the second research question focuses on collecting indicators from peer-reviewed academic literature to develop an indicator list for the analysis in Chapter 4. This review delves into the environmental impacts, measurement techniques and mitigation strategies relevant to urban roads. These indicators are accessed through online academic libraries at Leiden University and TU Delft. Additionally, the open online search engines Google Scholar and World Cat, along with relevant article bibliographies, were further utilized to gather academic publications. The literature selection process adhered to four research criteria, based on Halla & Merino-Saum's research (2022): (1) peer-reviewed and empirical orientation; (2) explicit focus on sustainability; (3) explicit focus on the urban scale; (4) preference for recent activity. This rigorous selection process ensures the validity and relevance of the indicators within the research field.

The last part of this chapter addresses the knowledge gap highlighted in Section 1.2 related to urban metabolism within the fields of Industrial Ecology (IE) and urban planning.

2.1 Impacts of climate change on urban infrastructure

The impacts of climate change on urban infrastructure are vast and multifaceted, often intensifying pre-existing challenges associated with urbanization (Huang & Luo, 2020). The convergence of these two aspects poses significant challenges for urban environments, as climate change impacts are accentuated due to cities' density, land-surface characteristics, and climatic structures (Ramyar et al., 2021). This in turn can have profound repercussions on the functioning of cities as they are vital drivers of innovation and economic growth (Sharifi, 2019). Numerous regions across the globe are anticipated to experience a rise in the frequency and intensity of floods, storm surges, heavy rains, elevated temperatures, heat waves, and droughts (Ji et al., 2022; Theeuwes et al., 2014). These extreme weather phenomena have a range of negative impacts on socioeconomic structures, populations, ecological systems, and urban infrastructures (Manola et al., 2019). In the Netherlands, climate change is projected to alter weather patterns with winters becoming wetter and less cold, and summers becoming hotter and drier (KNMI,2014). While there has been significant research on the magnitude and frequency of urban pluvial flooding and its management, the KNMI emphasizes the substantial impact of summer heatwaves, which are expected to be longer and more intense, leading to extended periods of drought (KNMI, 2014; Stehfest et al., 2014). Consequently, there has been a notable focus and warnings from the Dutch Council for the Environment and Infrastructure (RLI) regarding urban heat stress, as it significantly affects public spaces, their usage, and communities imminently. Particularly in terms of human thermal comfort and health (McCarthy et al., 2010; Stehfest et al., 2014).

On the urban scale, roads and the transport system experience significant impacts from climate change resulting in substantial social, economic, and environmental costs (Nevat et al., 2021). With the increasing frequency of extreme weather events, the ability of the transportation system to withstand and adapt to adverse weather becomes crucial (Orsetti et al., 2022). Table 2 provides a general overview of the potential direct physical consequences of extreme weather events on transportation infrastructure throughout the seasons. The impacts include pluvial events related to increased rainfall and heat events associated with global warming, which trigger a chain reaction of climate-related events and impacts (Ji et al., 2022).

Table 2 : Possible direct physical impacts of extreme weather events on road and transport infrastructure (adapted from Ji et al., 2022).

Types of extreme events	Impact on transportation and infrastructure
Extreme heat events	Asphalt cracking Asphalt aging/oxidation Migration of liquid asphalt Asphalt softening rutting Railway bucking Catenary wire sag Failed expansion joints Concrete pavements blow-ups
Season shift in temperatures	More frequent landslides/mudslides
Extreme precipitation events	Flooding of roadways Overloading of drainage systems Roadway washout Bridge scour / washout Reduced structural integrity from soil moisture More frequent landslides / mudslides
Droughts	Greater chance of wildfire Road closure from wildfire & reduced visibility Increased flooding in a deforested area More debris in stormwater management systems Reduced pavement integrity due to ground shaking
Sea level rise / storm surge / coastal flooding	More frequent / intense floods in low-lying areas Erosion of road base Erosion of bridge supports / bridge scouring Land subsidence

These impacts highlight the urgency to reassess cities’ long-term growth and development plans, prioritize infrastructure investments, and implement adaptive measures (Ahvenniemi et al., 2017). Urban planning strategies such as restoration, conservation, adaptation, and sustainable development, have been implemented to varying degrees to improve the resilience of urban ecosystems (Teixeira et al., 2021). The spatial arrangement of urban environments presents an opportunity to mitigate the adverse effects of climate change to establish more comfortable living conditions. However, the effective implementation of mitigation measures in urban areas requires a thorough understanding of the impacts of urban morphology on urban environmental physics (Orsetti et al., 2022; Theeuwes et al., 2014). These will be further discussed in the following sub-section.

2.2 Environmental characteristics of the urban microclimate

Urban microclimates are characterized as localized atmospheric phenomena occurring within urban areas, but distinctive from the surrounding rural areas (Manola et al., 2019). Urban microclimates are influenced by various factors, including urban morphology, which is defined as the spatial arrangement and geometry of materials and buildings, land cover of impervious and pervious surfaces, and urban metabolism (Kamal et al., 2021; Jalali et al., 2022).

Furthermore, physical transformations of urban areas can alter and play a significant role in influencing environmental and atmospheric parameters in the urban mircoclimat. For instance, temperature, wind speed, solar radiation and air flow, amongst other (Chapman et al., 2017). Due to fast urban expansion, the densification of built environments in cities is converting natural spaces into impervious surfaces, resulting into larger concentrations of buildings and densities (Wolff et al., 2017). This aggravates heat stress, which is also expected to intensify due to climate change (Jalali et al., 2022). The ability of the built environment to retain and release heat, combined with the diminishing presence of flora and green infrastructure, influences the effectiveness of urban microclimates in mitigating the effects of climate change (Emmanuel & Loconsole, 2015). Urban vegetation such as trees and parks, can successfully cool their surroundings by providing shade, consuming heat through evapotranspiration, storing runoff water, and regulating ambient temperatures (Martino et al., 2021; Weeks, 2010). The example of urban vegetation, highlights the significance of urban metabolism at the urban and microclimate scale, as it provides a systematic view of the environmental pressures caused by urban life (Zhang, 2013). In fact, using urban metabolism to identify energy flows in urban microclimate evaluations can lead to more effective design of urban resource planning. Contrary to the conventional holistic view of urban systems, urban metabolism can be used to examine flows in heat exchange networks at a localized scale between the natural and the built environments in urban microclimates (Roth & Chow, 2012).

Modifications on the street layouts and road infrastructure in the urban microclimate thus play a critical role as they can have broad implications for local ecological resources as well as the overall well-being of city dwellers (Bartesaghi-Koc et al., 2021; Ramyar et al., 2021). Outdoor comfort and health are jeopardized through rising ambient temperatures and become a serious issue for urban residents (Orsetti et al., 2022). Particularly exposed are the vulnerable populations, including the very young, the elderly and individuals with pre-existing health conditions (Schinasi et al., 2018). Previous studies have demonstrated that prolonged exposure to high outdoor temperatures between 35 °C to 50 °C, causes physiological responses in the human body. These responses include increases in heart rate and sweating. Further consequences include cardiovascular illnesses and respiratory disorders, with severe cases leading to mortality and morbidity (Wong et al., 2017). These findings emphasize the importance of mitigating adverse effects of high temperatures on human well-being in the context of climate change at the urban scale.

The following section of this study will delve into further investigations on the urban microclimate's environmental characteristics. Specifically, it will concentrate on three main components that have been found to have significant impact on temperatures within the urban microclimate and climate resilience: urban morphology, materials, and vegetation. Henceforth, each of these three components will be described individually, studying their impacts on the urban microclimate and investigating the attributes and measuring methods associated with them.

2.2.1 Temperature and urban morphology

Spatial geometric parameters such as street orientation, building block profile (i.e., height, size, volume), building density, and layout (i.e., road widths, vegetation, spacing between elements in the outdoor environment) have considerable influence on the urban microclimate (Bottema, 1997). These urban design elements have a direct impact on the microclimate as they modify solar exposure, ventilation patterns, and thermal (i.e., heating) qualities of built environments (Pacifici et al., 2017; Yang, 2021). The limited permeability for air ventilation and run-off water in high-density areas, coupled with the varying structures of urban canyons (streets with buildings on both sides), results in amplified urban heat islands (UHI) (Dhalluin & Bozonnet, 2015). This phenomenon of higher temperatures in urban areas relative to surrounding suburban or rural zones is the result of a complex interplay of factors subject to spatial and temporal variability (Johnson & Watson, 1984; Magli et al. 2016).

In a case study in Thessaloniki, Greece, Kantzioura et al. (2015) concluded that surface temperatures and microclimatic conditions depend on the heights and orientations of urban canyons. Their research revealed that the design of dense urban canyons can impede ventilation and crosswinds, trapping pollutants locally, resulting in poor air quality and the retention of higher air temperatures (2015). Nonetheless, Giridharan et al. (2004) identified sky view factor (SVF), height-to-width ratio (H/W) of buildings and infrastructure, building density, and the reflective properties of surface materials albedo, as key determinants for midday air temperatures in relation to UHI.

Similarly, several studies in countries, including Brazil, Tunisia, and Singapore, have consistently demonstrated a strong correlation between SVF, H/W, and air temperature. Higher SVF values were associated with elevated temperatures and increased daytime discomfort due to direct solar exposure and radiation (Achour-Younsi & Kharrat, 2016; Yu et al., 2020). The SVF, depicted in Fig. 1, is measured on a scale from 0 to 1, where values near 0 indicate almost no visibility of the sky, while values near 1 indicate clear visibility of the entire hemisphere (Kokalj et al., 2011). A study in Beijing, showed that highly shaded locations (SVF < 0.3) benefit from reduced heat in summer, while moderately shaded areas exhibit higher SVF values between 0.3 and 0.5 (He et al., 2015).

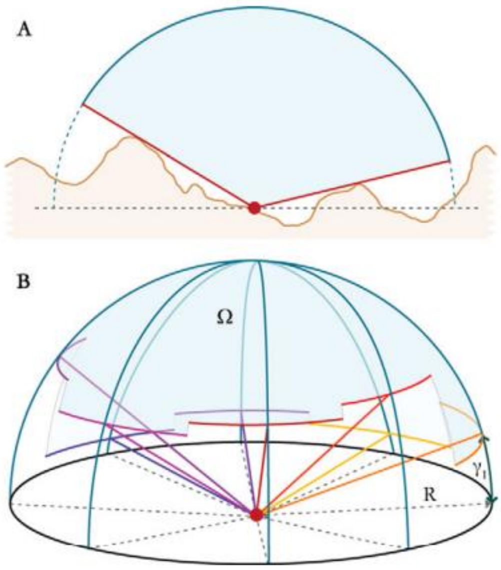
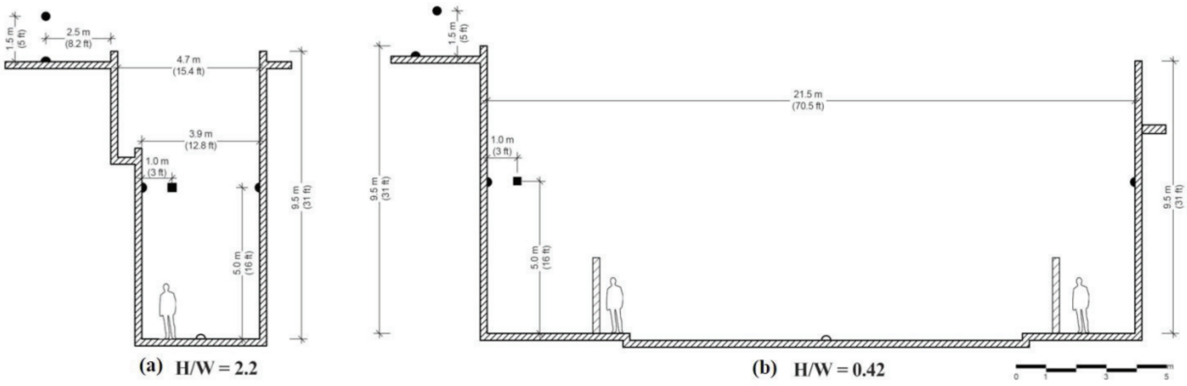


Fig. 1 : Illustration of the sky view factor (SVF) model. Panel A shows a two-dimensional representation of the fraction of visible sky above a specific observation point. Panel B depicts a three-dimensional representation model of the SVF, providing a more comprehensive view of the visibility of the sky from a certain observation point. In this figure, the blue surfaces represent the celestial hemisphere visible from the observation point, while the coloured lines indicate obstacles that block direct sunlight in different directions (Kokalj et al., 2011).

Furthermore, one of the defining factors in urban geometry is the heigh-to-width ratio (H/W) of urban characteristic canyons, which determines the inflow of air and solar radiation (Nasrollahi et al., 2021; Oke, 1988). The H/W ratio is determined by the ratio of the building height to the width of the adjacent street (Chun & Guldmann, 2012). Higher H/W ratios are preferred in summer for their shading effects, but their potential impact on heat accumulation and UHI needs consideration (Tsitoura et al., 2016).

Research shows that comparing H/W ratios is challenging due to the distinctive morphology of streets and the wide range of H/W ratios observed (Karimimoshaver et al., 2021). Additionally, research often focuses on symmetrical urban canyons, leaving the performance of H/W ratios in asymmetrical canyons unclear (Vartholomaios, 2021). The optimal H/W ratio in urban canyons is not universally accepted as it depends on geographical location, climatic conditions, and urban design planning (Bakarman & Chang, 2015; Hunter et al., 2012). Various studies suggest an optimal value of around 1.8, while others propose values ranging between 0.7 and 2 (Fereidani et al., 2021; Shareef & Altan, 2022). Therefore, Karakounos et al. (2018) argue that the findings of these investigations cannot be generalized. They stress the importance of exploring the relationship between urban canyons microclimatic parameters like H/W and SVF for each specific case. In Fig. 2, Bakarman & Chang (2015) compared the H/W ratio of an urban canyon in a city centre (a) to that of a residential suburban canyon (b). The urban canyon in the city centre (a) had a H/W ratio of 2.2, thus classified as a shallow canyon, while the suburban canyon (b) had a lower H/W ratio of 0.42, thus classified as a deep canyon. It is worth emphasizing that both canyons had the same height of 9.5m, but the length varied with (a) measuring 4.5m and (b) measuring 21.5m. In the case of lower H/W values, as in (b), there is an increased solar radiation exposure and potential air ventilation within the street. Contrarily, higher H/W values, as in (a), indicate reduced solar exposure but limited ventilation resulting in heat accumulation within the urban fabric.



(a) H/W = 2.2

(b) H/W = 0.42

Fig. 2 : Comparison of urban (a) shallow canyons with a higher H/W ratio of 2.2, compared to (b) a deep canyon with a H/W ratio of 0.42 (Bakerman & Chang, 2015).

Lastly, in urban canyons, the building density (BV) exerts considerable impacts on the previously mentioned factors: SVF and H/W ratio (Bakerman & Chang, 2015). High building density typically results in larger H/W ratios, causing radiation reflections between buildings. This leads to enhanced heat absorption and decreased heat loss (Acosta et al., 2021; Nasrollahi et al., 2021). Similarly, higher building density reduces SVF by restricting solar radiation absorption on ground-level infrastructure such as roadways and air circulation (Nasrollahi et al., 2021). Low building density, on the other hand, increases heat absorption and local temperatures. A greater SVF enables more direct sun radiation on surfaces, which increases surface heat fluxes and temperatures, impacting the surrounding urban environment. Low building density has the opposite effect (Hunter et al., 1992; Nasrollahi et al., 2021).

Finally, the interplay between urban morphology and the microclimate is a complex and multi-faceted relationship that influences the climatic conditions experience within urban environments. Several key factors such as ventilation, air temperature, building density, height-to-width ratio, and sky view, which are summarized in Table 3. Therefore, the understanding of these relationships is essential for effective urban planning and design, in the face of climate change and climate resilience.

Table 3 : Overview of key indicators from urban morphology that influence temperatures in the urban microclimate. The nomenclature, units and/or coefficients were adapted from Toparlar et al., (2017).

Theme	Indicators	Nomenclature (if applicable)	Units / coefficients
Temperature & urban morphology	Wind speed	.	(m/s)
	Building density	BD	Dimensionless/ unitless
	Height-to-width ratio	H/W	Dimensionless/unitless
	Sky view factor	SVF	0 – 1
	Air temperature	T_a	°C

As discussed, both material surfaces and vegetation, in relation to urban geometry, have impacts on microclimatic conditions and urban heat island effects (UHI). These two factors will be examined individually in the two subsequent sections.

2.2.2 Surface materials

The planning and design of urban public outdoor spaces and infrastructure require thermohydrometric considerations for citizens’ thermal comfort (Erell et al., 2014). Thermohydrometric comfort refers to the temperature and air movement conditions that are favourable to human comfort. Creating environments that meet these conditions, is critical for enhancing the liveability and usability of urban spaces to prevent neglect or underutilization by residents. In this regard, careful selection of outdoor paving materials is essential as their thermo-physical properties on city constructions shape urban microclimates (Salata et al., 2015; Yang et al., 2021).

In fact, when ground surface temperatures exceed the temperatures of near-surface air, heat transfer happens in an upward direction, resulting in the air temperature rise within the local atmospheric canopy layer (Aboelata, 2021). Materials commonly used in outdoor areas, such as asphalt and pavement tiles, can attain surface temperatures during summer of up to 50 °C – 56 °C (Li et al., 2020). Pavements make up to 30% of urban areas, and their ability to absorb and retain radiant energy is significant (Falasca et al., 2019). In contrast with rural environments, vegetation and soil moisture evaporation contribute to mitigating increasing surface temperatures by absorbing solar radiation (Yuan et al., 2017). In urban areas nevertheless, a significant fraction is made up of dry impermeable materials such as pavements and buildings (Acoste et al., 2021).

Scholars, including Erell et al., (2014), have insisted on implementing high albedo surfaces in public outdoor spaces to mitigate surface heating and reduce UHI. Taha (1997, p. 100) defines the albedo of a surface as: "its hemispherically- and wavelength integrated reflectivity […] on uniform and heterogenous surfaces". Urban albedo values typically range from 0.10 to 0.20, although higher values may be observed in cities (Salata et al., 2015). Taleghani and Berardi (2018) provide albedo values for common urban surface materials, with asphalt and concrete pavements exhibiting low albedo values of 0.05-0.2, and 0.1-0.35, respectively (see Table 4). In contrast, white plaster, commonly used for finishing material walls ceilings for interior construction design, display a high albedo value of 0.93. Taha (1997) further highlights that increasing the surface albedo from 0.25 to 0.4 can reduce air temperature on an average summer day by 4 °C as demonstrated by meteorological simulations in mid-latitude locations such as Europe.

Strategies aimed at replacing conventional materials with cool materials have gained increasing attention (Salata et al., 2015). While most attention has been dedicated to the development of materials for cool roofs, notable efforts have been placed on "cool paving" which integrates pavement with high albedo materials (Falasca et al., 2019). High albedo surfaces, characterized by their high reflectivity, offer an effective approach to reduce solar radiation absorption and subsequent heat build-up of the urban fabric (Taleghani & Berardi, 2018). Therefore, the substitution of dark materials with alternatives that possess high albedo values, has been widely advocated as a means to counteract the UHI phenomenon (Salata et al., 2015).

Table 4 : Albedo values for common urban surface materials (Taleghani & Berardi, 2018)

Material	**Albedo values**
Asphalt	0.05 – 0.2
Concrete	0.10 – 0.35
Red brick	0.30
Gravel	0.72
White plaster	0.93

In a comparative study by Doulos et al. (2004) on 93 outdoor flooring materials, it was established that the albedo of a material is primarily defined by its thermal balance. This, in turn, is determined by its surface colour, and its construction material (2004). The study revealed that light-coloured surfaces (in order: white, grey, red, black, brown and green) exhibited lower mean surface temperatures compared to darker-coloured surfaces. Among the materials tested, asphalt and concrete had the lowest mean surface temperatures, followed by marble and stone. Additionally, the study examined thermos white markings on street, which have a high albedo effect do to their white colour. However, their relavtiely small coverage ons trees compared to other urban elements renders their impact almost negligible.

In addition, as highlighted by Salata et al. (2015), certain studies have overlooked the significance of evaporative cooling from urban surface materials, despite its influence on weather conditions. Porosity of materials has been identified as a critical factor in this context, as it allows for stormwater runoff, moisture storage, and water evaporation, which contribute to the cooling down of the surrounding ambient air (Kubilay et al., 2019). Pavement materials are critical in stormwater runoff management since materials differ in composition and therefore in porosity and water runoff (Xu et al., 2020). Values for runoff coefficient span from 0 to 1, where 0 implies no runoff, while 1 indicates that all rainfall is runoff (Santero & Horvath, 2009). In other words, a lower runoff coefficient is frequently associated with permeable surfaces and greater infiltration capacity, where water can be absorbed into the soil instead of running off. Table 5, presents the following run-off coefficients for various urban road surfaces from a study conducted by Angrill et al., (2017) in Western Europe. Their findings indicate that concrete pedestrian areas and concrete roads had the lowest runoff coefficients, while asphalt surfaces had higher ones, and thus greater impermeability than concrete.

Table 5 : runoff coefficient values for different material catchment surface (Angrill et al., 2017)

Urban surfaces	Runoff coefficient
Asphalted pedestrian area	0.54
Concrete tiles in pedestrian area	0.77
Concrete pedestrian area	0.53
Asphalt road	0,89
Concrete road	0.67

The design and use of paving materials with characteristics such as surface colour, material type, albedo, and permeability are the relevant variables impacting the urban road fabric in relation to the urban microclimate (see Table 6).

Table 6 : Overview of key indicators from paving materials that influence climatic conditions in the urban microclimate.

Theme	Indicators	Nomenclature (if applicable)	Units / coefficients
Paving materials	Surface colour	.	.
	Material albedo	.	0 – 1
	Material type	.	.
	Permeability	.	Dimensionless/unitless.

2.2.3 Vegetation

Impacts of vegetative properties on microclimatic regulations in urban areas is of outmost importance. As highlighted in Section 2.2.1 on urban morphology, the strategic placement and utilization of vegetation is critical in addressing various urban challenges, particularly the UHI effect and its associated consequences.

Integrating vegetated surfaces, including grass, shrubs, and trees, can effectively decrease heat by providing shade, reducing solar radiation absorption, and enabling evaporative cooling via plant transpiration (i.e., evapotranspiration). According to Berland et al., (2017), trees should receive additional consideration as a climatic control measure, particularly for stormwater and air temperature reduction. Trees and plants are common features of urban landscapes, contributing to the regulation of the urban hydrological cycle (Szota et al., 2019). They create permeable areas and function as catchment zones for rainfall storage, influencing the distribution of rainfall on impermeable surfaces such as roadways. The abilities of trees to intercept in rainfall catchment is determined by their canopy structure and layout, such as foliation and leaf surface area, which depends on the species (Berland et al., 2017; Xiao et al., 2000). Trees can also evaporate significant amounts of soil moisture, due to their large roots and leaf areas, resulting in increased infiltration rates during storms (Berland et al., 2017; Kuehler et al., 2017). Despite space restrictions for root growth in urban spaces, street trees face less competition for water and sunlight than trees in rural and open areas, allowing for possible large crowns and leaf surface areas (Lu & Ma., 2020). As a result, trees are key components for the urban water cycle, and their interaction influences the precipitation runoff response in urban areas.

Furthermore, in Priya and Senthil's research (2021), shading capabilities impacted local air temperatures with canopy coverages exceeding 70%, and those ranging from 40% to 70%, effectively reduced air temperatures by 2.1 °C and 1.9 °C. Similarly, as with paving materials, vegetation cover absorbs, stores and emits solar radiation. However, the surface albedo of vegetation differs as vegetation typically only displays values between 0.1 and 0.25, meaning only 10-25% of sunlight is reflected from vegetation (Ziter et al., 2019).

Table 7 : Overview of key indicators from vegetation in urban microclimates

Theme	Indicators	Nomenclature (if applicable)	Units / Coefficients
Urban vegetation	Precipitation	.	mm
	Tree shade	.	m^2
	Vegetative catchment area	.	m^2
	Surface run-off	.	0 - 1

2.2.4 Indicator list

In sum, the urban design of roads, streets, and the overall urban fabric plays a significant role in enhancing cities' climate resilience. Thirteen key elements in shaping microclimatic conditions and mitigating the adverse effects of climate change, specifically the urban heat island (UHI) effect, are summarized in Table 8. In Chapter 4, this indicator list will be studied and applied to the case study .

Table 8 : Key indicators at urban scale retrieved from the literature review. The themes covered relate to temperature, urban morphology, paving materials, and vegetation in the urban microclimate

Theme	Indicators	Nomenclature (if applicable)	Units / coefficients
Temperature and urban morphology	Wind speed	.	(m/s)
	Building density	BD	Dimensionless/ unitless
	Height-to-width ratio	H/W	Dimensionless/unitless
	Sky view factor	SVF	0 – 1

	Air temperature	T_a	°C
Surface materials	Surface colour	.	.
	Material albedo	.	0 – 1
	Material type	.	.
	Permeability	.	Dimensionless/unitless.
Vegetation	Precipitation	.	mm
	Tree shade	.	m^2
	Vegetative catchment area	.	m^2
	Surface run-off	.	0 - 1

2.3 Synergies between IE and urban planning

To further elaborate on the integration of Industrial Ecology (IE) and urban planning, it is important to address how the indicators in Table 8 play a critical role in assessing, measuring, and designing urban streets and environments at local scale.

The interdisciplinary field of IE provides a holistic approach to study the interconnectedness of urban systems and their environmental impacts (Andrews, 2001). The indicators from Table 8 offer insight into the dynamics of urban infrastructure and their interactions with the natural environment. The literature review in chapter 2, has shown that aspects such as urban morphology, surface materials and vegetation directly influence microclimatic conditions of urban streets. For instance, the energy exchange between surface temperatures and air temperature is one example of the biological processes that occur in urban environments (Isenmann, 2003). The concept of urban metabolism, as part of IE, enables to study these energy and material flows at local scale, although identified as uncommon practice in Section 1.2. The application of urban metabolism at local scale can thus enable the understanding of urban system's environmental impacts, and account for the inputs, outputs and transformations in cities (Kennedy, 2016). Therefore, by including indicators from Tabl 8 into urban design practices, city planners and policy makers can strengthen cities’ climate resilience and create more sustainable environments.

The literature review furthermore points out the interconnectedness and the symbiotic relationship between IE and urban planning in addressing sustainability challenges. Both fields seek to promote sustainable principles with significant overlap in their strategies and challenges. By integrating their interdisciplinary and systematic approaches, more effective solutions for mitigating environmental impacts and urban sustainability can be achieved.

3. Research Methodology

The research consists of three successive phases (see Figure 14). First, the input phase where data and literature are collected to answer theoretical questions 1 and 2 through a review of the relevant literature (see Chapter 2). Second, the process phase pertains to an explanatory approach, wherein secondary data and the results from the literature review are applied and analysed to the case study of this research. The third phase, labelled as outputs, comprises the findings from the process phase which answer the sub-questions 3 and 4.

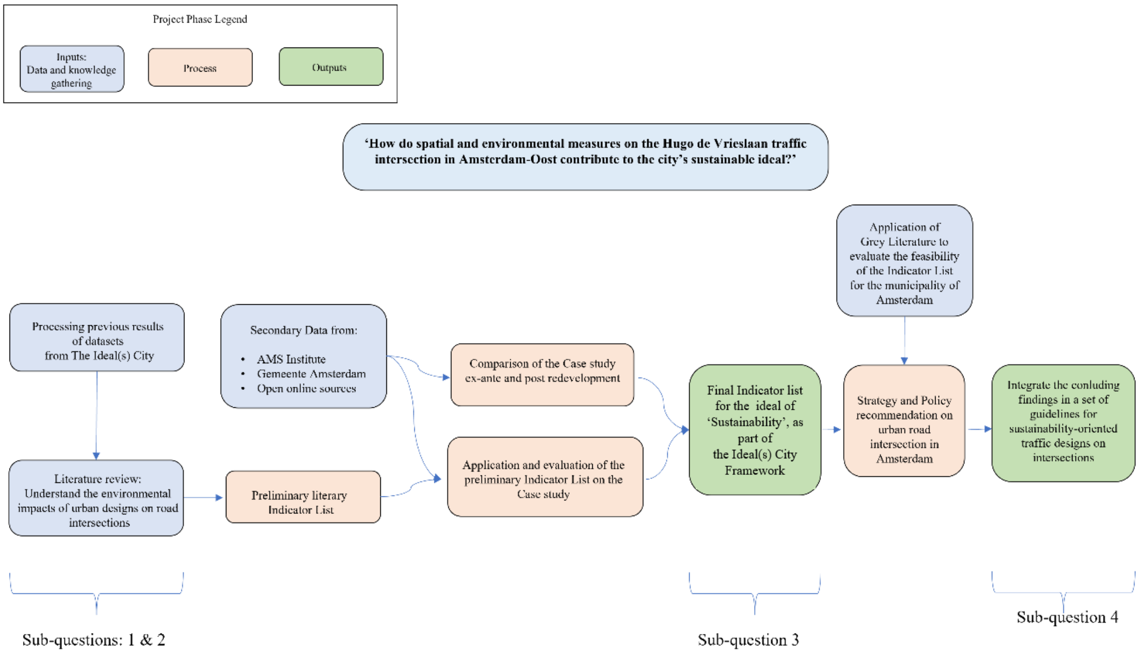


Fig. 3 : Research flow diagram showing the different steps to be undertaken with the attributed sub-research questions.

In this chapter, the research methodology used to analyse the case study central to this thesis project is described. The following sub-questions are addressed:

3. Which applicable indicators to the case study can contribute to The Ideal(s) City framework?
4. Which spatial and environmental guidelines can improve the designing of road intersections for the municipality of Amsterdam?

This chapter starts with the rationale behind using a case study as a research method, and introduces this case study in particular. The case study is subsequently introduced by offering a general overview of the project, including its geographic and demographic context, and characteristics of the redesigned traffic intersection before and after the redevelopment.

Subsequently, in the data collection section the specific requirements for data are outlined, including the types of data needed and the sources from which data is obtained.

3.1 Purpose and rationale for a case study

A case study, defined as an in-depth investigation of a contemporary and specific phenomenon within its real-life contexts, facilitates an effective understanding of the complexities associated with a particular site (Bhattacherjee, 2012; Yin, 1981). Several factors influenced the decision to use a case study in this thesis.

Firstly, given the exploratory nature of this project and the multifaceted dynamics it presents in new research areas, a single case study was deemed suitable (Bhattacherjee, 2012). More specifically, using a case study approach allows the research to explore and understand the complexities and deficiencies identified as literary gaps (in Section 1.2) on urban metabolisms at the local scale (Yin, 2009). The chosen case study focusses on an urban form, specifically a traffic intersection, and can therefore provide insights that are valuable and context-dependent at the local urban scale. This can hence provide understanding on the dynamics of urban systems and their localized urban metabolisms.

Additionally, the decision to select Hugo de Vrieslaan as a case study stems from practical considerations as well. Firstly, the availability of diverse data strategies and data sources, contributes to its suitability for a thorough investigation. Secondly, in the Ideal(s) City program AMS Institute and FPA decided to apply a first version of Ideals framework to a redevelopment project in public space. They chose a to select a smaller scale project that could include potential effects on different ideals. The redevelopment of the intersection at the Hugo de Vrieslaan appeared to be an interesting case.

3.1.1 The study area: geographic an demographic characteristics

The study area, as depicted in Fig.5 and Fig.6, is on the 1.3-kilometre-long Hugo de Vrieslaan Road (52.346° N, 4.925° E). The street serves as a significant thoroughfare in Amsterdam Oost due to its proximity to the Amsterdam Amstel station which includes bus-terminal, metro, tram, and train stations. Furthermore, as the road connects various neighbourhoods in Amsterdam Oost, both the road and intersection, experience high volumes of traffic from pedestrians, cyclists, vehicles, and public transport. On a typical weekday in 2019, for instance, traffic intensity on the road approximately amounted to 10,000 vehicles (Gemeente Amsterdam, 2022).

The Hugo de Vrieslaan not only functions as a relevant arterial road for crossing Amsterdam Oost, but it also connects three adjacent residential districts, namely Julianapark, Tuindorp Amstelstation, and De Wetbuurt (see Fig.4). The importance of the four-way traffic intersection on Hugo de Vrieslaan is heightened by the fact it serves as the sole entry and exit point for these neighbourhoods, which on their ends lead to cul-de-sacs.

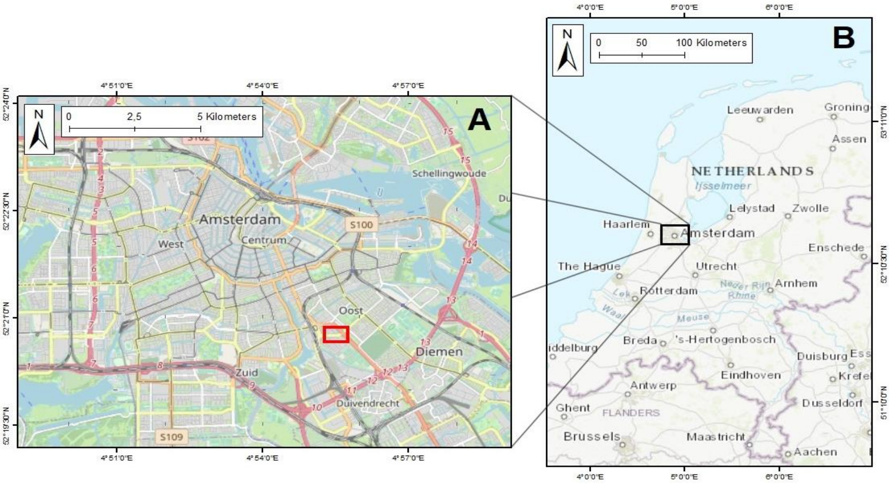


Fig.4 : The location of the research area : Amsterdam's urban agglomeration (panel A) and a map of the Netherlands (panel B). Panel A's red rectangle marks the position of the investigated intersection on Hugo de Vrieslaan, in Amsterdam Oost. (Esri, 2022).

Fig. 4 : Topographic map of the study area with image-based aerial views of the neighbourhoods around the traffic intersection, marked in red as "Research Location". The intersection connects three residential areas Julianapark, Tuindorp Amstelstation, and De Wetbuurt via, respectively, Schagerlaan, Rusthofstraat and Fizeaustraat. The map shows important access locations nearby such as the Amsterdam Amstel station (in grey), and the Amsterdam highway ring via Gooiseweg (s112)(adapted from OpenStreetMap, n.a).

Moreover, the intersection is located in an "extremely urbanised" area with a population of 3,720 inhabitants distributed over only 0.59 km^2 (CBS, 2022). The average population density of Amsterdam is 5,270 inhabitants per km^2, which in comparison to the same coverage area, translates to an estimated 3,110 inhabitants (CBS, 2020).

Error! Reference source not found. depicts a pie chart that presents two layers of demographic i nformation for the three neighbourhoods combined according to population data from CBS as of 2022. The inner layer illustrates the average age distribution per age cohort across the three neighbourhoods in the study area. According to the inner layer, the largest group consists of individuals aged 25-45 accounting for 31% of the local population. Followed by the 45-65 age group which represents 26%, and the 65+ age group which comprises only 20% of residents. The smallest age groups represented are children and early teenagers (aged 0-15), and adolescents and young adults (age 15-25) with 14%, and 9% of the local population, respectively. A detailed overview of the age groups per neighbourhood and the computations used is provided in Appendix B.

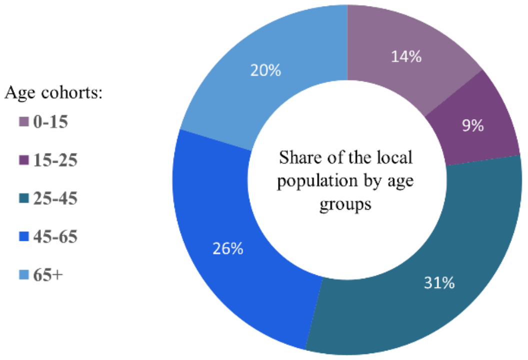


Fig. 5 : Nested Doughnut Chart illustrating the distribution (%) of the local population by age group (CBS, 2022).

In the context of ensuring liveable spaces in the face of climate change, it is notable that individuals most at risk of heat stress include the very young, elderly aged 65+, and those with health conditions, as explained in Section 2.1. By identifying the share of age groups present in the neighbourhoods surrounding the traffic intersection, one can highlight the social relevance for the neighbourhoods to improve the environment and address the challenges posed by climate change.

3.1.2 Characteristics and redesign of the new traffic intersection

The study focuses on a redesign with a surface area of 2.137 m^2 outlined by the red lines in Fig. 6. The designated area includes the entirety of the renovated traffic intersection on Hugo de Vrieslaan, but excludes the perpendicular streets as they were not part of the renovation project. The study area includes 399m^2 of green surface and 1738 m^2 of paved (i.e., artificial) surface. Additionally, the study area comprises three distinct road components, as defined by Evert (2011):

1. The Hugo de Vrieslaan Street which serves as a "important traffic road in cities and suburban areas (p. 560) ".
2. Two median strips, located to the west and east of the Hugo de Vrieslaan traffic intersection, are characterised as: "barrier located along the centre line of a road, often comprising curb stones and/or guardrail/crash barrier, which separates traffic flowing in opposite directions; such strips may vary in width and contain planting […] (p. 576) ".
3. Two tree lanes placed north-west and south-west of the traffic intersection, functioning as separation between the road and the adjacent bike lanes, characterised as: "long, narrow separation piece of land, small in area and often only a few metres wide (p. 97) ".

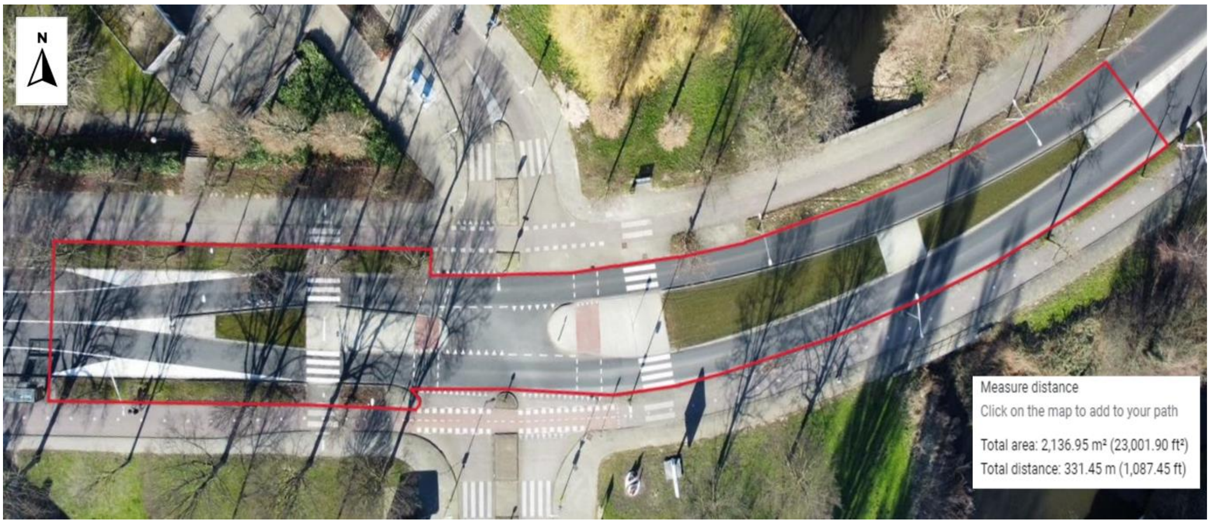


Fig. 6 : In red, the selected boundary of the study area with a surface of 2.137 m2 (adapted from Google Maps, 2023).

The proposed greening interventions are furthermore delineated in the landscape blueprint shown in Fig.7. It includes two elements: first, planting six Tilia Europea (or Hollandse Linde) trees in the medians that intersect the Hugo de Vrieslaan (shown as green circles covering 20-25 m); and second, the allocation of 25 m^3 of dedicated tree soil (shown as red-dashed rectangles). It is noting that the scale of the green sections in this blueprint does not represent their true size. For the accurate dimensions, see Fig. 21in Section 4.2.

Furthermore, greening the intersection was welcomed by local authorities as it increase water storage capacity, promote biodiversity, and enhance the overall inhabitant experience (Gemeente Amsterdam, n.d.).

Fig.7 : Urban plan of the crossing describing the spatial distribution after the intervention. (Gemeente Amsterdam, n.d.)

Furthermore, the municipality welcomed the decision to use this tree species since they wished to reduce the possibility of alternative tree species with greater roots damaging the urban infrastructure over time. This damage would have resulted in increased maintenance costs. However, the municipality revised their initial intentions and the trees were not planted (Spokesperson from Gemeente Amsterdam, n.d). At its current stage, the vegetation in the median strips only includes grass.

While this section offered a general overview of the intersection's redesign and its components, the following section 3.1.5 will provide a more detailed examination of the physical transformations.

3.1.3 The case study: The Hugo de Vrieslaan traffic intersection

The redesign of the traffic intersection included replacing the central medians of the intersection's lanes with green strips and increasing the height of the curbs throughout the intersection. Thereby, ensuring pedestrians' and cyclists' safety concerns. The greening on the road redevelopments was opted for as "[…] there was a lot of space left in the central reservation that would have had to be re-surfaced unnecessarily otherwise" (Spokesperson from Gemeente Amsterdam, 2022). According to the AMS Institute (n.d.), the redesign provided an opportunity to investigate and evaluate the identified ideals (in Table 1).

Multiple sections of the street on Hugo de Vrieslaan were subject of repair and maintenance (see also Appendix C)[1]. The redevelopment of the traffic intersection was ordered by the local district of Watergraafsmeer in Amsterdam Oost, and construction began on June 13th, 2022, for a period of two weeks. The proposed road improvements carried an investment of 412.000 euros according to the construction company Heijmans Infra B.V. (2022). **Error! Reference source not found.** depicts aerial images of the original (top image) and the renovated intersection (bottom image) after the redevelopment. The most notable changes include: the implementation of green spaces in the medians to replace the previously unused concrete spaces located at the centre of the road, the removal of marked pavements, the covering of new asphalt pavement, and the relocation of bike- and pedestrian crossings on the central medians.

Fig. 8 : Aerial view of the crossing in the winter of 2022 before renovation (top), and after the renovation in the winter of 2023 (Picture on the top was retrieved from Bing Maps, 2023; picture on the bottom is the author’s own, 2023).

3.1.4 Pre- and post-redevelopment analysis of the road intersection

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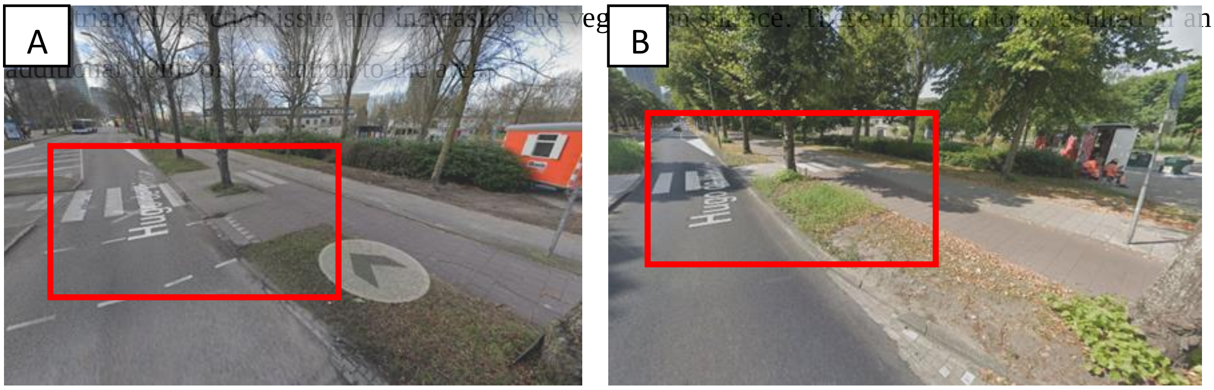
[1] This thesis case study corresponds to the project “Deklaag Hugo de Vrieslaan Fase 3”.

Images before and after show the physical transformations (alterations are highlighted by a red box). Images on the right depict the intersection prior to the renovation, captured in February 2022, while images on the left showcase the post-renovation state, in August 2022.

The physical transformations on the traffic intersection are as follows:

Between Images A and B, one can observe that the vegetation surface on the north-west tree lane was extended to include more greenery, and thus remove the bike crossing that previously existed between the western median strip and the bike lane. Furthermore, the zebra crossing, initially obstructed by a tree in Image A, has been relocated between two trees in Image B. Thereby, resolving the previous trian obstruction issue and increasing the veg n surface. These modifications resulted in an additional 10m² of vegetation to the area.



[Fig. 9: Tree lane north-west of the intersection with added 10m^2 of green surface.]

A similar procedure was implemented on the south-west facing tree lane of the traffic intersection, specifically between the road and the bike lane. This resulted in an additional green surface area of 10 m^s.

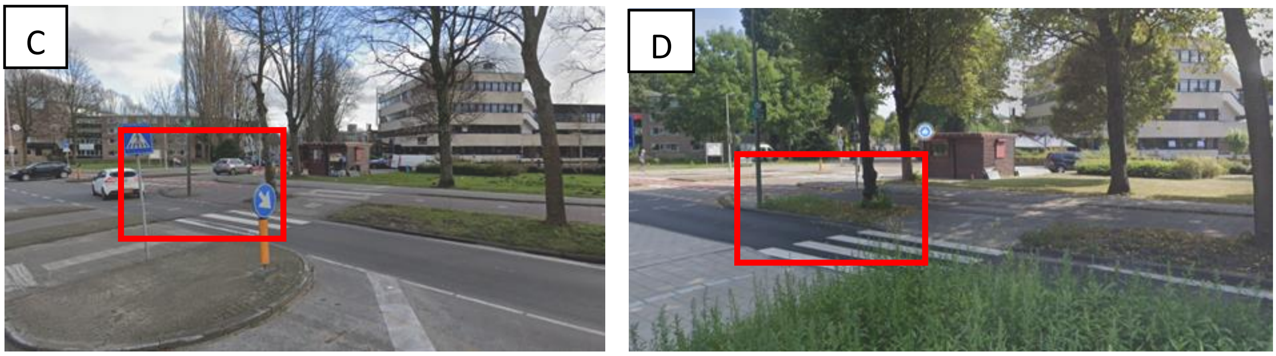


Fig. 10 : Tree lane south west of the intersection with added 10 m^{2}of green surface

From both sets of images above, the bike crossing paths that were removed from tree lanes in Images A and C, were relocated towards the intersection platform. This relocation was accompanied by an enhanced delineation of the crossing, which can be observed in Image F, contrasting with Image E.

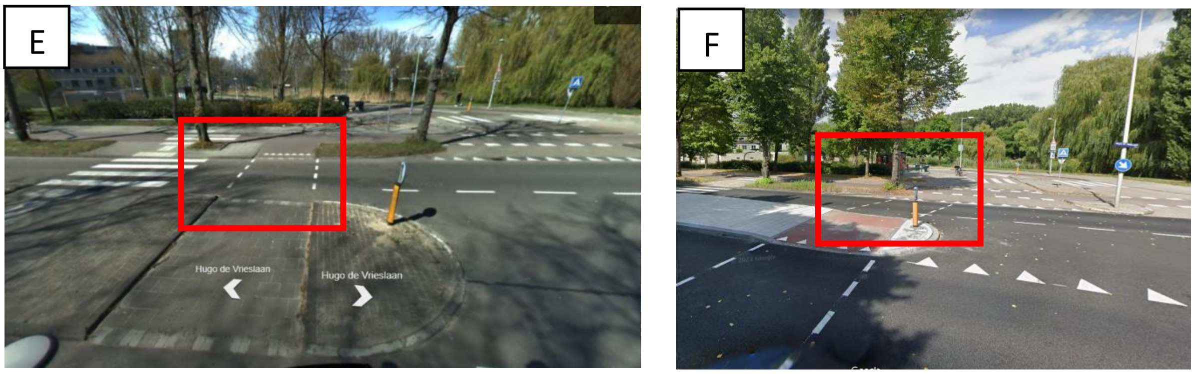


Fig. 11 : Shifting of the bike crossing from (E) to (F). The change undergone consisted in placing the crossing on the intersection in order to increase the green space on the north-west tree lane in Image B.

When comparing Images G and H, it is evident that significant transformations were made to the median strip and adapted primarily to address pedestrians' safety concerns. In its previous state (Image G), the median consisted of two small and raised crossing islands located one at each end of the median, and connected by a pedestrian crossing that was level with the road surface. Additionally, as shown in Image G, the median featured pavement markings. After the renovation (Image H), these were replaced by a larger median that now features raised curbs. This modification provides enhanced separation and protection for pedestrians. The expanded space on the median was utilized for landscaping, resulting in the inclusion of 80m^2 of vegetation, as depicted in Image H.

Fig. 12 : Transformations of the median strip West of the intersection with added raised curbs and added greenery of 80 m^2

On the eastern side of the study area, the second median strip within the renovation project underwent significant modifications. Similar to the first median strip, the second median was elevated and made continuous, ensuring the safe usage of pedestrians and cyclists.

In Image I, the pavement markings between the two-way lanes were replaced by a median strip with raised curbs, resulting in an additional 300 m^2 of greenery and landscaping. To accommodate a water canal running underneath from the adjacent pond (as depicted in Image J), a 20m^2 portion of the division was paved.

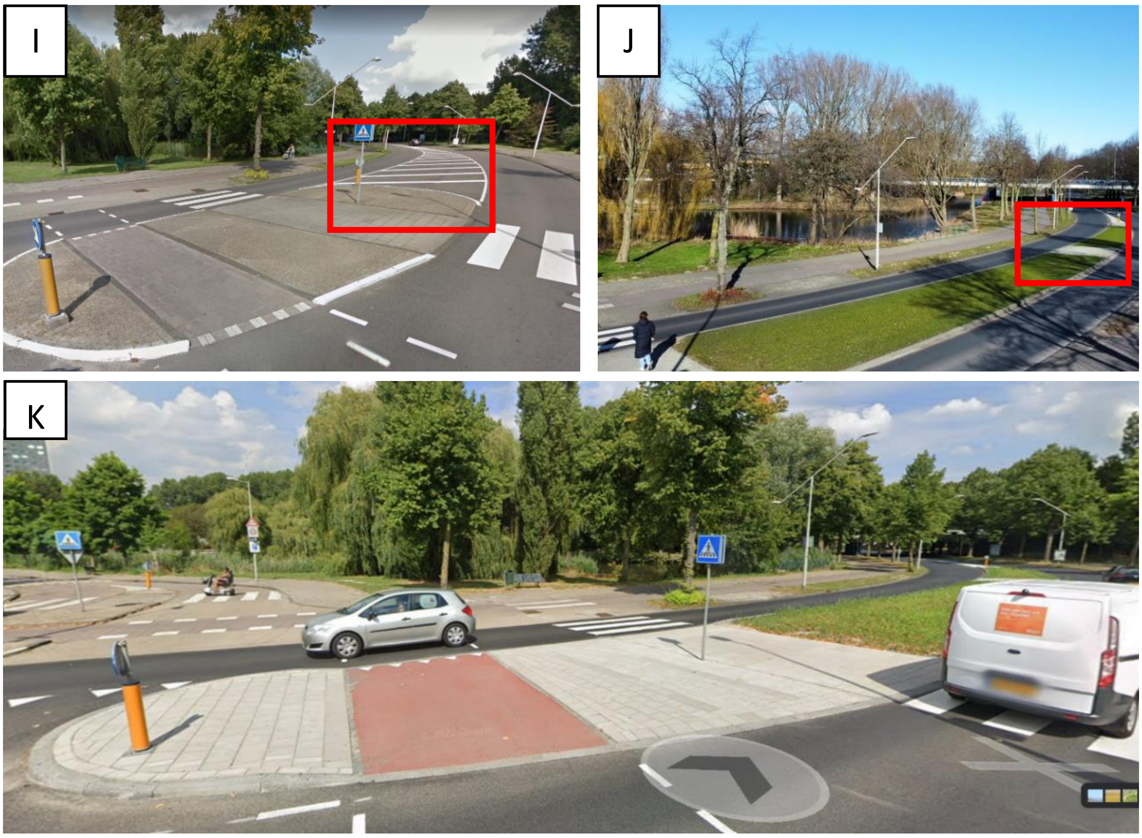


Fig. 13 : Median strip East of the intersection with added raised curbs and 300 m^2 of vegetation.

3.2 Data collection

In the third step of the research procedure, data about the traffic intersection is gathered. This includes the acquisition of data on the renovation states of the intersection, and site-specific data on the literature-based indicators from Section 2.2.4. For the analysis, data on the following themes is gathered:

1) Temperature and urban morphology
2) Surface materials
3) Vegetation

The data collection relies exclusively on secondary data, which refers to data originally collected by an institution or individual separate from the researcher, and with a different intent than that of the study (UNEP, 2020). To analyse the case study, both quantitative and qualitative secondary data are gathered Utilizing secondary data for the analysis of this case study offered a significant advantage due to the extensive scope and diverse range of resources and datasets already available to the researcher (Clifford et al., 2016). These data sources had been previously collected by entities such as the AMS Institute, and the municipality of Amsterdam, more specifically the FPA department.

To ensure the reliability and validity of the site-specific data used for the application and analysis of environmental indicators, the most favourable choice was to opt for official governmental sources if available, and prioritize the availability of most recent data for each indicator. This approach recognizes the importance of employing reliable and valid data in accurately analysing and applying environmental indicators. Governmental entities mostly provide official sources with up-to-date, quality and different levels of data which aligns with the urban scale this project is analysing (Zhou et al., 2021).

Data for the redevelopment analysis was obtained from various sources including the AMS Institute, the municipal spokesperson involved in The Ideal(s) City project, and the construction company responsible for the redevelopment. Desk research was conducted to gather online sources for the satellite and close-up images of the traffic intersection. It should be noted that due to the recent completion of the renovation, only close-up shots of the traffic intersection from Google Street View were available. The aerial view of the location had not been updated on Google Earth during the research period, and therefore drone shots of the location were captured.

3.2.1 Data sources for the case study analysis

To provide a clear overview of the various secondary data sources utilized for this project, two summary tables outlining the input data have been compiled below as Table 9, and Table 10.

In Table 9, an overview is offered on the data sources used for the indicators before-and-after on temperature and morphology, surface materials, and vegetation specific to the study. Due to the unavailability of relevant records and data from the municipality, information for these indicators was collected from various alternative sources: academic literature, online weather forecasts, and the construction company involved in the renovation of the intersection. It is important to note, that two indicators, namely building density and air temperature, were excluded from the analysis. The building density indicator is not applicable to study its impacts due to the absence of nearby buildings. As for the air temperature indicator, local data was not available from the municipality or other sources.

Table 9 : Data sources for indicators related to temperature and urban morphology, surface materials, and vegetation

Theme	Indicators	Objects of interest	Data type	Year	Source
Temperature and urban morphology	Wind speed	Local weather station	Numerical value (m/s)	2020 - 2022	Weather Spark
	Building density	N/A	N/A	N/A	N/A
	Height-to-width ratio	H/W formula; street measurements	Numerical value (dimensionless)	2020; n.a.; 2023	Aboelata; Gemeente Amsterdam; Google Maps
	Sky view factor	SVF 2D formula	Numerical value (0 - 1)	2019	Dirksen et al.
	Air temperature	N/A	N/A	N/A	N/A
Surface materials	Surface colour	Urban pavement	Categorical (color spectrum)	2022	Heijmans Infra B.V.
	Material albedo	Urban materials used on the intersection construction	Numerical value (0 - 1)	2018	Taleghani & Berardi
	Material type	Urban materials used on the intersection construction	Categorical (type)	2022	Heijmans Infra B.V.
	Permeability	Urban materials used on the intersection construction	Numerical value (0 - 1)	2021	Akhtar et al.
Vegetation	Precipitation	Local weather station	Numerical value (mm)	2019	Climate data
	Tree shade	N/A	N/A	N/A	N/A
	Vegetative catchment area	Urban green spaces	Numerical value (m^2)	2022	Heijmans Infra B.V.
	Surface run-off	Urban green spaces	Numerical value (0 - 1)	2022	Shi et al.

Table 10 provides an overview of the objects of interest used, to describe the renovation process of the traffic intersection before and after, along with the corresponding data sources.

Table 10 : Input data used for the comparison of the road intersection (ex-ante and post) in Section 4.1.

Objects of interest	Data type(s)	Year	Source(s)
Layout of the old road intersection, and metrics	Google Street View Bing Maps	2022	Google Earth Bing
Layout of the new traffic intersection, and metrics	1. Urban plan guidelines of the intersection 2. Google Street View 3. Aerial drone shots and close-up photographs	1. 2021 2. 2022 3. 2022-2023	1. Gemeente Amsterdam. 2. Google Earth. 3. Author.
Material composition of the intersection ex-ante redevelopment	GeoPackage on Amsterdam's road materials (ArcGIS)	n.a.	AMS Institute
Material composition of the intersection post redevelopment	1. Spreadsheet of the construction materials 2. Excel sheet	2022	1. Heijmans Infra B.V. 2. Gemeente Amsterdam

To analyse the GeoPackage, attached as "*Street_surfaces_Amsterdam.GPKG*" on the material composition of the intersection prior to redevelopment, the file was processed on ArcGIS. The dataset contained geographic information on the street layout and composition of the municipality of Amsterdam. By selecting the traffic intersection via attributes in the dataset, the required data was exported as an Excel file (see "Selected_street_surfaces_Amsterdam "). This process aided in the cleaning phase, which involved translating the content to English, and filtering the relevant information. Further details are outlined in Appendix C.

3.3 Analysis, evaluation, and guidelines for sustainable road intersection designs in Amsterdam

In the next chapter, the before-and-after situation of the intersection will be described and compared using the datasets that were collected for the different indicators. In addition, the indicator list generated by this case study will be compared to the indicator inventory from the Ideal(s) City framework. This approach results in the development of a refined and definitive set of indicators that will contribute to the foundation for The Ideal(s) City's framework for the ideal of "Sustainability: a city with planetary boundaries" in the city of Amsterdam.

Following the study's discussion and limitations, the research will conclude with a series of recommendations to the scientific community, the Ideal City programme, and the municipality of Amsterdam. To provide specific recommendations to the municipality, the proposal for the intersection's redevelopment will adhere to the municipal guidelines known as "Leidraad Centrale Verkeerscommissie". This document includes the city's policy and design framework for street designs, namely the Puccini method.

4 Results

This chapter presents the findings of the case study with a central focus on the analysis of the indicators derived from the literature review, in 8, on the Hugo de Vrieslaan road intersection. The analysis is structured into three thematic sections, corresponding to the main indicator themes: (1) temperature and urban morphology, (2) paving materials in the urban microclimate, and (3) vegetation in the urban microclimate. Additionally, each section compares the before and after situations of the traffic intersection to highlight the observed differences and results.

The results of this analysis will support the development of a new and final indicator inventory, which specifically addresses the third sub-question of this research: “Which sustainability indicators that are applicable to the case study are suitable for The Ideal(s) City framework?”. In the final paragraph of this chapter, a comparison will be made between the indicators obtained in this master thesis and the indicators that are part of current monitors.

4.1 Temperature and urban morphology

The theme of temperature and urban morphology includes five indicators.

Wind speed

The wind speed indicator was obtained by averaging the recorded values for the city of Amsterdam during the hottest months of June, July, and August in the most recent years of 2020, 2021, and 2022. This yielded an average wind speed of 4.81 m/s. It is important to note that data for the current year 2023 is not available, which prevents the observation of any difference in wind speed before and after the interventions at the traffic intersection.

Building density

The indicator on building density (BV) is considered negligible within the context of the traffic intersection due to the absence of surrounding structures that could hinder air circulation or create urban canyons affecting temperatures. The nearest buildings are located at a distance of approximately 54 m to the northwest, and 53 m to the southwest from the centre of the intersection. Consequently, the redesign of the traffic intersection does not interact with the surrounding urban fabric, minimizing its influence on the building density indicator.

Height-to-width ratio

The height-to-width ratio was calculated by measuring the width as the distance between the trees, which serve as the identified vertical obstacles at the traffic intersection. The measured height (H) and width (W) were determined to be 10.5m and 14.2 m, respectively. As a result, the calculated coefficient of H/W was determined to be 0.74. Since no trees were introduced as part of the intervention measures, there is no observable difference in the height-to-width ratio before and after the renovation.

Sky view factor

The two-dimensional sky view factor (SVF2D), was determined by placing the observation point at the centre of the traffic intersection. The corresponding height and width parameters were measured as 10.5m and 7m, respectively. This resulted in a calculated coefficient of 0.32.

Similarly, as with the previous indicator, the SVF2D indicator did not exhibit any noticeable variations before and after the renovation. This is due to the absence of trees or vertical obstacles introduced during the intervention, which prevented any changes in the sky view factor around the intersection.

Air temperature

Measurements for the "air temperature" indicator at the specific location were not available by the municipality or online. Consequently, the air temperature indicator remains unavailable for analysis and cannot be included in the results of this study.

In sum

Upon examination of the temperature and urban morphology indicators, it becomes evident that the physical renovation of the intersection did not produce any noticeable effects on these indicators. No observable impacts on the wind speed, the building density, the height-to-width ratio, and the sky view factor could be concluded.

4.2 Surface materials

The theme of surface materials includes four indicators.

Material type

Based on the analysis of the municipal geospatial file provided in Appendix C, the materials used for the former intersection were as follows: (1) asphalt concrete for the road pavement; (2) concrete tiles for the bike lanes and the pedestrian crossings on the road medians; and (3) concrete bricks for the unused sections of the medians on the Hugo de Vrieslaan, as depicted in Fig 15. The figure presents a colour-coded illustration of the material composition of the former intersection. These materials were initially laid out in 1981 and 1992, with periodic maintenance carried out only on the bike paths, the pedestrian crossing in 2017, and a minor section of the road once in 2013. Other areas of the traffic intersection did not undergo any maintenance or infrastructure improvements.

This figure was adapted from an excerpt from the geospatial database of the municipality (see Appendix C) and is meant for a visual representation of the former traffic intersection and its surface materials.

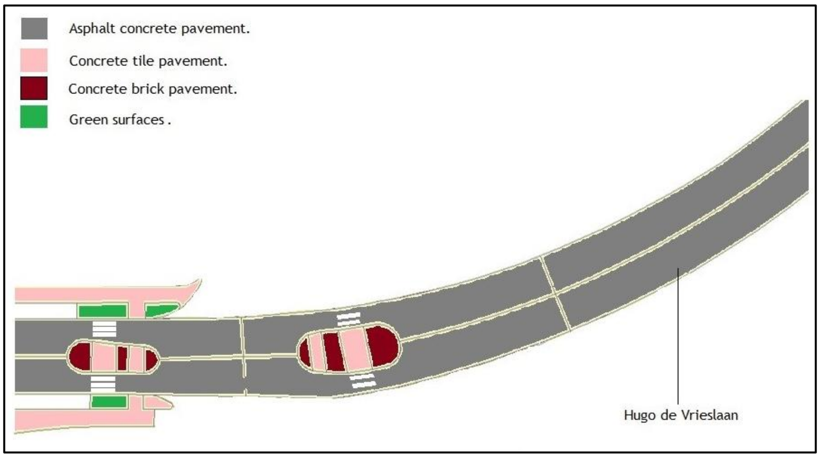


Fig. 14: Schematic depiction of the former traffic intersection's layout, and material composition. The colour-coded areas represent the specific construction materials that were previously applied, along with the previous utilization of green space on the tree lanes. This figure has been adapted from an excerpt of the municipality's geospatial database in Appendix C (Gemeente Amsterdam, n.a.).

In Fig.14, a depiction of the three construction materials used in the previous traffic intersection is presented. It shows the distinction between the concrete tile pavement used for the pedestrian crossing (on the left) and bike path (on the right) located on the traffic median. Additionally, it highlights the utilization of concrete brick pavement for the remaining sections of the median.

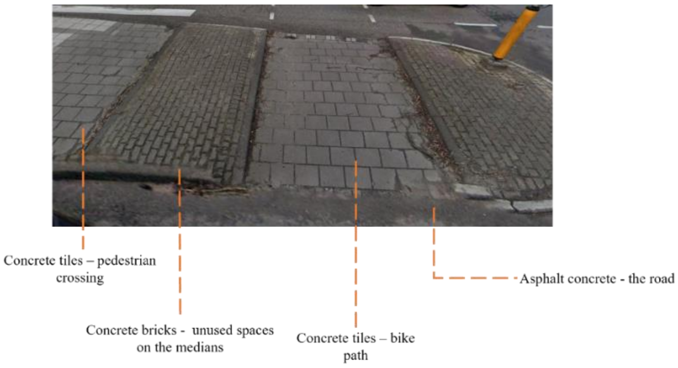


Fig. 15: Distinction of the various building materials used on the previous state of the intersection (Google Maps, 2022).

Following the renovation, up-to-date documentation (2022) about the building materials used for the redevelopment of the intersection was acquired. Notably from the Gemeente Amsterdam and the construction company Heijmans Infra B.V.

Error! Reference source not found. presents the urban plan used as a guideline by the construction company for the redevelopment of the crossing. The plan offers a scaled representation, in meters, of the new street design and layout. Furthermore, the accompanying legend contains additional information regarding the materials, including their dimensions and labelling. It is important to note that the provided information in Fig. 16 includes details on road pavement's various layers and thicknesses. However, these specifics fall outside the scope of research and are excluded from the analysis for this study.

Based on the information provided in Fig. 18 and a spreadsheet detailing the construction phases and materials (see Appendix D), it can be determined that the renovation project made use of the following materials: (1) asphalt pavement, (2) red asphalt pavement, and (3) concrete tiles. Further details on the composition of the construction materials specific to the project, (asphalt concrete pavement, concrete tiles, and bricks) were unavailable.

In contrast to the previous state of the intersection, the renovation project no longer included the use of concrete bricks. Instead, the new crossing predominantly features an increased use of asphalt. The surface area did not change in total, but instead what changed was the usage of the materials. For a detailed comparison of the quantities, Table 11 presents the differences in material usage in m^2 before and after the redevelopment.

Table 11 : Comparison of construction material coverage before and after the intersection redevelopment

Materials	**Quantity in previous intersection (in m^2)**	**Quantity in new intersection (in m^2)**
Concrete bricks	75	0

Concrete tiles	54	179
Road Asphalt pavement	2008	1530
Red asphalt pavement	0	29

Surface colour

Before the renovation, each component of the traffic intersection had a uniform dark grey surface colour as seen in Fig. 15.

After the renovation, significant changes in surface colours were observed, as depicted in Fig. 16. The road surface transformed into a light grey shade, the medians were paved with light grey tiles, and newly added vegetative areas appeared in green on the median strips. Furthermore, the crossing paths for bikes were distinctly marked in a light red colour, providing demarcation from other surfaces on the crossing.

These modifications appeared in a visually transformed and enhanced appearance of the traffic intersections, as summarised in Table 12.

Table 12 : Colour scheme comparison per material before and after the intersection redevelopment

Before		**After**	
Asphalt road pavement	Dark grey	Asphalt road pavement	Light grey
Concrete bricks	Dark grey		
		Asphalt bike pavement	Light red
Concrete tiles	Dark grey	Concrete tiles	Light grey
		Vegetation areas	Green

Material albedo

The material albedo of the intersection components could not be retrieved specifically for the renovation of the project. Therefore, standard coefficient values from the literature were used. On the new intersection, concrete bricks were excluded and replaced by concrete tiles. According to Taleghani & Berardi (2018), the material albedo for the materials on the intersection is as follows:

(1) Asphalt concrete for the road pavements: 0.05 – 0.2

(2) Concrete tiles for the bike lanes and the pedestrian crossings on the road medians: 0.10 – 0.35

While the impact of the new materials on land surface temperature is unknown for the current year 2023, the traffic intersection prior to renovation had exhibited certain land surface temperature patterns, as depicted in Fig. 17. Over the course of three years, measurements recorded average surface temperature ranging between 27.4C and 32.3C on a typical summer day along sections of the Hugo de Vrieslaan Road. The traffic intersection, marked by the red circle, is located in the yellow temperature category. According to Fig. 17, the intersection falls within the middle category of temperatures. In contrast, the blue areas exhibited the lowest temperatures, measuring below 22.4C, while the residential neighbourhoods exhibited the highest temperature measurements up to 37.3 degrees (in orange).

Fig. 16 - Land surface temperature (in C°) on an average summer day in the study area before the renovation of the intersection. The Hugo de Vrieslaan (in red) experiences temperatures between 27.4 – 32.3 C ° (AMS Institute,2021).

This difference in land surface temperatures can be attributed to the presence of vegetation, including trees, canals, and grass, as shown in Fig. 18. By comparing both figures, Fig. 17 and Fig 18, observations reveal that the green areas, representing the existence of ecological passages, have recorded the lowest surface temperatures.

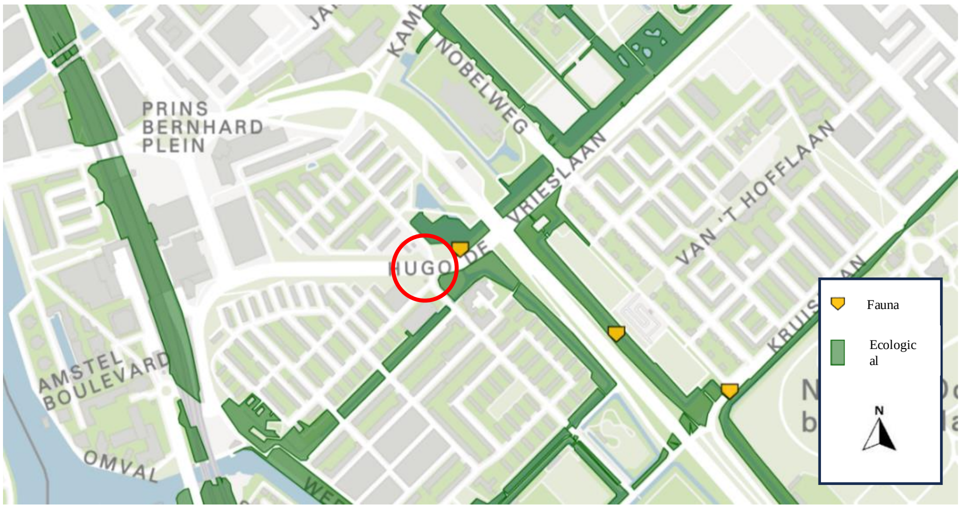


Fig. 17: The ecological features present on and around the Hugo de Vrieslaan road include designated ecological passages (in green), specifically for fauna (in orange) (Gemeente Amsterdam, n.a.)

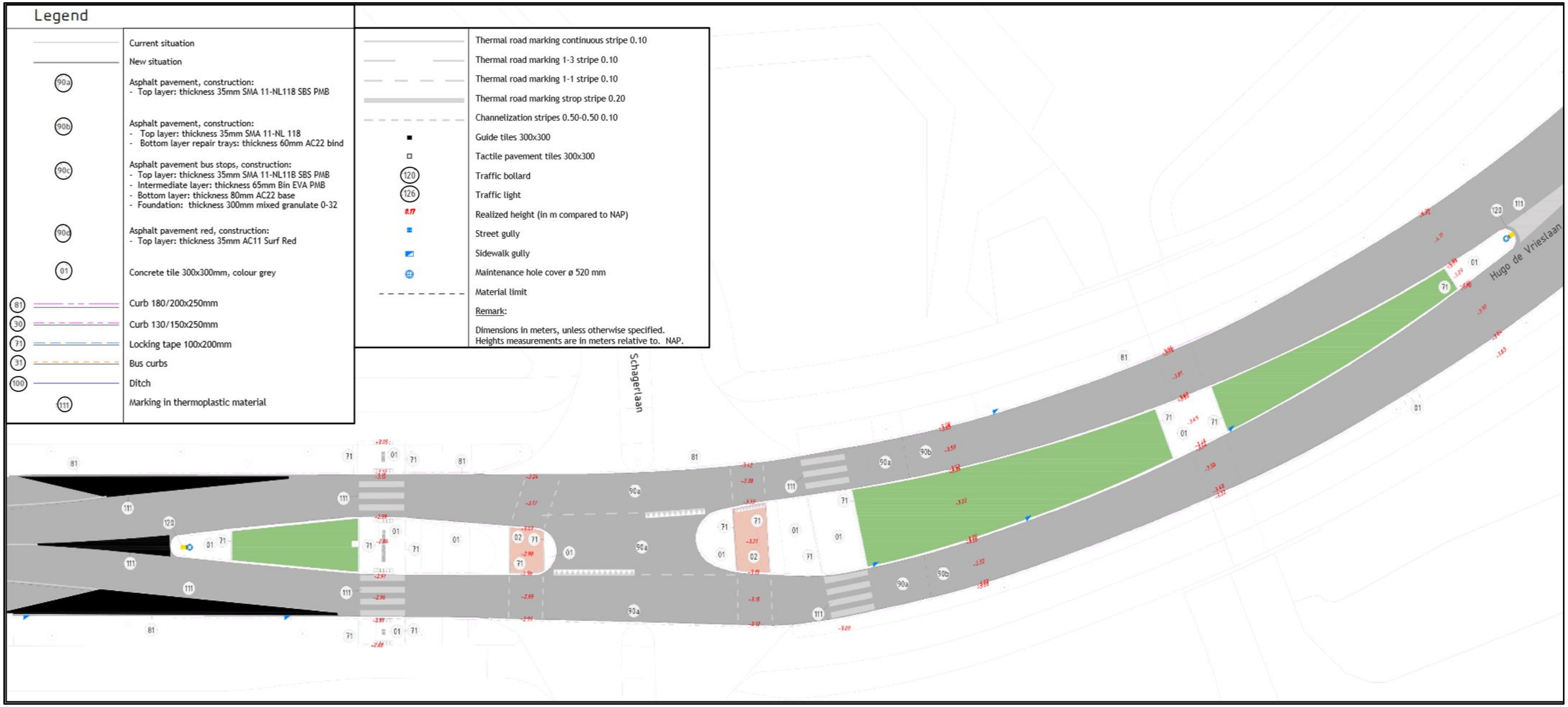


Fig.18: Urban plan guidelines of the renovated intersection showing the new layout, materials applied, and their respective dimensions. The original urban plan can be found in Appendix C (adapted from Heijmans Infra B.V., 2022)

Permeability

Before the redevelopment of the traffic intersection, the permeability of the materials used was unknown. However, after the renovation, it appears that the materials used in the redesign are similar to those used previously. Therefore, it is assumed that the permeability coefficient values for the materials used after the renovation are as follows:

Table 13 : Permeability coefficient values for the materials used

Road elements	Permeability coefficient
Road asphalt pavement	0.04 – 0.4 cm/sec
Red asphalt pavement	0.04 – 0.1 cm/sec
Concrete tiles	$0.02 \times 10{-}11$ and $1.2 \times 10{-}11$ m/s

In sum

Upon examination of the indicators pertaining to the material surface of the traffic intersection, there has been considerable change in its components given the added value of the green areas on the median strips. The renovation of the intersection has contributed to a reduction in permeable surface resulting in less significance of the colour schemes of materials to impact the local microclimate. However, the lack of site-specific data before and after the renovation, particularly for the indicators on material albedo and permeability, poses a challenge in accurately quantifying these changes.

4.3 Vegetation

The theme of vegetation in the urban microclimate included five indicators.

Precipitation

From a climatological perspective, the study area's climatic conditions are characterized by Amsterdam's location with the North Sea to the west and north of the city. Based on the Köppen climate classification system, the city has a maritime climate with temperate conditions that are mild and humid, and fall under the "Cfb" category (Beck et al., 2018). The weather is dominated by precipitation throughout the seasons with mostly a mild and cool summer, and westerly winds from the sea (Manola et al., 2020). **Error! Reference source not found.** Presents the monthly averages of precipitation and t emperatures for Amsterdam.

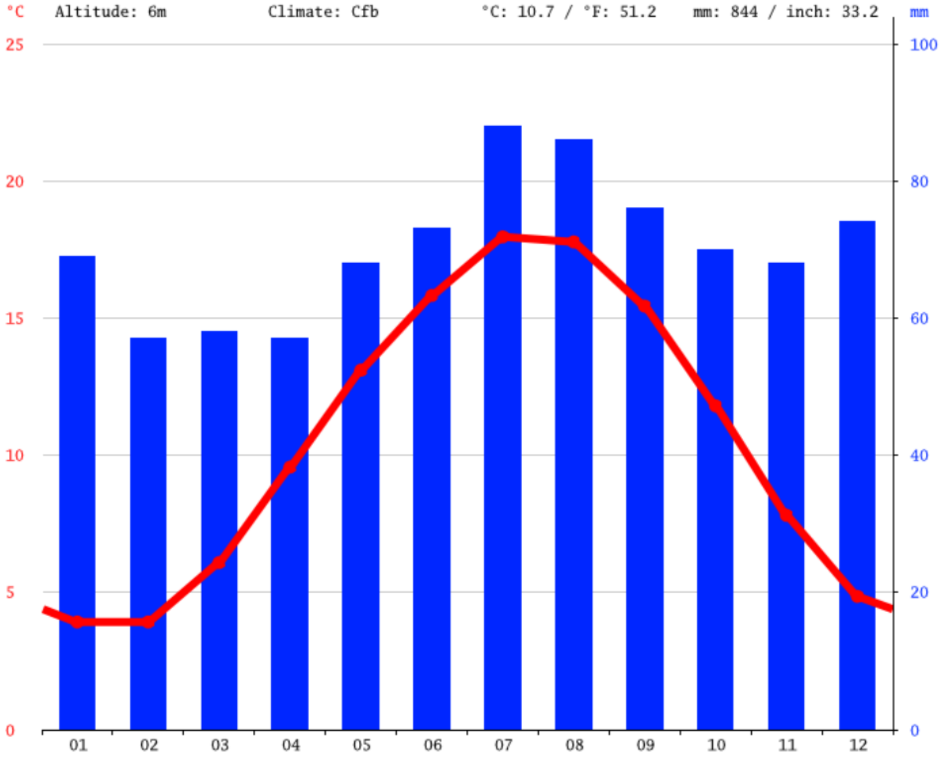


Fig. 19: Monthly averages of precipitation (in mm), and temperature (in °C) for the city of Amsterdam. The average number of mm of rain per year amounts to 844mm. The average yearly temperature is 10.7 °C. (Climate Data, 2019).

In this study, it is assumed that the precipitation values are not influenced by the redevelopment of the intersection, and thus remain the same before and after the renovation.

Tree shade

Before the redevelopment, the Hugo de Vrieslaan intersection lacked any green spaces or vegetation, resulting in the absence of tree shade. Following the renovation, no additional tree shade was created as no trees were added to the vegetative areas of the median strips. Although the green areas are now covered with grass, these do not provide any shading opportunities due to their low height and limited canopy coverage. Consequently, there are no noticeable differences in tree shade between the pre-and post-renovation conditions of the intersection.

Vegetative catchment area

Before the renovation, the vegetative catchment area of the Hugo de Vrieslaan intersection was devoid of any greenery and comprised paved surfaces. However, following the renovation, the incorporation of an additional 399 m^2 of grass has introduced a significant catchment area for precipitation on the median strips of the road., facilitating the infiltration of water into the soil. The increase of vegetative catchment area on the road intersection from $0m^2$ to 399 m^2 introduces an enhancement in the vegetative cover which allows for quicker infiltration of water into the soil.

Surface run-off of grass

Prior to the renovation of the traffic intersection, the absence of vegetative areas on the intersection precluded the consideration of an indicator for surface run-off. However, the intersection post-renovation, introduces a surface run-off indicator ranging from 0.3 to 0.6.

In sum

In sum, the theme of vegetation in the urban microclimate at the Hugo de Vrieslaan intersection involved several indicators. Prior to the redevelopment, the intersection lacked green spaces and vegetation, resulting in the absence of tree shade. However, through the renovation process, an additional $399m^2$ of grass was incorporated. Overall, the redevelopment of the Hugo de Vrieslaan intersection introduced a significant increase in vegetative cover and catchment area.

4.4 Comparing the list of indicators with the Ideals city inventory

In this section, a comparison is made between the literature-based indicator list and the indicators obtained from the existing monitors and frameworks used by the Ideal(s) City. The purpose of this comparison is to ascertain the significance of certain indicators and determine whether they are included in the dataset of The Ideal City. Additionally, any instances of missing data for these indicators are identified. To do this comparison, the programme's latest version of the monitoring framework is used. Each Excel spreadsheet compiles all the indicators per monitor for the city of Amsterdam. It can be found in the attachment of the thesis under "*Inventory_Monitors_V06*".

Based on the comparison, none of the indicators examined in this study are present within the eight existing monitors and frameworks employed by the Ideal(s) City. This observation indicates an absence of data on each of the indicators within the current inventory of the Ideal(s) City. While no direct match is available, the indicators investigated in this study will be associated to the second higher-level category (theme) of the inventory, if possible. The purpose is to identify the gaps between the themes. Since the research's focus is on sustainability within the Ideal(s) City, the comparison will be conducted on the branch of "Natural Capital" from the dendrogram in Appendix A, Appendix fig. 3. In cases where a suitable match cannot be established, the indicator will be denoted as "not available" (n.a.).

Table 14 : Comparison between the literature-based indicators and the Ideal City dendrogram, sub-branch: Natural Capital.

This thesis		**Ideal(s) City Inventory: sub-branch 'Natural Capital'**
Theme	**Indicator**	**Theme**
Temperature and urban morphology	Wind speed	n.a.
	Building density	Land
	Height-to-width ratio	Land
	Sky view factor	Land
	Air temperature	State of the climate
Surface materials	Surface colour	n.a.
	Material albedo	Land
	Material type	Land
	Permeability	Land

	Precipitation	State of the climate
Vegetation	Tree shade	Species/Ecosystems
	Vegetative catchment area	Land
	Surface run-off	Land

The assessment reveals that the majority of indicators can be associated to existing themes in the inventory of the Ideal City. The main themes to which they can be associated are: land, state of the climate, and species-ecosystems. However, two specific indicators, namely wind speed and surface colour, do not show a connection with any of the themes within the sub-branch “natural capital”.

5 Discussion & Limitations

In this chapter, key findings from both the literature and the results will be discussed to answer the research questions of this study. Constraints will be furthermore addressed, and insights into this study's contributions to the Ideal(s) City Framework and its development are discussed.

The main question of this thesis was how spatial and environmental measures on the Hugo de Vrieslaan traffic intersection in Amsterdam-Oost contribute to the city's sustainable ideal. This question was divided into four sub-questions. Two of those questions were addressed in Chapter 2, the literature review.

The literature review

1. How do extreme climate events impact urban road infrastructure?
2. How can spatial designs of road intersections affect cities' climate resilience, and how are they measured?

In sum, the literature review revealed firstly that climate events, such as extreme heat, floods, and storm surges, have significant impacts on urban roads and transportation infrastructures. These events amplify pre-existing challenges linked to urbanization, which pose challenges to urban environments due to their density, land-surface characteristics, and climatic structures.

Secondly, the literature highlighted thirteen key indicators related to urban road infrastructure and climate resilience. These were grouped under three main themes: temperature and morphology, surface materials, and vegetation.

Under the theme of temperature and morphology, the following indicators: wind speed, building density, height-to-width ratio (H/W), sky view factor (SVF), and air temperature were found to be most influential on the urban microclimate. Within the context of surface materials, the thermophysical properties of outdoor paving materials were found to shape the urban microclimate. During summer, material's surfaces with darker hues exhibit elevated surface temperatures, potentially exacerbating heat accumulation in urban spaces. Conversely, boasting high albedo surfaces however, have the potential to counteract heat absorption and curb urban heat island effects, Moreover, the porosity and permeability of paving materials exert a dual influence: they modulate stormwater run-off while also acting as a cooling effect to lower temperatures. Lastly, the vegetation theme underpinned the vital role of including green spaces. Trees, shrubs, and grass not only provide shade but also mitigate solar radiation impact, and actively function as cooling agents to regulate microclimatic conditions in cities.

The third sub-question of the research was guided in Chapter 4 under: “Which sustainability indicators that are applicable to the case study are suitable for The Ideal(s) City framework?”

The methodology and results

The analysis of the results shows that the main challenge in addressing the applicability and suitability of the indicator list with the inventory of The Ideal(s) City framework resides in the limited availability of data at the local urban scale. In research, this has been identified as a major challenge and limitation for assessing existing and future situations in cities (Orsetti et al., 2022). Despite the wide acknowledgment that data must be collected at different city scales, Klopp & Petretta (2017) further highlight that no set of indicators can capture and reflect upon the diverse scales of urban complexities and impacts. The incompatibility in accessing adequate and relevant data arises from different practical needs of city politics and administration in contrast to the requirements of the scientific community for conducting research on urban complexities. In addition, Moreno Pires et al. (2014) put forth that the lacking consensus on available methodologies or standards for developing indicators poses another limitation and constraint. The lack of uniformity leads to a complex landscape of existing indicator frameworks and systems, each serving different purposes and being context-dependent.

During the data collection process, two primary constraints were encountered which posed challenges to the analysis. Firstly, a notable absence of available municipal data for each indicator, which limited the scope of assessment for this research. Secondly, data on the indicators specifically for the intersection before its renovation was also absent, making it difficult to establish a clear before-and-after comparison for both, the states of the indicators and the project. These constraints significantly limited the assessment of the project’s impacts on the urban microclimate. Additionally, the absence of localized data impeded the application of common environmental assessments methodologies within the field of IE. The application of a Life Cycle Assessment (LCA) could not be performed because data was only available by the construction company on the “Product stage A1-3” as shown in Fig. 18.

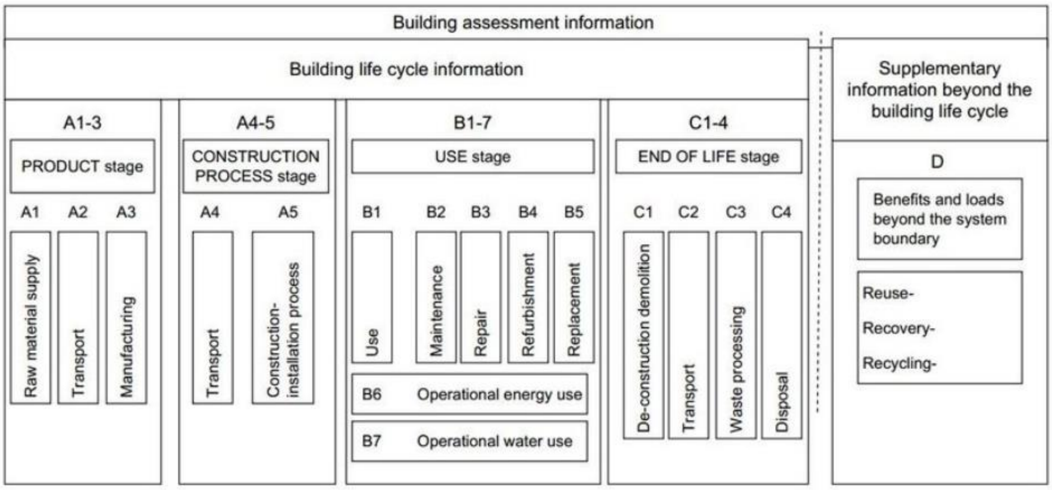


Fig. 20 – Overview of the LCA stages (Obrecht et al., 2018)

Due to the absence of data on the remaining life cycle stages, as depicted in Fig. 18, and only partial availability of information concerning the cradle-to-gate stage (up to stage A4-5), an accurate depiction of the carbon impacts and the sustainability of the products under scrutiny could not be reliably conducted. Consequently, the usage of an LCA, or even partial evaluation, was excluded from this study's scope to ensure the integrity of the findings.

Furthermore it is essential to acknowledge the limitations of relying on a single case study. Using multiple case studies could enhance the validity, generalizability, and the robustness of the research findings. In fact, multiple case studies could help to minimize the impact of biases by showcasing trends and patterns across the different indicators for this study. Multiple case studies hold the opportunity to study causal relationships between traffic intersections' characteristics in the context of the themes studied here (Bhattacherjee, 2012).

In the following sections, a discussion on the indicators will be carried out, organized under the guiding themes of the research.

Temperature and morphology

The examination of the temperature and urban morphology indicators reveals that the redesign and physical renovation of the intersection did not have any discernible effects on the literature-based indicators. No significant changes were observed in the wind speed, building density, height-to-width ratio, and sky view factor. The absence of available and up-to-date data for two indicators, namely wind speed and air temperature at the specific location, is a limitation of this study and its results. However, it is crucial to consider the potential implications of it.

First, the lack of data for 2023 hinders a direct comparison of wind speed before and after the intervention. By comparing wind speed, evaluations could determine if the intervention altered wind flow patterns around the intersection. Despite the small scale of intervention at the city level, changes in wind speed could suggest changes in airflow, such as redirection or acceleration, as a result of the design modifications. This analysis may provide insight into the intervention‘s effectiveness in increasing natural ventilation and air movement in the urban context. Higher wind speeds may improve air circulation and reduce heat accumulation.

Second, air temperature is important in determining the thermal conditions and heat distribution in urban environments. Data on post-renovation air temperature could be used to assess the influence of the renovation on local microclimatic conditions and identify temperature changes before and after the intervention. This would facilitate the understanding of air temperature patterns and the assessment of the intersection’s redesign.

According to research, the other indices (building density, H/W, and SVF) exhibit equal importance in influencing the microclimate. Yet, since the traffic intersection is located in a residential neighbourhood, their effects are minor in this study. These indicators become more significant and decisive in more compact and densely-built environments. A narrow street (i.e., urban canyon), is a prime example, where increasing building densities and H’W ratios result in increased heat absorption and a value of SVF closer to 0 due to reduced sky visibility. These will trap heat, and raise surface and air temperatures.

In summary, the absence of air temperature data hinders a complete assessment of the intersection’s renovation impact on atmospheric conditions and urban morphology. Access to this data would have allowed for a detailed assessment of microclimatic changes, investigations on mitigating local urban heat stress, and potential linkages between the five indicators.

Surface materials in the urban microclimate

The surface materials, similar to the previous theme, lacked data. Considering no data on the previous state of the intersection could be acquired, the before-and-after assessment is inconclusive. Data on the material albedo and permeability of the construction materials used for both versions of the intersections were missing. These could have reflected on differences or similarities in how they affect the local climate. This could have provided further explanations of Fig.17 on the measured land surface temperatures of the intersection and analysed how the new design influences these measurements.

According to the analysis of the municipal geospatial file, the materials used for the intersection before renovation had an additional construction material that was removed from the intersection’s current design: concrete bricks. The availability of information on the material type, their colours, and material albedos allow to give an estimate of their influence on the intersection’s climatic state in comparison to its previous design.

Prior to refurbishment, the traffic intersection exhibited distinct characteristics. The absence of concrete bricks and the introduction of new materials, notably vegetative features, are likely to have altered the intersection's surface characteristics: the permeability, material albedo, and material colours. The components of the traffic intersection used to have a uniform dark grey surface colour. However, the redevelopment initiatives ushered significant changes in surface colours: a light grey colour for the road pavement, the deployment of light grey tiles on the medians, the integration of verdant vegetation zones, and distinctive light red markings specifically for the bike paths. Notably, these surface colour variations hold the capacities to wield a non-negligeable impact on the thermostatic attributes of the materials. By modifying the absorption and reflection properties of solar energy on them, as delineated in Section 2.2.2, the material's thermal behaviours are reshaped. However, quantifying the real influence of surface colour changes on the microclimate is difficult without particular information on the spectral reflectance qualities of the materials and their albedo values for the intersection, despite the available information on material quantities, material types, and permeability values. It is assumed that the materials used in the project were conventional due to the material information provided in Appendix D. The values in Table 13 indicate that the construction materials used in asphalt pavement and concrete tiles for the renovation exhibit low permeability, as they are closer to 0. This implies that these materials have a limited ability to allow water or air to pass through, resulting in reduced drainage as rainwater accumulates on impermeable surfaces and flows over the pavements (Salata et al., 2015).

In sum, the lack of data on surface materials and the material's characteristics for both the pre-and post-renovation states of the intersection makes it challenging to draw definitive conclusions on their impacts. Although visible changes to the layout and composition of the intersection are noticeable, the impacts cannot be quantified.

Vegetation

Precipitation in the study area is influenced by Amsterdam's maritime climate, with mild and humid conditions. The assumption made is that the precipitation values remain unaffected by the intersection's redevelopment given that the impact scale of it is insignificant for a large-scale phenomenon.

The integration of vegetative areas provides new characteristics to the intersection. Indicators influenced by the addition of 399 m^2 are: vegetative catchment area and surface run-off. For both indicators, the presence of vegetative areas influences the surface run-off of the intersection. The grass on the median strips reduces run-off on previously paved areas and absorbs a larger portion of the rainfall. This indicates a clear reduction in surface runoff on impermeable surfaces (see the previous section), and aids the microclimatic properties of the intersection through water retention on soil and thus its cooling effect.

Indicator list

The comparison between the literature-based indicator list and the existing monitors of The Ideal(s) City has revealed a significant mismatch and absence of availability in the datasets. The purpose of this comparison was to assess the significance of the indicators and identify gaps that may exist within The Ideal(s) City's inventory.

To answer the third research question, the results of this comparison indicate that none of the sustainability and environmental indicators examined in this study are currently present within the eight existing monitors and frameworks utilized by The Ideal City. However, the purpose of associating the indicators to higher-level categories, as shown in Table 14, highlights the potential suitability and inclusion of eleven indicators in the Ideal City inventory. In other words, this finding also suggests that there is a notable lack of scale between the literature-based indicators and those by the Ideal(s) City. Two indicators could not be associated with the second-degree category: wind speed and material colour. For wind speed, the was no direct link despite its environmental characteristics. However, on the highest level of the sub-branch, this indicator could be included in multiple themes such as "land and ecosystems", "air quality", and "climate". For material colour, however, none of the themes or categories in the sub-branch match the indicator's physical characteristics.

Despite the missing match with direct indicators from the existing frameworks within the sub-branch "natural capital", the eleven indicators identified can complement and expand The Ideal(s) City framework. The programme can thus, broaden their monitoring scope of data collection and analysis to provide a detailed scale understanding of the urban environment's complexities and interactions.

In conclusion to the third research question, the following table of indicators is suitable for The Ideal(s) City:

Indicators	
Building density	Tree shade
Height-to-width ratio	Vegetative catchment area
Precipitation	
Sky view factor	Surface run-off
Air temperature	
Material albedo	
Material type	
Permeability	

6 Conclusions

In this study, a single case study focussing on a Dutch traffic intersection in Amsterdam Oost was used to identify eleven spatial and environmental measures (indicators) with significant influence on the urban microclimate. By combining these indicators based on a literature review and The Ideal(s) City's foundations, a thematic analysis resulted in the categorizing of indicators under three main themes related to the urban microclimate: temperature and morphology, surface materials, and vegetation. Despite the encountered limitations and challenges stemming from data availability for the indicators at a local scale and the absence of pre-redevelopment data for the traffic intersection, the following key conclusions can be drawn:

(1) The considerable difference in spatial scale between the indicators used in this study to evaluate the urban microclimate and those employed in eight existing monitor systems and frameworks in Amsterdam, highlights a significant gap in available data. Consequently, the disparity introduces complexities in assessing the environmental impacts resulting from the intersection's redevelopment. The absence of a harmonized approach to data collection across the varying spatial scales with The Ideal City(s) framework hinders the ability to precise quantify and interpret the intersection's redevelopment impact. This highlights the need for a more standardized data acquisition to perform an environmental assessment.

(2) In response to the main research question 'How do spatial and environmental measures on the Hugo de Vrieslaan traffic intersection in Amsterdam-Oost contribute to the city's sustainable ideal?': The findings from this study unveils insight into the potential contributions of eleven key indicators toward Amsterdam's state of sustainability. The diverse range of indicators spans across factors such as building density, height-to-width ratio, precipitation, sky view factor, air temperature, material albedo, material type, permeability, tree shade, vegetative catchment area, and surface run-off. They highlight the multifaceted nature of urban sustainability. The analysis reveals the collective and complex nature of the city's environmental and climatic dynamics. By acknowledging the interconnectedness and relevance of these indicators, The Ideal City Project and the city of Amsterdam detain a set of indicators that can better align their efforts in achieving the overarching goal of creating resilient and sustainable urban developments and spaces.

In conclusion, this research underscores the pivotal and critical importance of the built environment in shaping local-scale urban designs and influences designs, and microclimatic conditions. To foster climate-resilient design principles, cities can integrate these indicators to minimize their adverse effects.

The study concludes with recommendations for further research directed toward the scientific community, The Ideal(s) City programme, and the municipality of Amsterdam are provided in the final chapter, Chapter 7.

7 Recommendations

The final chapter of this thesis aims to provide a set of recommendations derived from the findings and analysis presented in the preceding chapters. This chapter is divided into three sections. Each section focuses on specific areas of recommendations, aiming to contribute to the continuous efforts in developing sustainable and resilient urban environments for the City of Amsterdam. In addressing the last recommendation, the fourth research question of this study is answered:

‘Which spatial and environmental guidelines can improve the designing of road intersections for the municipality of Amsterdam?’

7.1 Scientific recommendation

1. Further research and application of the indicator methodology on other traffic intersections

In light of the limited availability of data on environmental indicators at the urban microclimate scale, it is imperative to carry out further research for data collection. For the scientific community the following recommendations are suggested:

(1) Applying the literature-based indicator list to other traffic intersections with both similar and different characteristics. Applying the indicators to traffic intersections that exhibit distinctive characteristics and varying urban conditions, can offer insights into the versatility and adaptability of this study’s indicator list. Within the city of Amsterdam, the recommendations for the locations on which to conduct supplementary research should focus on: residential neighbourhoods, city centre(s), and business districts. Prioritizing these locations would help to determine whether the set of indicators can be strengthened or if adjustments need to be made.

(2) Extending the analysis beyond single case studies across to multiple intersections throughout the city. By implementing this approach, a comprehensive understanding of the collective impacts on a city level can be attained. This aids to highlight the importance of local impacts, and allows to identify common trends, variations, and potential patterns that could appear

across road intersections (Kennedy et al., 2014). This in turn, would aid to study effective strategies that can enhance a city's overall urban sustainability.

(3) Including a Life Cycle Assessment (LCA) as an integral step to evaluate the environmental impacts of construction materials. The application of an LCA should focus on surface materials to align with the scope of this study. The significance emanates from the LCA's utility to quantify the overall footprint attributed to a product (e.g. construction material) (Gonzalez-Garcia, 2018). The quantification provides a basis for informed decision-making regarding more sustainable material options for future road intersection construction. Performing a cradle-to-gate approach enables to determine the environmental profile of traffic intersection at Hugo de Vrieslaan, and contribute to relevant additional data collection for the inventory of The Ideal(s) City.

Within the domain of Industrial Ecology, Guinée et al. (2011) additionally emphasize that the application of LCAs in urban metabolism studies can be synergistically be combined with a material flow analysis (MFA) on micro and meso levels in cities. By adopting these system's perspectives, the environmental understanding of the renovation's direct and indirect impacts on the products and technologies can be scrutinized within the context of the city's metabolism.

7.2 The Ideal City

1. Review and evaluation of the spatial scale of the indicators in The Ideal(s) City's framework

Referring to the comparison in Section 4.4., it is important to acknowledge the disparity between the indicators used in the Circularity Monitor at the city level, and the indicators specifically focusing on the microclimate (at local scale) as discussed in the academic literature. The indicators employed in this thesis project are on a smaller spatial scale and are only partially included at higher-level order in the inventory of the Ideal City framework.

To overcome this mismatch, it is recommended to conduct a review and evaluation of the existing indicators within the Ideal City framework. This review should specifically consider the inclusion of indicators that capture the local-scale impacts, such as the microclimate conditions in Table 14, as they are crucial for assessing the sustainability and resilience of urban environments. In doing so, a contribution to the development of indicators for the sub-branch "*Natural Capital*" can be carried out which aligns with the objectives of the fifth ideal "Sustainability: a *city within planetary boundaries*".

Furthermore, it is recommended to explore potential synergies and opportunities for integrating these local-scale indicators into the broader framework of the Ideal City project, since many indicators are interrelated with different subjects and have a multifaceted purpose (Klopp & Petretta, 2017). By addressing these key points, the Ideal(s) City framework can improve its effectiveness in understanding sustainable and resilient urban developments within the City of Amsterdam.

2. Strengthen data collection for local-level indicators

While the indicator list in this study holds relevance for understanding and mitigating the impacts of climate change and urbanization, data gaps on the indicator persist. To address this gap, future research efforts must focus on systematically collecting data at the microclimatic level, using the parameters found in this research. By intensifying research endeavours in this direction, a deeper and more tailored understanding on the intricate interactions between urban environments and climate can be attained. Consequently, more robust strategies for sustainable urban development can be formulated.

The integration of local data can significantly enhance the engagement between The Ideal(s) City project with Amsterdam's policymakers and stakeholders, as it allows for more informed decision-making and actions. Concrete and local data strengthens the credibility of the project's findings and recommendations as they become more actionable and tangible for city planners, stakeholders, and policymakers (Broto et al., 2012). Finally, the availability of local-level indicators sets the ground for continuous improvement on urban development as it allows to track progress, adapt strategies as needed and ensure that urban development is aligned with the goals set in the fifth ideal of The Ideal(s) City.

7.3 Municipality of Amsterdam

1. Increase diversified tree planting on the east median of the Hugo de Vrieslaan's traffic intersection for enhanced environmental resilience

To promote environmental resilience and the sustainable urban development of traffic intersections in the city, it is strongly recommended to increase tree plantings. The strategic and widespread planting of trees can play a pivotal role in mitigating the effects of climate change, improving air quality, enhancing biodiversity, and reducing heat stress (Orsetti et al. 2022). The inclusion of a diverse range of tree species in urban landscapes is essential to maximizing the environmental benefits and creating resilient ecosystems (Berland, 2017).

The proposal takes into account Amsterdam's Central Traffic Commission (CVC) and the Puccini approach to design street features (see Appendix E). Following the guidelines of the CVC and the Puccini method, the west median of the Hugo de Vrieslaan traffic intersection offers the most potential to grow trees due to its surface area of 187 m^2 given that:

1. (1) The planting of trees on that surface does not interfere with street signs on the intersection or other obstacles that could limit vision for cars and pedestrians, and hence affect safety.
2. (2) Trees must have a minimum width of 2.00 m for root growth. The green surface on the median has a width varying from 5.20 m to 6.80 m, and a length of 31.50 m.

To comply with the safety rules of the CVC, the proposal suggests planting between two to four trees on the west median. Although the length of the surface amounts to 31.50m, 4.00m of length per tree has to be considered, as well as space between the trees and the surrounding area.

The following criteria for the selection of a tree species were derived from a study on 75 tree species planted in cityscapes across the Netherlands by a Dutch scholar, Hiemstra (2011), over an eight-year period (see Appendix E.):

(1) Crown density: dark and dense crown. – This attribute was chosen to increase tree shade, catchment area, and increased surface run-off on the median.
(2) Dimensions: maximum height 6.00 m to 12.00 m. – This category was deemed appropriate based on the average tree height of 9.50 m near the intersection.
(3) Tree type: suitable as a street tree.

This resulted in the following selection of trees species for the west median on the Hugo de Vrieslaan:

- Acer campestre 'Green Column'.
- Acer campestre 'Huibers Elegant'.
- Carpinus betulus 'Columnaris'.

In response to the fourth research question, the strategic planting of various tree species on free green road surfaces is one of the spatial and environmental recommendations that can improve the design of road intersections in Amsterdam. Following the guidelines established by the CVC and the Puccini method, as well as the selection criteria for the tree species, the proposed tree species include: Acer campestre 'Green Column'; Acer campestre 'Huibers Elegant'; and Carpinus betulus 'Columnaris' as alternatives to the prevalent Hollandse Linde on the Hugo de Vrieslaan.

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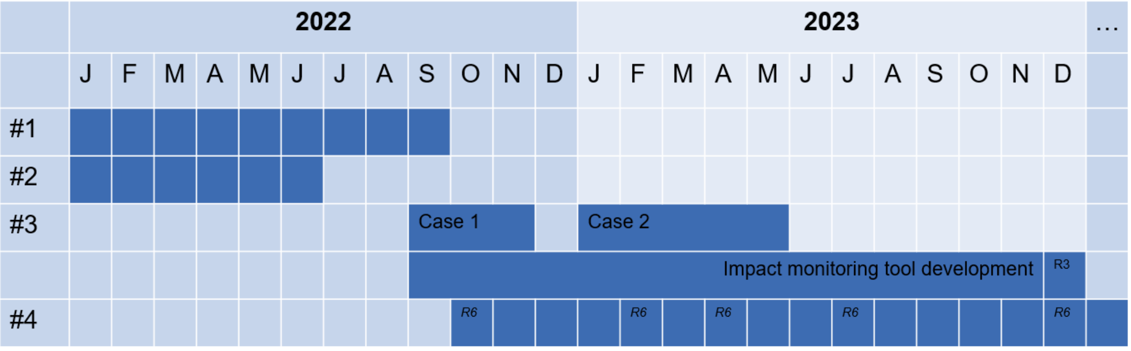
Appendices

A. Structural overview of ‘The Ideal’s City’: The Basis for Research Question 3

a) A review of the previous efforts in the Ideal(s) City Program

In the following section, an explanation of research questions 1 and 2 are presented to provide understanding on the work that has been done previously, and which lays the foundations for the third research question of the

The ongoing phase of the Ideal(s) City Programme spans from 2022 to 2023, as illustrated in Figure 1, where each row corresponds to the planned duration for a research question. Research questions 1 and 2 have already been concluded.



Appendix fig. 1: Planning Phase of The Ideal(s) City (The Ideal’s City,2022)

Figure 1 indicates that the research on questions 3 and 4 is currently in progress. The focus of this thesis, however, is exclusively on question 3, with an emphasis on Case 1. Case 1 pertains to a traffic intersection located at the Hugo de Vrieslaan in Amsterdam Oost.

The programme’s research questions:

1. <u>What kind of city does Amsterdam want to be and what are the ideals of Amsterdam?</u>

The first research question aimed to define the ideals of Amsterdam through a combination of desk research and workshops with civil servants. A text analysis was conducted on over three decades of political agreements (1990-2022), where terms and phrases were coded to provide an overview of the most frequently used concepts. The result of this analysis was the identification of seven ideals, serving as the foundation for the Third and Fourth research questions of the Ideal(s) City Program (as illustrated in Figure 3).

Together, collective
Everyone in Amsterdam, residents and administration, is involved in maintaining and improving life in the city

Equal opportunities
All people in Amsterdam get equal opportunities to develop themselves. Amsterdammers show solidarity with each other.

Better administration
The administration of Amsterdam adheres to the rules of good governance. It operates in an efficient and effective way, and is impartial, open, transparent, accountable, demand-driven and participatory.

Freedom and open minded
In Amsterdam everyone can live and work in freedom regardless of sexual orientation, origin, gender or age

Growth and progress
With the creativity and entrepreneurship of all residents and businesses, the city continues to grow and develop in a sustainable way.

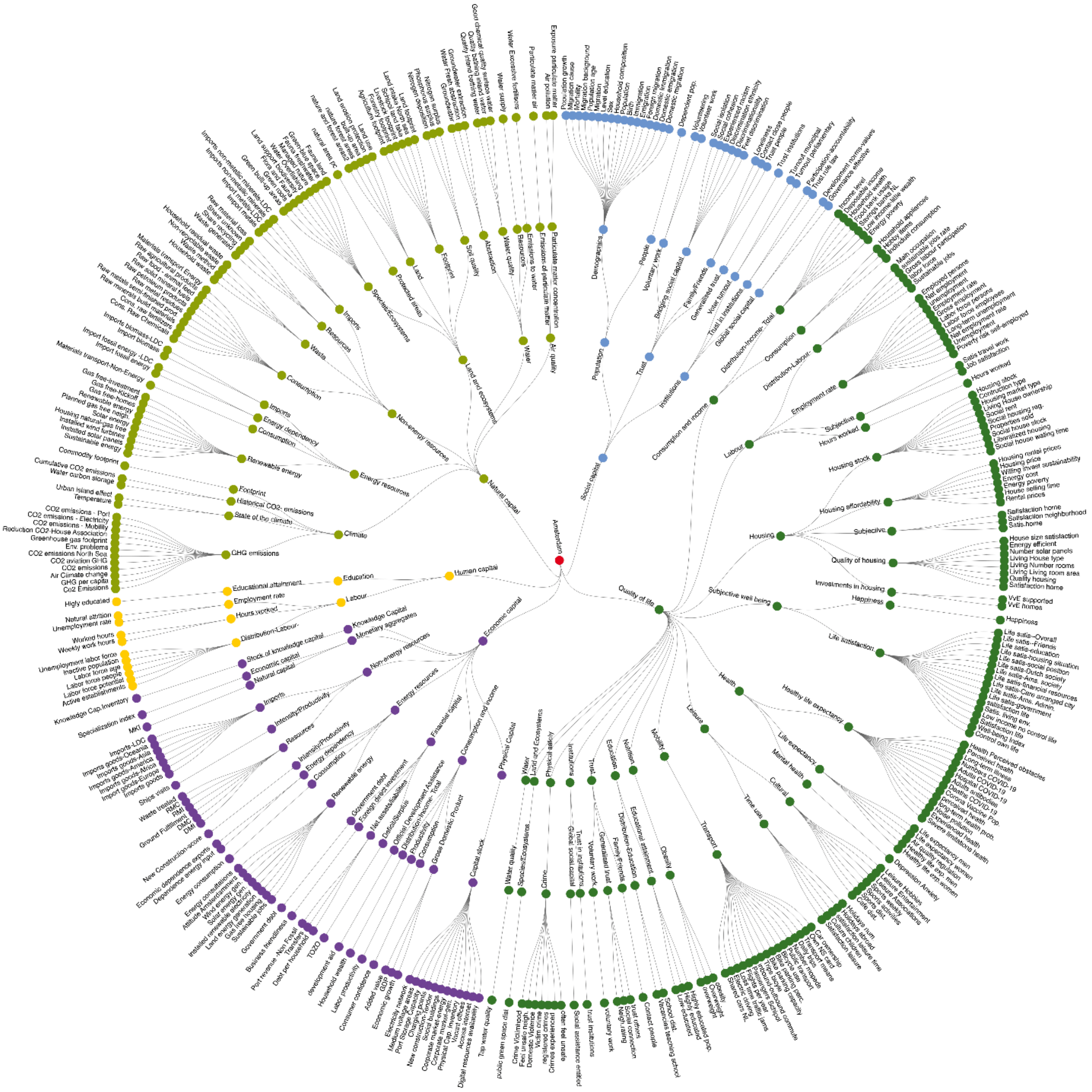
Sustainability
Amsterdam is a sustainable frontrunner and an example to other cities in the world.

Safety
Everyone is safe on the streets of Amsterdam

Appendix fig. 2: Seven Ideals used as the basis for the programme (The Ideal(s) City, 2022)

2. <u>How can we measure these ideals?</u>

The second research question involved conducting workshops on indicators with key stakeholders from the AMS Institute and the municipality of Amsterdam. These workshops aimed to create a comprehensive inventory of existing monitoring systems. The layout of the network graph was based on the Circularity Monitor at city level for the city of Amsterdam, created as a measurement framework to track circular progress (Metabolic, 2018). The results of this effort were presented as a network graph of monitor metadata, which integrated data from seven different frameworks focused on Amsterdam and divided into five main categories: quality of life, economic capital, natural capital, human capital, and social capital.

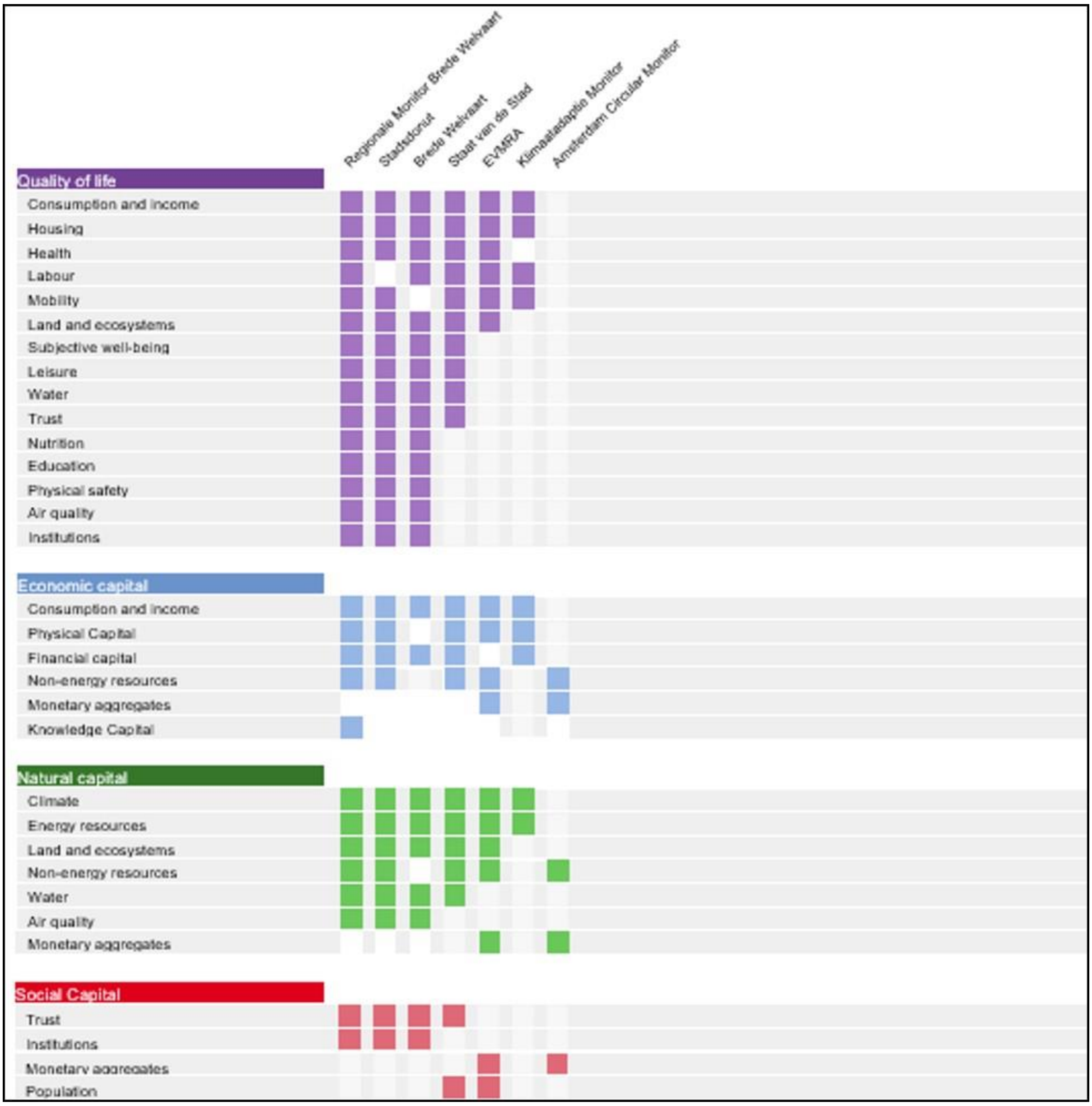


Appendix fig. 3: Overview of network graph displaying the indicators used in seven frameworks for the city of Amsterdam (The Ideal(s) City, 2022).

b) The network graph – overview of subjects and frameworks

The subsequent table, Appendix Table 1, presents a comprehensive record of the diverse indicators listed and chosen from the seven frameworks that the municipality of Amsterdam uses. These indicators are also depicted in the network graph presented previously as Appendix Figure 3.

Appendix Table 1: List of indicators by theme, retrieved from the municipality's different frameworks Overview of network graph displaying the indicators used in seven frameworks for the city of Amsterdam (The Ideal's City, n.a.)



	Regionale Monitor Brede Welvaart	Stadsdonut	Brede Welvaart	Staat van de Stad	EVMRA	Klimaatadaptie Monitor	Amsterdam Circular Monitor
Quality of life							
Consumption and income	🟪	🟪	🟪	🟪	🟪	🟪	
Housing	🟪	🟪	🟪	🟪	🟪	🟪	
Health	🟪	🟪	🟪	🟪	🟪		
Labour	🟪		🟪	🟪	🟪	🟪	
Mobility	🟪	🟪		🟪	🟪	🟪	
Land and ecosystems	🟪	🟪	🟪	🟪	🟪		
Subjective well-being	🟪	🟪	🟪	🟪			
Leisure	🟪	🟪	🟪	🟪			
Water	🟪	🟪	🟪	🟪			
Trust	🟪	🟪	🟪	🟪			
Nutrition	🟪	🟪	🟪				
Education	🟪	🟪	🟪				
Physical safety	🟪	🟪	🟪				
Air quality	🟪	🟪	🟪				
Institutions	🟪	🟪	🟪				
Economic capital							
Consumption and income	🟦	🟦	🟦	🟦	🟦	🟦	
Physical Capital	🟦	🟦		🟦	🟦	🟦	
Financial capital	🟦	🟦	🟦	🟦		🟦	
Non-energy resources	🟦	🟦		🟦	🟦		🟦
Monetary aggregates					🟦		🟦
Knowledge Capital	🟦						
Natural capital							
Climate	🟩	🟩	🟩	🟩	🟩	🟩	
Energy resources	🟩	🟩	🟩	🟩	🟩	🟩	
Land and ecosystems	🟩	🟩	🟩	🟩	🟩		
Non-energy resources	🟩	🟩		🟩	🟩		🟩
Water	🟩	🟩	🟩	🟩			
Air quality	🟩	🟩	🟩				
Monetary aggregates					🟩		🟩
Social Capital							
Trust	🟥	🟥	🟥	🟥			
Institutions	🟥	🟥	🟥				
Monetary aggregates					🟥		🟥
Population				🟥	🟥		

c) The Future-Proof Assets department (FPA)

As explained in Section 1.4, the case study was selected in partnership between the AMS Institute and the Future Proof Assets department (FPA) from the Engineering Office within the Municipality of

Amsterdam. In this section, a brief overview of the FPA and its objectives will be provided to clarify its function and role in this thesis project.

The Engineering Office encompasses expertise in various domains including civil engineering, urban planning and the environment, infrastructure and traffic advice, amongst others (Gemeente Amsterdam, n.a.). Within this scope, the primary objective of the Future-Proof Assets department (FPA) is to prepare the City of Amsterdam for the challenges and impacts related to climate change, energy transition, raw material transition, and the continuing development of smart cities (Openresearch Amsterdam, n.a.).

Given the overlapping expertise and the research conducted by the Ideal City project, the FPA is involved through the presence of an advisor and representative, Christina Ottersberg. The role of the FPA in this thesis project has been to actively provide assistance and valuable municipal data during the data collection phase of this thesis. While the FPA’s direct involvement in the project concluded there, a dedicated recommendation section is developed in Section 7.2 to provide further insights into the municipal measures taken for climate resilience. For detailed information, please refer to Section 7.2.

B. Computations for demographic statistics

The age categories and the population numbers for each neighbourhood used in the following calculations were retrieved from the Dutch open source data “CBS”. For this calculation worksheet, the columns coloured in blue represent the output numbers computed for this research. Columns with numbers in black represent the input data.

Appendix Table 2: Numerical overview of the population per age group and per neighbourhood

Age groups	**Julianapark**	**Tuindorp-Amstelstation**	**De Wetbuurt**	**Total:**
0-15	105	135	285	525
15-25	50	75	195	320
25-45	595	175	390	1160
45-65	175	245	540	960
65+	135	200	420	755
Total	1060	830	1830	3720

First, for each neighbourhood, the population of each age category was added. Second, to find the share (in %) of x age group within the total population, the following formula was used:

$$\frac{\text{Total population by selected age group}}{\text{Total population}} \text{ x } 100 \qquad (1)$$

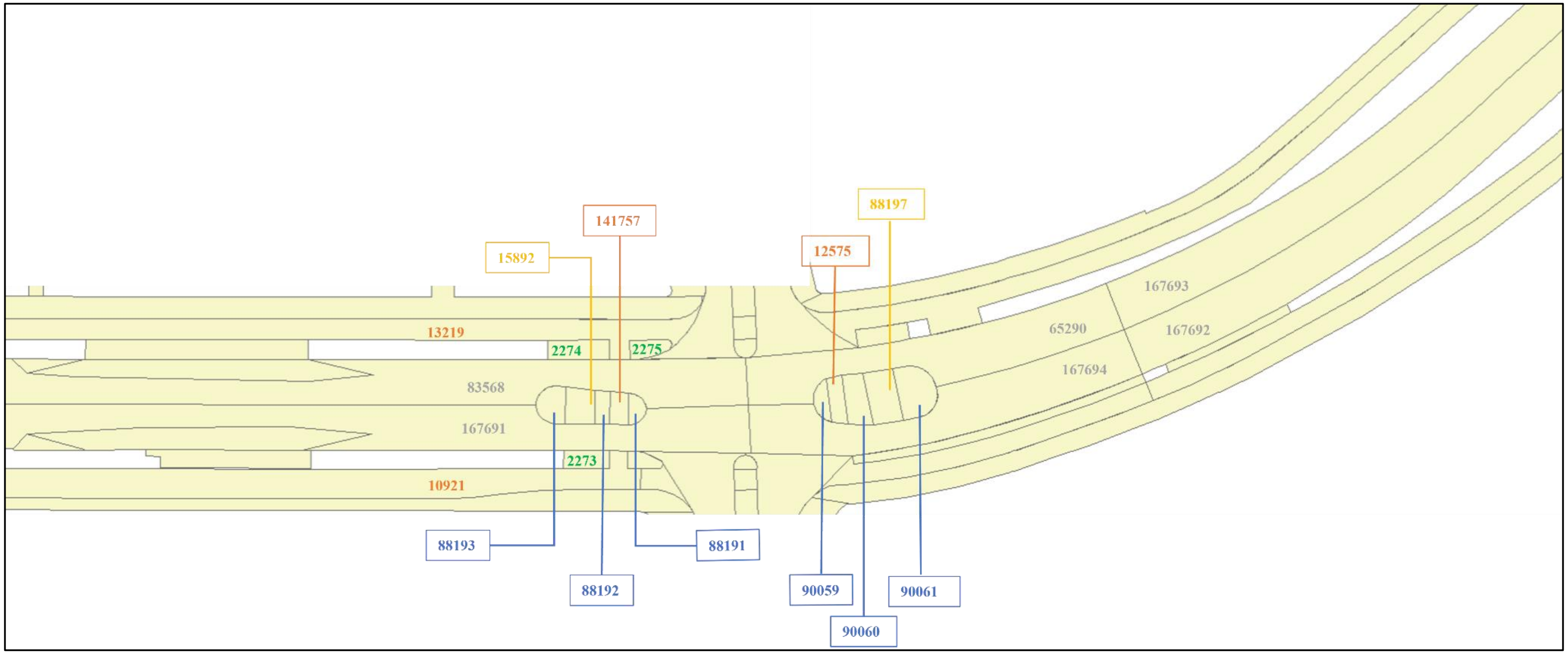
The following numbers were computed to represent the inner layer of the Nested Doughnut Chart (i.e., Fig. 7). For layout purposes, the programme Excel rounded to the nearest integer (i.e., whole number).

Appendix Table 3: Share of the combined population (in %) by age group

0-15	14.11%
15-25	8.60%
25-45	31.18%
45-65	25.81%
65+	20.30%
	Total: 100%

The outer layer of Fig.7 representing the share of the population by age group with a health condition, was found by using the given data for each neighbourhood, and computing the average.

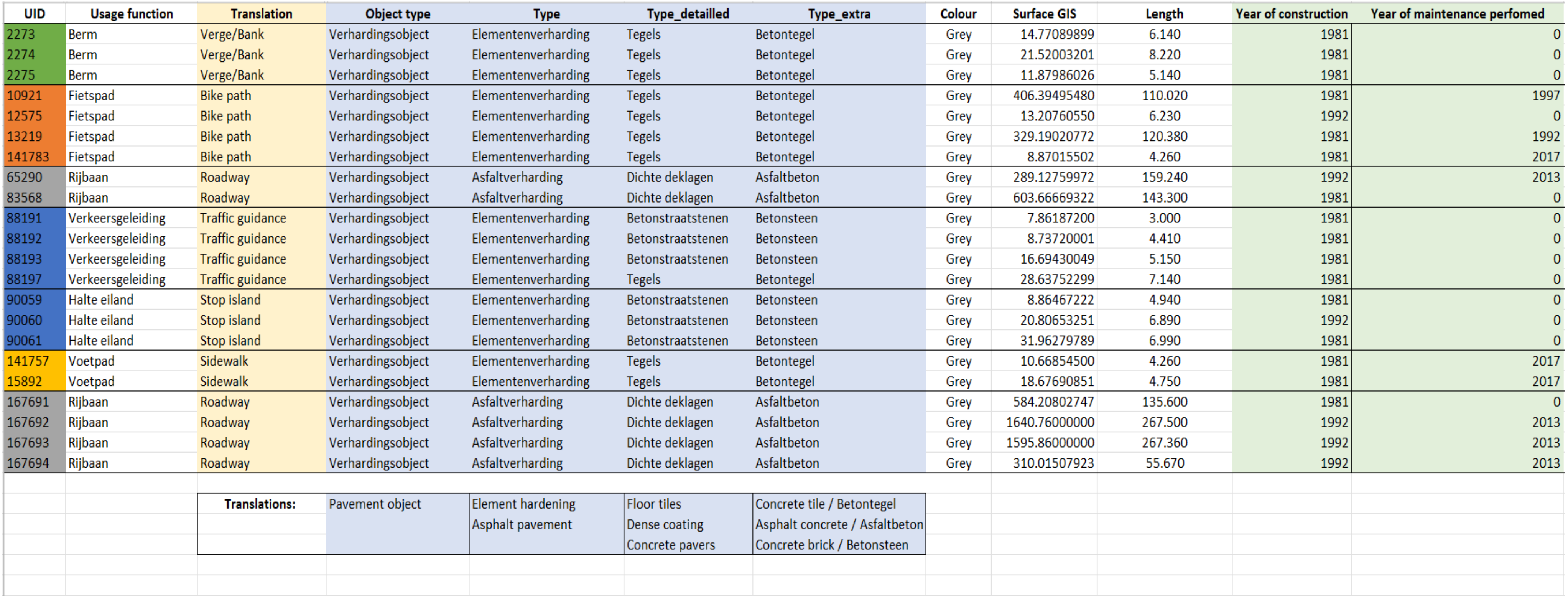
C. Urban plans of the former and the new traffic intersection



Appendix fig. 4: Two-dimensional representation of the former traffic intersection on Hugo de Vrieslaan, retrieved as a screen capture from the GeoPackage file provided by the municipality of Amsterdam. The traffic intersection in the municipal database is divided and labelled by polygons. The polygons of interest to this study are colour-coded by function.

Urban plans for the construction of the previous state of the traffic intersection were not available, and thus, the author created a simple representation of the former traffic intersection for visual and analysis purposes. In the municipal database, the geospatial information is represented by polygons that follow the street layout of the city. The files can be found in the attachment (i.e. Geo Package & Excel Sheet). In Appendix Figure 4, one can observe an excerpt from the database showing the "aerial" or two-dimensional view of the former traffic intersection. As can be seen in Appendix Figure 5, the polygons have an identification number, which in the database are represented with additional information, namely: type of usage, building material, colour, size, length, year of construction, the latest year of maintenance, and constructor(s). The polygons were deliberately colour-coded by usage to facilitate the analysis of the former intersection. One can distinguish between the following five elements: orange – bike paths; yellow – the pedestrian crossings on the medians; green – vegetation; grey – road pavement; blue – the paved areas of the medians.

In Appendix Figure 5, an overview of the geospatial information recorded by the municipality can be observed. Each row presents information for one polygon. The original file can be found in the attachment. Here, the author first translated the file from Dutch to English, cleaned the data to only include information that is useful to the study of this thesis, and colour-coded the polygons to match their functions. For analysis reasons, the author kept the "Usage function" in Dutch and provided the translated names under the column "Translation". Likewise, the translation of the materials is provided at the bottom of the figure with their English terminology.

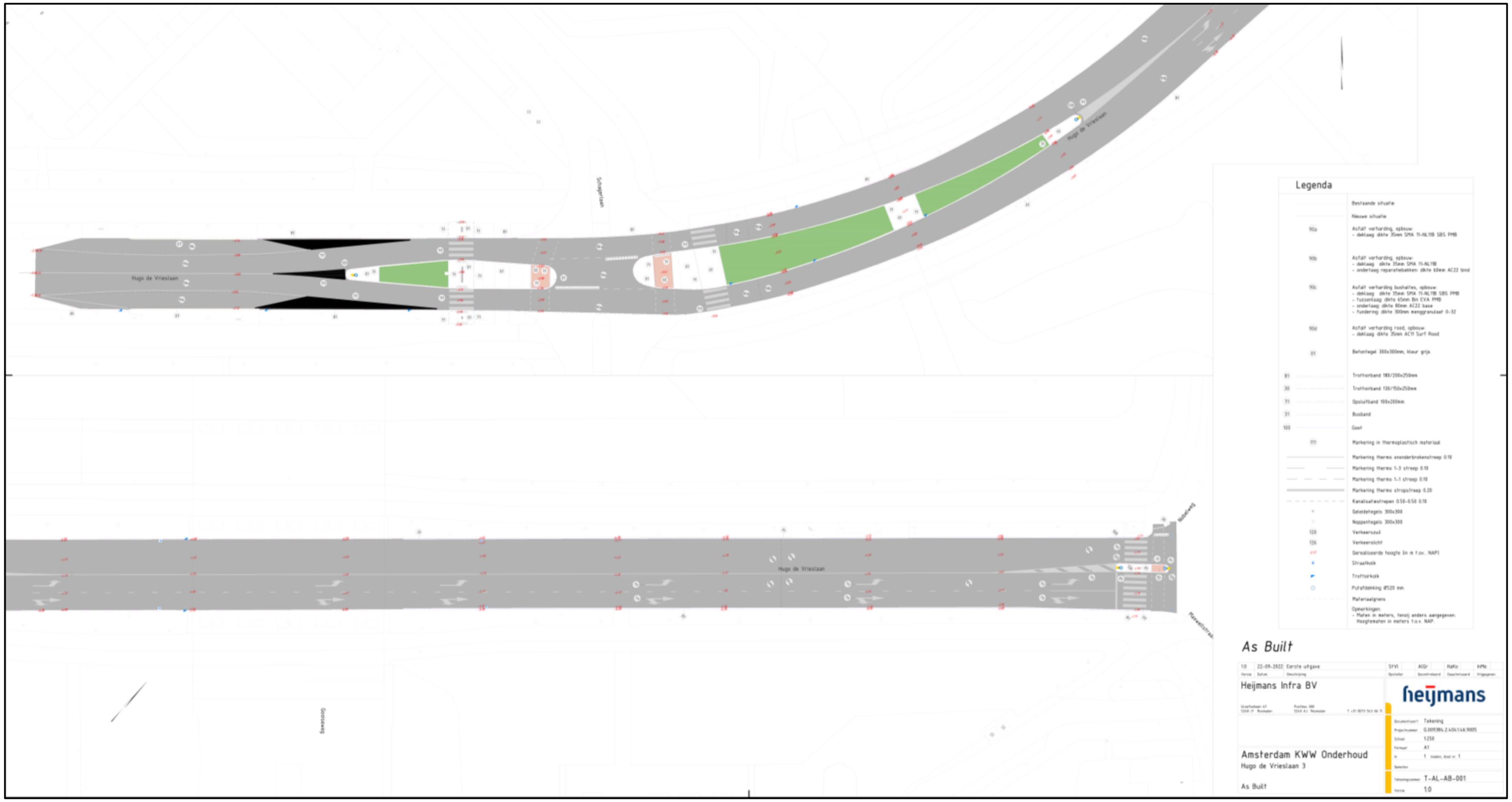


UID	Usage function	Translation	Object type	Type	Type_detailled	Type_extra	Colour	Surface GIS	Length	Year of construction	Year of maintenance perfomed
2273	Berm	Verge/Bank	Verhardingsobject	Elementenverharding	Tegels	Betontegel	Grey	14.77089899	6.140	1981	0
2274	Berm	Verge/Bank	Verhardingsobject	Elementenverharding	Tegels	Betontegel	Grey	21.52003201	8.220	1981	0
2275	Berm	Verge/Bank	Verhardingsobject	Elementenverharding	Tegels	Betontegel	Grey	11.87986026	5.140	1981	0
10921	Fietspad	Bike path	Verhardingsobject	Elementenverharding	Tegels	Betontegel	Grey	406.39495480	110.020	1981	1997
12575	Fietspad	Bike path	Verhardingsobject	Elementenverharding	Tegels	Betontegel	Grey	13.20760550	6.230	1992	0
13219	Fietspad	Bike path	Verhardingsobject	Elementenverharding	Tegels	Betontegel	Grey	329.19020772	120.380	1981	1992
141783	Fietspad	Bike path	Verhardingsobject	Elementenverharding	Tegels	Betontegel	Grey	8.87015502	4.260	1981	2017
65290	Rijbaan	Roadway	Verhardingsobject	Asfaltverharding	Dichte deklagen	Asfaltbeton	Grey	289.12759972	159.240	1992	2013
83568	Rijbaan	Roadway	Verhardingsobject	Asfaltverharding	Dichte deklagen	Asfaltbeton	Grey	603.66669322	143.300	1981	0
88191	Verkeersgeleiding	Traffic guidance	Verhardingsobject	Elementenverharding	Betonstraatstenen	Betonsteen	Grey	7.86187200	3.000	1981	0
88192	Verkeersgeleiding	Traffic guidance	Verhardingsobject	Elementenverharding	Betonstraatstenen	Betonsteen	Grey	8.73720001	4.410	1981	0
88193	Verkeersgeleiding	Traffic guidance	Verhardingsobject	Elementenverharding	Betonstraatstenen	Betonsteen	Grey	16.69430049	5.150	1981	0
88197	Verkeersgeleiding	Traffic guidance	Verhardingsobject	Elementenverharding	Tegels	Betontegel	Grey	28.63752299	7.140	1981	0
90059	Halte eiland	Stop island	Verhardingsobject	Elementenverharding	Betonstraatstenen	Betonsteen	Grey	8.86467222	4.940	1981	0
90060	Halte eiland	Stop island	Verhardingsobject	Elementenverharding	Betonstraatstenen	Betonsteen	Grey	20.80653251	6.890	1992	0
90061	Halte eiland	Stop island	Verhardingsobject	Elementenverharding	Betonstraatstenen	Betonsteen	Grey	31.96279789	6.990	1981	0
141757	Voetpad	Sidewalk	Verhardingsobject	Elementenverharding	Tegels	Betontegel	Grey	10.66854500	4.260	1981	2017
15892	Voetpad	Sidewalk	Verhardingsobject	Elementenverharding	Tegels	Betontegel	Grey	18.67690851	4.750	1981	2017
167691	Rijbaan	Roadway	Verhardingsobject	Asfaltverharding	Dichte deklagen	Asfaltbeton	Grey	584.20802747	135.600	1981	0
167692	Rijbaan	Roadway	Verhardingsobject	Asfaltverharding	Dichte deklagen	Asfaltbeton	Grey	1640.76000000	267.500	1992	2013
167693	Rijbaan	Roadway	Verhardingsobject	Asfaltverharding	Dichte deklagen	Asfaltbeton	Grey	1595.86000000	267.360	1992	2013
167694	Rijbaan	Roadway	Verhardingsobject	Asfaltverharding	Dichte deklagen	Asfaltbeton	Grey	310.01507923	55.670	1992	2013

Translations:	Pavement object	Element hardening	Floor tiles	Concrete tile / Betontegel
		Asphalt pavement	Dense coating	Asphalt concrete / Asfaltbeton
			Concrete pavers	Concrete brick / Betonsteen

Appendix fig. 5: Representation of the geopackage and the relevant attributes for this study

In contrast to the previous visualisations, Appendix Figure 6 illustrates a real construction plan and guideline for the renovation of the traffic intersection. The legend includes relevant information on the materials used for the construction, along with their respective dimensions, and the new design.


Hugo de Vrieslaan
Legenda
Bestaande situatie
Nieuwe situatie
90a Asfalt verharding, opbouw:
- deklaag dikte 35mm SMA 11-NL11B SBS PMB
90b Asfalt verharding, opbouw:
- deklaag dikte 35mm SMA 11-NL11B
- onderlaag reparatiebakken: dikte 60mm AC22 bind
90c Asfalt verharding bushaltes, opbouw:
- deklaag dikte 35mm SMA 11-NL11B SBS PMB
- tussenlaag dikte 65mm Bin EVA PMB
- onderlaag dikte 80mm AC22 base
- fundering dikte 300mm menggranulaat 0-32
90d Asfalt verharding rood, opbouw:
- deklaag dikte 35mm AC11 Surf Rood
01 Betontegel 300x300mm, kleur grijs
81 Trottoirband 180/200x250mm
30 Trottoirband 130/150x250mm
11 Opsluitband 100x200mm
31 Busband
100 Goot
111 Markering in thermoplastisch materiaal
Markering thermo ononderbrokenstreep 0.10
Markering thermo 1-3 streep 0.10
Markering thermo 1-1 streep 0.10
Markering thermo stopstreep 0.20
Kanalisatiestrepen 0.50-0.50 0.10
Geleidetegels 300x300
Noppentegels 300x300
120 Verkeerszuil
126 Verkeerslicht
Gerealiseerde hoogte (in m t.o.v. NAP)
Straatkolk
Trottoirkolk
Putafdekking Ø520 mm
Materiaalgrens
Opmerkingen:
- Maten in meters, tenzij anders aangegeven.
Hoogtematen in meters t.o.v. NAP.
As Built
1.0
22-09-2022
Eerste uitgave
StVl
AlGr
HaKo
InMe
Versie
Datum
Omschrijving
Opsteller
Gecontroleerd
Geautoriseerd
Vrijgegeven
Heijmans Infra BV
heijmans
Documentsoort Tekening
Projectnummer G.009384.2.404146.9005
Schaal 1:250
Formaat A1
1 bladen, blad nr. 1
Tekeningnummer T-AL-AB-001
Versie 1.0
Amsterdam KWW Onderhoud
Hugo de Vrieslaan 3
As Built

Appendix fig. 6: Urban plans of the renovation measures for on the Hugo de Vrieslaan Phase 3, provided by the construction company. The construction is divided into two sections: The upper section showcases the redesign of the traffic intersection (of relevance to this study). The bottom section shows the repaving of the Hugo de Vrieslaan road (excluded from this study) (Heijmans Infra B.V., 2022).

D. Construction materials spreadsheet

Appendix Table 3 was adapted from a letter exchanged between the construction company, Heijmans Infra B.V., and the municipality of Amsterdam before construction began in 2022. The file can be found attached as "*Information_on_construction_phases_&_materials_HeijmansBV*".

The letter comprises a detailed list of the renovation work executed on the traffic intersection on Hugo de Vrieslaan, including information on the tasks, materials, units, quantities, and prices per unit (in euros). The list is structured by section. In the "Description" column, headings in red highlight the different phases of the project, while headings in black point to the specific tasks or materials laid out.

The following table has been adapted to only contain relevant information for this thesis project, such as materials used, their quantities, and their colours.

Appendix Table 4: Adapted spreadsheet to filter out the construction materials and colours used for the redesign of the intersection (adapted from Heijmans B.V., 2022)

Description (translated into English)	**Description (in Dutch as stated in the document)**	**Unit**	**Quantities**	**Price per unit in euros**	**Total amount in euros**
1. Groundwork	Grondwerk	.	.	.	.
2. Edging stones	Banden	.	.	.	.
3. Curbs	Trottoirbanden	.	.	.	.
4. Retaining edging / Border stones	Opsluitbanden	.	.	.	.
5. Tiles and stones	Tegels en stenen	.	.	.	.
Concrete tiles	Betontegels	Sqm (m^2)	180,00	40,22	7.239,60
6. Repaving	Herstraten	.	.	.	.
7. Asphalt application	Aanbrengen asfalt	.	.	.	.
Levelling and asphalt application wearing course SMA-NL 11B black (44004) […]	Lev. en aanbrengen deklaag asfalt SMA-NL 11B zwart (44004) […]	Ton	202,00	166,93	33.719,86
Levelling and asphalt application wearing course AC11 surf red (65007) […]	Lev. en aanbrengen deklaag asfalt AC 11 surf rood (65007) […]	Ton	5,00	591,62	2.958,10
8. Road marking	Wegbebakening	.	.	.	.
9. Thermoplastic markings	Markering thermoplast	.	.	.	.

E. Leidraad CVC 2020 – Recommendation for the city of Amsterdam

CVC 2020 & Puccini Method – Recommendation

This section gives background information on the documentation used to make the recommendation for the intersection redesign. The Central Traffic Commission, abbreviated as Leidraad CVC (Gemeente Amsterdam, n.a.), is responsible for examining all traffic plans in Amsterdam for safety. The CVC reviews designs for public places that incorporate traffic-related concerns and it has to comply with the Puccini method, or have gained approval from the Puccini method committee to diverge. The CVC's street safety recommendations use the Puccini approach to promote consistency and recognizability in the cityscape, which is a critical factor for traffic safety.

In the context of street trees (straatbomen), the document "Leidraad CVC 2020" primarily and exclusively emphasizes the following aspects on page p. 74:

8.13 Trees, Poles, and Traffic Signs (Bomen, masten en verkeersborden):

- Trees are planted in planting beds with a minimum width of 2.00 meters to accommodate growth requirements.
- Special attention should be paid to the placement of trees in relation to general visibility requirements for a safe and clear traffic situation at intersections. In practice, this often means that trees cannot be extended up to the intersection, both in the central reservation and on the side, particularly when traffic lights need to be visible. As a rule of thumb, a space of 10 meters is kept clear from the stop line for this purpose. However, this distance may vary depending on the distance between the tree and the roadway.
- Obstacles (traffic signs, traffic poles, etc.) along a roadway are preferably placed at least 0.35 meters from the edge of the roadway, following the requirements of the motor vehicle Performance Requirement (PvE) of ASVV. This means that the pole of a traffic sign is placed at a minimum distance of 0.65 meters from the roadway.
- General visibility requirements should always be taken into account when placing obstacles.
- It is not desirable to install traffic signs without a legal basis.

The document can be accessed through the following municipal website "Handboek Inrichting Openbare Ruimte".

Tree species selection:

Documentation on the tree species was retrieved from the study of 75 tree species planted in cityscapes across the Netherlands by a Dutch scholar, Hiemstra (2011), over an eight-year period. The document contains a legend with the criteria and a table listing all 75 tree species from his study. The document can be found in the attachment under ‘*overview_tree_species_Hiemstra_2011’*.