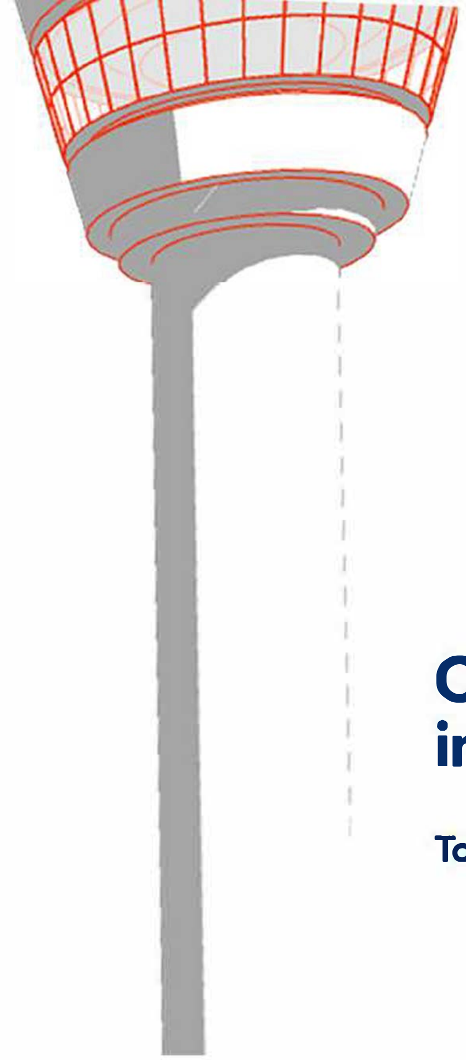
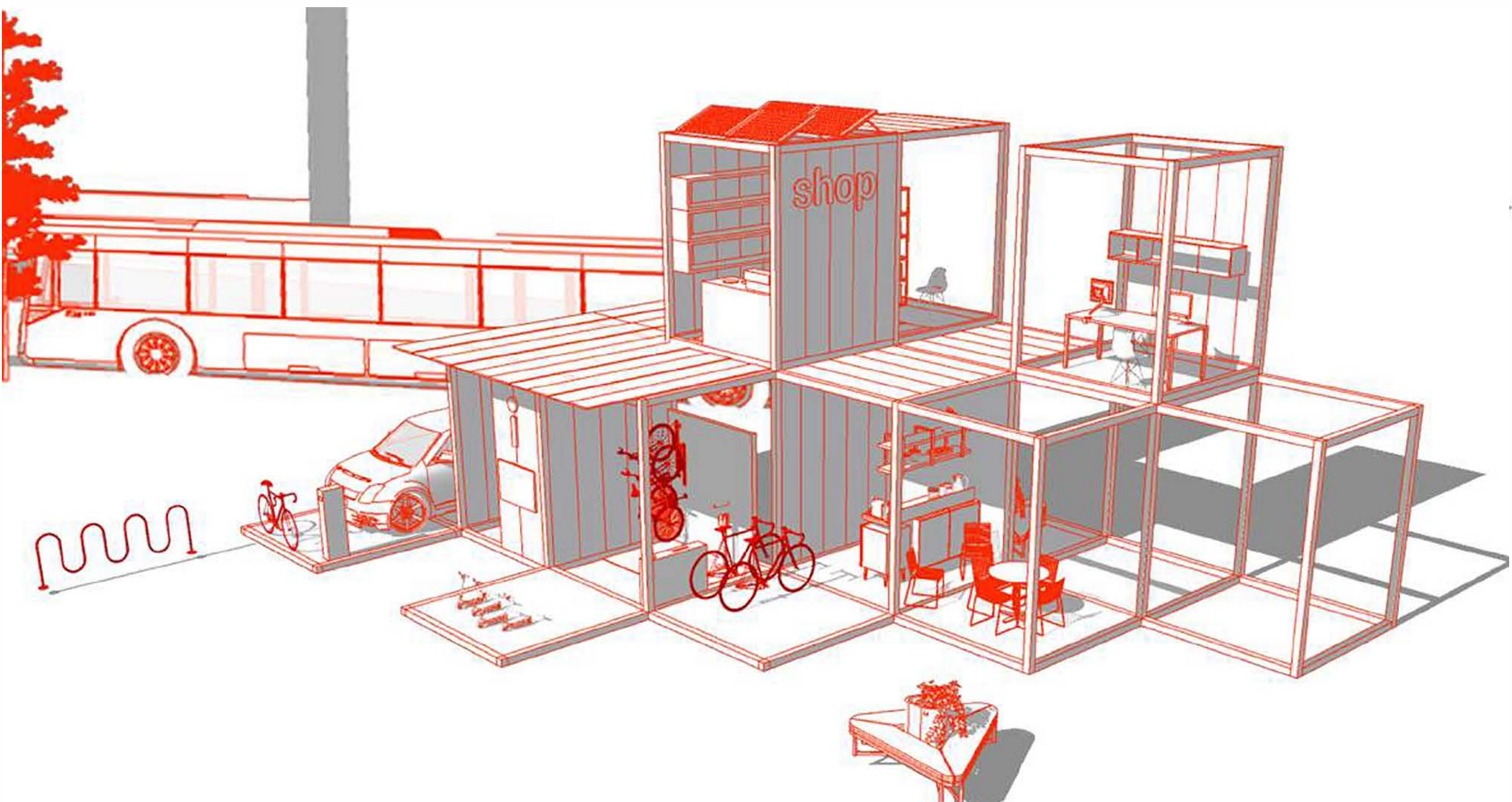


Car-Free Development in landside airport areas

Towards Low Car(bon) policies for airport commuters



Car-Free Development in landside airport areas

*Towards **Low Car**(bon) policies for airport commuters*

Aslınur Bali

in partial fulfillment of the requirements for the degree of

Master of Science

to be defended publicly on ; 21 August 2023 at 14.30 PM.

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"Designing the city for people, not for the vehicles."

J. Gehl

Preface

So,
in essence,
this thesis is about cars. about the removal of them from our day-to-day life.

From an enlightened reader's eye, when I read "Speed and Politics" by Paul Virilio, I became familiar with having a statement for global concerns. Virilio underscores conventional notions of progress and interplay between technological advancement, societal transformation, and the dynamics of control and governance.

In an era marked by urbanization and evolving transportation paradigms, the pursuit of sustainable and efficient mobility solutions has become a pivotal concern for cities and communities. This thesis embarks on a comprehensive exploration of this imperative issue by delving into the strategic realm of urban transportation. Focusing on the contrast between door-to-door private car transport and the goal of public transit, this study leads to a transformative journey that goes beyond transportation modes, encapsulating broader societal and environmental implications.

As readers embark on this thesis, they are invited to engage with a multi-dimensional exploration of the potential for strategic transportation interventions to shape more vibrant, accessible, and environmentally-conscious urban landscapes. Through empirical insights, informed analysis, and visionary perspectives, this study seeks to inspire a broader conversation on the vital role of strategic transportation choices in airports by redefining the urban experience for the betterment of present and future generations.

"It is not reached by walking, but those who arrive are those who walk." said Khalil Gibran. Although it fits the car-free theme, it is to me an aphorism that corresponds my feelings during this process of my life, in a single sentence. A bitter-sweet path where I got excited, learned, struggled, and grabbed another cup of coffee to continue producing, but mostly conflicted with myself. Being aware that this tough path would have been even more burdensome without my supporters and guides, I owe it to myself to convey my sincere wishes.

To my thesis advisors ***Aksel Ersoy*** *and* ***Simeon Calvert*** *that shared their valuable expertise with me and patiently stood by me throughout this process,*

To my TNO supervisor ***Yashar Araghi****, that not only provided an academic contribution to my thesis, but also shed light to my journey whatever the circumstances are -even when the world doesn't look that rosy in my eyes,*

To my guest examiner ***Ron van Lammeren****, for kindly accepting to join my defense and also for teaching the GIS software in the first year of my master's which I used in my thesis,*

Thank you.

My dearest mother and father, my companion/colleague/sister, and everyone who devotedly walked with me in this process,

Please keep walking with me, thank you once again.

Aslınur Bali, August '23

Executive Summary

Approximately 200,000 individuals travel to & from Schiphol Airport daily through various means such as cars, taxis, buses, shuttles, trains, motorcycles, scooters, and bicycles. With this perspective, Schiphol Airport is the largest mobility hub in the whole Netherlands, making accessibility a critical aspect. The Schiphol Group is responsible for providing/ensuring accessibility. Their main goal is to alleviate accessibility for Schiphol's customers, including passengers, personnel/commuters, business partners, and cargo, by focusing on different transportation modalities.

To achieve the goal of "the best airport for accessibility and sustainable aviation as well as land-side transport in Europe," Schiphol Group works toward a car-free, emission-free vision and plans to apply on-site.

This thesis conjugates Schiphol's and European Union's (EU) goals (EGD, TULIPS) set for the aviation sector and further investigates the possibility of reaching the "Car-free Schiphol Centrum". The objectives designated the reach this primary goal.

- A combined method to design and evaluate the car-free Schiphol Airport efficiency
- A system that uses the methods to display the efficiency of the car-free Schiphol Airport.

By exploring these objectives, the thesis aims to contribute to the overall goal of making Schiphol Airport a sustainable, accessible, and car-free hub for all commuters and users. The problem statement and main research question gather around this unifying goal:

"How can Schiphol Airport become ***car-free*** *in its land-side areas?"*

To address this question, the thesis proposes a combined method to design and evaluate the efficiency of a car-free Schiphol Airport. This method considers the goals set by the Schiphol Group and the European Union.

The methodology constitutes the combination of the literature-based frameworks to create anew the thesis as well as finding the best measurement tools to seek the results of a successful car-free Schiphol Centrum. Car-free Development and Transit-oriented development allow for discussing and creating the framework for a car-free Schiphol Airport. The evaluation of this framework will be done by implementing new modalities to the Schiphol to ensure a possible/potential modal shift of the users and assess the walkability of the land-side areas.

Along with the theoretical work, a case study for the thesis is conducted to apply the proposed methodology and evaluate its effectiveness. The case study focuses on the land-side areas of Schiphol Airport and aims to assess the feasibility of implementing car-free measures in these areas.

The case study's findings show that a car-free Schiphol Centrum is feasible and should be implemented in real life. The proposed measures depict such as improving public transportation, promoting cycling and walking, and providing efficient and sustainable alternatives to private cars (micro mobility options), can contribute to reducing car dependency and creating a more sustainable and accessible airport.

Overall, this thesis provides valuable insights and recommendations for achieving a car-free Schiphol Airport. By combining theoretical frameworks, measurement tools, and a practical case study.

Keywords: car-free development, transit-oriented development, micro mobility, walkability, airport landside transportation

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Glossary

CFD - Car-Free Development

EGD - European Green Deal

GGE - Greenhouse Gas Emissions

GIS - Geographical Information System

ITS - Intelligent Transportation Systems

K&R - Kiss&Ride

LEV - Light Electric Vehicle

MM - Micro Mobility

MRQ - Main Research Question

OSM – OpenStreetMap

PP – Policy Package

SG - Schiphol Group

SQ - Sub-question

TOD - Transit-Oriented Development

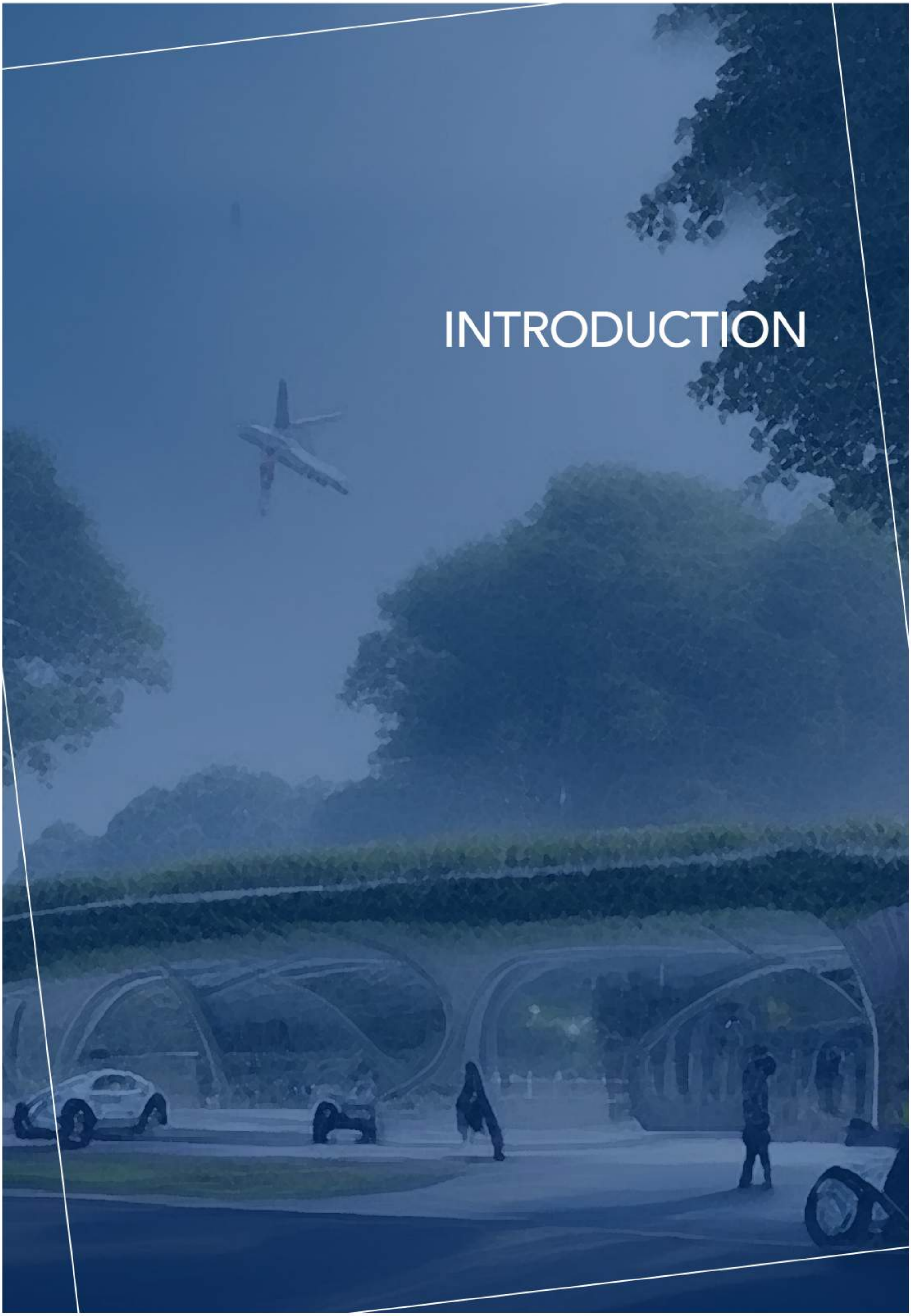
WB - World Bank

WP – Work Package

WTC - World Trade Center

ZEZ - Zero-Emission Zone

INTRODUCTION



1. INTRODUCTION

One of the primary contributors to greenhouse gas emissions (GGE) is the transportation sector, which also contributes to regional pollution (Yi & Yan, 2020). As stated in the European Green Deal (EGD), the transportation issue, which accounts for 25% of the GGE, states that rail travel should have encouraged rather than driving for passengers, visitors, commuters, and drop-offers (https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en). This is because, compared to car-based systems, railways, public transportation, and new mobility solutions have greater capacities, resulting in fewer issues like traffic congestion and other environmental pollution.

The World Bank (WB) (World Bank, 2012) points out that the lack of a universal cooperative global climate policy will result in temperature rises exceeding a disastrous 4°C increase within this century—perhaps as early as 2060. Meanwhile, transportation is 22 % of the global total and the fastest-growing sector of GGE, forecast to grow by 40% by 2035 (International Energy Agency., 2013). Besides, reductions in motorized road traffic, particularly when complemented by increases in active transport (de Nazelle et al., 2011), are also likely to benefit public health in the short and long term.

At this point "car-free" concept becomes prominent. Various examinations have been proposed in the literature to address the issue of increasing car numbers in cities. Researchers (Van Oort et al., 2017) advocate for investing in public transport as a solution, citing its numerous advantages in managing growing traffic demand. Alternatively, some researchers (Dill & Carr, 2003; Hamilton & Wichman, 2018), suggest promoting alternative modes of transportation like bicycles or walking as a practical approach to tackle this problem.

In the literature, there are different variations/definitions for "car-free" or "carfree" areas. Crawford (Crawford, 2000) introduced a more unconventional strategy by presenting the concept of "Carfree Cities" in his book. The author put forward a comprehensive plan for cities that eliminate the presence of cars. Car-free cities are directly related to reducing greenhouse gas emissions, primarily associated with transportation.

Car-free cities aim to minimize or eliminate private car usage within a designated area while often prioritizing compact, mixed-use development and the availability of essential services and amenities within walking or cycling distance (Bertolini & le Clercq, 2003). Car-free cities promote more efficient land use by reducing the need for long-distance travel and reducing sprawl and associated emissions from longer commutes.

One of the other concepts, low car(bon) refers to communities that offer paths to significant reductions in carbon and other GGE by limitin g and discouraging car use and car ownership. These intentional communities can be "car-free," with heavy restrictions on car use or car ownership, such as streets closed to car traffic and measures such as priced or rationed parking. Besides, "car-lite" development is similar to but not as restrictive as car-free development (CFD).

A car-free city is a broader concept that applies to an entire urban area or a significant part of it, while a car-free development refers to a smaller-scale initiative within a larger urban context. Car-free cities aim to transform the overall transportation landscape of an entire city or region, while car-free developments focus on creating localized, self-contained neighborhoods or districts that prioritize sustainable transportation options and discourage private car usage (Melia, 2014b).

Airports are significant contributors to GGE due to the considerable vehicle traffic associated with passenger dropping off and picking up (Kiss&Ride, (K&R)), commuters' transport, and parking. By implementing a car-free approach, airports can significantly mitigate the carbon footprint and enhance environmental sustainability efforts. This aligns with global goals to mitigate climate change and promote a greener future.

Moreover, air transportation has experienced a challenging process over the past few years, particularly in the ongoing process since 2021. When COVID-19 first appeared, this process in the flight market decreased by 76%, and the industry struggled to return to its pre-pandemic air transport movements (IATA, 2022). While efforts are being made to regain the old momentum, sustainable transport policies aiming to reduce the impact of greenhouse gases are implemented within the EGD scope.

Therefore, as a case study of the thesis Amsterdam Schiphol Airport was chosen to investigate more on reducing GGE and implementing CFD policies. Amsterdam Schiphol Group (SG) focuses on various policies to reduce carbon emissions (see Figure 1) in line with its 2030 targets (for example, to create a zero-emission Schiphol Center) both on the landside & airside of the airport area (Schiphol Group, 2022).

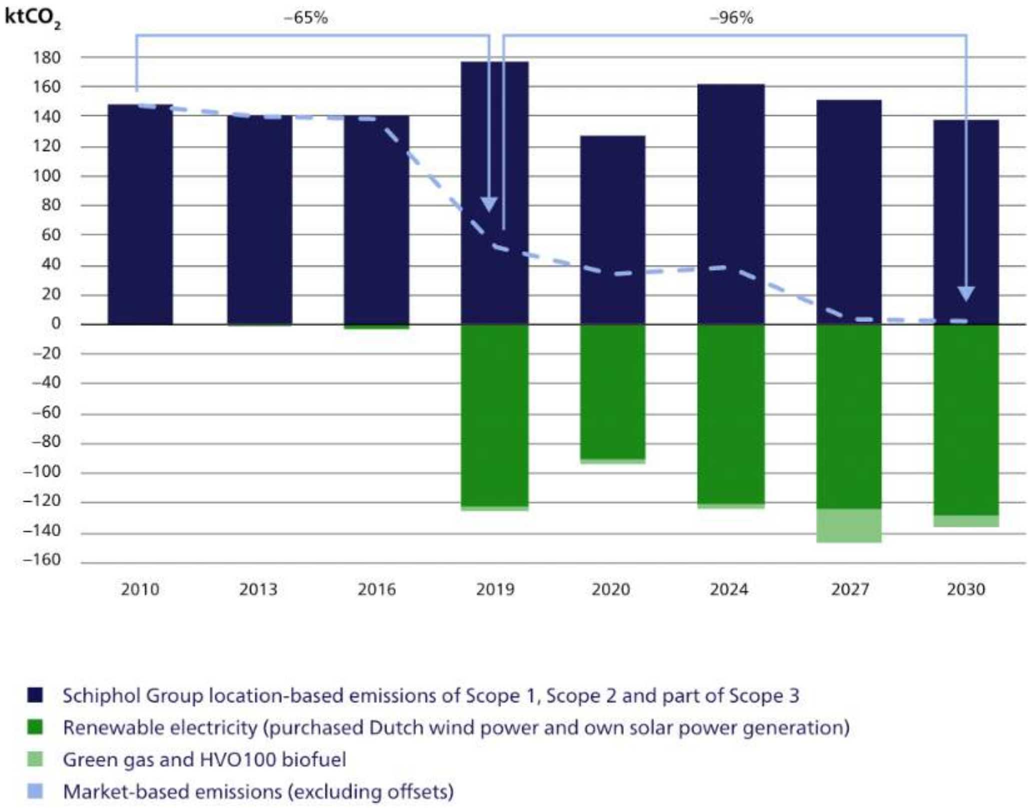


Figure 1: Schiphol CO2 emissions 2010-2030 within "zero emissions airports 2030" target (Schiphol Group, 2022)

Since this thesis will examine CFD in Schiphol Airport, the transit feature of the airport should be considered by an elaborative literature search. Over the past ten years, there has been much interest in Europe in the idea of transit-oriented development (TOD), which is a development close to or aligned with transit facilities (Bertolini et al., 2012). Since the 90s, European cities have prioritized the renovation of railroad stations and the areas around them (Bertolini & Spit, 2005), but airports and their facilities remained relatively undercover. In academia, TOD principles are also essential to plan car-free environments. TOD is designed to prioritize the needs of pedestrians, bicyclists, and public transit users rather than cars. This requires careful planning and strategic policies to ensure that travel by foot, bicycle, or public transportation is safe, efficient, and convenient. This type of planning is also envisaged in the Schiphol Airport to increase mobility options and reduce car use.

To achieve a greener non-car-dependent transport environment in airports, as another essential concept Intelligent Transportation Systems (ITS) find a place in literature as well as on-site applications. Industry actors, decision-makers, and academics are picturing a more sustainable form of transportation in which shared micro mobility and public transit can take the place of private car ownership as the predominant mode (Shaheen & Cohen, 2018). The possible micro mobility connectivity with public transportation depends on several variables (e. g., accessibility of people, less GGE, livability, and security), many of which are concerned with the design of transit stations and the areas around them (Ferguson & Sanguinetti, 2021). Likewise, in built environments where transit transportation and micro mobility are applied, designing safe and attractive connections increases reaching low-cost public transportation (Giles-Corti et al., 2016).

Together with the micro mobility solutions, walking is one of the primary transport choices to reach a greener transport system. Walking is not only a healthy option but also a sustainable one. It produces no emissions, and it is accessible to all individuals. Therefore, cities should prioritize walking infrastructures by creating pedestrian-only zones and improving sidewalks. Furthermore, providing public facilities for walkers, such as public amenities and well-lit paths, would encourage more people to walk in their daily routines. Ultimately, achieving sustainable transportation requires a combination of various modes of transportation, including public transport, micro mobility solutions, and active transport options such as walking and cycling.

In conclusion, cities and airports can be re-designed as car-free developments to create a greener future. As significant contributors to GGE, the aviation industry can benefit from implementing a car-free approach to mitigate their carbon footprint. A case study of Amsterdam Schiphol Airport is chosen to investigate reducing GGE and implementing car-free policies. Together with CFD, Transit-oriented development (TOD), micro mobility, and walkability concepts are also essential in planning car-free environments and prioritizing pedestrians, bicyclists, and public transportation. Ultimately, achieving sustainable transportation requires a combination of various concepts and modes of transportation.

1.1. Problem Statement

Besides the increasing greenhouse gas emissions and regional pollution caused by the transportation sector, there is a need to explore sustainable transport solutions, particularly in landside areas of airports where car use prevails.

Low-carbon communities, characterized by limited and discouraged car use or ownership, offer significant potential for reducing GGE. However, there is a lack of comprehensive research and planning focused on implementing car-free or car-lite development strategies in airport areas. Moreover, while previous studies have proposed investing in public transport and promoting alternative modes of transportation like bicycles, there needs to be more literature regarding the integration of micro-mobility and walkability in sustainable transport planning for airports. Therefore, there is a need to consider and develop TOD principles that prioritize pedestrians, bicyclists, and public transit users, while considering the connectivity of micro-mobility solutions and improving walkability within airport environments. By addressing these research gaps, airports can enhance various mobility options and create a greener non-car-dependent transit environment.

1.2. Objectives

Determining the main objectives gives a holistic perspective to achieve the desired results. This also lights a beacon concerning taking action toward the solution to the abovementioned problem. Based on discussions with experts and the given case study's directives, two primary objectives have been identified.

- A combined method to design and evaluate the car-free Schiphol Airport efficiency
- A system that uses the methods to display the efficiency of the car-free Schiphol Airport

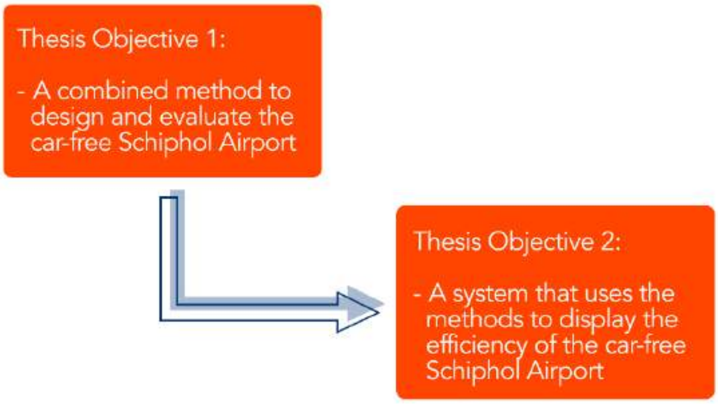


Figure 2: Thesis objectives

The designated objectives help to elaborate the research goals and provide a clear direction for the methodology. The first objective aims to create a design and evaluation method for the car-free Schiphol Airport that considers different factors, including the accessibility of pedestrians, implementation of micro-mobility, and application of TOD principles. This method will help decision-makers evaluate the proposed car-free policies' efficiency and identify improvement areas. The second objective involves developing a system to display the efficiency of the car-free Schiphol Airport. This system will allow decision-makers to track the progress toward achieving a sustainable and pedestrian-friendly transportation system in the Schiphol Centrum area. By achieving these objectives, the research aims to contribute to the academic and societal discussions on sustainable transportation and urban planning.

RESEARCH DESIGN

2. RESEARCH DESIGN

The aforementioned research problem and the thesis objectives constitute the foundation of the second chapter. To achieve the desired results, there are several steps to consider. These steps will also show how to reach from the current situation to the design of the end goals. Figures 3 and 4 visualize the relation between objectives and the current situation.

Figure 3: The steps in relation to the current situation and thesis objective and goals.

As depicted in the figures, objective 1 entails tasks such as problem identification, data collection from the client and literature, developing and visualizating the concept design. On the other hand, objective 2 encompasses a cohesive system guided by user feedback and assessing the design's overall efficiency.

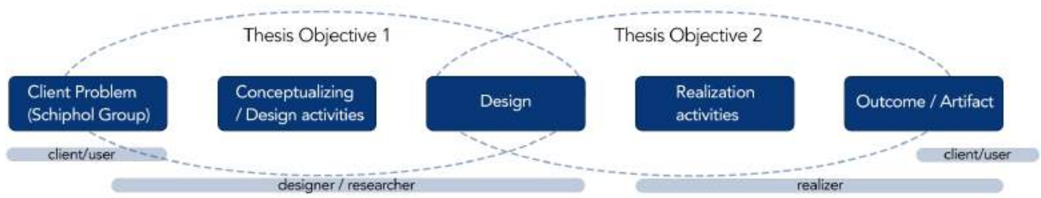


Figure 4: The flow of the design process with thesis objectives

Considering Figures 3 and 4, the "Research Design Framework" was created better to convey the overall thesis (Figure 5). The chart consists of 4 main parts: *Research Problem, Theoretical and Methodological findings, Empirical Analyses and Design, and lastly, Discussion and Conclusion. It also shows in which chapter the sub-questions answered along the report.*

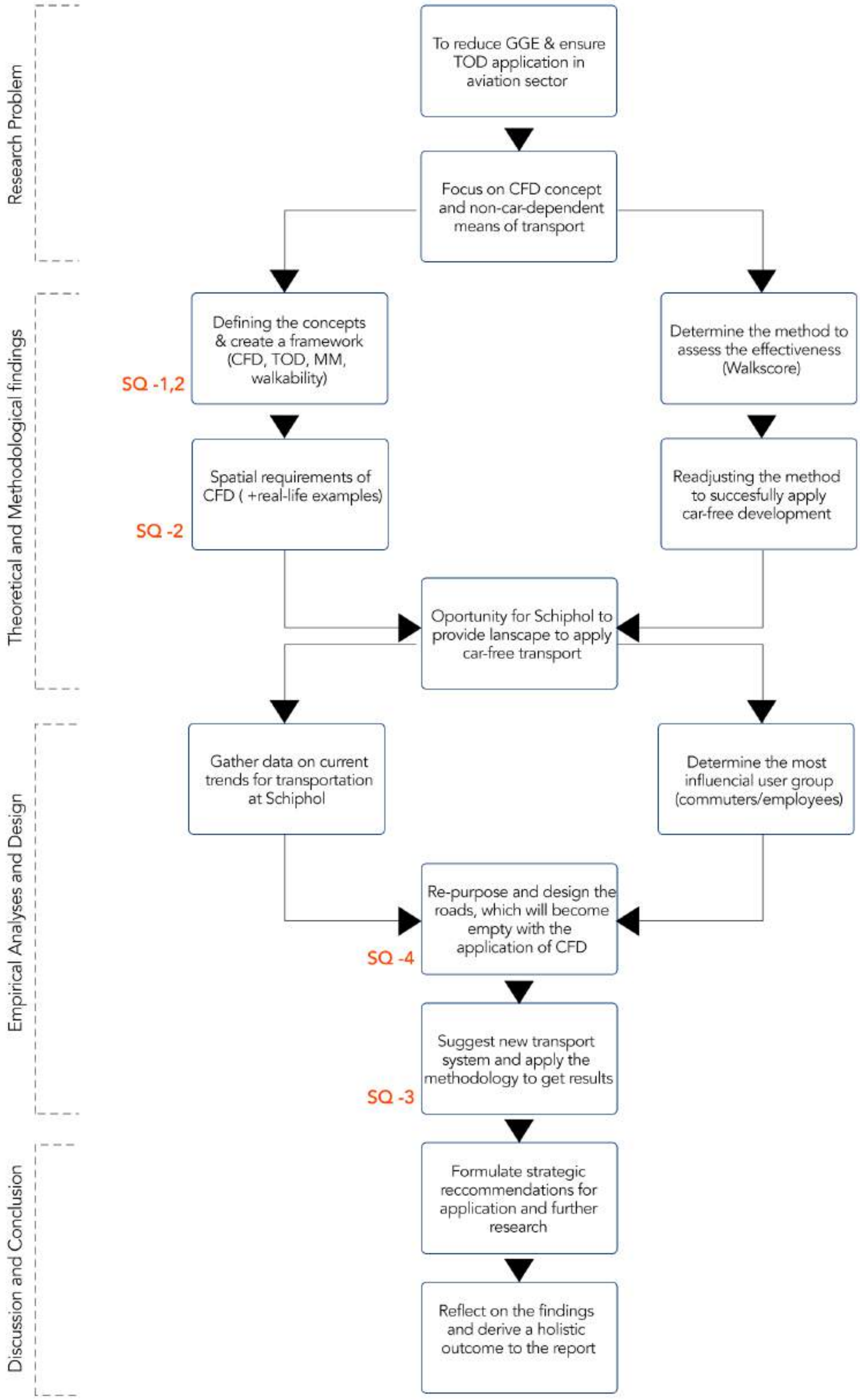


Figure 5: The Research Design Framework

2.1. Research Aim & Research Gap

In light of increasing concerns about sustainability and the adverse environmental and social impacts of car-dependent travel, this study aims to investigate the feasibility of achieving a car-free Schiphol Centrum through repurposing existing infrastructure to promote micro mobility and increased walkability. Furthermore, discussing the potential for low-car(bon) design features in landside airport areas, focusing on car-free development (CFD) as a way to reduce GHG emissions and promote alternative modes of transportation with the help of TOD and other literature-based frameworks.

In this thesis, the car-free concept is taken as an offset for investigating the stated problem. Defining the distinction between the car-free concept and CFD is essential to clarify the following parts of the thesis. The "car-free concept" refers to an urban planning and transportation ideology that advocates for creating environments, neighborhoods, or zones where private motorized vehicles, particularly cars, are discouraged or wholly prohibited (Bieda, 2016; Doheim et al., 2020; Khreis et al., 2017; Nieuwenhuijsen & Khreis, 2016). Conversely, "car-free developments" represent concrete and tangible implementations of the car-free concept in urban planning and architecture. These are specific projects or areas intentionally designed and developed to be entirely or predominantly free from private cars. Car-free developments typically encompass mixed-use neighborhoods, town centers, or districts that are carefully planned to encourage non-motorized transport options and maximize access to public transit (Melia, 2014b; Wright, 2005). These developments often integrate pedestrian-only streets, bike lanes, green spaces, and well-connected public transportation systems to support car-free living.

Various factors played a role in taking the car-free concept as the starting point. First, Amsterdam Schiphol Group has set the "zero-emission zone (ZEZ) Schiphol" bar in its 2030 targets. In order to achieve this, many stakeholders are currently working on the issue and developing solutions for both airside and landside transport emissions. Second, one of the prepared policy packages for the project is to make Schiphol Centrum (Figure 6) car-free. In the predicted future scenario of a car-free Schiphol City (Figure 6), commuters and travelers must abide by the new regulations. This requires the removal of a significant amount of parking lots in the area (Figure 37). This creates much space that can be used for other requirements, like walking areas, greenery, micro mobility, and recreational areas.

Additionally, the research showed that among all other traveler groups (such as passengers, visitors, pick-up or drop-off'ers), the employees in the Schiphol Centrum have the highest rate of using private vehicles for commuting (a more detailed explanation can be found in the following section). In addition, the majority of employees arrive at the airport by private vehicle. For passengers, transportation to the airport is predominantly by train. For this reason, the target group studied within the scope of the thesis was determined as airport commuters (Figure 30 and Table 4).

This thesis aims to fill the current knowledge gaps regarding car-free land-side air transport and to come up with research combining practical and feasible TOD policies to help decision-makers and practitioners for future implementations of more sustainable transportation.

The research gap in the study encompasses multiple dimensions, including limited research on implementing CFD in airport landside areas and the need to explore the effect of micro-mobility and walkability implementation in CFD.

The mentioned knowledge gap can be stated;

- Lack of car-free concept studies for airports in academia via implementing TOD policies to achieve anew ***car-free development in Schiphol Airport***.
- Scarce knowledge of effective literature-recommended strategies and how to reduce reliance on cars by implementing sustainable transport modes in ***airport settings***;
    - o Need to examine the design and measurements of ***micro mobility*** applications and increased ***walkability*** in airport landside areas.

Firstly, there is a scarcity of academic literature focusing on TOD policies specifically designed for airports. While TOD principles have been widely studied in urban contexts, their application and adaptation to airport environments still need to be explored. The research aims to bridge this gap by investigating how TOD policies can be integrated with airport landside areas to facilitate the transition toward a car-free environment.

Secondly, the study addresses the gap in research related to CFD in airport settings. While Schiphol Airport is a notable example among airports worldwide, the carbon emissions associated with the airport are still higher than desired, and sustainable transportation options are limited for landside travel and commuting. The research seeks to fill this gap by examining the challenges and opportunities of achieving a car-free Schiphol Centrum and developing design features that enable sustainable modes of transportation.

Thirdly, the research addresses the need to explore micro-mobility and walkability applications and measurements of landside transportation in airport settings. The role of micro-mobility in providing first and last-mile travel at Schiphol Airport is significant but requires further investigation. Although there are many examples worldwide related to the application of micro mobility vehicles, there is a lack of examples for airports (similar to the TOD policies).

Similarly and lastly, the concept of pedestrian-friendly and walkable streets in the Schiphol Centrum area needs to be explored in terms of redesigning the current streets, a methodological measurement of walkability, and the inclusion of introducing necessary amenities. By incorporating these aspects, the research aims to contribute to a more comprehensive understanding of sustainable transportation options and the enhancement of walkability in airport environments.

In conclusion, the research gap in this study encompasses the lack of TOD policies tailored for airports, limited research on car-free concepts in airport landside areas, and the need to explore micro-mobility and walkability aspects. By addressing these gaps, the research aims to provide insights and recommendations for achieving low-carbon and pedestrian-friendly design features for airport commuters.

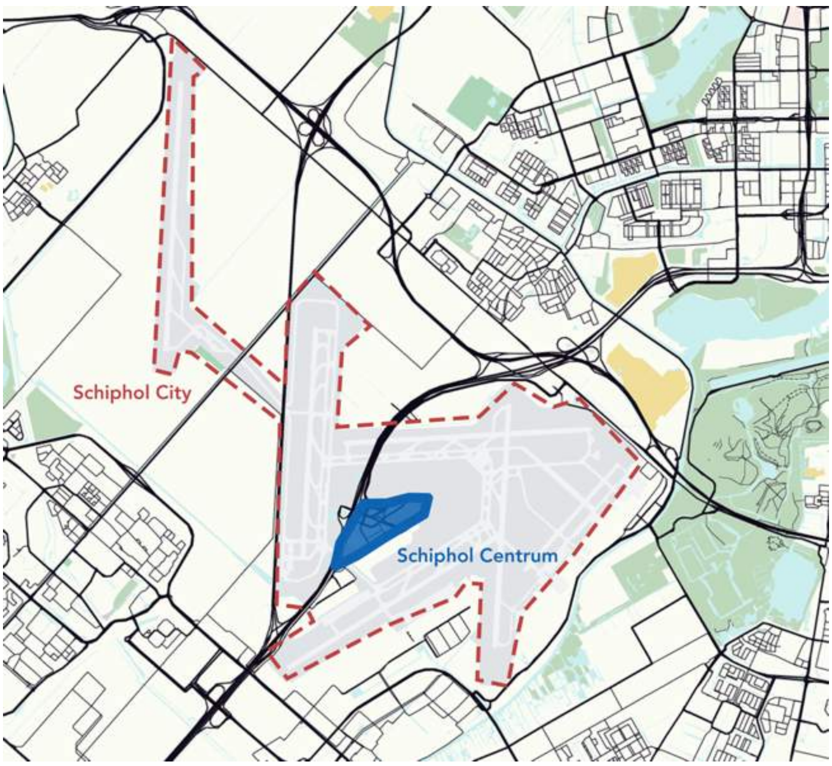


Figure 6: Schiphol City and Schiphol Centrum

2.2. Research Question and Sub-questions

2.2.1. Main Research Question

The main research question was formulated to cover the research gap and aim mentioned in the previous section. Therefore, the main research question is constituted as follows.

"How to achieve a car-free Schiphol Centrum that enables a shift towards sustainable modes of transportation by repurposing existing infrastructure?"

Although Schiphol airport is a decent example among other airports worldwide, the carbon emissions are higher than desired, and mode of transport options do not widely exist for landside travel and commuting.

The concepts of TOD and car-free, which have a particular place in the literature, are closely related. Due to their function, airports are modern hubs where transit-oriented transportation is intensely prevalent. Therefore, car-free transportation should be implemented by considering these principles. Since passengers and commuters will change modes regarding first & last mile transportation, these modes should be determined in accordance with the car-free development. One of the thesis' aims is to reduce emissions in the area. For this reason, transport modes such as micro mobility, light electrical vehicles (LEV), bicycles, and walking should be provided at the airport.

Applicable policies can be determined with the help of the literature review, data analysis, comparison of existing examples, and the case study. These policies provide a starting point for decision-makers to achieve more sustainable and/or car-free transportation. With the given recommendations, consultancy can be provided to the decision mechanisms.

To address this issue, the research also includes the following sub-questions:

- *How do the TOD principles help to convert Schiphol Centrum into a car-free development? (Chapter 4)*
- What are the literature-recommended strategies to facilitate sustainable modes of transport and reduce reliance on private cars? *(Chapter 4)*
- *How does micro-mobility affect the modal shift in commuters' first and last-mile travel in Schiphol Airport? (Chapter 5,6)*
- *How should pedestrian-friendly/walkable streets be conceived at the Schiphol Centrum area? (Chapter 6)*

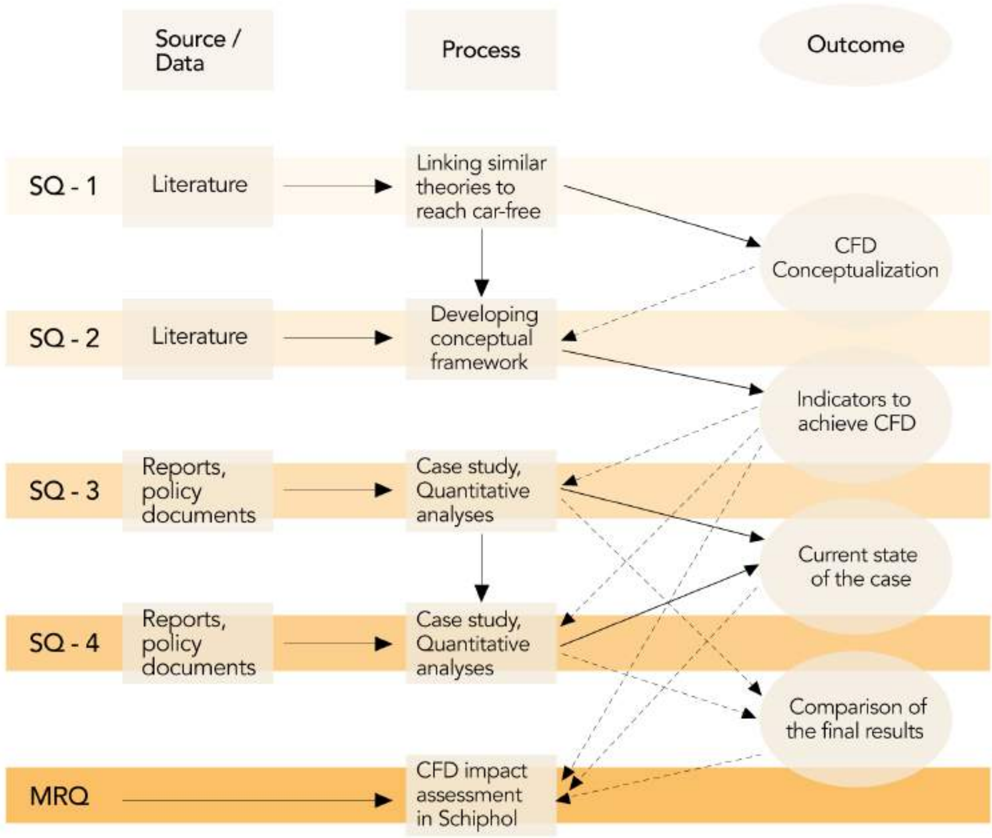


Figure 7: Outline of the main research question (MRQ) and sub-questions' (SQ) process relations and expected outcomes

Figure 7 visualizes the relation between source, process, and outcome for main/sub-research questions. While the continuous line arrows show direct relations, dashed line arrows demonstrate general/indirect contributions between questions designed.

In conclusion, achieving a car-free Schiphol Centrum is a complex issue that requires addressing numerous infrastructural challenges and implementing sustainable modes of transportation. A foundation can be laid to create low-car(bon) design features for airport commuters by answering the main research question and sub-questions. A more sustainable future can be achieved by repurposing existing infrastructure and providing various transportation modes. In addition, policies can be developed to support a car-free environment and provide decision-makers with recommendations. It is essential to consider the principles of transit-oriented transportation and car-free development to achieve a successful outcome while combining with other modes like walking, micro mobility, and other light-electric vehicles (LEVs).

2.2.2. Sub-questions

Several sub-questions are formulated to clarify and further answer the main research question successfully. The study aims to provide insights and recommendations for future low-car (bon) design features for airport commuters by answering these questions.

Sub-question 1:

- *How do the TOD policies help to convert Schiphol Centrum into a car-free development? (Chapter 5)*

To make the research scope more concrete, it is essential to define the TOD parameters as a priority and to integrate them with car-free development. Constitute a combined roadmap for future applications will not only facilitate the decision-making process but also enable it to designate consistent designs suitable for function and use. To elaborate on the question, it could be beneficial to answer the following;

- o *What are the essential parameters/principles of transit-oriented development (TOD) that can be applied to Schiphol Centrum?*
- o *How can the TOD principles be integrated with the car-free development of Schiphol Centrum?*

An inclusive framework can be created due to mutual literature reviews of these two concepts. It can accelerate the implementation process of decision mechanisms. Formulate how a holistic TOD and CFD framework is explained in more detail later in the thesis. *(Chapter 3)*

Sub-question 2:

- What are the literature-recommended strategies to facilitate sustainable modes of transport and reduce reliance on private cars? (Chapter 4)

A literature review is requisite to fit the study into the academic context and to define the research gap. In addition, allowing for a better understanding of the relevant theoretical frameworks and making comparative inferences with applied examples. So that theoretical frameworks can merge to achieve the intended results. The research will seek to explore various modes of transportation and examine how they can be integrated into the first and last mile of travel to/from Schiphol Airport. Additionally, the study will consider how pedestrian-friendly streets can be conceived in the Schiphol Centrum area.

Airports are industrial buildings. In addition to air travelers, airports host their employees and short-term visitors. It is necessary to meet the needs of these people outside of the airport hub. And to make walking, the most basic transportation method, as attractive as possible. Therefore while creating walkable streets, re-scaling the urban form should be demonstrated based on humans rather than vehicles.

Sub-question 3:

- *How does micro-mobility affect the modal shift in commuters' first and last-mile travel in Schiphol Airport? (Chapter 5,6)*
    - *Where will be the new micro-mobility hubs located?*
    - *How will the new micro-mobility hubs look like in the area? (a conceptual design)*

Micro-mobility plays a vital role in providing first and last-mile travel at Schiphol Airport. The airport has implemented several initiatives designed to reduce travel times for passengers, such as implementing bike-sharing systems and launching electric scooters. This allows passengers to quickly and conveniently reach their destination, improving the overall passenger experience and reducing congestion.

The specific details regarding the location of new micro-mobility hubs would require further information or consultation with the relevant authorities responsible for Schiphol Airport (Schiphol Group, KLM, Going Dutch, Goudappel, etc.). However, these hubs are typically strategically positioned at crucial access points like terminals, parking areas, or public transportation stations to ensure easy access and seamless integration with other transportation modes. It is worth considering such elements as available space, existing infrastructure, and aesthetic considerations when conceptualizing the design of micro-mobility hubs in the area.

Sub-question 4:

- *How should pedestrian-friendly/walkable streets be conceived at the Schiphol Centrum area? (Chapter 6)*
    - *How can we measure the walkability of the area?*
    - *What amenities should be added to the design?*
    - *Where will be these new amenities in the Schiphol Centrum?*
    - *How will the additional amenities look like in the area? (a conceptual design)*

Since our streets are designed to depend on vehicles, motor roads create almost invisible walls in the space. After these barriers are removed, new solutions should be produced for re-purposing the vehicle roads.

Currently, Schiphol Airport has also been designed based on vehicles. For this reason, there are not enough facilities to meet daily needs outside of Schiphol Plaza, or their numbers need to be increased. It is aimed to measure the effectiveness and applicability of the design with the developed scenarios.

2.3. Academic Relevance

From the academic perspective, this study contributes to the existing literature on car-free development (CFD) and transit-oriented development (TOD) by explicitly focusing on the case of Schiphol Centrum. This research fills a gap and adds value to knowledge by exploring the parameters and principles of TOD that can be applied to Schiphol Centrum area along with CFD policies. It provides valuable insights for future airport planning and design for future transit environments.

Furthermore, the study will contribute to sustainable transportation by analyzing the literature-recommended strategies/methods to facilitate sustainable modes of transport and reduce reliance on private cars. By examining various modes of transportation and their integration into the first and last mile of travel to/from Schiphol Airport, this research will provide practical recommendations for improving accessibility and sustainability in the Schiphol Centrum.The study will also address the role of micro-mobility in providing first and last-mile travel at Schiphol Airport. It will seek the potential locations and design of micro-mobility hubs, considering accessibility, integration with other transportation modes, and aesthetic considerations.

In addition, including academic literature reviews and theoretical frameworks also adds to the research's significance in urban planning and transportation. The proposed conceptual designs and recommendations for additional amenities and walkable streets can benefit the airport and the surrounding communities and businesses in the long run.

2.4. Societal Relevance

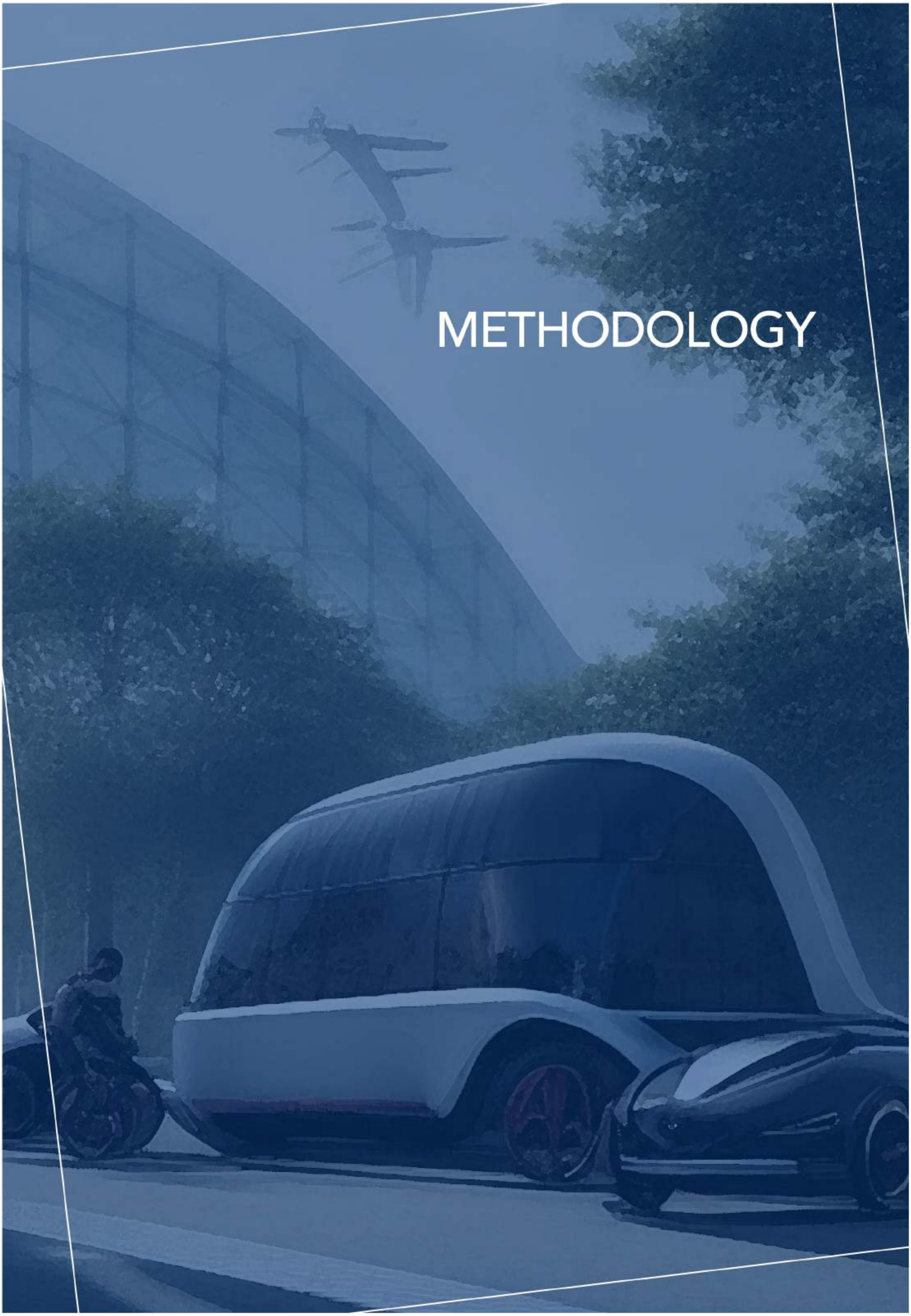
The societal relevance of the study is significant due to the increasing importance of sustainable transportation options and the need to reduce reliance on private cars for every user group. Implementing low-carbon design features for airport commuters has the potential to improve air quality, reduce traffic congestion, and enhance the overall passenger experience.

The study will also focus on the concept of pedestrian-friendly and walkable streets in the Schiphol Centrum area. As Gehl stated, *"Designing the city for people, not for the vehicles"; this research takes this approach to reach an equitable and healthier transport experience.*

Cities with fewer cars on the road may become more accessible and livable, which will benefit locals, tourists, businesses, and policymakers who want to improve their cities. It is critical to ascertain the viability and effectiveness of the policies necessary to achieve car-free areas. The issue's complexity is reflected in the sheer number of parties and participants as well as the range of disciplines (technical details, economics, law, organizational science, behavioral science) involved (Floor, 2020). Based on the study's findings, policymakers can make recommendations to lead to new design principles and to improve the existing and future airports.

Figure 8: Illustration of advocating car-free rights

METHODOLOGY



3. METHODOLOGY

The methodology of this thesis involves four main parts: the aim of the methods, desk research, a walkability measurement, and a case study.

Firstly, the aim of the thesis will give a holistic approach to combined methods to answer the research questions and show how the different techniques are related to the research to conduct the results.

Secondly, the literature review will search for relevant academic papers and analyze them to identify transit-oriented and car-free developments' characteristics and desired outcomes.

Thirdly, the walkability analyses will be evaluated any challenges and barriers to their implementation based on Walk Score. OpenStreetMap, Basisregistratie Adressen en Gebouwen (BAG) data, and Geographical Information System (GIS) were used to measure this part of the methodology.

Finally, a case study (TULIPS) will be conducted on Schiphol Airport, which has proposed policies toward a car-free city, using quantitative and qualitative research methods to analyze the findings. The data collection will involve looking at the current situation or comparing mobility changes to achieve a car-free development and evaluating them based on the area design needs.

By combining these different approaches, the research aims to provide insights into the characteristics, desired outcomes, and comparison of the scenarios towards achieving a car-free Schiphol Centrum.

3.1. The Aim of the Method

The methodology of this thesis aims to provide a comprehensive approach to answering the research questions and achieving the desired outcomes for creating a car-free area. It involves three main parts: a literature review, a walkability measurement, and a case study. By combining these different methods, the research aims to identify CFD characteristics and evaluate the current situation based on the design needs in the scope of Amsterdam Schiphol Airport.

The reason to chose these methods is to ensure a thorough analysis of the research topic. The **literature review** will provide a foundation of existing knowledge and inform the study's theoretical framework. The **walkability measurement** will allow for an assessment of the area's current walkability and identify areas for improvement. The **case study** and data analysis will provide real-world examples and data to evaluate the effectiveness of proposed policies and design needs.

By combining these methods, the study aims to provide a holistic understanding of the characteristics, challenges, and desired outcomes of transit-oriented and car-free developments. This comprehensive approach will contribute to the existing literature and provide valuable insights for urban planning and design in the Schiphol Centrum area.

Although CFD is a hot topic for the last decade, there are some necessary improvements and contributions that should be taken to methodological integrity:

Comparative analyses of different airports with varying degrees of walkability and car-free development can offer valuable insights into successful practices and lessons learned.

Exploring how technological advancements, such as intelligent mobility solutions and sustainable urban technologies, can complement the walkability pleasure of commuters and shift to car-free development strategies.

3.2. Desk Research

With the introduction of the theme of reducing emissions and sustainable transportation, many articles have been written about transit-oriented and car-free development. Although the number of articles is high, only a few resources show these concepts' applicability in an interactive way. The review aimed to analyze the characteristics of TOD and CFD, their application and forms, desired results, and design/policy strategies for developing them. To create a shortlist of papers for the review, it is conducted a broad search on Scopus and Google Scholar, using English keywords such as "car-free," "transit-oriented development," "car-free development," “landside airport transportation,” and “first and last mile transportation,” with the use of Boolean operators. This search resulted in over 40,000 results. Besides the online operators, back- and forward-referencing is used to find relevant literature. Van Wee and Banister (2015) suggest describing the review methodology and being explicit about selecting materials used in the review.

3.2.1. Transit-oriented and Car-free Developments

Regarding the impact of built environment factors on car ownership and usage, previous studies (Cao et al., 2007; Scheiner & Holz-Rau, 2007)have demonstrated a direct correlation between travel behavior and car ownership, as well as the built environment. Factors such as land use diversity and proximity of residences and workplaces to railway stations have been found to influence travel behavior substantially. In turn, car ownership itself is also influenced by the built environment. It is discovered that the distance to and from railway stations and personal travel behavior characteristics hold equal significance in influencing car usage and ownership (Dieleman et al., 2002)."

Other built environment factors, such as the density and accessibility of public transport infrastructure, also play a role. In cities where public transport is easily accessible and affordable, car ownership tends to be lower. However, in areas with poor public transport infrastructure, car ownership becomes a necessity. These show the importance of considering the built environment when developing strategies to reduce car dependence and promote sustainable travel behavior. Policymakers should prioritize improving public transport infrastructure and promoting mixed-use development to create more sustainable urban environments.

Previous studies that have evaluated the success of Transit-Oriented Development have typically focused on a limited number of success factors. These include travel behavior, vehicle ownership/usage, property value, and urban/regional design. However, TOD principles are essential in designing car-free areas there is very limited literature that can be found.

Since it is mentioned in previous chapters, TOD is a method to prioritize the needs of pedestrians, bicyclists, and public transit users, and less depending on private cars. Therefore, this research combines (Figures 5b and 6a) these two approaches and creates a more comprehensive method to analyze the case study.

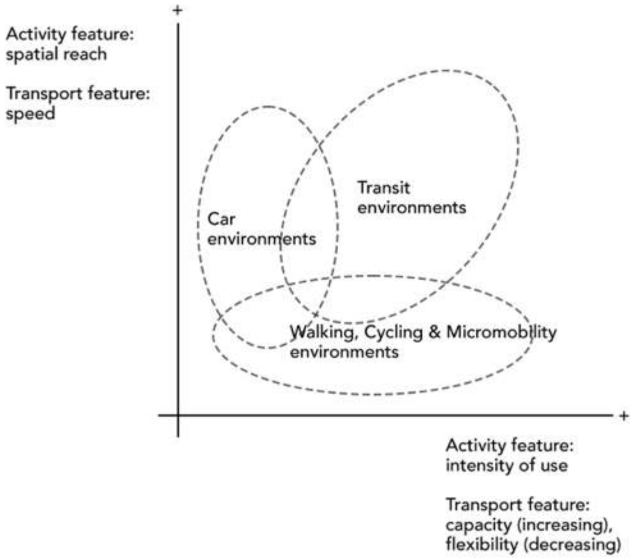


Figure 9: Graph of TOD components and their relations (Bertolini & le Clercq, 2003)

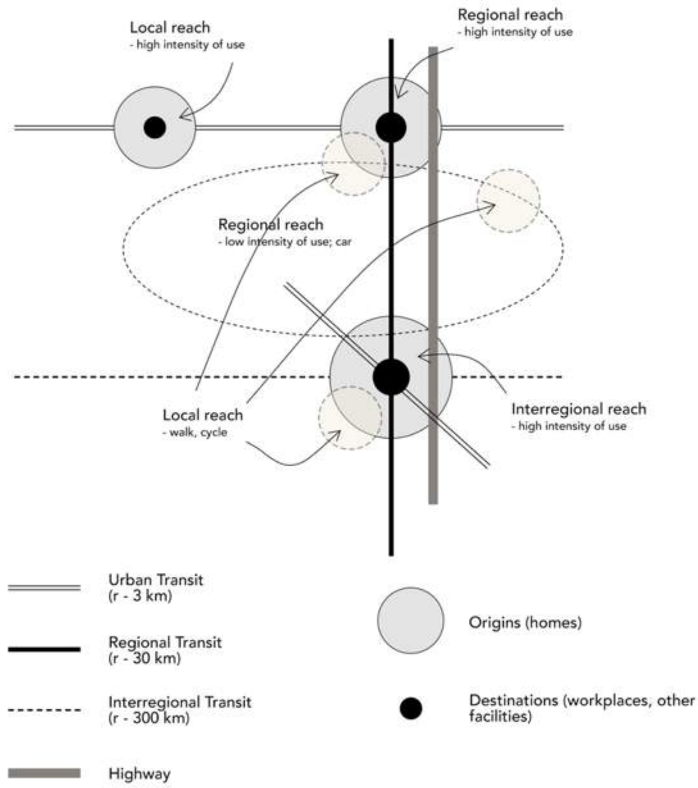


Figure 10: Diagram illustrating an integrated approach leveraging the synergies between transportation and land-use characteristics. (Bertolini & le Clercq, 2003)

While Figure 9 shows the interaction of TOD components, Figure 10 schematizes the local/regional/interregional scale interactions of the urban environment and transportation connections within the scope of TOD.

Despite its numerous possibilities, integrating transportation and urban development in station areas, as promoted by TOD, poses a highly puzzling challenge. Station areas serve as both '*nodes*' and '*places,*' functioning as crucial points within the transportation and non-transport networks (such as lifestyle, business, and consumption) within the city (Bertolini and Spit, 1998).

For this reason, it is a necessity that the area is transit-oriented in order to design a car-free area. This can be achieved by developing more green spaces, pedestrian-only zones, cycling and micro mobility infrastructure. When designing a car-free area, it is crucial to prioritize the needs of pedestrians and cyclists over vehicles.

Additionally, to help citizens adopt a car-free lifestyle, policymakers can incentivize public transport by providing affordable, convenient, and accessible options. By taking a holistic approach that considers the built environment and travel behavior, it is possible to create sustainable, car-free areas that promote a healthier, more livable urban environment.

Figure 11 illustrates the present state of the TOD components at Schiphol Airport, acknowledged by the Schiphol Annual Report. The airport exhibits robust transit options and well-established transportation connections. However, there are notable deficiencies, particularly concerning last-mile transportation, where the available modes of transportation from the Schiphol Airport Hub are primarily car-centric and lack adequate provisions for pedestrians and cyclists. The graph demonstrates a juxtaposition of walking, cycling, and micro-mobility options between the realms of car and transit environments. Consequently, reconfiguring these domains' interplay and segregation is imperative for realizing a car-free Schiphol Centrum.

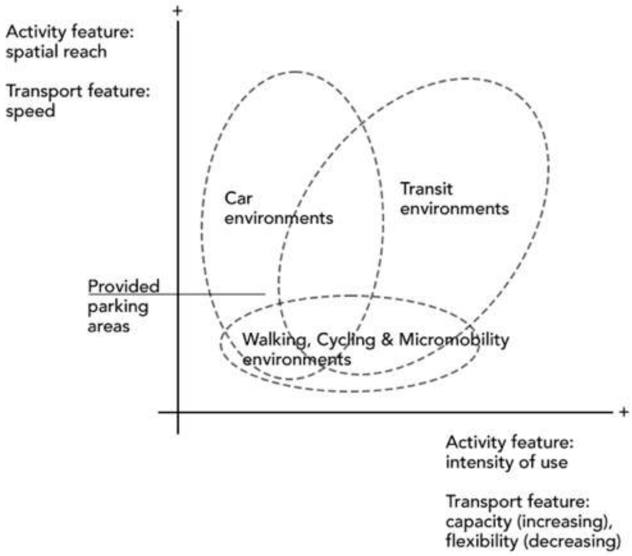


Figure 11: Current TOD components and their relations in Schiphol Centrum

Figure 12 demonstrates the targeted transitional harmony in TOD and car-free Schiphol. The interactions of the different components are shown in the graph. The airport's transit identity forms an interface between car environments and walking, cycling, and micro mobility environments. The points where these three spaces meet are defined as the transition area. Driving is prohibited or restricted in required areas. A link has been established between the kiss & ride for the airport or the transit and car environments for emergency vehicle use. Implementing these measures and methods makes it possible to achieve a more sustainable and livable urban environment for Schiphol.

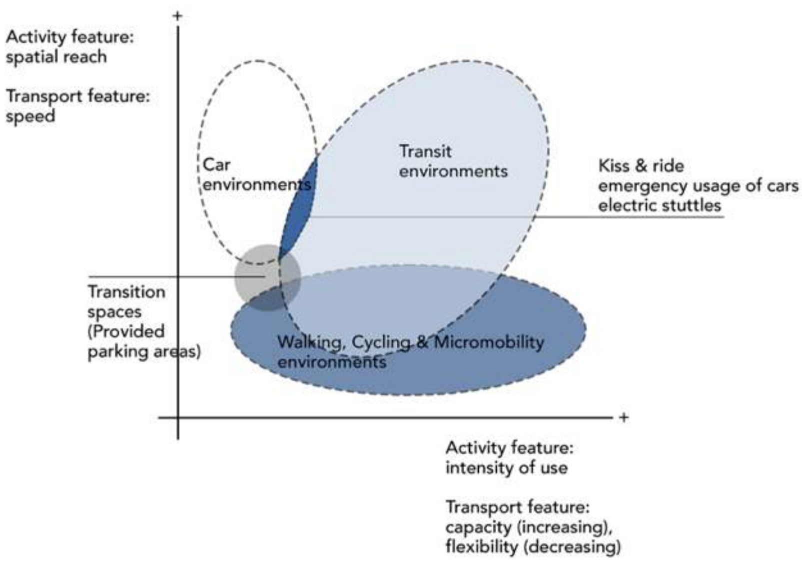


Figure 12: The goal; TOD and CFD components and their relations in Schiphol Centrum

As depicted in the following diagram, establishing the desired connections necessitates understanding the transportation-land use relationship across various scales. To align with the objectives of car-free and transit-oriented developments, instrumental links have been outlined to reconfigure Schiphol Airport (Figure 13), presently functioning as a transit hub.

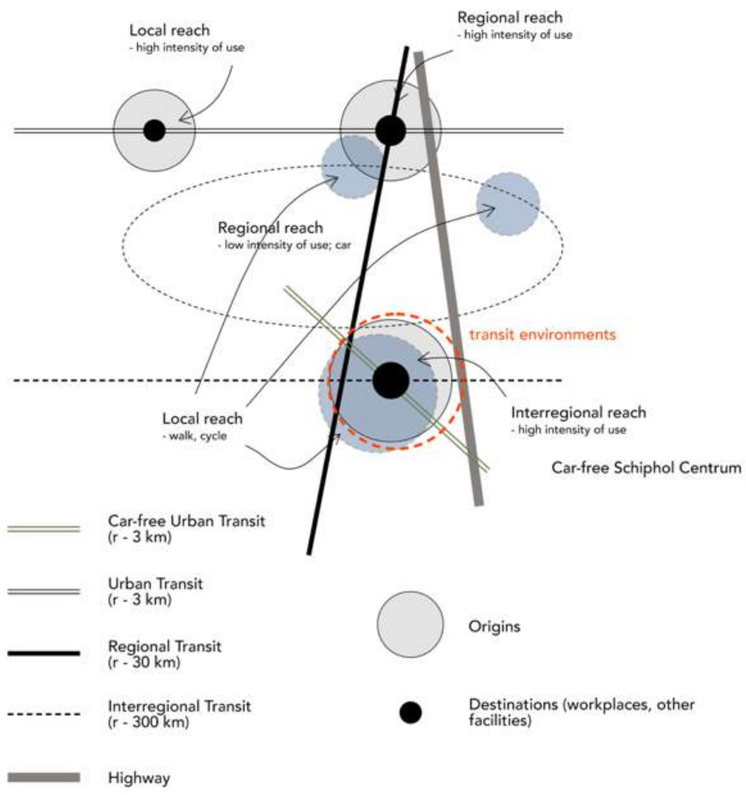


Figure 13: Diagram illustrating an integrated approach leveraging the synergies between transportation and land-use characteristics for car-free Schiphol Centrum.

In conclusion, developing sustainable, car-free areas is an ongoing challenge that requires a holistic approach. The built environment and travel behavior are closely interlinked, and policymakers should prioritize improving public transport infrastructure, promoting mixed-use development, and incentivizing sustainable modes of transportation. Transit-Oriented Development principles are essential in designing car-free areas that prioritize the needs of pedestrians, bicyclists, and public transit users. By integrating transportation and urban development, it is possible to create a more sustainable and livable urban environment. The case study of Schiphol Centrum demonstrates the challenges and opportunities of implementing car-free and transit-oriented development principles in a real-world setting.

3.3. WalkScore

Walk Score is a videly preferred index and method to analyze walking measures. The patented measurement system uses data such as walking, urban planning, housing, and transportation. Meanwhile, the company has the same name, and the application is easily accessed via a website (https://www.walkscore.com). Moreover, to the walkability metric provided by Walk Score, the platform offers various other measures that assess different aspects of accessibility. These include Transit Score, which evaluates transit accessibility, Bike Score, which assesses bike accessibility, Opportunity Score, which measures the ease of accessing nearby job opportunities without relying on a car, adjusted for population, as well as indicators of pedestrian friendliness, public transit data, score details specific to walking destinations, and travel time analysis.

The Walk Score methodology integrates three key elements: the shortest distance to predetermined destinations (amenities), block length, and intersection density nearby the starting point (Hall & Ram, 2018). Data from various sources, including Google Maps, Open Street Map, and user input, are utilized. The score is computed based on a gravity-based measure and topological accessibility (Vale et al., 2016).

The analysis revealed several factors that influence walking activity. Walk Score, transparency, street furniture, the number of buildings, and noise level were found to positively impact pedestrian volume, while on the other hand, enclosure and the primary color of buildings exhibited a negative relationship with walking activity (Zhang et al., 2023).

The term "Walk Score" was searched in bibliographic web servers during the literature research and detected 123 times. It indicates that Walk Score is a widely used index and method for analyzing walking measures. The system uses data from various sources such as walking, urban planning, housing, and transportation. It offers not only the walkability metric but also other measures that assess different aspects of accessibility, including transit, bike, and opportunity scores.

How does it work?

The first category of the measurement, consisting of nine units, encompasses amenities such as grocery stores, restaurants, shopping options, coffee shops/cafes, parks, schools/education, books, entertainment, and banks. However, in this thesis, the inclusion of banks has been excluded, and instead, micro mobility hubs have been introduced as an updated and adjusted version of the method. This decision aligns with stakeholder discussions held with the Schiphol Group, acknowledging the current prevalence of online banking services. By replacing banks with micro mobility hubs, the goal is to promote a broad approach to the project, considering walkability and various modes of transportation, and to develop a measurement method suitable for the entire project.

Each category carries different weights based on the functions necessary for urban space (Figure 14). For instance, having just one grocery store corresponds to a weight of 3 points, while the weight for restaurants is set at 10. If multiple categories are present, their weights are determined based on the distance from the origin point. Amenities within a 1.5 km radius are not considered, as walking time would be at most 15 minutes. The distance decay function is employed to calculate this distance, which will be further examined in subsequent sections.

In conclusion, the first category is assigned a score ranging from 0 to 100. Subsequently, an address could incur a penalty due to unfavorable metrics related to pedestrian friendliness, such as long-length blocks or low intersection density (Figures 15 and 16). The following categories, counts, and weights are included in the chosen methodology.

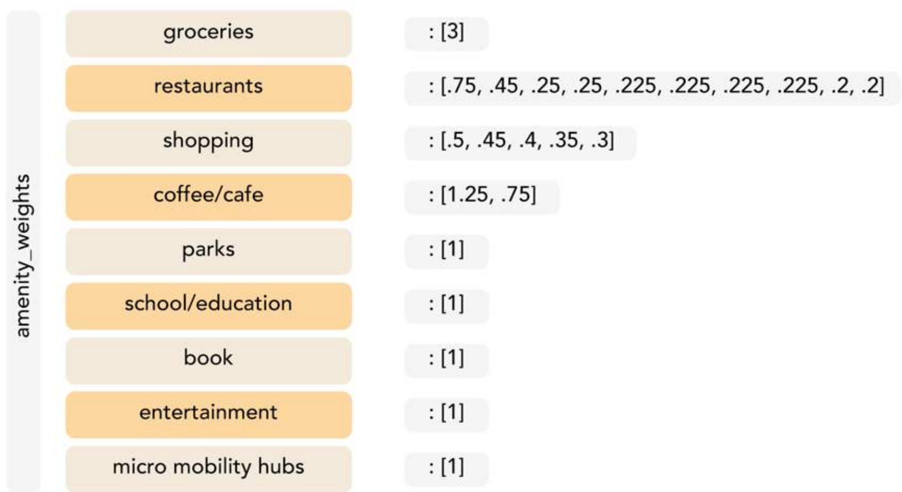


Figure 14: Walk Score amenity weights matrix

The selection of amenity categories was based on existing research, which classified them as having high, medium, or low importance for walkability. This distinction is reflected in the assigned category weights. Specifically, grocery stores and restaurants/bars have a combined weight of 3, while shopping and coffee shops have a combined weight of 2. The remaining categories contribute a combined weight of 1 (https://www.walkscore.com/methodology.shtml).

Applied surveys have shown that these amenity categories are the preferable walking destinations (Lee & Moudon, 2006; Owen et al., 2007). Additionally, this method was used in other studies that focused on walkability and accessibility (Cui et al., 2019; Deboosere et al., 2018; Iacono et al., 2010).

intersection_density (per square mile)	
over 200	= no penalty
150-200	= 1% penalty
120-150	= 2% penalty
90-120	= 3% penalty
60-90	= 4% penalty
under 60	= 5% penalty

average_block_length (in meters)	
under 120 m	= no penalty
120-150 m	= 1% penalty
150-165 m	= 2% penalty
165-180 m	= 3% penalty
180-195 m	= 4% penalty
over 195 m	= 5% penalty

Figure 15: Penalty application for intersection density calculation (on the left)

Figure 16: Penalty application for average block length (on the right)

The calculation of the average block length can simply be reached through the following equation:

" Average Block Length = Total Length of Streets / Total Number of Blocks "

Distance Decay Function

Utilizing the distance decay function, the relative proximity of an amenity to the chosen starting point/origin determines the percentage of the complete score allocated to each category.

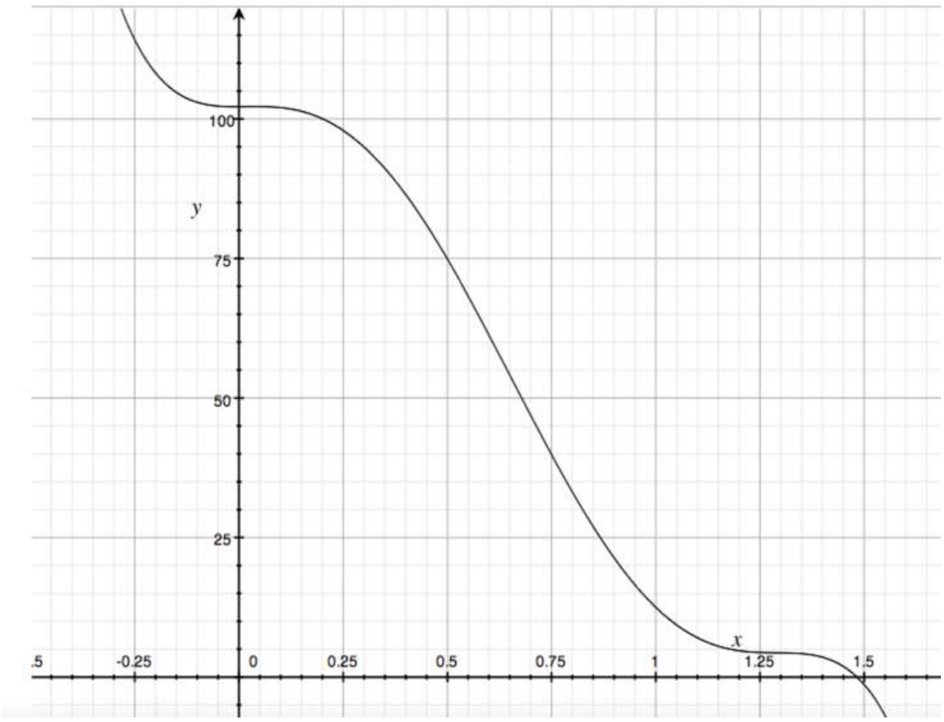


Figure 17: Distance decay function (Walk Score Methodology, 2011).

Figure 17 demonstrates that the x-axis represents how far the specific address or origin point is, while the y-axis represents the total score percentage that an amenity will attain. The scoring ranges between 0 and 100 points (*Walk Score Methodology*, 2011).

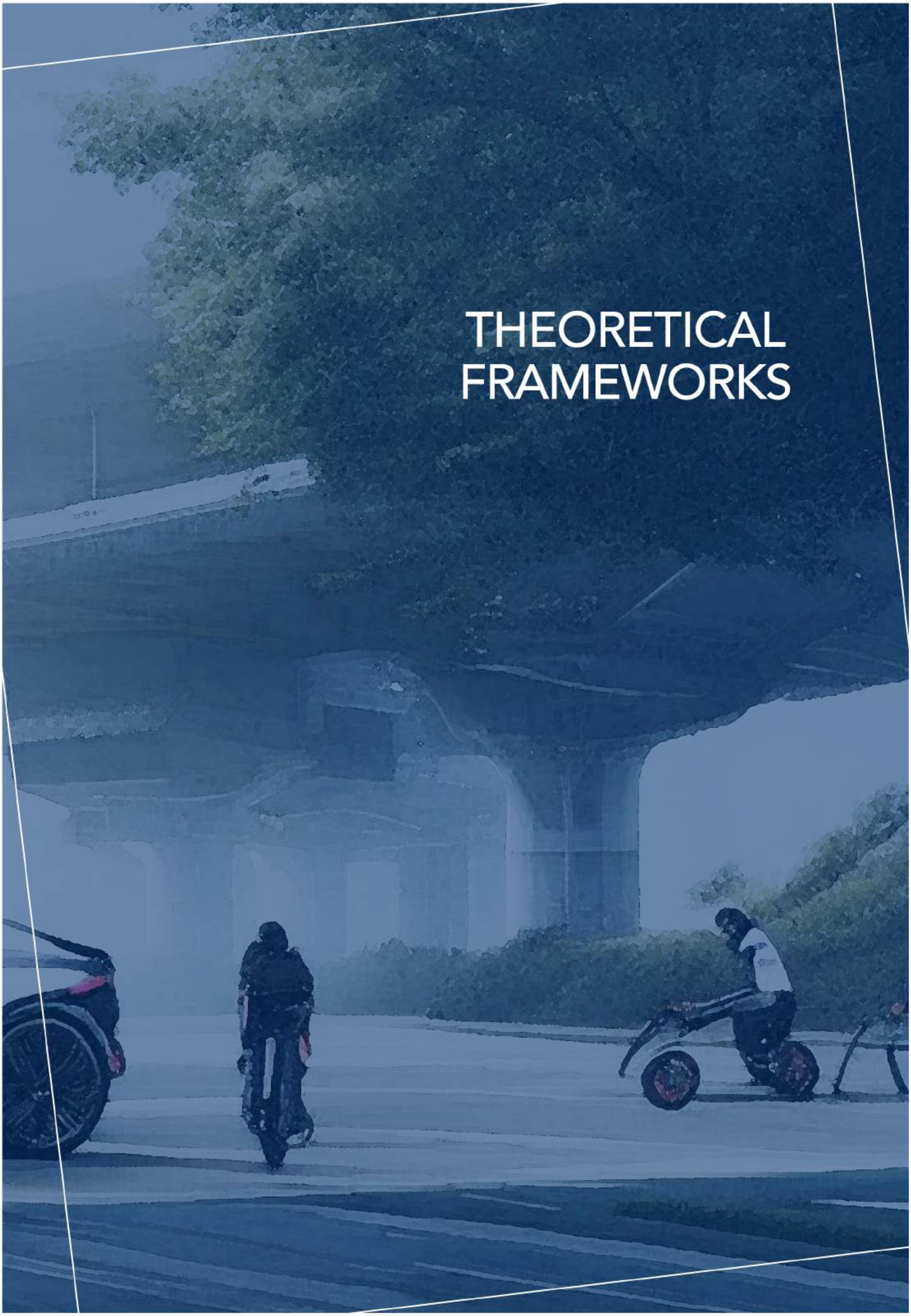
3.4. Case Study & Data Collection/Analysis

The case study demonstrates the current situation of the particular urban area. It is critical to understand the current trends and pitfalls considering user satisfaction. The analyses incorporate data from diverse sources, including Schiphol Group Annual Reports, Goudappel Mobility Reports, Open Street Map, user contributions, etc., to assess the current condition of the area to lead the car-free Schiphol Centrum. The methodology assigns different weights to specific clusters based on the critical principles deemed essential for the car-free urban space.

The case study will elaborate on the specific challenges and opportunities of the area under consideration. It will also examine the impact of the proposed changes on the environment, economy, and society. The data collection and analysis process will involve various quantitative and qualitative techniques to gain comprehensive insights into the current situation. This will include commuters' travel habits analysis, current infrastructural analyses as well as feedback from multiple stakeholder meetings. The findings will be presented using various visualization tools, such as charts, graphs, and maps. Overall, this study aims to provide a holistic understanding of the situation and identify effective strategies for a car-free Schiphol Centrum.

Additionally, the study will explore the potential for alternative modes of transportation, such as micro mobility, bikes, public transportation, and walking. The ultimate goal is to create a sustainable, livable, and vibrant urban environment that prioritizes the needs of its users, businesses, and visitors. Through careful analysis and strategic planning, the car-free Schiphol Centrum can become a leading example of urban sustainability and innovation.

THEORETICAL FRAMEWORKS



4. THEORETICAL FRAMEWORKS

In this chapter, it will be found that the theoretical background of the thesis includes a detailed search for car-free development and transit-oriented development, along with identifying the relationships of micro mobility and walkability aspects. It provides a structured foundation for understanding and analyzing these concepts within the context of urban planning, transportation, and sustainable development.

To illustrate how to reach the "Car-free Schiphol Center," a flow chart was conducted (Figures 18 and 19). The conceptual framework encompasses key theories, principles, and models that underpin each concept's rationale and implementation. A brief overview of the theoretical components is defined as follows:

> Car-Free Development; emphasizes creating walkable, mixed-use settlements with accessible amenities, reducing the need for private car usage. This theory also advocates for environmentally responsible urban planning, promoting reduced carbon emissions, green infrastructure, and preservation of natural resources by minimizing car dependency.

> Transit-Oriented Development; focuses on designing urban environments centered around transit nodes and corridors, encouraging land use patterns that facilitate convenient access to public transportation. CFD often integrates with TOD principles to enhance accessibility to public transportation and foster pedestrian-friendliness. It also emphasizes the importance of providing efficient and reliable transportation options, promoting a shift towards transit usage, and reducing reliance on private cars. TOD theory also stands by higher urban density around transit hubs to maximize transit ridership and create vibrant, mixed-use facilities.

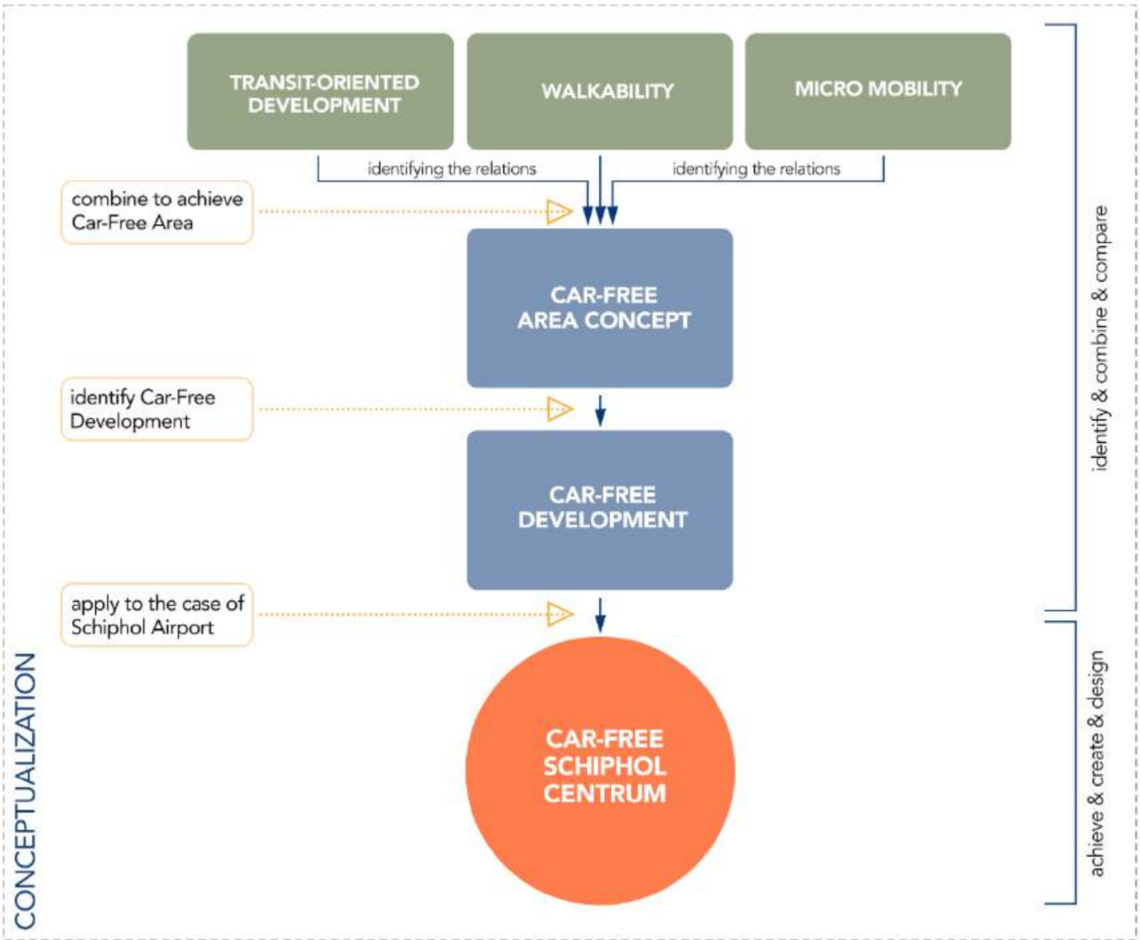


Figure 18: Conceptual framework

Integrating these theoretical components provides a comprehensive framework for analyzing, designing, and evaluating urban environments that prioritize car-free development, transit-oriented development, walkability, and micro-mobility. This interdisciplinary approach supports informed decision-making, policy development, and the creation of more livable, and resilient airport settlements of the future.

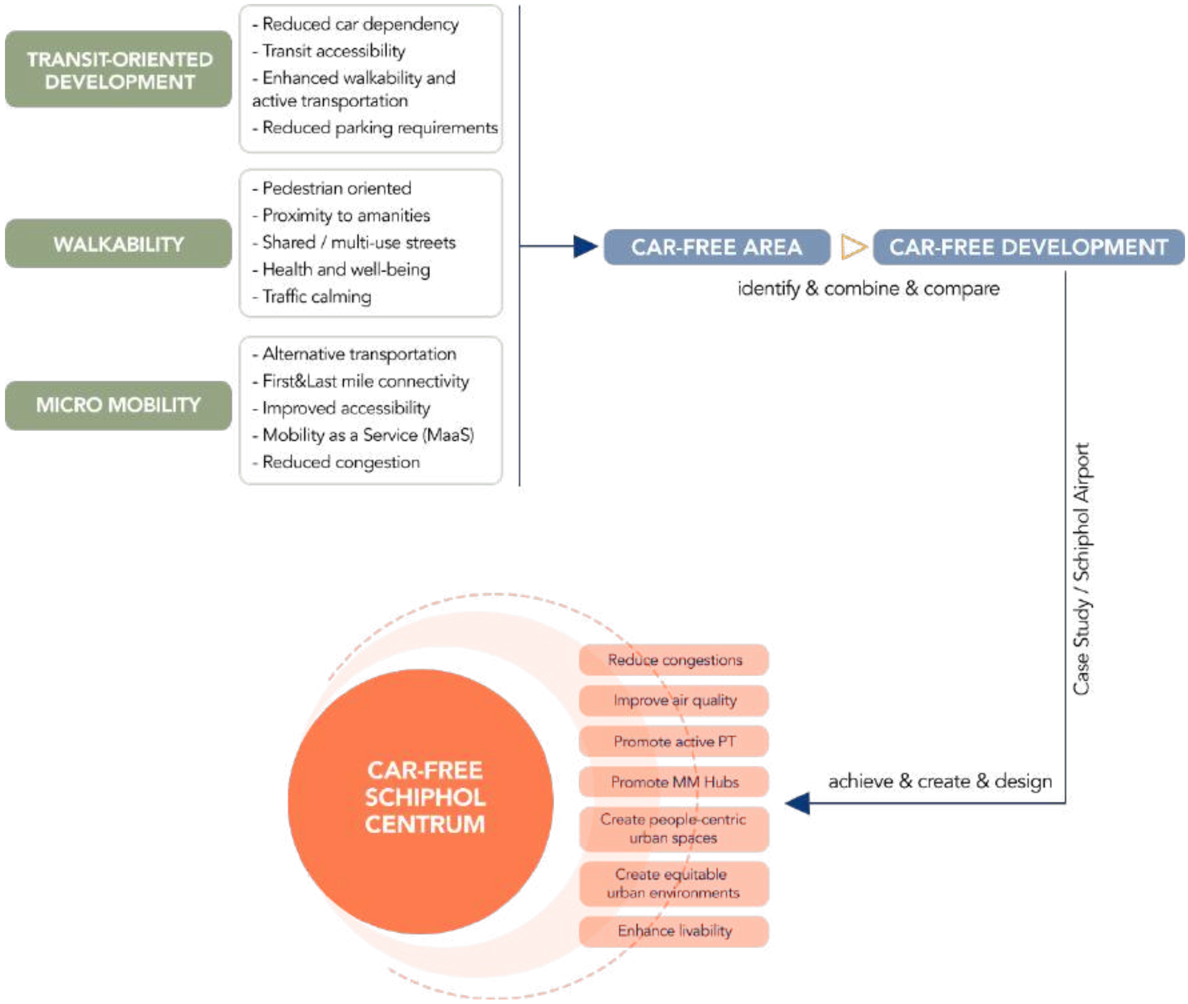


Figure 19: Elaborated version of conceptual framework

In the subsequent sections, the relation between CFD and TOD is defined broadly, aiming to gain a more specific understanding through relevant literature. Additionally, micro-mobility and walkability aspects will be examined, which also complementary to CFD, and discussed more in the results chapter.

4.1. Car-free Development

Car-free development, also known as car-free living or car-free communities, is an innovative approach to urban planning and design that aims to create sustainable and livable environments by minimizing or eliminating the reliance on private automobiles. In car-free developments, the focus is shifted toward sustainable alternative modes of transportation; for example, walking, micro mobility, cycling, public transit, and shared mobility options. By prioritizing pedestrians and creating a comprehensive network of non-motorized transportation infrastructure, car-free developments seek to reduce traffic congestion, improve air quality, enhance public health, and foster vibrant and inclusive communities.

The concept of car-free development has gained significant attention in recent years as cities and urban areas grapple with the challenges posed by rapid urbanization, environmental degradation, and the negative impacts of automobile dependency. Car-free developments offer a promising solution to mitigate these issues and create more sustainable and people-centric urban spaces.

This chapter explores the various aspects of car-free development and how these aspects make way for creating car-free environments, pedestrianized streets, and transportation demand management with a mixed-use innovative urban design.

Car-free development, also known as car-free living or car-free The notion of a car-free city emerged as a counter-concept to the car-oriented city during a conference presentation in 1996 by J. H. Crawford. Then it was published as a book called "Carfree Cities"(Crawford, 2000). A car-oriented city refers to a low-density residential area characterized by long travel durations. Conversely, while defining car-free cities as areas, where vehicle usage is prohibited may be suitable, the literature on this subject encompasses various transitional phases and employs different terminology. This variation stems from the diverse degrees of car-free implementation observed in different locations. The car-free spectrum captures this transition in various scales and forms (Figure 20) (Wright, 2005).

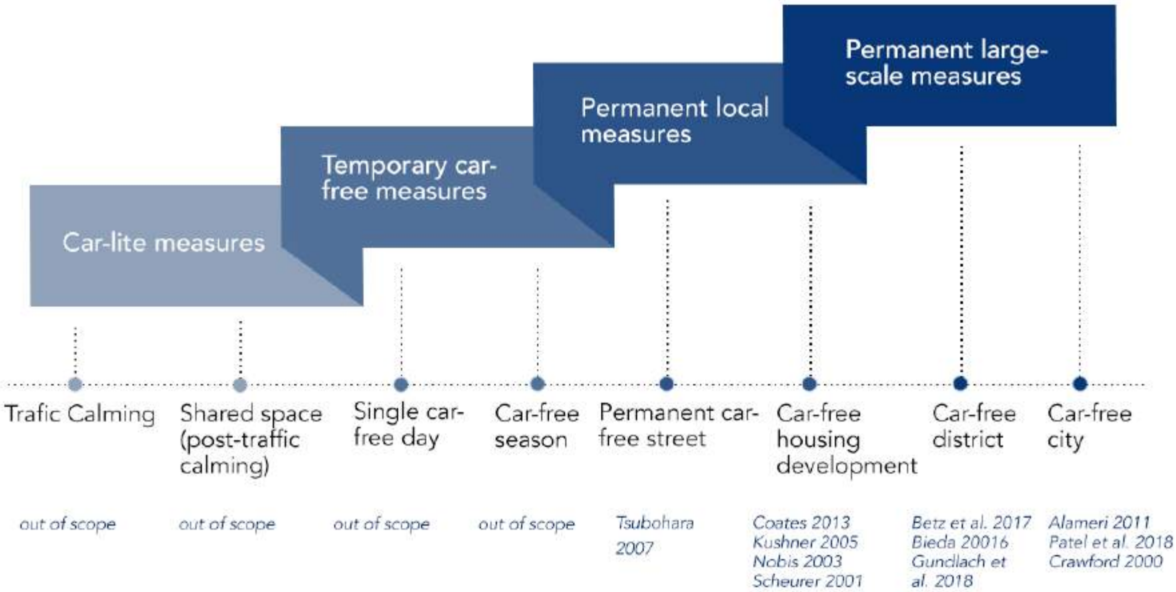


Figure 20: Carfree Spectrum (Adopted from Wright, 2005).

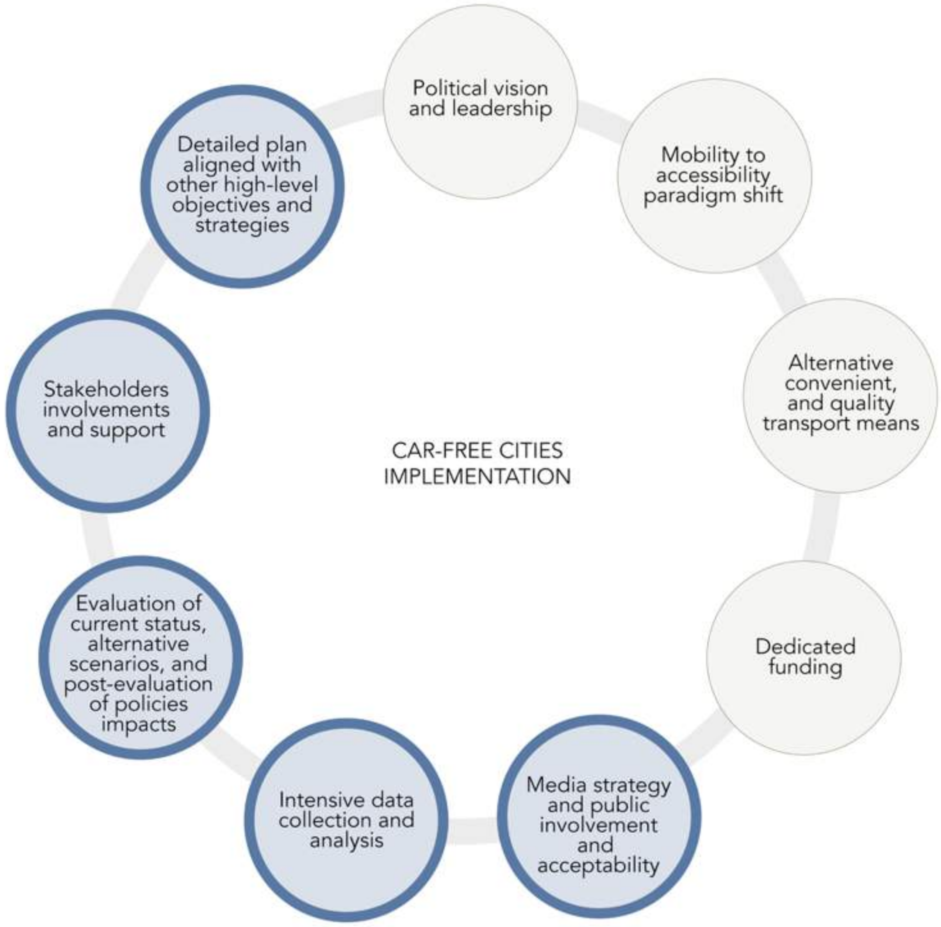


Figure 21: Prerequisites of carfree cities (Khreis et al., 2017)

4.1.1. Definition of Car-free Development

The concept of the "car-free city" can be perceived as easy to explain at first glance. It can be simply explained as cities where there is no use of cars. However, there are many different approaches to the subject in the literature. For example, the differentiation of the concepts of "car-free city" and "car-free development". Or, in addition to the concepts of "car-lite" and "car-free", situations where only emergency vehicles are allowed to be used or pedestrianization of streets be included in the scope of this concept. Therefore, before deciding on the definition to be chosen, the literature should be scanned in detail.

Generally, the concept of car-free is explained with theoretical explanations in some academic texts and application-based definitions in others. While theoretical approaches (Crawford, 2000; Foletta & Henderson, 2016; Melia, 2014a; Nieuwenhuijsen & Khreis, 2016)help to make a general judgment about the whole subject, application-based approaches (Bieda, 2016; Coates, 2013a)can give more detailed results. In the case study context, the concept of "car-free development" constitutes a more appropriate definition for the thesis since Amsterdam Schiphol Airport is already a car-dependent built environment. As a result of the research, the approach of Melia (Melia, 2010), which is also one of the most cited approaches academically, was chosen. As Steven Melia (2010) states, "Car-free developments are residential or mixed-use developments that consist of three components.".

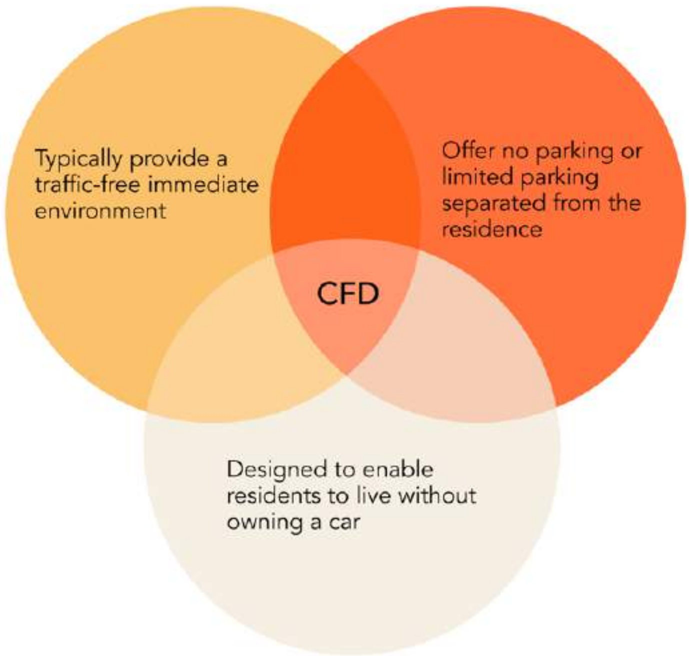


Figure 22: Car-free Development Components (CFD)

Even though Melia (2010) mentions the 'residential area' and 'residents', the definition can also be applied to developments in different functions. The residential area can be replaced by workplaces, transport environments, and/or commercial settlements; daily users and/or employees can replace residents.

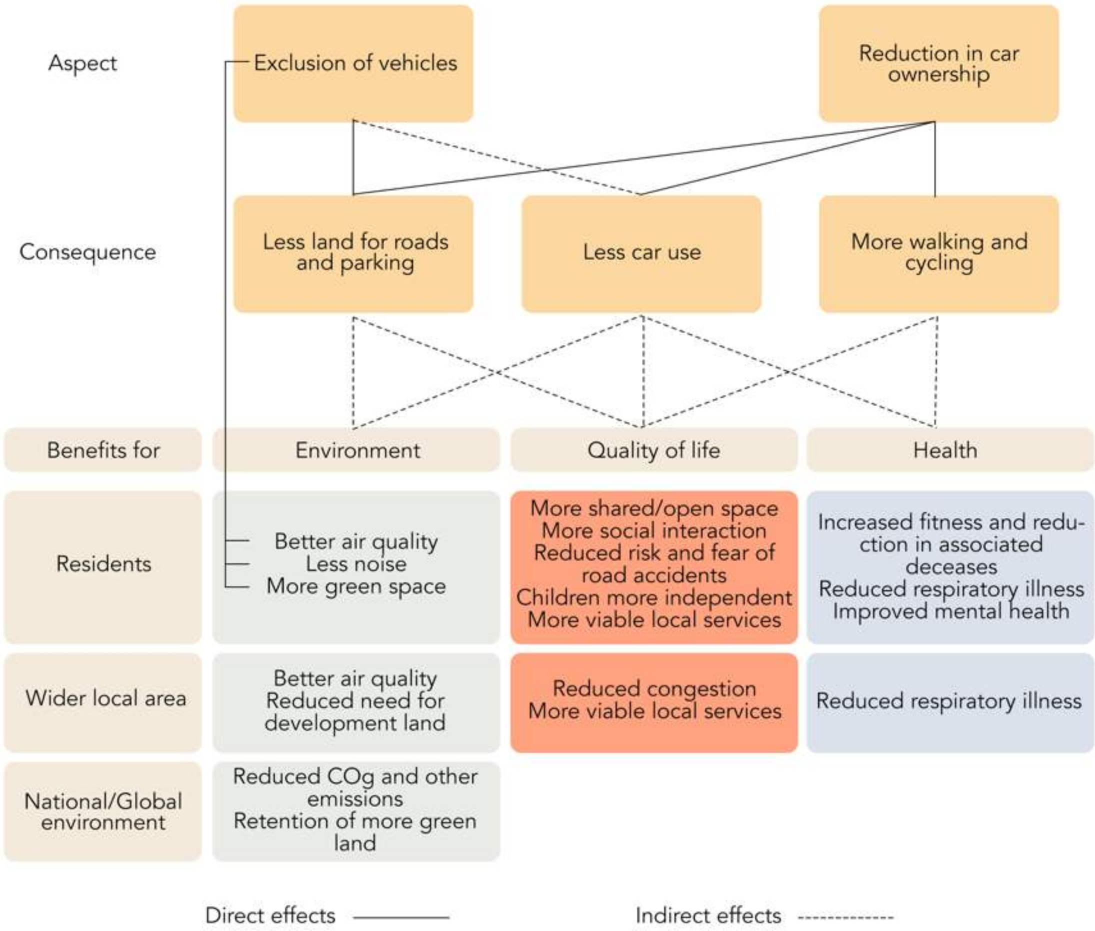


Figure 23: Benefits of car-free development (Adapted from Melia (2014))

Why Car-free Development?

Cities are active catalysts that are constantly moving—the movement of goods and humans possible through infrastructured transportation systems. Mobility demand has increased significantly with the globalizing world. As a result, motor vehicle mass production started. This transport boom has resulted in motor vehicle traffic and the release of many harmful chemicals into the environment, especially in cities with large populations and commercial value. While the speed increase in mobility shortened the arrival times, environmental deterioration caused the loss of time-space perception over a long time. Studies have shown that 14.5% of carbon gas emissions are generated by transportation (Intergovernmental Panel on Climate Change. Working Group III & Edenhofer, 2014).

Society suffers from car-centric transportation. Rapid transportation causes accidents and kills people. According to the World Health Organization (WHO) data, 1.24 million people lost their lives in traffic accidents in 2013 (World Health Organization., 2013). This number is unacceptable. In addition, car-centric developments adversely affect access to the necessary amenities(Centre for Liveable Cities & Urban Land Institute, 2016). Including the elderly and disabled, a considerable amount of people experience difficulties due to car dependency. There are several compelling reasons why choosing a car-free development over a car-dependent transport system can be advantageous.

Figure 24 compares the Car-dependent/heavey and Car-free/lite developments to give a better, literature based understanding.

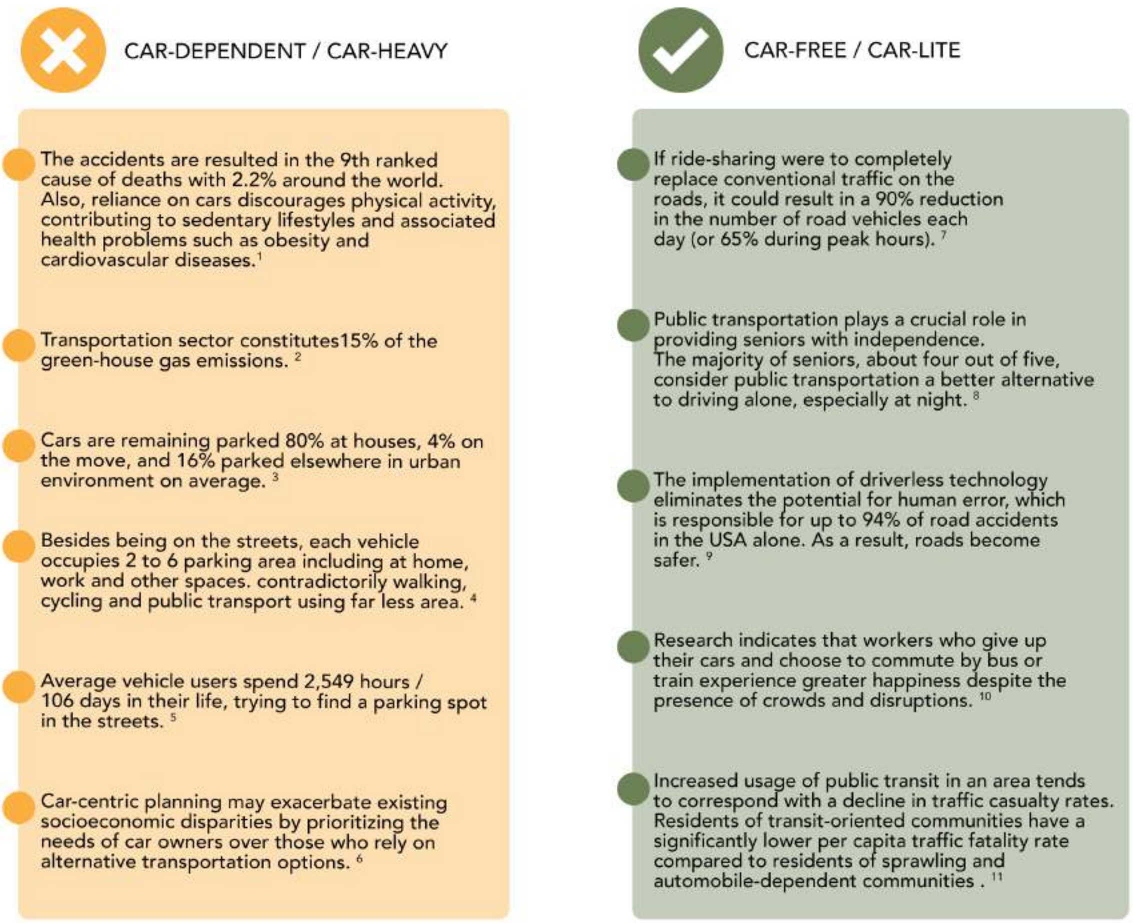


Figure 24: Car-dependent and Car-free development comparison (Association for Safe International Road Travel (ASIRT), n.d.; Bacigalupo et al., 2007; Bates & David, 2012; Centre for Liveable Cities & Urban Land Institute, 2016; Highway Traffic Safety Administration & Department of Transportation, n.d.; Litman, 2010, 2014; "Motorists Spend 106 Days Looking for Parking Spots," 2013; Rodrigue, 2020; Smith, 2015; Urban Land Institute, 2015)

4.1.2. Car-free city/development examples

By mitigating air and noise pollution, easing traffic congestion, and making more space for daily social and physical activities, car-free cities aim to improve urban areas while taking into account sustainability, accessibility, livability, and health.

As the concepts of traffic calming and car-free cities become widespread, applications in this direction have been developed at different scales in various parts of the world. Some cities are naturally organized without private cars, depending on geography or the speed of settlement. Others have come to life by adopting various policies and implementing the laws taken by the authorities.

Freiburg, Vauban

Vauban is a car-free neighborhood in Freiburg, Germany, known for its sustainable design and emphasis on alternative transportation. Here is a summary of key points:

- Vauban prioritizes sustainable transportation modes like walking, cycling, and public transit.
- The neighborhood features pedestrian-friendly streets, extensive cycling infrastructure, and well-connected public transit options.
- Private car ownership is discouraged, and car-sharing initiatives are promoted instead.
- Car-free zones within Vauban create pedestrian-friendly spaces and reduce traffic congestion.
- The development focuses on sustainability, incorporating energy-efficient buildings, renewable energy sources, and eco-friendly practices.
- Vauban emphasizes community engagement, with shared spaces, community gardens, and social amenities fostering a strong sense of community.
- The neighborhood encourages residents to use bicycles as a primary mode of transportation, providing cycling infrastructure and facilities.
- Sustainable living practices, such as renewable energy usage and resource conservation, are embraced by Vauban residents.

Vauban is a notable example of a car-free neighborhood that promotes sustainable living, fosters community, and prioritizes alternative transportation modes for a more livable urban environment. (Benfield, 2017; Broaddus, 2010; Coates, 2013b)

Image 1: Public transit in Freiburg

Image 2: Car-free streets in Freiburg (Melia, 2014a)

Singapore (car-lite)

Singapore is known for successfully implementing the "car-lite" initiative, which aims to reduce reliance on private cars and promote sustainable transportation options. Here is some information about Singapore's car-lite city approach:

- The city has developed a comprehensive public transportation system consisting of buses, trains, and taxis, providing convenient options for residents to commute within the city.
- Singapore's Electronic Road Pricing (ERP) system charges vehicles for road usage during peak hours and in high-demand areas, effectively managing traffic congestion and encouraging alternative modes of transportation.
- Integrated land use and transportation planning ensure that residential areas, workplaces, amenities, and transportation nodes are strategically located in proximity, promoting compact and walkable neighborhoods.
- The city provides dedicated infrastructure for pedestrians and cyclists to promote active mobility, including cycling paths, pedestrian-friendly streets, and park connectors.
- Car-sharing and ride-hailing services are encouraged as convenient alternatives to private car ownership.
- The government actively promotes sustainable commuting habits through campaigns and incentives, encouraging the use of public transportation, cycling, walking, and telecommuting.
- Car ownership is controlled through a Vehicle Quota System (VQS) and high taxes, making private car ownership relatively more expensive compared to other modes of transportation.

(Basu & Ferreira, 2020; Land Transport Authority, 2015; Litman, 2010; LTA Annual Report, 2019; Rojas López & Wong, 2017; Urban Redevelopment Authority, 2012).

These measures and initiatives in Singapore have contributed to developing a car-lite city where sustainable and efficient transportation options are prioritized, reducing congestion, promoting active mobility, and improving the overall livability of the urban environment.

Image 3: A transformed shopping Street in center of Singapore

London, Oxford Street

Oxford Street is one of the busiest retail streets in the world, known for its heavy traffic congestion and high pedestrian volumes. There have been proposals to transform Oxford Street into a car-free or pedestrian-friendly zone. While there have been various initiatives and trials, a permanent car-free application on Oxford Street has not been fully implemented yet.

The "Oxford Street Transformation" project in London aimed to pedestrianize a significant portion of the street, restricting vehicle access, improving walking and cycling infrastructure, and creating pedestrian public spaces. However, the project has faced delays and revisions since its proposal in 2018. Temporary car-free trials and events like "Summer Streets" and "Christmas Lights Switch-On" have been conducted on Oxford Street to assess the feasibility and impact of reducing traffic. Stakeholder views on the project have been mixed, with supporters emphasizing enhanced shopping experiences, improved air quality, and safer public spaces. At the same time, concerns have been raised by local businesses, residents, and transportation organizations regarding deliveries, traffic diversion, and accessibility to surrounding areas (Crook, 2021; London & Westminster, n.d.; Turner & Giannopoulos, 1974).

Image 4: A Street art appliction on Oxford Street

Image 5: Life between buildings with no cars in London

Example Airports

Berlin; Tegel

Berlin Tegel Airport, officially known as Berlin-Tegel "Otto Lilienthal" Airport, has made strides toward promoting sustainable transport options. The airport has recognized the importance of reducing emissions, improving air quality, and providing eco-friendly transportation alternatives for passengers and employees. Here are some key features of Berlin Tegel Airport's sustainable transport initiatives:

- Public Transportation Connectivity: Tegel Airport is well-integrated into Berlin's public transportation system, making it easily accessible via various sustainable transport modes. The airport is served by multiple bus lines, providing convenient connections to the city center and surrounding areas.
- Bike-Friendly Infrastructure: The airport encourages cycling as a sustainable mode of transportation by offering bicycle parking facilities. Passengers and airport employees can utilize these facilities to securely park their bicycles, promoting active and environmentally friendly travel options.
- Electric Vehicle Charging Stations: Berlin Tegel Airport has installed electric vehicle (EV) charging stations to support the growth of electric mobility. These charging facilities enable travelers and airport staff to charge their electric cars, promoting the use of clean energy for transportation.
- Car-Sharing Services: The airport promotes car-sharing as an alternative to private vehicle usage. Car-sharing companies have partnered with the airport to provide convenient access to shared vehicles, reducing the need for individual car ownership and encouraging more sustainable transportation choices.
- Green Ground Transportation: Tegel Airport encourages using environmentally friendly ground transportation options for airport-related services. This includes promoting low-emission vehicles, hybrid taxis, and eco-friendly shuttles within the airport premises.
- Sustainable Airport Operations: Berlin Tegel Airport implements various measures to improve its sustainability performance, including optimizing energy efficiency, utilizing renewable energy sources, implementing waste management strategies, and reducing water consumption.
- Collaborative Efforts: The airport collaborates with local authorities, transportation agencies, and environmental organizations to advance

sustainable transport initiatives. This includes participating in city-wide sustainability programs and working towards shared goals of reducing emissions and enhancing sustainable mobility,

(Bahu et al., 2017; Finney, 2022; Flughafen Berlin Brandenburg, 2020; Projekt GmbH, 2022).

Image 6: A Project render of car-free Tegel Airport

Image 7: Berlin Autofrei protests

These sustainable transport initiatives by Berlin Tegel Airport contribute to the city's overall efforts to create a greener and more sustainable transportation system. The airport aims to reduce carbon emissions, improve air quality, and provide passengers with eco-friendly travel options by promoting public transportation, cycling, electric mobility, and car-sharing.

Tokyo, Haneda

Tokyo Haneda Airport, also known as Tokyo International Airport, has taken significant steps towards implementing sustainable transport solutions. The airport recognizes the importance of reducing environmental impact and providing efficient transportation options for passengers and employees. Here are some critical aspects of Haneda Airport's sustainable transport initiatives:

- Public Transportation Connectivity: Haneda Airport is well-connected to Tokyo's extensive public transportation network. It has direct access to the Tokyo Monorail and Keikyu Railway lines, enabling convenient travel to and from the airport using environmentally friendly mass transit options.

- Bicycle Facilities: Haneda Airport encourages cycling as a sustainable mode of transportation. It provides bicycle parking areas and rental services, making it convenient for passengers and employees to use bicycles for short-distance travel to and from the airport.

- Electric Vehicles (EVs): The airport promotes the use of electric vehicles by providing charging stations for electric cars and taxis. This infrastructure supports the growth of clean and sustainable transportation options for passengers and airport-related services.

- Shuttle Services: Haneda Airport operates shuttle buses within the premises to facilitate convenient movement between terminals, parking areas, and other facilities. These shuttle services help reduce the need for private vehicle usage and contribute to efficient transportation within the airport.

- Eco-Driving Initiatives: The airport implements eco-driving programs for ground vehicles operating within its premises. These initiatives promote fuel-efficient driving techniques, reduce emissions, and optimize fuel consumption.

- Collaborations and Partnerships: Haneda Airport collaborates with transportation authorities, local communities, and environmental organizations to enhance sustainable transport practices. This includes participating in initiatives to reduce carbon emissions, improve air quality, and promote sustainable mobility,

  (Air Transport Bureau (ICAO), n.d.; Hussain & Ramdan, 2020; Japan Airport Terminal Co., n.d.; Siu, 2007; Wang & Song, 2020).

Image 8: An electric shuttle service vehicle in Haneda Airport

Image 9: An autonomus electric shuttle bus in Tokio Haneda Airport

These efforts by Tokyo Haneda Airport demonstrate a commitment to sustainable transport and align with broader goals of reducing carbon footprint, improving air quality, and enhancing the overall environmental performance of the airport.

Oslo, Avinor

Oslo Avinor Airport, also known as Oslo Airport Gardermoen, is committed to promoting sustainable transport options and reducing environmental impact. As the primary international airport serving Oslo, Norway, it has implemented various initiatives to enhance sustainability in transportation. Here are some key features of Oslo Avinor Airport's sustainable transport efforts:

- Public Transportation Connectivity: The airport is well-connected to the city of Oslo and surrounding regions through efficient public transportation options. The airport has a dedicated train station near the terminal, offering frequent train services to Oslo city center and other destinations. Passengers and airport employees can easily access the airport using eco-friendly public transport,
- Electric Vehicle Infrastructure: Oslo Avinor Airport has installed many electric vehicles (EV) charging stations throughout its parking facilities. This encourages the use of electric cars by providing convenient charging options for passengers and employees, promoting cleaner and greener transportation choices,
- Bicycle Facilities: The airport promotes cycling as a sustainable mode of transport by providing bicycle parking areas and facilities. Passengers and employees who prefer cycling can safely park their bikes at designated areas, encouraging active and environmentally friendly commuting options,
- Carpooling and Ridesharing: Oslo Avinor Airport encourages carpooling and ridesharing as sustainable transportation choices. The airport supports various carpooling initiatives and works with transportation providers to facilitate ridesharing services, reducing the number of single-occupancy vehicles and promoting the efficient use of transportation resources,
- Green Ground Transportation: The airport actively seeks to reduce emissions from ground transportation within its premises. It encourages using low-emission vehicles, including hybrid and electric cars, for airport-related services such as taxis, shuttles, and transportation providers operating at the airport,
- Sustainable Airport Operations: Oslo Avinor Airport implements sustainable practices to minimize its environmental impact. This includes

energy-efficient infrastructure, waste management strategies, recycling programs, and using renewable energy sources. The airport continuously strives to reduce its carbon footprint and improve its sustainability performance,

- Collaborative Initiatives: The airport collaborates with local authorities, transport agencies, and environmental organizations to advance sustainable transport goals. It actively participates in city-wide initiatives and regional programs to reduce emissions, improve air quality, and promote sustainable mobility,

(Airports Council International (ACI), 2022; Avinor, 2022; Baxter, 2020, 2021).

Image 10: The first fully electric shuttle bus in Avinor Airport

Through its focus on public transportation, electric mobility, cycling, carpooling, and sustainable airport operations, Oslo Avinor Airport aims to provide passengers and employees with environmentally friendly travel options. By integrating sustainable transport practices, the airport contributes to Oslo's broader efforts to achieve a greener and more sustainable transportation system.

Car-free developments in the Netherlands

Besides the Netherlands being one of the countries where bicycle use is most common, it is a highly developed European country with its infrastructure and accessible public transportation opportunities for pedestrians. The Netherlands is one of the top cycling nations in the world due to its long history of promoting cycling and supporting cycling infrastructure. This has had significant benefits, helping the nation achieve a high standard of living and a physically active and healthy population. It's essential to remember that it hasn't always been this way. The country was well ahead of its time thanks to significant decisions made in the 1970s and 1980s, such as prioritizing cycling and attempting to ensure protection from the developing automobile culture at an early stage. Table 1 shows some of the car-free developments in the Netherlands.

Table 1: Car-free developments in the Netherlands

Houten: Houten is a town near Utrecht that has implemented car-free and car-restricted areas. The town's design emphasizes cycling and walking, with a comprehensive network of cycling paths, pedestrian zones, and limited car access.
De Hoven, Delft: De Hoven is a residential neighborhood in Delft that aims to create a car-free environment. The development includes pedestrianized streets, green spaces, and cycling infrastructure, while parking facilities are located on the neighborhood's outskirts.
De Nieuwe Stad, Amersfoort: De Nieuwe Stad is a sustainable redevelopment project in Amersfoort that promotes car-free living. The area prioritizes walking, cycling, and public transit, with limited car access and shared electric vehicles available for residents.
Noorderhaven, Zutphen: Noorderhaven is a car-free housing development in Zutphen that focuses on sustainable living and active mobility. The neighborhood features pedestrianized streets, cycling infrastructure, and access to public transit, with parking located on the outskirts of the area.
Strijp-S, Eindhoven: Strijp-S is a former industrial area in Eindhoven that has been transformed into a mixed-use development with car-restricted zones. The area prioritizes walking, cycling, and public transit, creating a vibrant and sustainable urban environment.

Image 11: A secreenshot from the website of Strijp-S

4.1.3. The future of car-free developments

The future of car-free development appears promising; increasing urbanization is acknowledging the significance of creating sustainable communities that prioritize people's needs. The recent pandemic has further emphasized the importance of accessible and safe transportation options and the necessity for active modes of transportation such as walking and cycling. The emergence of smart cities and the growing availability of alternative transportation modes have made car-free communities more attainable. By emphasizing sustainability, accessibility, and community, car-free developments can foster more livable, equitable, and resilient cities, benefiting present and future generations.

4.2. Transit-Oriented Development

While others had supported related ideas and contributed to the design, Peter Calthorpe identified the idea of Transit-Oriented Development (TOD) at the end of the 1980s. When Calthorpe published "The New American Metropolis" in 1993, TOD cemented its place in contemporary planning. In general, TOD is described as "a mixed-use community that encourages people to live near transit services and to lessen their dependence on driving (Pojani & Stead, 2014). In a broader sense, TOD is a neo-traditional manual for designing sustainable communities (Calthorpe, 1993) and leads the urban sprawl. Beyond its definition of built form, it was also a sustainable transport design principles that promised to deal with a wide range of social and technical parameters.

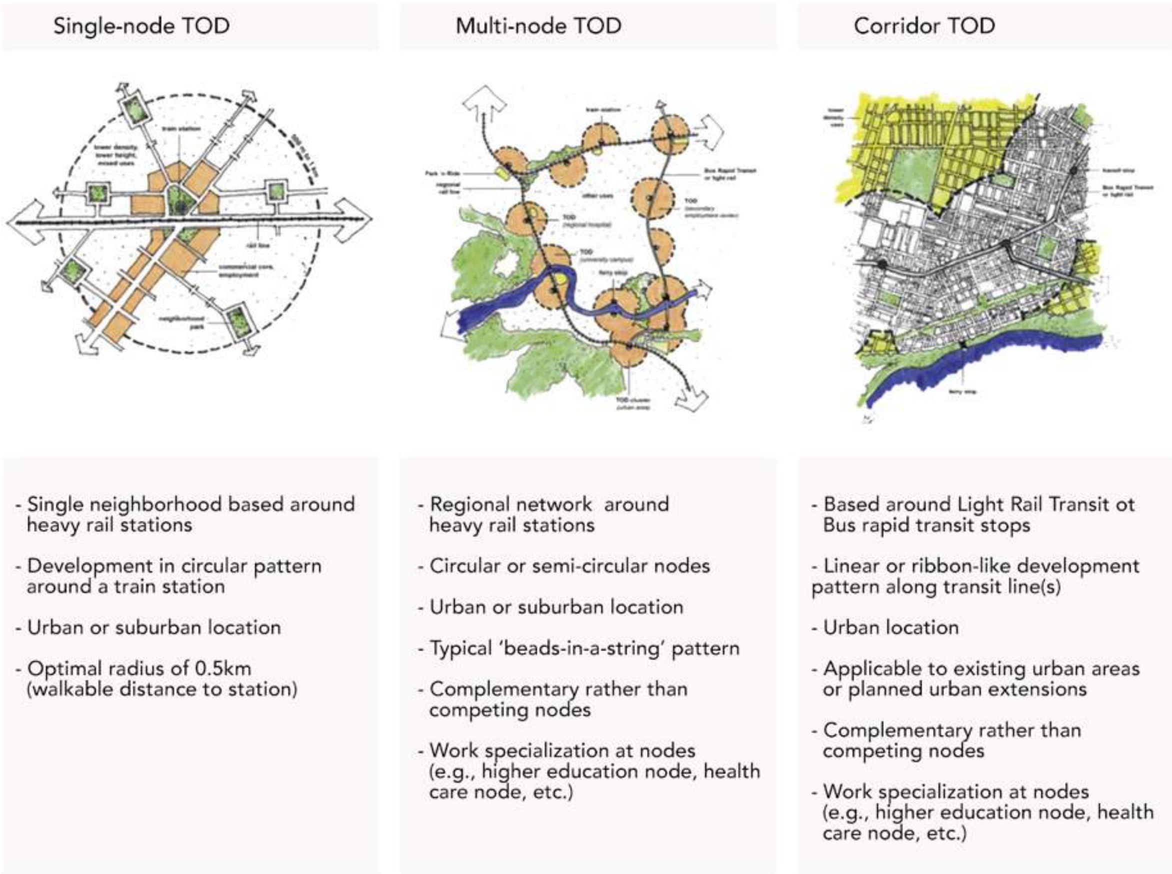


Figure 25: Main types, characteristics, and design of TOD. Source (Pojani & Stead, 2018)

The definition of TOD should be examined together with other frameworks within the scope of the thesis.

Definition

In transit-oriented development, the use of public transportation, walking, and cycling are prioritized over the use of automobiles. TODs are typically constructed around transit stations and include a mix of residential, commercial, and retail space in addition to other features like parks and public areas. TOD aims to build compact, walkable communities that decrease reliance on private cars and make it simpler to access public transportation, thereby reducing traffic congestion and environmental pollution.

As a design and planning strategy TOD aims to promote compact urban spheres conjugated with public transportation and other new means of light transport vehicles. Designing the street level to engage with walkable pavements, bike lanes, and other surrounding facilities is essential.

In addition, the transit hub areas (like train stations, airports, etc.) serve as the focal point of a destination for mixed-use developments. The parking lot is strategically positioned, planned, and operated. The availability of well-planned public transportation and services constitutes one of the most crucial factors.

Effective TOD projects in car-free areas can be strategically propelled using various tools (Figure 26). These include transportation demand modeling for informed planning, zoning regulations promoting mixed-use density, accessibility indices for transit connectivity, intelligent mobility solutions enhancing convenience, and economic impact assessments evaluating benefits.

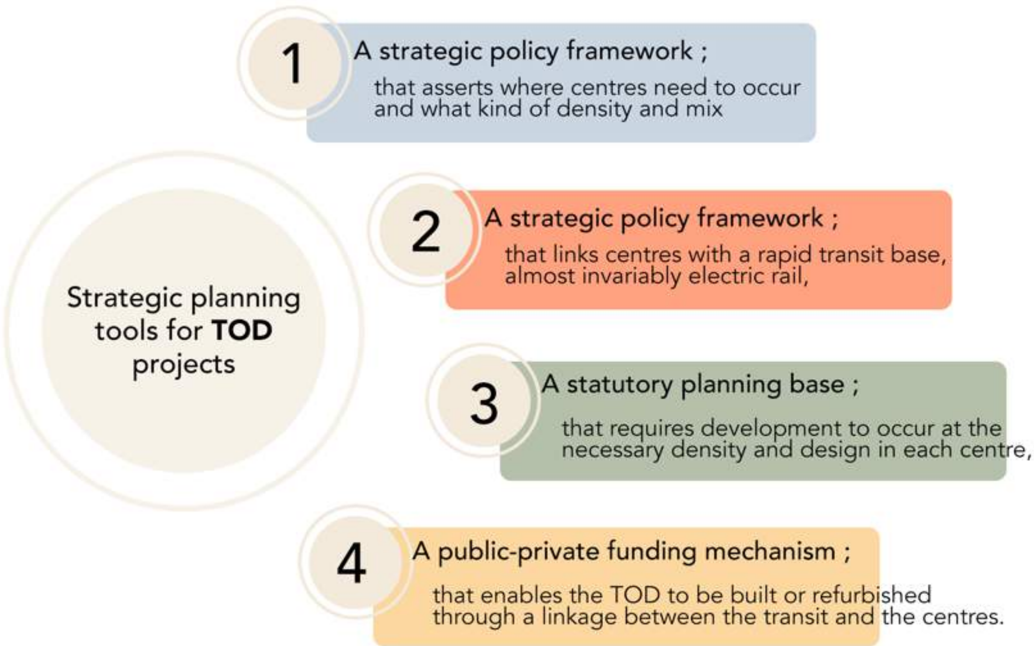


Figure 26: Four strategic planning tools for TOD projects. Source (Curtis et al., 2009)

4.2.1. Key Principles of Transit-oriented Development

As a result of the literature search, the parameters are prioritized by different scales. This diversity is shaped according to the functionality of the transit-oriented urban developments (high-density residential / business districts, mixed-use, transportation hubs, etc.).

Compact and mixed-use urban environments are encouraged by TOD around transport stations. Understanding land use and design elements that promote greater reliance on walking and cycling, public transportation use, and less reliance on car station zones requires an analysis of the built environment (Renne, 2009). Therefore, various principles are needed to analyze the environment. These analyses should cover the complications such as energy spent during trips, costs, natural surroundings, as well as habitats, user satisfaction, sociocultural diversities, and administrative operations during the daily trips.

The regional transportation system may be impacted by the development near stations; thus, the trips are changed to be more transit, shorter, and decreases overall vehicle travel, pollution, congestion, and external costs (Noland et al., 2014). To be able to evaluate TODs, six key principles were adopted from the literature (Table 2).

Table 2: Six key principles of TOD (Renne, 2005)

1. *Travel behavior*
2. *Economy*
3. *Natural environment*
4. *Built environment*
5. *Social environment*
6. *Policy*

Why Transit-Oriented Development?

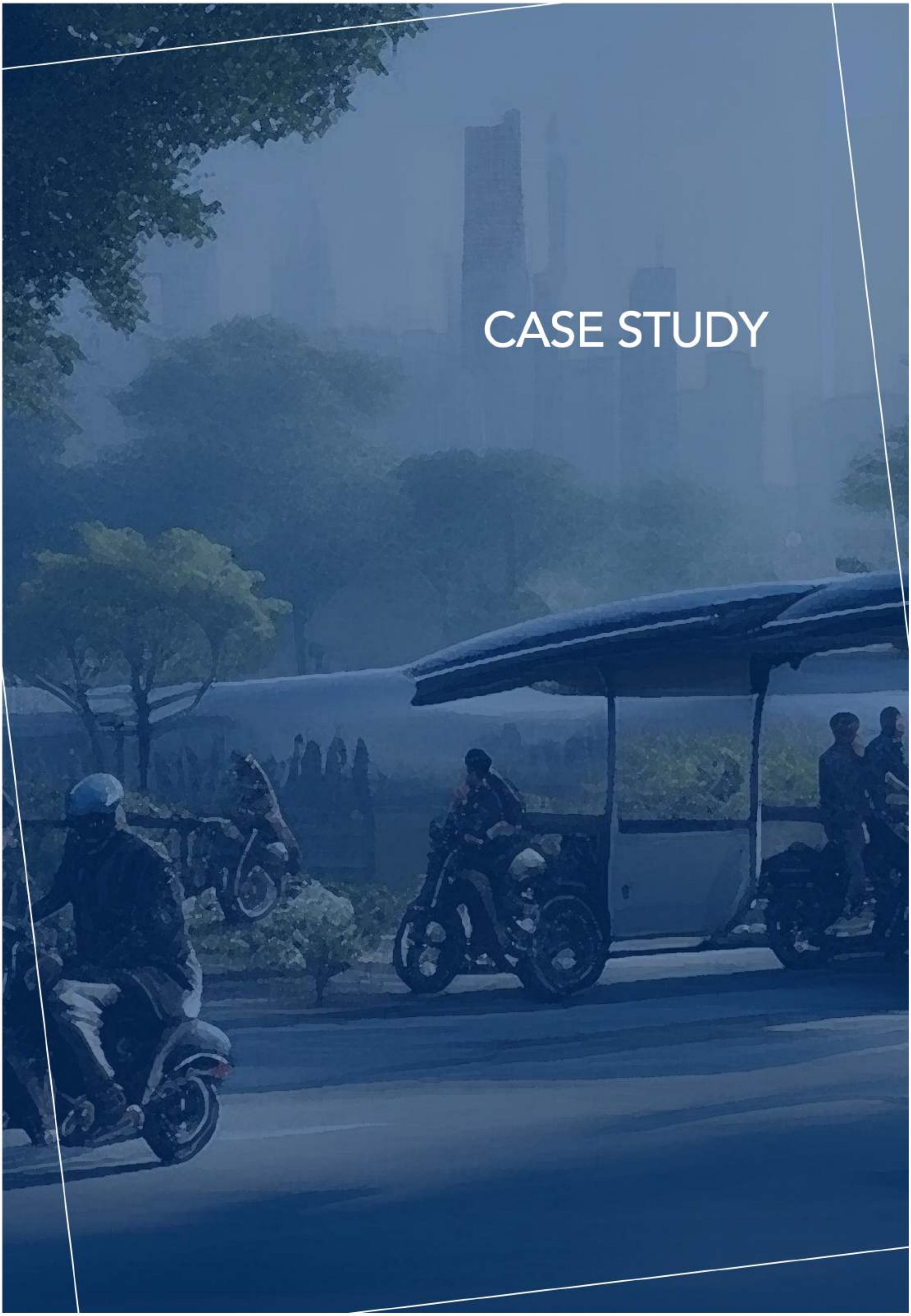
Due to its inherent characteristics and strategic benefits, transit-Oriented Development is a valuable tool for car-free development. TOD and CFD are closely related and often complement each other in urban planning strategies. TOD significantly promotes and supports car-free development by providing the necessary transportation infrastructure and alternative mobility options. Here are some reasons why transit-oriented development is indtrumental/chosen to enhance designing car-free Schiphol Centrum:

- **Access to Public Transportation:** TODs are designed around transit nodes, such as train stations or bus stops, making public transportation easily accessible to residents and visitors. This encourages people to rely on public transit for their daily commute, reducing the need for private car usage. Schiphol Airport already serves as a transport hub to enhance the mobility variations. TOD offers promoting different modalities.

- **Reduced Reliance on Cars and Traffic Congestion:** The availability of efficient and convenient public transportation in TOD areas provides an attractive alternative to owning and using private cars. As a result, residents are more likely to choose public transit for their transportation needs, leading to decreased car dependency and congestion.
- **Walkability and Active Transportation:** TODs are often designed to be pedestrian-friendly, with well-connected sidewalks and bike lanes. This walkable environment promotes active transportation, such as walking and cycling, further reducing the need for cars within the development.
- **Behavioral Shift:** TOD offers physical infrastructure and cultivates a cultural shift towards sustainable transportation. Providing appealing alternatives to car travel gradually changes users' (commuters, passengers, visitors, residents etc.) travel behavior.
- **Policy Support:** Many urban planning policies encourage TOD to achieve sustainable development goals. Integrating TOD principles can garner support from policymakers for transitioning to car-free environments. SG (Schiphol Group) can create their transport policy benefitting TOD's key aspects.
- **Long-Term Viability:** TOD offers a scalable and adaptable model for urban development that can be modified to fit various contexts and accommodate future changes in Schiphol Airport.

In summary, TOD facilitates CFD by providing three main aspects: efficient public transportation, promoting walkability, and creating a mixed-use and compact urban environment. The first aspect discussed adding MM hubs and offering new modalities. Secondly, to reach walkable streets in Schiphol, TOD should be taken as a tool to achieve car-free Schiphol Centrum. By integrating these approaches, airports can move towards more sustainable and livable spaces rather than being only industrial areas that people have to pass by.

Transit-Oriented Development provides a roadmap for transforming urban landscapes into thriving, car-free communities. Its emphasis on accessible transit options, mixed land use, and sustainable design aligns perfectly with the vision of car-free living and represents an effective tool for achieving this objective.



CASE STUDY

5. CASE STUDY

5.1. Case description, status quo

Global institutions and organizations such as the World Bank (WB), The International Air Transport Association (IATA), European Green Deal (EGD), International Civil Aviation Organization (ICAO) have been working on reducing carbon emissions at airports especially in recent years. As this task encompasses, various projects have been put into effect. Green airports-themed TULIPS (DemonsTrating lower pollUting soLutions for sustaInable airPorts acrosS Europe) is one of these projects. Until the end of 2025, the EU will provide 25 EUR million in funding to the TULIPS consortium to help it create innovations that will ease the transition to low-carbon mobility and improve sustainability at airports (https://tulips-greenairports.eu). The project is carried out in 4 airports (Amsterdam, Schiphol; Oslo, Avinor; Cyprus, Hermes; and Torino, SAGAT).

The study is divided into 13 work packages (WP) to examine the arousing problem of sustainable transport from a broader perspective. And each work package consists of numerous tasks. Table 3 demonstrates the work packages and their scope. The case study of the thesis investigates work package 1, task number 4 (WP-1.4.: Increase the use of public transport and shift to the use of green commuting modes).

WP-1 aims to reach sustainable intermodal connections in landside Schiphol Airport transportation. This work package comprehensively describes five policy packages designed for the digital twin model of Schiphol's intermodal hub area demonstrated by TNO. The objective is to assess the impact of these policy packages on mode choice, traffic flow, and emissions by utilizing the digital twin. Each policy package consists of a set of measures specifically designed for implementation in the landside intermodal hub of Schiphol. The primary goal of these measures is to decrease emissions associated with passengers' transportation to and from the airport (Araghi et al., 2022).

Table 3: WP-1 Policy packages

	Policy package names (PP)	Description
WP 1.4.	PP-1	Schiphol Centrum to zero emission zone (ZEZ)
	PP-2	Inclusion of metro line + more Intercity trains
	PP-3	Remote Check-in for Schiphol passengers
	PP-4	Car-free Schiphol City
	PP-5	All options put together (wild card)

Within the context of the conducted project, PP-4 (Car-free Schiphol city) was examined as a specific case study; however, there was an active exchange of ideas and data sharing among other policy studies within the WP-1. Establishing a zero emission zone in Schiphol Centrum, aligned with the shared objectives of both Schiphol Airport and the European Union, necessitates the implementation of comprehensive instrumentation within the area. This is paramount to effectively achieving the desired emission reduction goals and ensuring the successful realization of a ZEZ in the Schiphol Centrum.

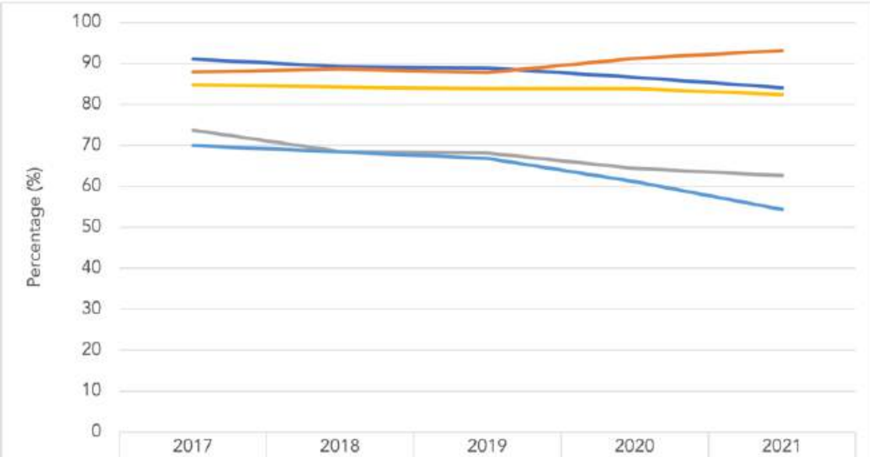
During the search of the TULIPS project, it was concluded that it serves as a pertinent case study for this thesis. This determination is predicated upon its direct alignment with the envisaged objectives given in the previous chapters. Furthermore, involving an ongoing project helps facilitate data accessibility and work with the experts in the area and Schiphol Group. Its applicability extends to select international airports, thereby presenting an invaluable avenue to exemplify the study's principles and elevate the scholarly discourse.

5.2. Values in practice: Current state of the case study

The current state of Schiphol Airport shows that progress has been made in reducing emissions through renewable energy sources and policies aimed at reducing carbon footprint. However, there is still a need for more sustainable and active transportation options for passengers and employees.

Given the absence of residential areas in Schiphol, the utilization of bicycles among its population needs to catch up to the national average. As for car usage, it aligns closely with the national average, with a slight inclination towards higher utilization. However, introducing electric bicycles has contributed to an upsurge in bicycle usage, enabling individuals to cover even longer distances (up to a maximum of 15 kilometers) previously deemed unsuitable for cycling (Mobiliteitsonderzoek Schiphol, 2017).

Due to this and other deterrent reasons and the inadequacy of the infrastructure, the use of cars is quite intense. Furthermore, the increase in NOx emissions on recent roads draws attention (Figure 27). As a result, in order to stop the increase in GGE, Schiphol management works to provide more sustainable commuting. The graph shows the current gas emissions at Schiphol Airport.

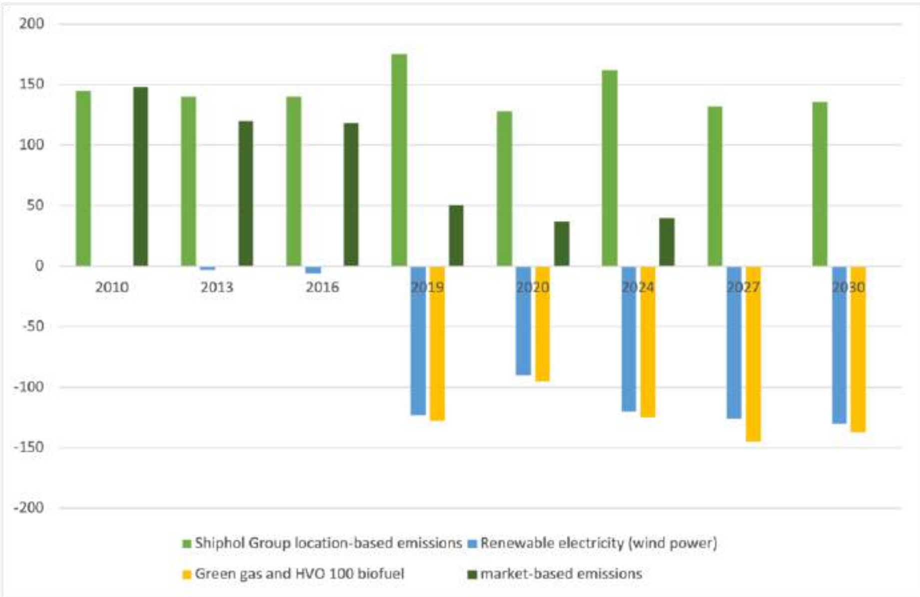


	2017	2018	2019	2020	2021
CO	91,05	89,22	88,85	86,64	84,05
NOx	87,91	88,65	87,76	91,19	93,1
FOX	73,69	68,45	68,1	64,4	62,6
SO2	84,76	84,29	83,81	83,81	82,4
PM10	70	68,4	66,8	61,2	54,4

Figure 27: Emissions in Schiphol Airport (Annual Report 2021 Royal Schiphol Group, n.d.)

Despite a decreasing trend in some toxic gas intensity over time, the production of highly toxic NOx gas continues to increase. In order to mitigate the greenhouse gas effect, implementing the car-free Schiphol Centrum design is expected to have a significant and positive impact. This can be achieved by creating a compact, mixed-use design that favors active transportation modes like walking and cycling. Car-free developments can reduce traffic congestion and promote better public health outcomes by minimizing the need for extensive road networks and parking spaces. Furthermore, car-free developments prioritize creating vibrant, pedestrian-friendly environments with ample green spaces, public amenities, and community-oriented designs, which can enhance residents' quality of life. However, the success of such initiatives depends on various factors that need to be considered, including urban context, infrastructure availability, and stakeholder engagement.

Furthermore, the Schiphol Group (SG) has made significant progress aligning with its long-standing 2030 targets. The following graphs depict the local and market-based emissions, as well as the utilization of renewable electricity, green gas, and biofuels. Notably, the upward trend of renewable energy sources and the downward trend in market-based emissions reflect encouraging advancements. In this regard, transport-based emissions can be addressed by implementing new policies, such as car-free developments. As seen in the TULIPS project, authorities also notice the importance of sustainable transport and enforce policies to reduce airports' carbon footprint.



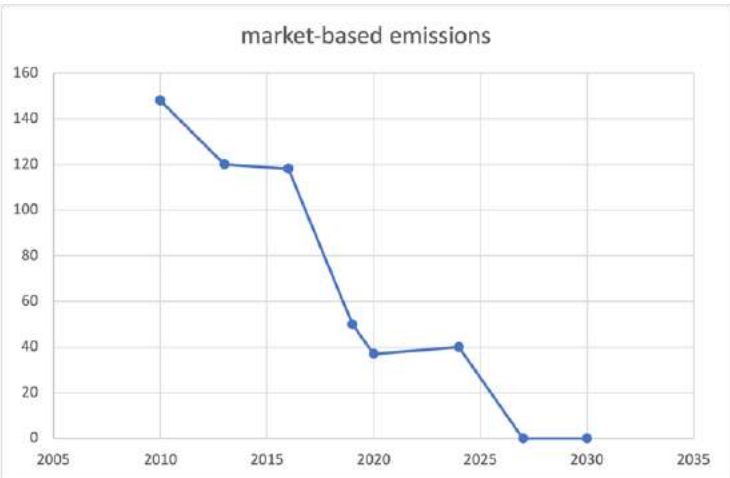


Figure 28a-b: Emissions in Schiphol distributed by years (SOAB, 2009; van den Berg & Mevissen, 2011)

5.3. The travel behavior of the commuters

Determining the target audience for decisions to reduce emissions is equally relevant. In aggregate, over half of the Schiphol workforce resides more than 25 kilometers away from the airport, and this figure continues to rise. These individuals typically consist of airline staff who commute outside peak hours and do not require daily airport access.

The utilization of the road network at Schiphol involves various target groups, including:

- Parking travelers
- Parking employees
- Parking hotel
- Crew center
- Front road departure
- Pre-way arrival
- Forwarding traffic
- Other (small groups with specific destinations)

Each target group experiences its peak moments. However, combining peaks across certain target groups is crucial for determining and evaluating the road network's capacity (Goudappel, 2016).

Table 4 shows that the majority of employees come to their workplaces by car. So much so that the number of employees who drive is even more than those who prefer another mode. For this reason, employees who come to the airport to work most days of the week constitute the most important target group.

This also helps to indicate the urgency and importance of implementing sustainable and active transportation options for employees. New policies should be implemented, particularly for those who live within a reasonable distance to the airport and can take advantage of cycling or walking and for employees who insist on coming to work by car to shift to a sustainable last-mile mode. To encourage more employees to shift away from driving alone, the implementation of incentives (e.g., discounted or free shuttle bus rides, car-pooling schemes, higher parking fees etc.) can be considered.

Moreover, employees who regularly come to the airport cause considerably more emissions than those who travel for work (Figure 29).

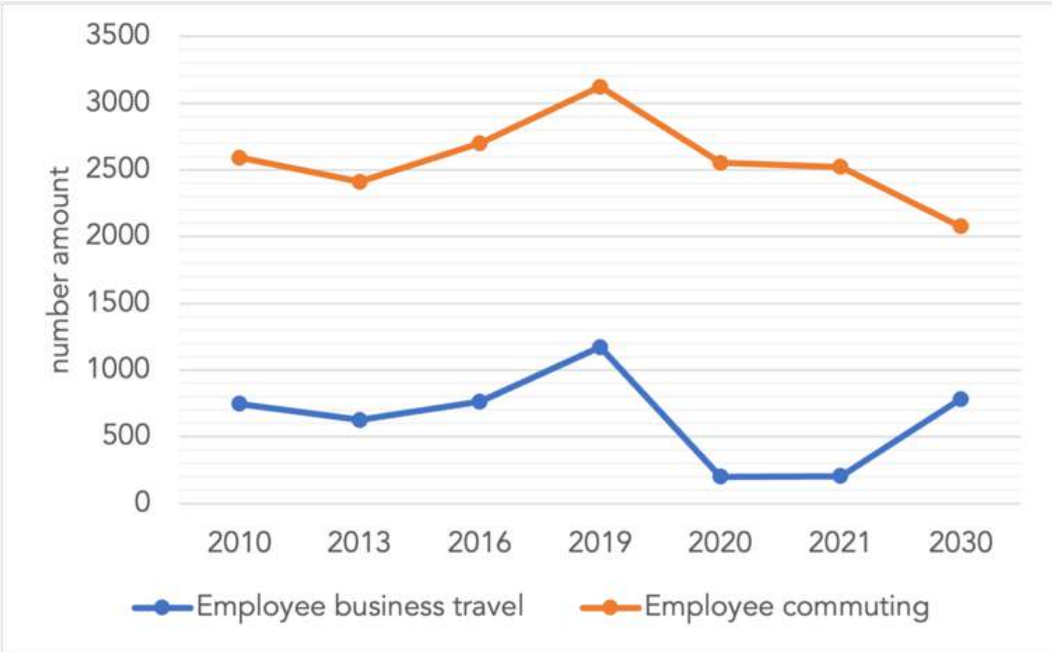


Figure 29: The impact of the employees on GGE

The objectives of the Mobility Survey for the TULIPS project encompass several key areas:

Handling Information:

- Monitoring the travel behavior of employees,
- Establishing a comprehensive database for transportation studies,
- Engaging in discussions with stakeholders, including government bodies and shipping companies,
- Assessing the extent of transportation challenges between employees' residences and work areas,
- Determining the travel characteristics of employees,
- Identifying traffic and transportation issues within the airport premises,

Perception of Schiphol Accessibility:

- Evaluating the perception of accessibility among Schiphol employees,
- Assessing the perception of accessibility based on the means of transportation used,
- Exploring opportunities to enhance the perception of accessibility and achieve higher scores,

Opportunities for Mode of Transportation Change:

- Collecting up-to-date information on the transportation options currently utilized by employees,
- Building a database for travel alternatives and policy-related matters (Mobiliteitsonderzoek Schiphol, 2017).

These objectives beg the questions to examine the holistic view further:

Quantitative Part:

- What is the current breakdown of transportation mode selection per mode of transport for Schiphol? (Figure 30)

Qualitative Part:

- How do employees evaluate the accessibility of Schiphol in suburban traffic? (Figure 31)

The provided graphs provide conclusive insights into the inquiries. The data reveals that a significant majority of employees opt for car transportation, which is followed by train transportation but at rates lower than desirable. The identity of Schiphol Airport as a transit hub is noteworthy, with a highly efficient rail system connection. Strengthening this connection and directing commuter transportation mode preferences would be beneficial. Promoting affordable and accessible sustainable land-side transportation, highlighting its positive impact on human health, and fostering public awareness can catalyze a shift in the transportation behavior of employees.

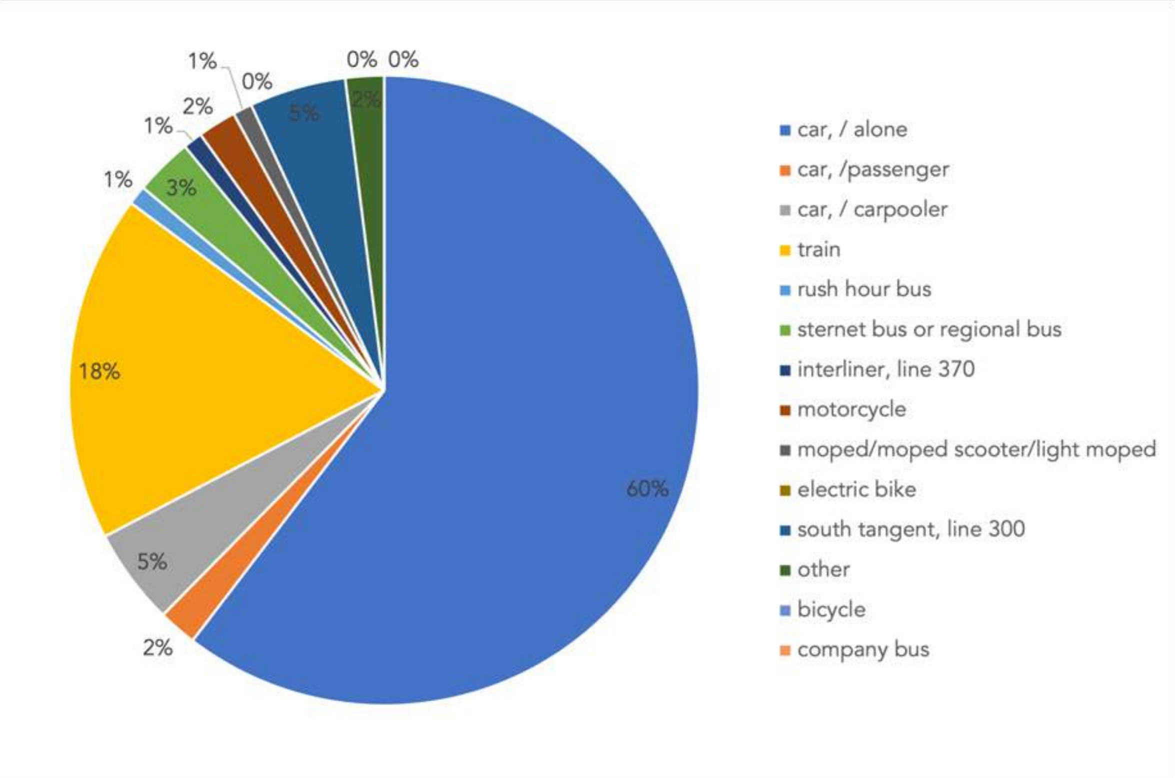
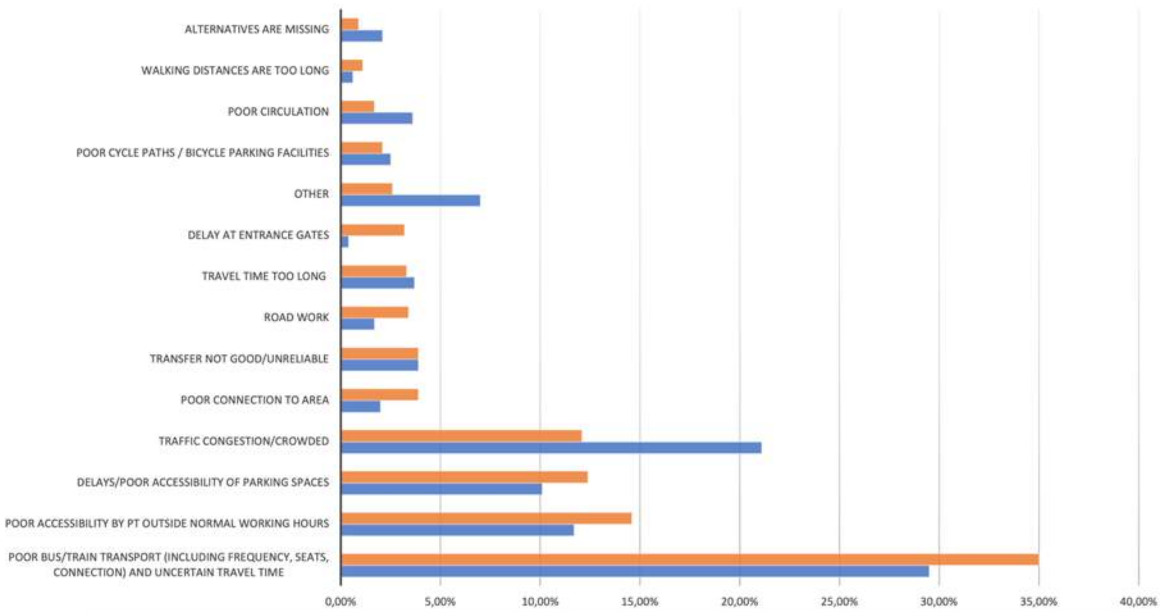


Figure 30: Modal-split of employees



	Poor bus/train transport (including frequency, seats, connection) and uncertain travel time	Poor accessibility by PT outside normal working hours	Delays/poor accessibility of parking spaces	Traffic congestion/crowded	Poor connection to area	Transfer not good/unreliable	Road work	Travel time too long	Delay at entrance gates	Other	Poor cycle paths / bicycle parking facilities	Poor circulation	Walking distances are too long	Alternatives are missing
2013 (in %)	35,00%	14,60%	12,40%	12,10%	3,90%	3,90%	3,40%	3,30%	3,20%	2,60%	2,10%	1,70%	1,10%	0,90%
2017 (in %)	29,50%	11,70%	10,10%	21,10%	2,00%	3,90%	1,70%	3,70%	0,40%	7,00%	2,50%	3,60%	0,60%	2,10%

Figure 31: Accessibility pleasure analysis of employees. Adopted from: (Mobiliteitsonderzoek Schiphol 2017, 2017)

Examining the level of accessibility satisfaction among visitors to Schiphol Airport provides valuable insights into the overall landscape. The data presented in the table highlights the dissatisfaction stemming from factors such as inadequate public transportation and traffic congestion. Moreover, the lack of reliable public transit options during off-peak hours and the disruptions encountered in the car park are essential concerns.

Among those significantly impacted by these issues are airport employees who rely on transportation to commute to their workplaces throughout the week. Additionally, given the irregular operating hours of airports, transportation needs arise around the clock. One possible solution is the implementation of electric shuttle buses and electric charging stations (esp. for bikes) to facilitate clean and sustainable mobility. Another solution is to improve the connectivity of public transportation systems and establish more reliable and frequent services to ensure that visitors and employees can access the airport without significant delays or disruptions.

The condition of existing parking lots

Schiphol Centrum is the primary parking area in front of the airport terminals (Figure 36). This parking area has a capacity of over 10,000 vehicles and is divided into different zones, each with its pricing structure. The P1 garage is the closest parking facility to the terminals and offers a covered walkway to Terminal 2. The P3 and P40 long-term parking area provides a free shuttle bus service to the terminals. The P6 valet parking service parks your car for you and delivers it back when you arrive at the airport.

In addition, in the part where the offices are located, there are P12, P22, P KLM, and private parking lots of the offices. Employees mostly prefer these parks. At the same time, vehicles accessing Schiphol from the south mostly use the P30.

Utilizing the biannual Mobility Research conducted by SOAB in 2009, we can classify the Workers based on their specific work locations (Janssen, 2011). The three main groups identified are as follows:

- Schiphol Centre Workers: Refers to all workers at businesses close to the Schiphol terminals (the majority of workers are located in Schiphol Centre, Figure 32).
- Schiphol non-Centre Workers: Encompasses all workers stationed at business locations in the South, North, Technical area East, East, and South-east areas of Schiphol.
- Schiphol Rijk / Anthony Fokker Business Park: Includes all workers employed at these two designated locations (SOAB, 2009).

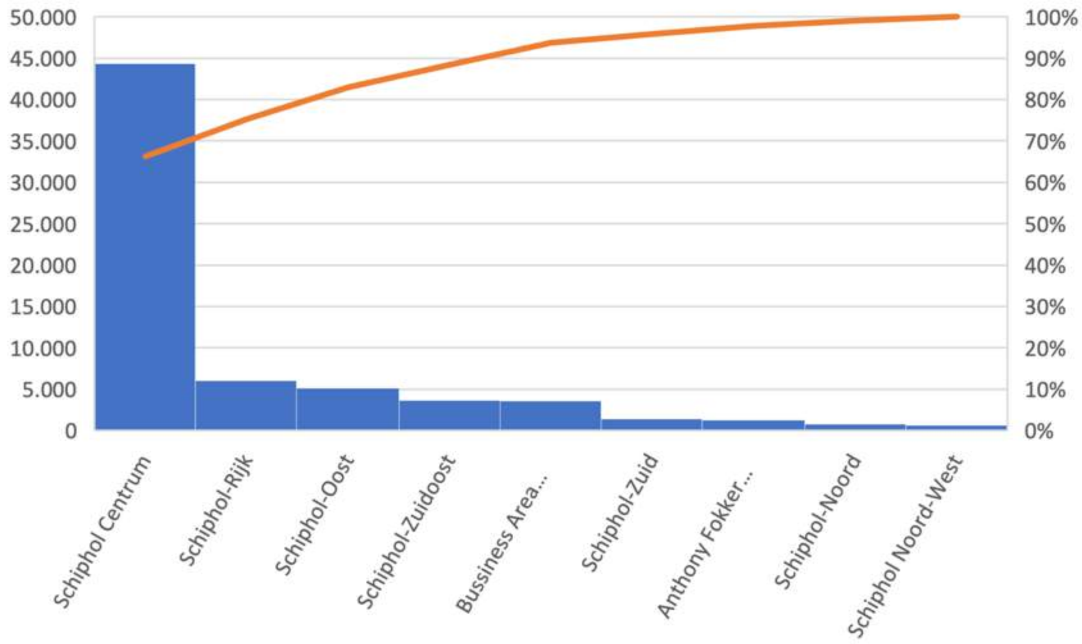


Figure 32: Distribution of Schiphol employees by their office location

Table 4: Schiphol employees' preferred mode of transport (de Groen et al., 2008; SOAB, 2009)

	Grand total	Train	Bus	Car	Taxi	Other	Motorcycle	Moped	Bicycle
Schipol workers total	37.909	7304	3407	23.450	0	0	1178	1134	1218
Schipol Center workers	22.291	5504	2201	12.910	0	0	592	554	506
Schipol non-Center workers	10.018	794	660	7061	0	0	460	483	537
Schipol Rijk/ AF Bus, Pare	5607	715	498	3798	0	0	151	124	226

Figure 32 shows the percentage of commuters' distribution in different areas at Schiphol Airport. The following Table 4 demonstrates the travel mode choice of workers according to their work location. The data reveals that most employees are based at Schiphol Centrum. Additionally, nearly half of the employees commute to work using private cars, contributing to approximately two-thirds of the overall employee transportation mode. These findings underline the critical need to mitigate the carbon emissions associated with airport employees by implementing measures to reduce car usage.

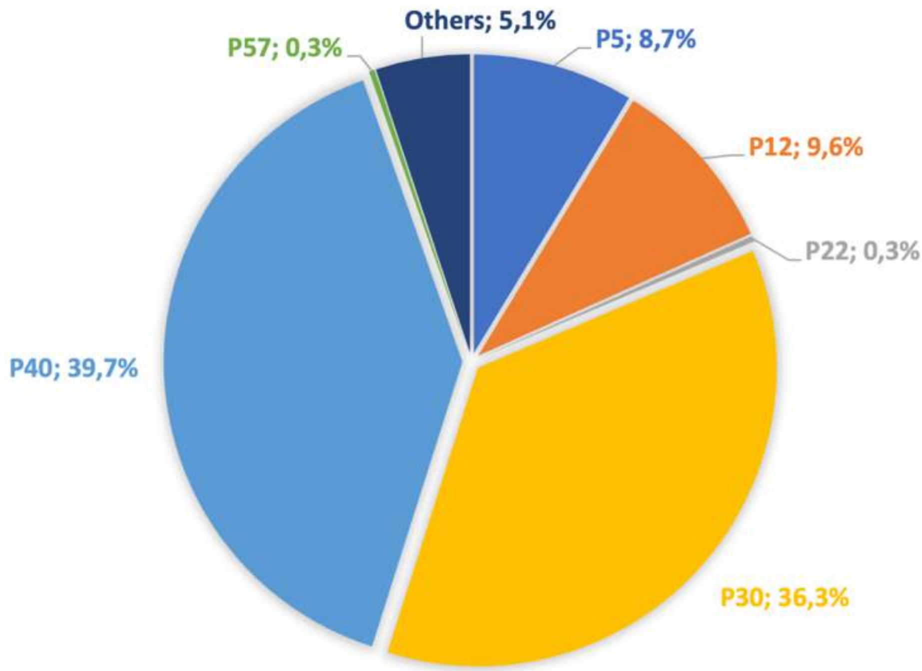


Figure 33: Parking lot choices of all users at Schiphol Airport

The upper graph (Figure 33) depicts the parking preferences of employees who commute to the airport by car. It should be noted that employees who exclusively rely on alternative modes of transportation are not represented in this table.

The data highlights the significant role played by various parking lots, primarily in the areas where they are conveniently situated. This indicates that each domain has its primary parking area, except for the Centrum, where P30 and P3/P40 are equally important. These areas also accommodate the highest number of vehicles numerically. Additionally, company-owned parking spaces also hold significance in terms of their quantity.

The positioning of P3/P40 and P4 also makes a positive contribution to the car-free Schiphol Centrum. P3/P40 is at Schiphol Nord and P30 is at Schiphol South.

At the same time, these parking areas act as catalysts so that commuters can perform modal shifts. The proposed concept for a car-free Schiphol Airport includes implementing sustainable mobility options such as electric shuttle buses and micro mobility hubs. Improving the connectivity of public transportation systems and establishing more reliable and frequent services is also crucial. For instance, it is envisioned that a free shuttle bus service will be located between P3/P40 and P30 parking areas.

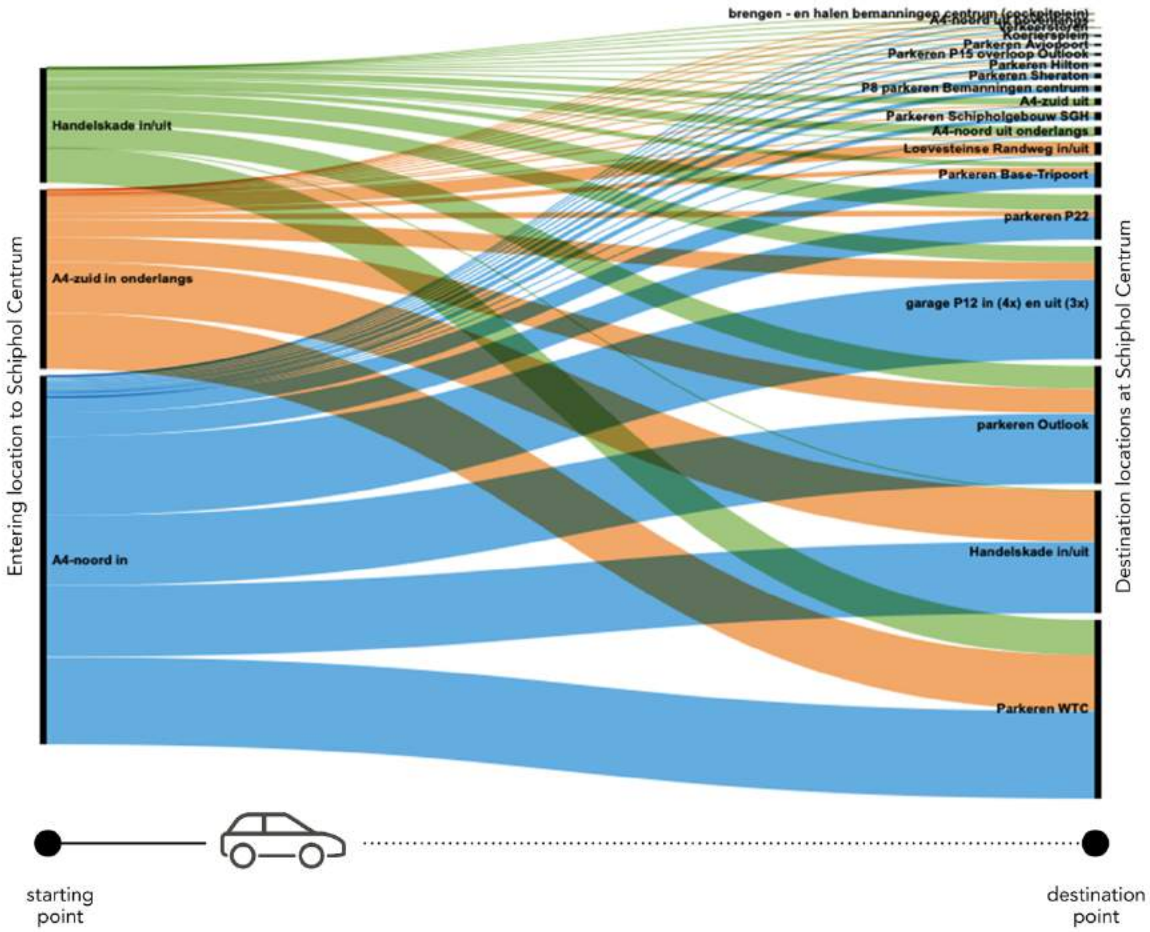


Figure 34: Sankey Diagram of commuters' travel pattern at Schiphol Centrum (Adopted from, (Mobiliteitsonderzoek Schiphol 2017, 2017))

The Sankey (Figure 34) diagram was used to analyze the distribution of Schiphol employees' destinations at the airport after entering with their vehicles. The diagram illustrates that the parking areas upon arrival differ based on the employees' respective workplaces and the three main entrances they utilize (A4-noord, A4-zuid, Handelskade). Notably, the graph excludes P3/P40 and P30 as they are situated outside the Schiphol Centrum. The analysis reveals a preference for office-based parking areas such as Parking WTC, Outlook, and Schiphol Base. Furthermore, the employees prefer P12 and P22, among Schiphol's parking lots. However, these parking lots, characterized by limited capacity and high demand, present challenges. The congestion and traffic congestion experienced in Schiphol Centrum during peak hours can be attributed to these busy parking areas. Consequently, it is recommended that these parking lots, located within the proposed car-free zone, be redirected to more extensive parking facilities such as P3/P40 and P30 in the north and south, and undergo a repurposed through new functions.

RESULTS

6. RESULTS

In the previous chapters, data collection, analysis, and a case study were seamlessly integrated with the existing literature, establishing a comprehensive framework for addressing the problem. In this chapter, we will present the outcomes of the design process and the applied methodology to realize the vision of a car-free Schiphol Airport.

The inclusion of TOD principles in the design of the car-free Schiphol Centrum, alongside CFD (Figures 25 and 26), expanded the boundaries of the design and mapping process and enriched the scope of CFD. This integration allowed for a synergistic combination of the two concepts, resulting in an adapted design of the car-free Schiphol Centrum.

The "Sub-question 1" answered by incorporating TOD principles, the car-free Schiphol Centrum design benefitted from:

- Integrating TOD principles facilitated better connectivity between the car-free development and public transportation nodes, such as train stations or bus and MM stops.
- The design incorporated amenities and services that catered to public transit users, ensuring the area surrounding the transit nodes was pedestrian-friendly and supportive of active transportation (micro mobility features).
- TOD principles encouraged the inclusion of mixed-use spaces within the car-free Schiphol, integrating organizational, commercial, and recreational areas. This mixed-use approach enhanced the vibrancy and accessibility of the Schiphol Centrum.
- The design emphasized creating better walkable environments with well-designed pedestrian pathways, leisure-time activity options and added cycling lanes, promoting active mobility and reducing the need for car travel.
- The aforementioned new amenities (MM and other amenities Figures 48 and 49) are added to create lively walking habitat and re-purpose the emptied space on the streets/car parks from the car dominance.

To discover deeper the project area, an urban design proposal was formulated, accompanied by meticulously crafted maps, allowing for a more detailed examination of the proposed concept.

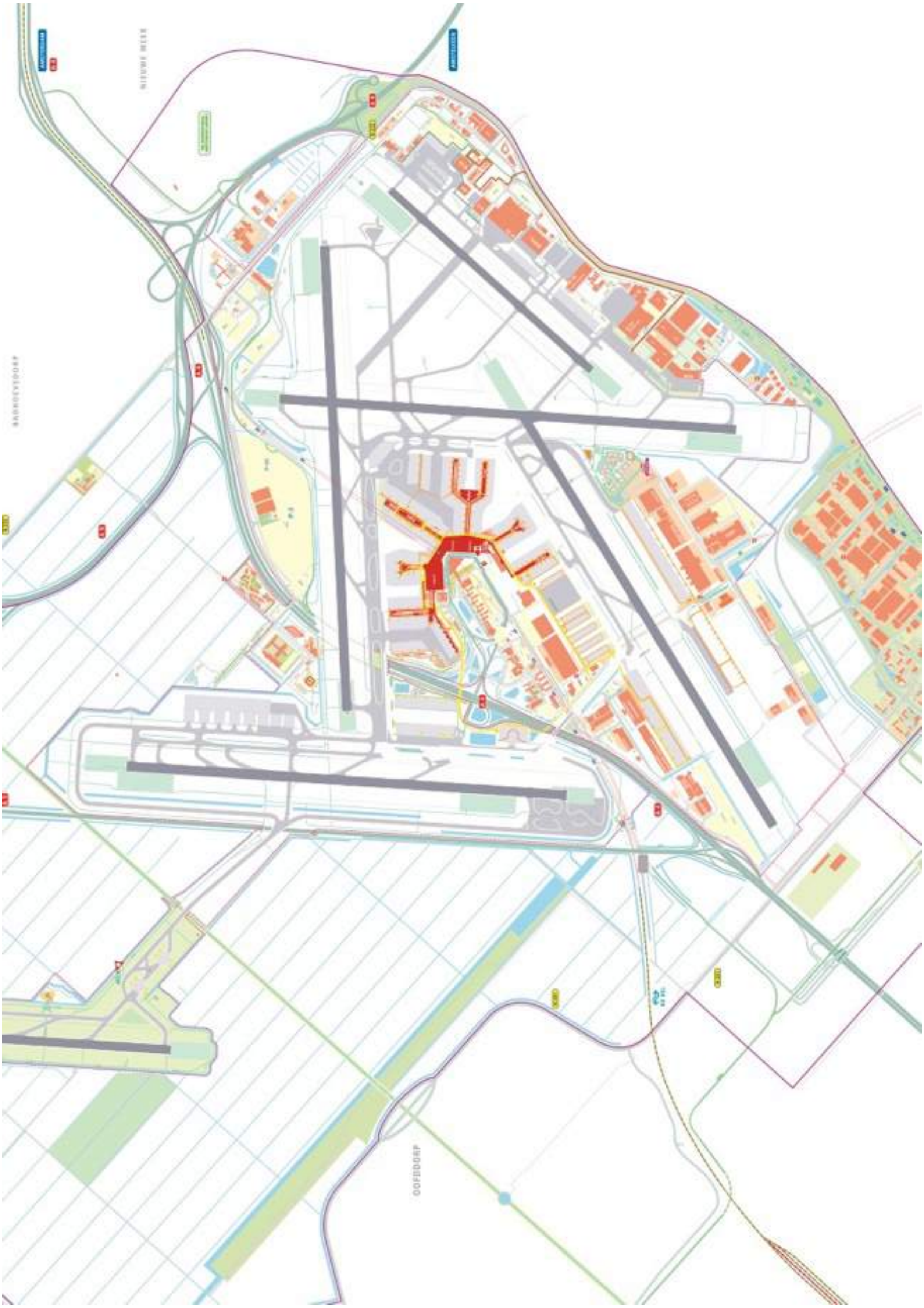


Figure 35: The Base Map of Schiphol Airport

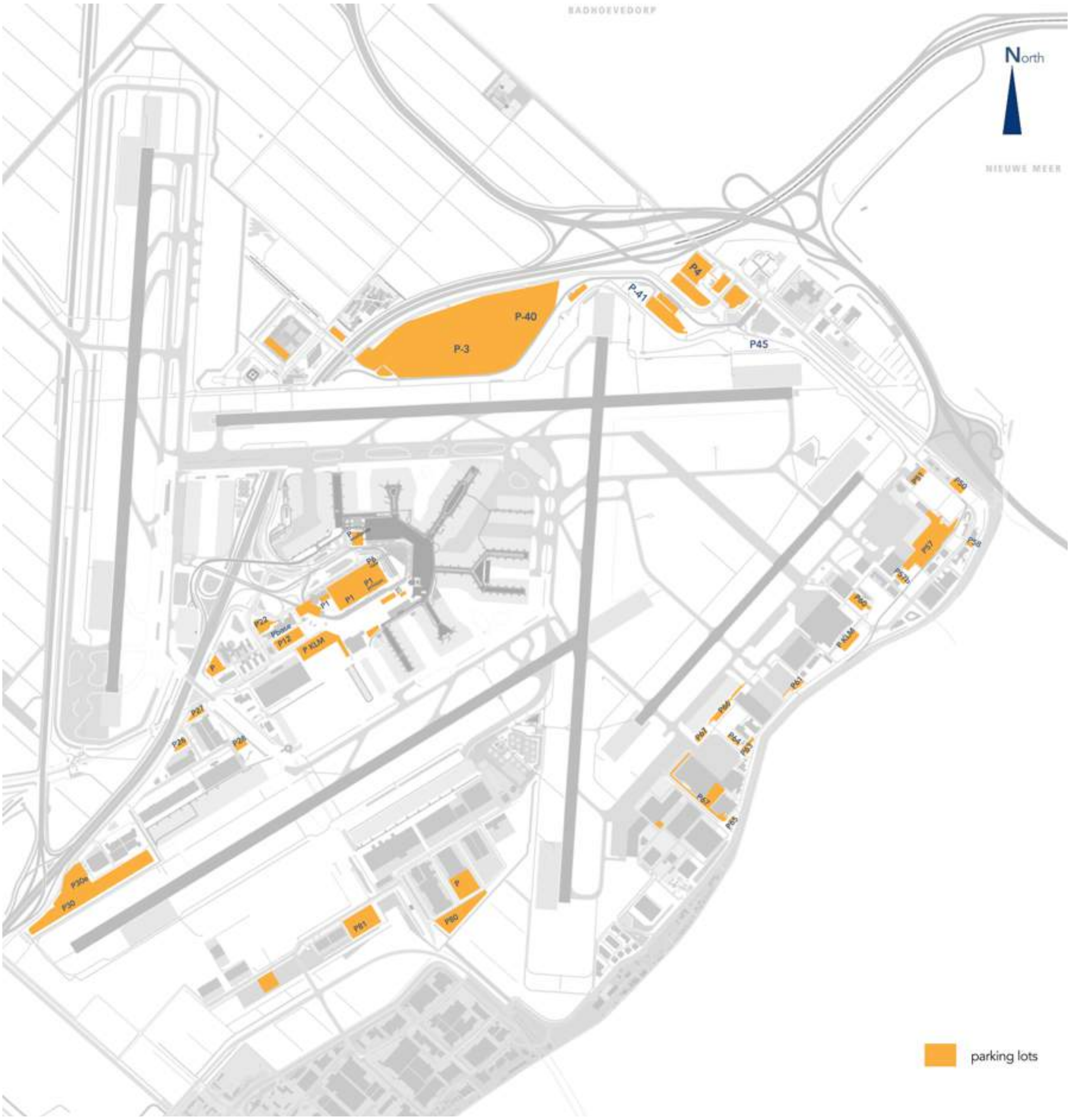


Figure 36: Current parking lots in Schiphol Airport

The map above (Figure 36) shows the current parking areas. The names of the parking areas will be mentioned in the following sections, and it provides a basis for discussing the parking lots within the Schiphol Centrum area. This will help readers better understand the current situation of parking facilities at Schiphol Airport.

6.1. Scenario Design

To further improve the sustainability and accessibility of Schiphol Airport, several scenario designs can be considered. These designs aim to address the challenges mentioned above and provide a more comprehensive and sustainable transportation system for both employees and passengers.

One of the possible scenarios is the implementation of car-free developments within the Schiphol Centrum area. This scenario aims to reduce/ban car usage and promote sustainable transportation modes such as cycling, walking, micro mobility, and public transit. This scenario can be supported by the implementation of cycling and micro mobility infrastructure (charging docks, subsidizing LEVs, providing hubs and amenities, etc.), expanded public transit options, and removing and/or charging more for the car parks.

6.1.1. Relocating the parking lots

The Schiphol Centrum area includes car parks such as P1, P6, P12, P22, Outlook Schiphol Base Hilton, Sheraton, and WTC. It is necessary to relocate these parking facilities to other locations. As mentioned earlier, P3/P40 in the north and P30 in the south are strategically positioned and possess sufficient capacity to accommodate the vehicles from the aforementioned car parks. Therefore, the plan entails relocating the parking lots within Schiphol Centrum to P3 and P40. Figure 37 provides a visual representation of this proposed transition.

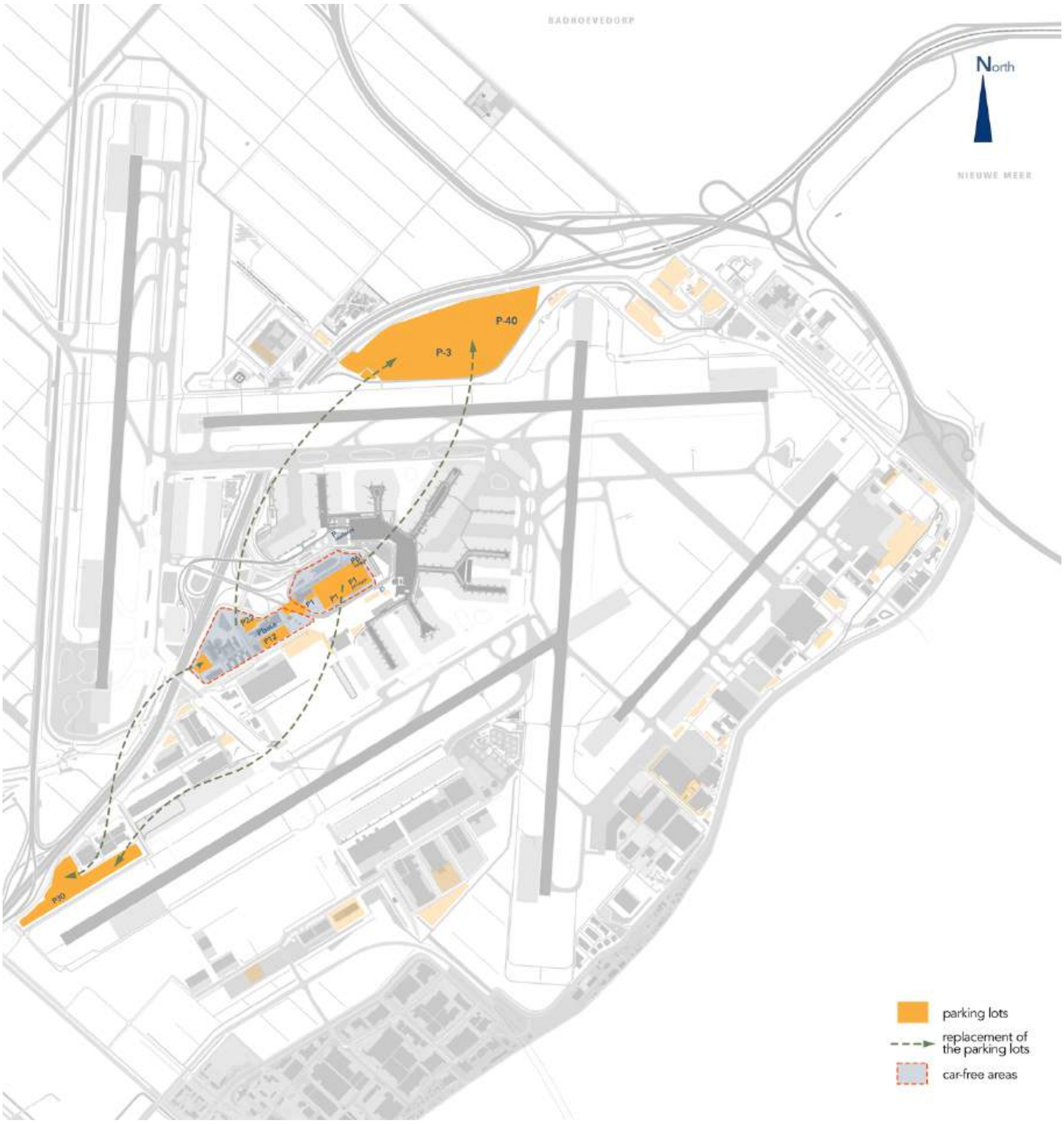


Figure 37: Suggestion of re-locating the parking lots that fall in the car-free areas

6.1.2. Scenario phases

It can be seen from the size of the project area makes the application longer, and the high investment costs in the transportation sector cause delays in the process. Therefore, the scenario design was planned in two phases.

The first phase would focus on implementing car-free zones in some regions of the Schiphol Centrum, which creates a divided car-free area without changing the existing main motorway infrastructure, and the second phase would expand the car-free areas to cover the entire Schiphol Centrum area, including the main roads (locating in the car-free area borders) and logistics units. The scenario designs will also answer the "Sub-Questions 3 and 4" using the design method with the created maps.

Phase 1 – Limited car-free development

In the first phase, car-free zones would be implemented in high-traffic areas such as Terminal 1, Schiphol Plaza, and office locations. The car-free zones would only be reserved for pedestrians, bicycles, and micro-mobility vehicles. More alluring cycling infrastructure would be built to encourage people to use bicycles as a sustainable transportation mode. This can include building more covered bicycle parking facilities and providing necessary amenities along. Furthermore, introducing mobility hubs will expand the range of available transportation modes, consequently fostering increased social interaction at these locations. This would reduce congestion and car emissions in these areas and create a safer and more pleasant environment for visitors and employees.

As shown in Figure 38, Phase 1 consists of two car-free area units, A and B, separated by the main road. Main road connections were preserved without changing Kiss&Ride (K&R) in this first phase, primarily focused on creating car-free Terminal and office areas. Parking lots (P1, P6, P12, P22, Outlook Schiphol Base Hilton, Sheraton, and WTC) within the A and B areas have been allocated.

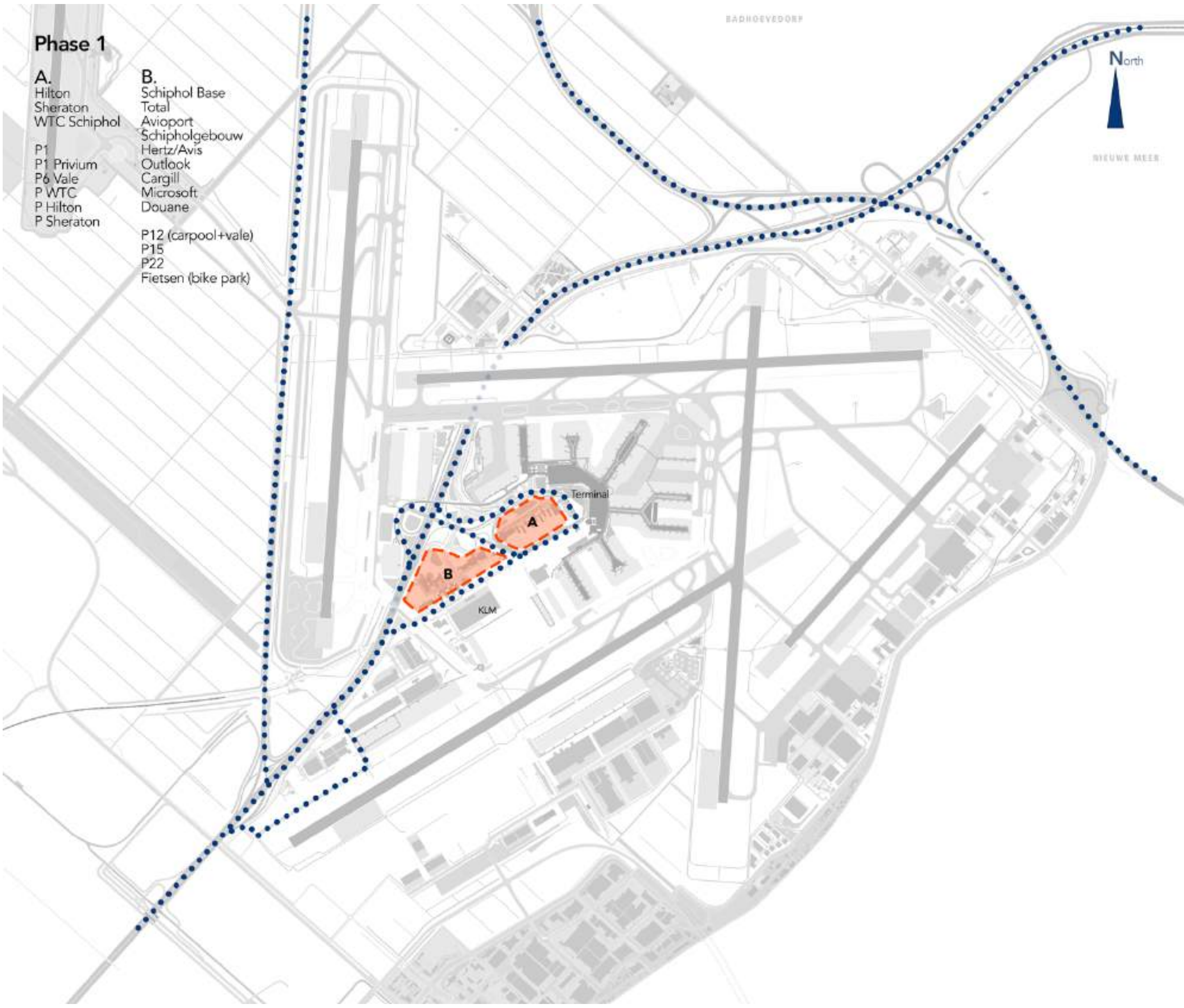


Figure 38: Phase 1 – Limited car-free area

Phase 2 – Car-free Schiphol Centrum

The second phase involves expanding the car-free zone to include the areas owned by logistics companies and modifying the functioning of the main roads. The main roads that previously formed the boundary between the A and B areas have now been incorporated into the car-free zone, ensuring the integrity of Schiphol Centrum. This expansion allows for completely car-free access to all office areas. Additionally, Area C has been included in the car-free zone. This decision is based on future plans of the Schiphol Group, which involve relocating logistics services outside of the Schiphol Centrum.

Stakeholder meetings with SG were held to discuss this plan. It is important to note that Area C is designed as a restricted car-free zone during this stage, as logistics companies inherently rely on vehicles. However, non-business vehicles will have limited access to this area to prioritize the expansion of green spaces and reduce GGE.

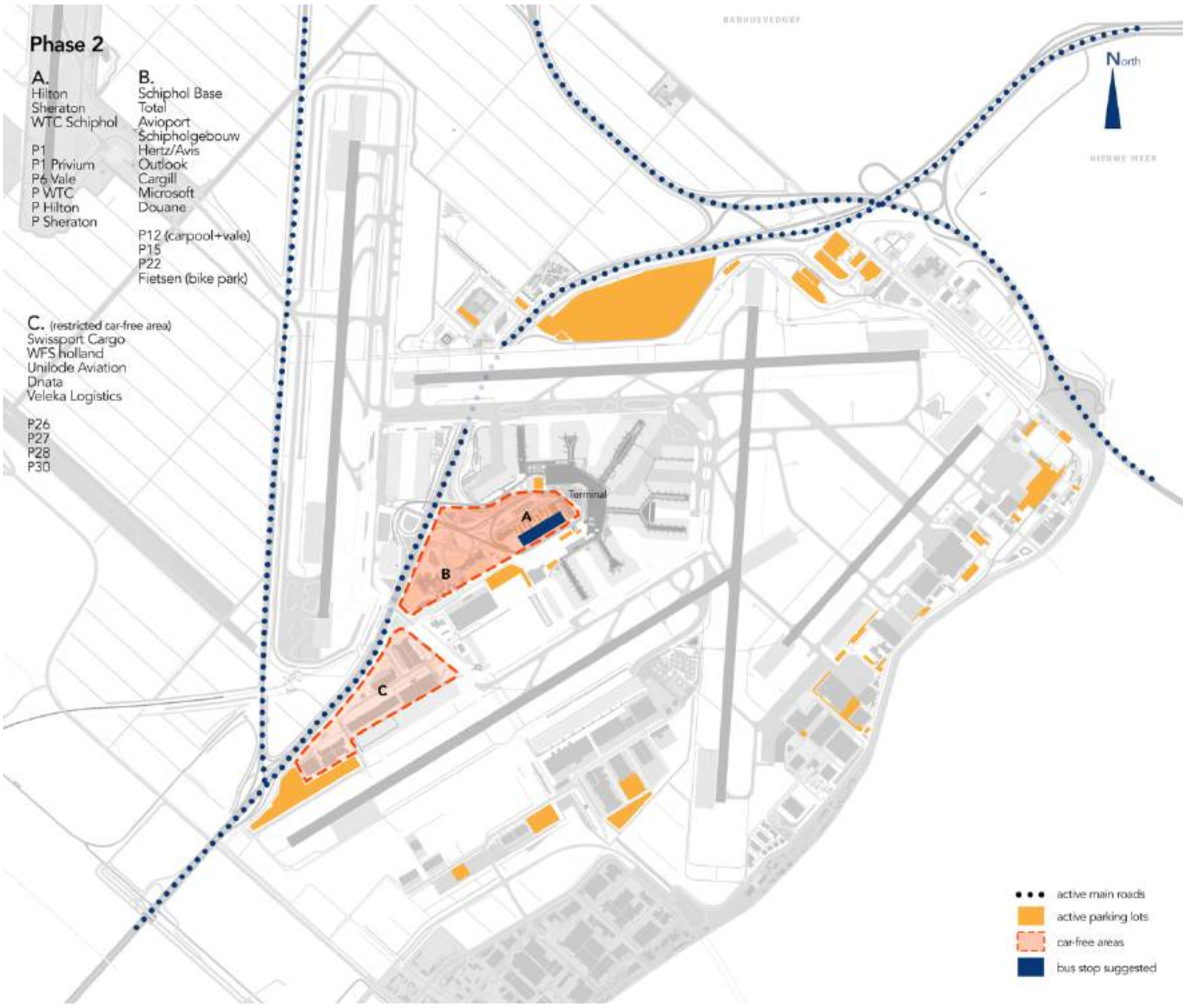


Figure 39: Phase 2 – Car-free Schiphol Centrum

In addition, the expansion of the car-free area establishes a direct connection with the Rozenburg public transport stops. This makes a positive contribution to commuters' modal shift into Schiphol Centrum and encourages the use of sustainable transportation modes. More bicycle parking facilities and amenities will be added to support cycling and micro-mobility use. Figure 39 shows the final design of the car-free zones, including the new logistics area and the expanded green spaces. The second phase demonstrates a more extensive version of the first Phase, covering the entire Schiphol Centrum area. It will create a safer and more sustainable environment, promoting a combination of different sustainable transportation modes, reducing the airport's carbon footprint, and contributing to healthier transport for visitors.

6.2. Designing a dedicated e-bus line (free of charge ring)

A dedicated e-bus line is proposed to feed the car-free area established in Phases 1 and 2 and encourage visitors to adopt more sustainable modes of transportation. Figure 40 schematizes the bus route and its respective stops. The e-bus line operates in a circular ring along the designated route, offering frequent service intervals to minimize waiting times.

The plan involves utilizing the space currently occupied by the P1 car park for parking the e-buses. Due to the structural challenges of constructing a new building on the open and multi-story P1 car park, it is more feasible to repurpose the remaining parking lot area as the e-bus park. Additionally, this area will accommodate new facilities such as repair units and kiosks, contributing to the revitalization of the space and increasing the convenience for visitors.

The e-bus line will be free of charge, making it more accessible for passengers. This will also encourage more visitors to use the public transport systems, contributing to the reduction of GGE from private vehicles. The e-bus line also serves as a feeder service to other public transport systems, facilitating connectivity and enhancing overall mobility.

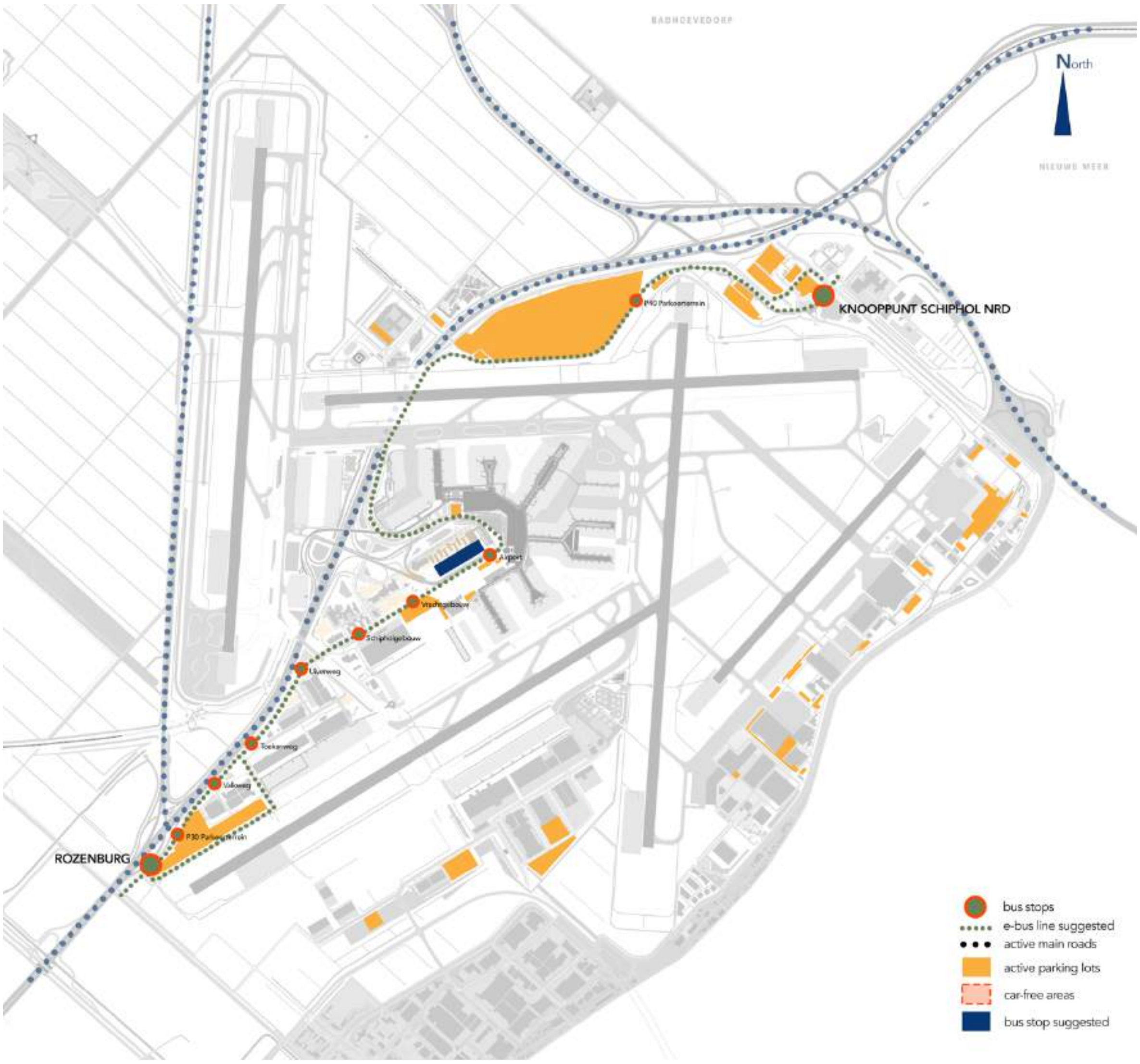


Figure 40: Dedicated e-bus ring

6.3. Designing the urban area with new elements

The expansion of the car-free areas and enhanced functionality were achieved through the development of larger-scale plans in this section. The objective was to create a pedestrian-friendly environment by incorporating necessary amenities. To successfully implement the methodology in the project, it was crucial to identify the specific locations for these functions. A preliminary urban project was formulated based on the insights from the literature review and the Walk Score method, emphasizing the relationship between amenities and their proximity to desired destinations. Figures 41 and 42 visualize a detailed version of the phases plans.

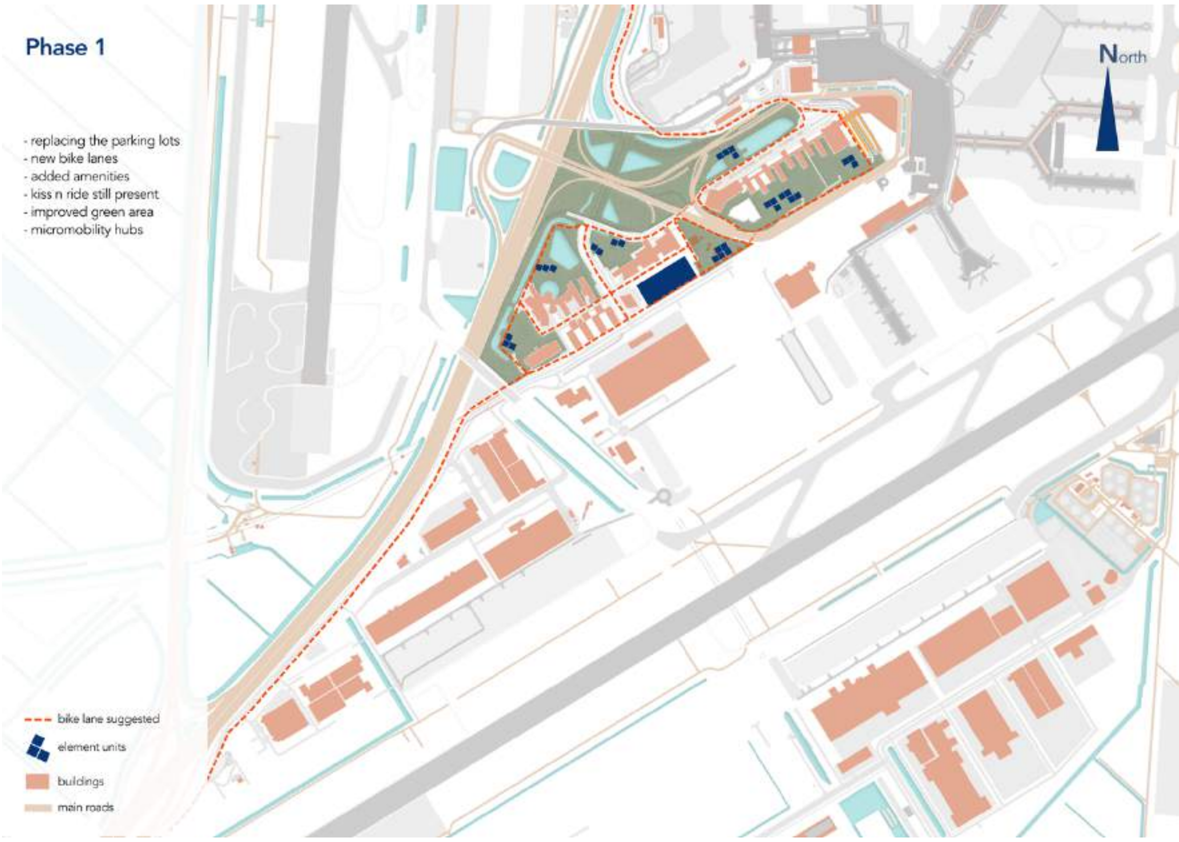


Figure 41: Phase 1 (limited car-free development) concept design

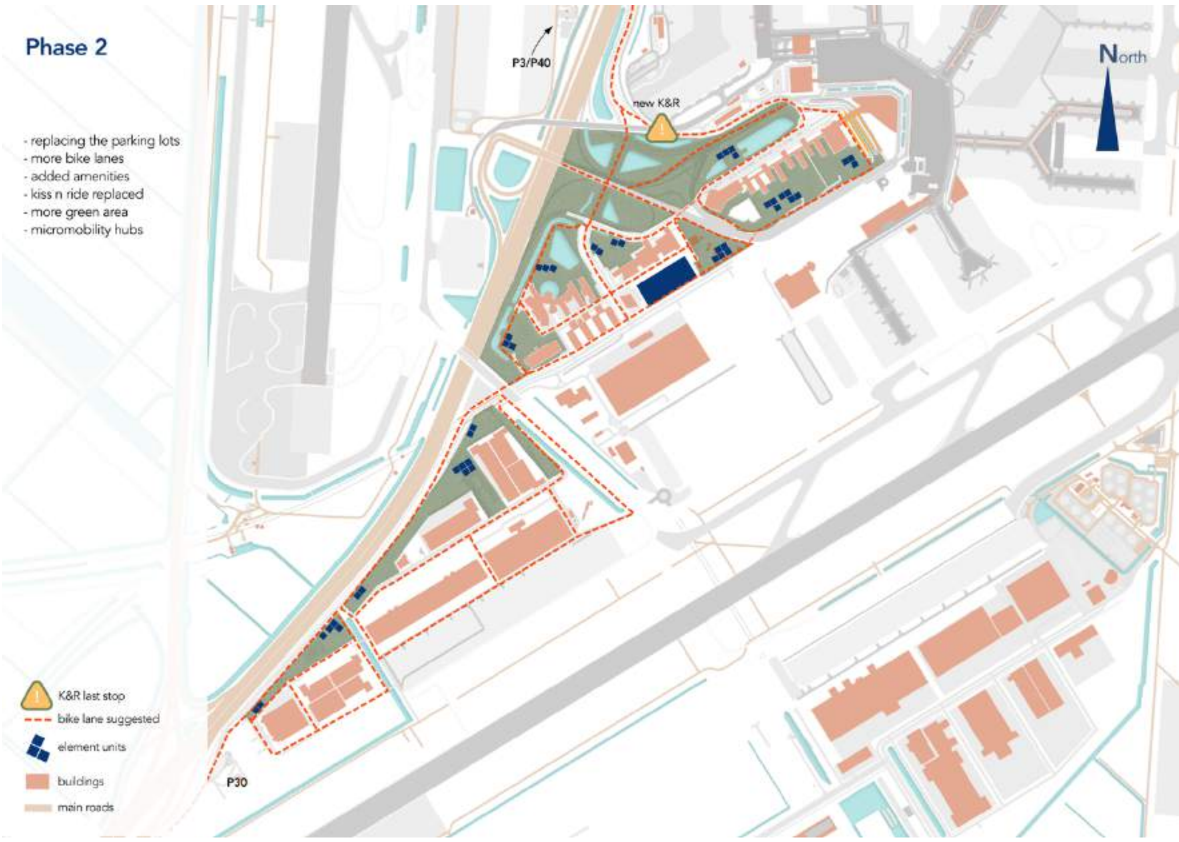


Figure 42: Phase 2 (car-free Schiphol Centrum) concept design

Table 5: Comparison of the scenario phases

	Phase 1 - Limited car-free developmet	Phase 2 car-free Schiphol Centrum
parking lots	P1, P6, P12, P22, Outlook Schiphol Base Hilton, Sheraton, and WTC are re-located	P27, P27, P28, are also re-located additionally to Phase 1
bike lanes	New bike lanes suggested	Continuous bike lanes in Schiphol
amenities	Various amenities added	More amenities added
greenery	Recreational green areas added	Green area size expanded more than100% comparet to Phase 1
kiss&ride	K&R is preserved	K&R replaced on the border of the car-free area on Schiphol North
hubs	Micro mobility hubs added	Micro mobility hubs nr increased by 100%

In conclusion, the design of the phases aimed to prioritize sustainable transportation modes and reduce the reliance on private vehicles. The car-free zones were strategically planned to incorporate office areas and logistics units while providing direct connections to public transport services and facilities for bicycles and micro-mobility vehicles. The proposed e-bus line operates as a substantial service and encourages visitors to adopt sustainable modes of transport. The overall goal of the project is to create a safer, more sustainable, and more pleasant environment for visitors and employees of Schiphol Centrum.

6.3.1. Applying the Walk Score Methodology

The Walk Score methodology is applied among relevant indicators to evaluate the feasibility of the scenario design. This methodology assesses the pedestrian-friendliness and accessibility of an area by analyzing factors such as proximity to amenities, public transit options, and building characteristics. Moreover, it considers the walkability of the surrounding areas based on the infrastructure availability and the urban context's design. Following this methodology, the Schiphol Centrum car-free zone project is evaluated regarding pedestrian accessibility and urban design. The analysis delivers a positive result as the scheme increases walkability and encourages sustainable transportation modes, prioritizing human-scale design over vehicles. This represents a significant step toward achieving a more sustainable and livable airport environment.

Calculating the methodology consists of three stages: assessing amenity weight score, conducting intersection density using GIS, and measuring the average block length. Together these three stages will conduct the final Walk Score for the current Schiphol Centrum and the Phases.

To measure the first stage, amenity amounts were counted with OSM data for Schiphol Centrum.

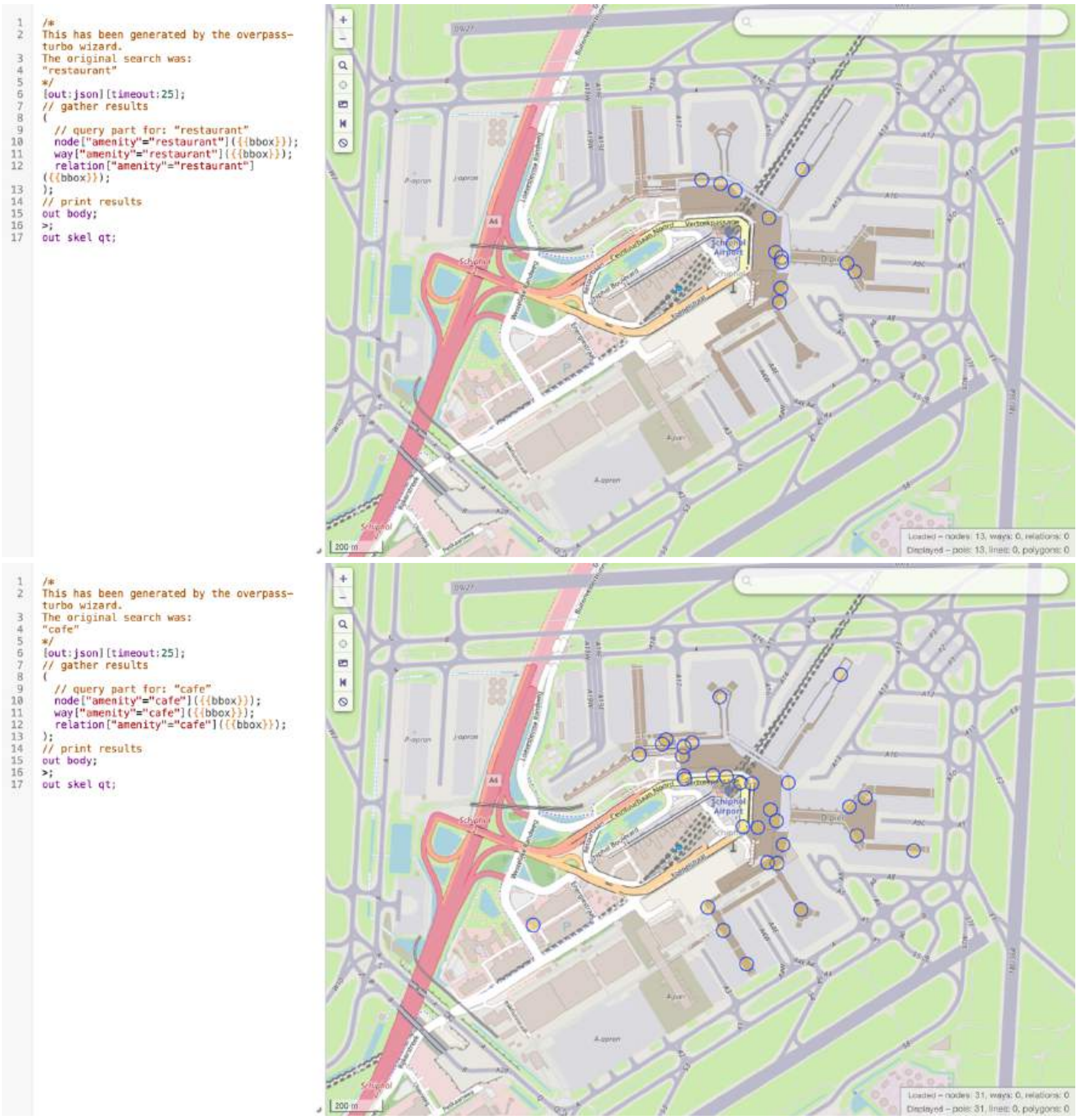


Figure 43: Example query results for "restaurants" and "cafes" in Schiphol Centrum. (generated with OSM data and https://overpass-turbo.eu)

The results were calculated using the "amenity weights" and "distance decay function" explained in the methodology section.

Secondly, the intersection density for Amsterdam and Haarlemermeer was mapped using QGIS. This is important to calculate how various the walking routes could be. Which means higher scored intersection density resuls better walking environment.

Calculating intersection density, a pivotal metric for urban network analysis, within the QGIS geospatial software framework entails a systematic process informed by spatial analysis principles. Intersection density, denoting the prevalence of street intersections in a defined area (Amsterdam city and Haarlemermeer mapped as a whole, Figure 44), offers substantive insights into urban connectivity. During the procedure for calculating intersection density, the following methodological steps were taken:

1. Data Preparation:
    - Preceding the analysis, ensure that a geospatial dataset housing the street network morphology typically represented as vector lines or polylines, is accessible.
    - Employ a projected coordinate reference system suitable for accurate area measurements to ensure precise computations.
2. Generation of Intersection Points:
    - Execute the "Intersection" geoprocessing tool housed within the "Geoprocessing Tools".
    - Designate the street network dataset as input and output layers, invoking the tool's mechanism to derive points of intersection where the network components converge.
3. Computation of Intersection Density:
    - Engage the "Analysis Tools" within the "Vector" domain.
    - Opt for the "Count Points in Polygon" tool, which quantifies points within designated polygons.
    - As input, select the generated intersection points layer, and as the reference, designate the polygonal layer representing the spatial unit of interest.
4. Calculation of Density Metric:
    - Pioneering an analytical approach, introduce a new attribute field that serves as the repository for computed intersection density values.
    - Leveraging the "Open Field Calculator" mechanism, ascertain the intersection density through the expression: "intersection_count" / $area, in which "intersection_count" encapsulates the count of intersection points and "$area" engenders the location of each polygon.
5. Symbolization and Geospatial Interpretation (Table 6):
    - Elevate the analysis to the cartographic sphere by methodically symbolizing the generated polygon layer contingent upon the calculated intersection density values.
    - Discern spatial patterns and gradients reflective of diverse degrees of urban connectivity as indicated by intersection density.

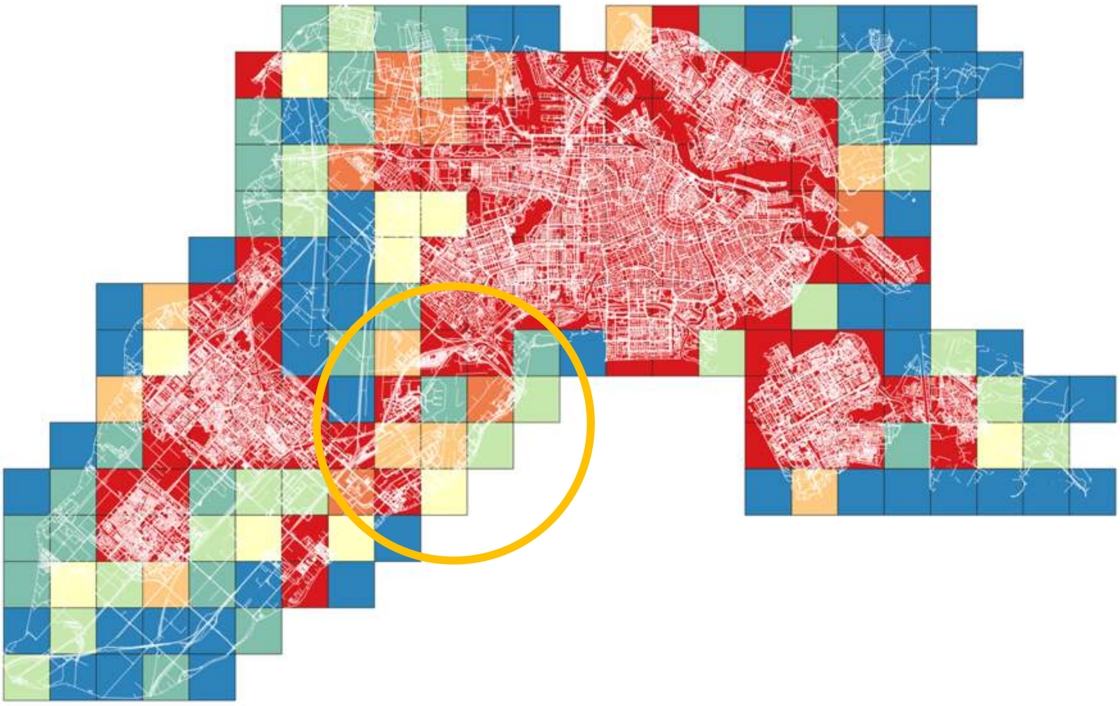


Figure 44: Intersection density of Amsterdam

Table 6: Intersection density scale

Symbol	Values	Legend
✓	1,000000 - 50,000000	1 - 50
✓	50,000000 - 100,000000	50 - 100
✓	100,000000 - 150,000000	100 - 150
✓	150,000000 - 200,000000	150 - 200
✓	200,000000 - 250,000000	200 - 250
✓	250,000000 - 300,000000	250 - 300
✓	300,000000 - 1855,000000	300 - 1855

As demonstrated in Figure 43, the area marked with a yellow circle shows Schiphol Airport. Although the airport is located in a rural area as it is a large-scale transportation hub, it has a very high intersection density due to its transportation and logistics connections. However, these connections consist mainly of street intersections used for cars. The pedestrianization of these streets and walkability with new functions should be supported for the car-free Schiphol design.

Finally, the average block length of the buildings within Schiphol Centrum was determined. Figure 45 illustrates the calculation of the average block length for the structures within the car-free area and presents the overall average result.

To manually calculate the average block length, these steps were followed:

1. Prepare Data:
    - o Prepare the current base map of the Schiphol area, showing the streets, intersections, and blocks. Make sure the map is to scale.
2. Identify Intersections and Blocks:
    - o Identify all the intersections on the map. These are points where streets intersect.
    - o Determine the blocks between consecutive intersections.
3. Measure Block Lengths:
    - To measure the lengths of each street segment within a block a ruler tool used. Measure from one intersection to the next.
        - o Repeat this measurement for all streets in each block.
4. Calculate Block Lengths:
    - o Sum up the lengths of all street segments within a block. This gives the total length of the streets surrounding a block.
    - o Repeat this calculation for all blocks on the base map.
5. Calculate Average Block Length:
    - o Add up the total lengths of all blocks.
    - o Count the number of blocks.
    - o Divide the total length by the number of blocks. This will provide the average block length. It gives insights into the scale and connectivity of the street network.

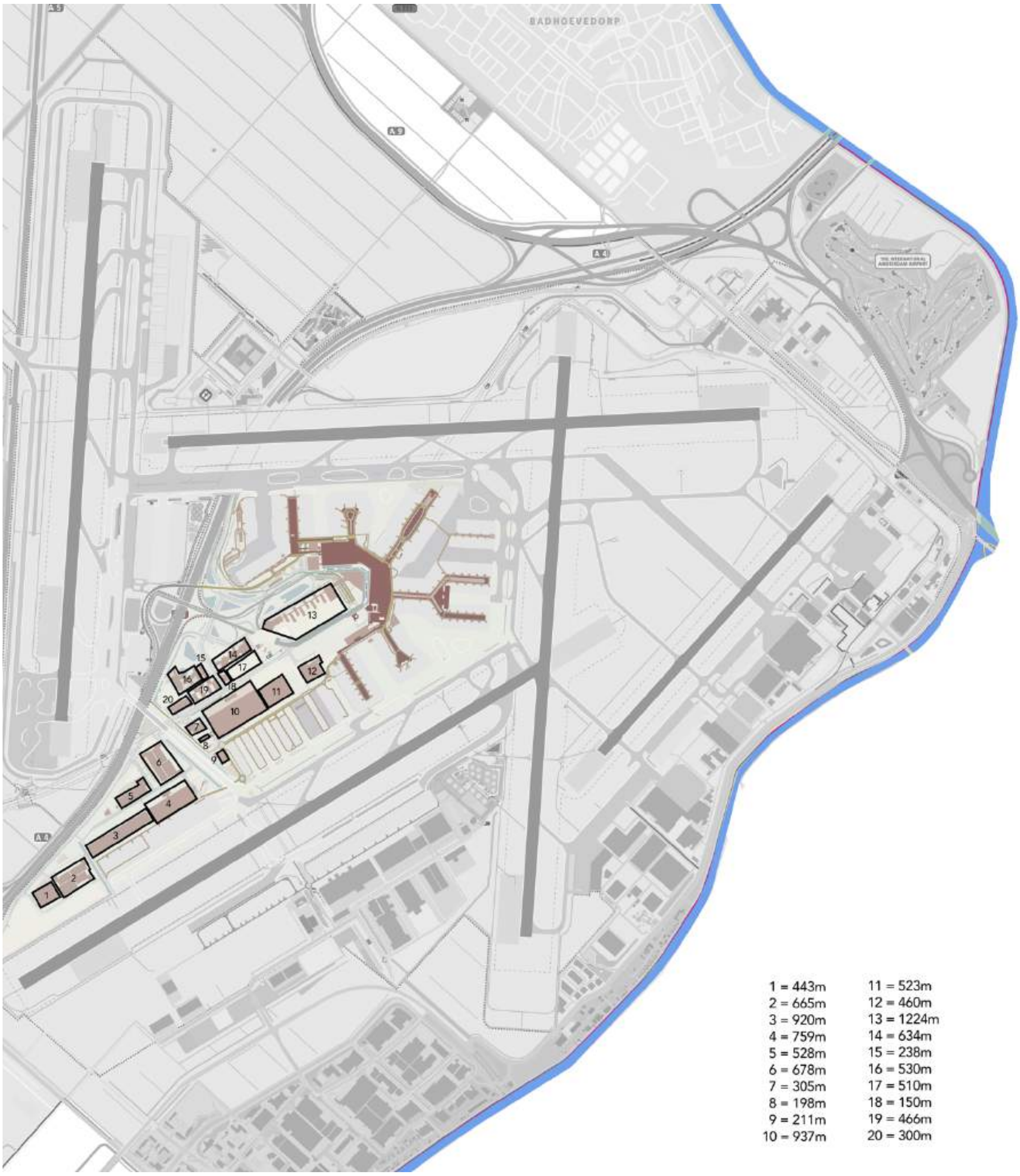


Figure 45: Average block length calculation in Schiphol Centrum

The obtained score falls below the desired target. This outcome can be attributed to larger structures and logistics connections associated with airport functions. To get a better walkability score, it is recommended to introduce passages between buildings and incorporate public corridors to create a more interconnected pedestrian-friendly environment.

6.3.2. Adding the micro mobility hubs and new functionalities

To create a car-free Schiphol Centrum, the thesis acknowledges the necessity of introducing new transportation routes to the existing airport infrastructure. To facilitate this, sample studies and micro-mobility elements (as depicted in Figure 48) were carefully identified as the most suitable solutions. These elements were conceptualized and designed to function effectively within the airport environment.

As first, in the Figures 46 and 47 down below, the distribution of the new MM hubs and bike parking areas were shown in Phase 1 and 2. These locations have been identified considering the e-bus (ring) stops and the specific points where the peaks of pedestrian movement.

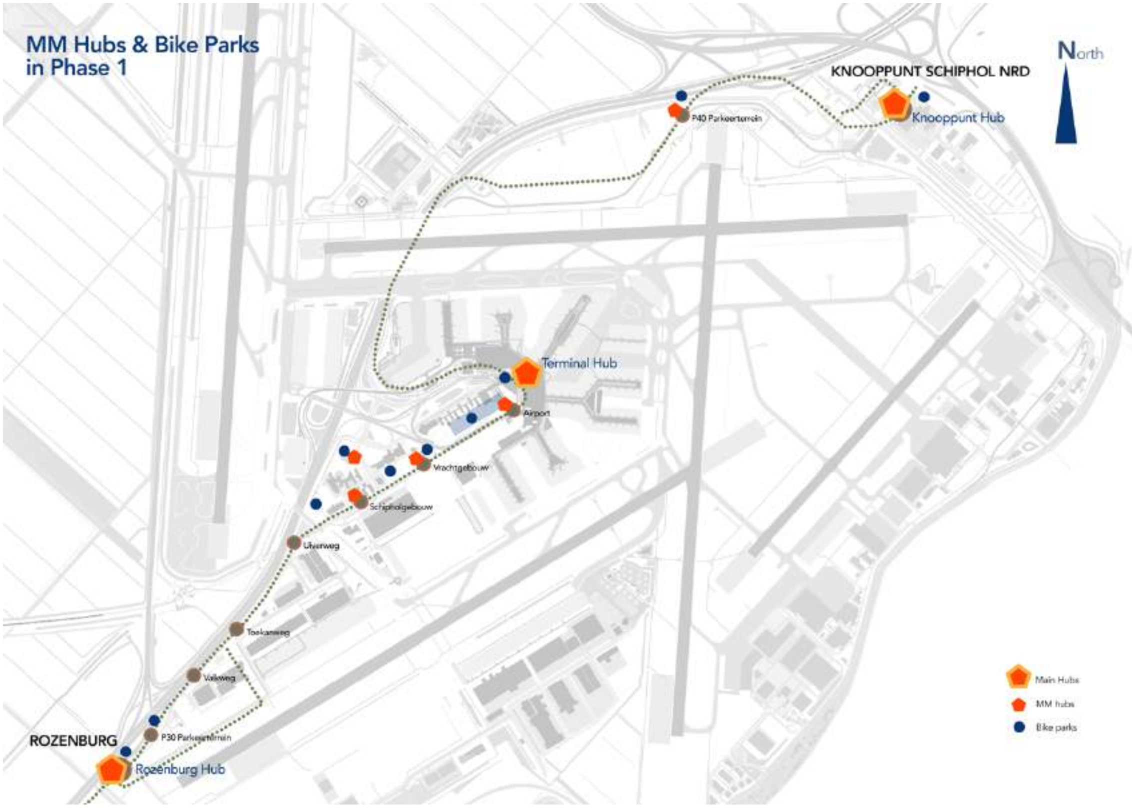


Figure 46: Micro mobility hubs and bike parking areas in the design of Phase 1

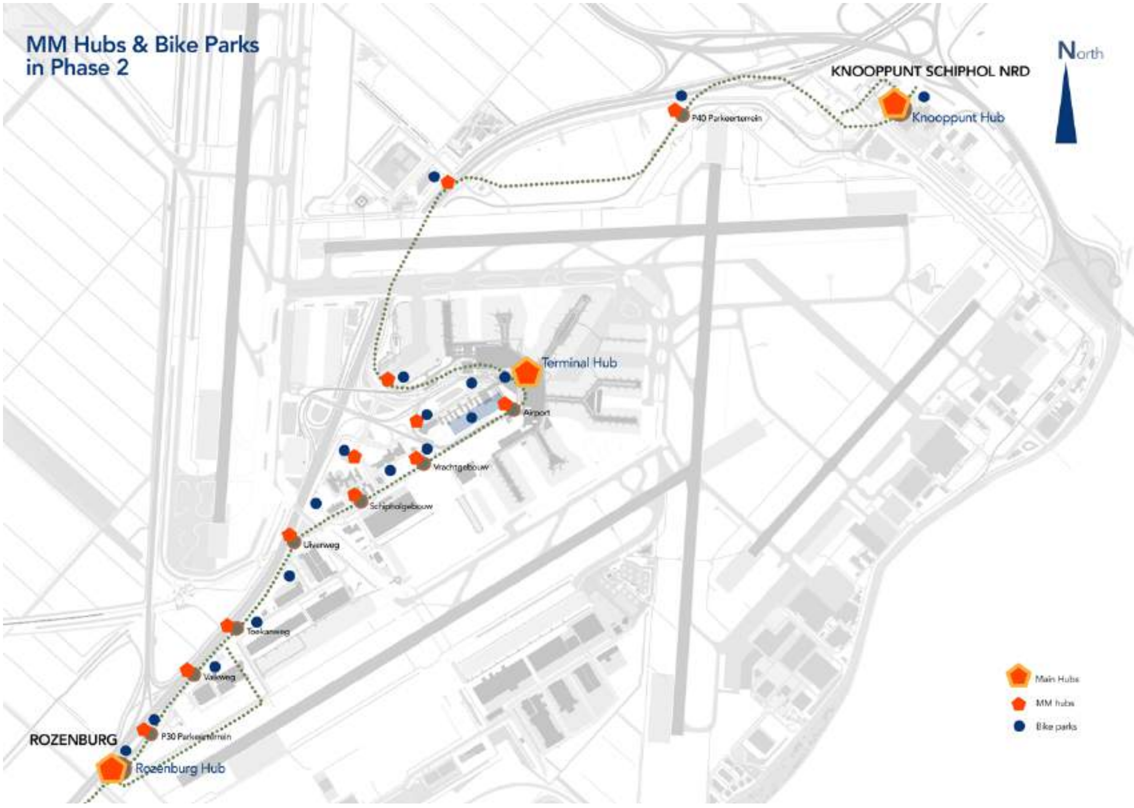


Figure 47: Micro mobility hubs and bike parking areas in the design of Phase 2

The micro-mobility elements represent essential features that support sustainable and alternative modes of transportation within the car-free Schiphol Centrum. These elements are adaptable and can be increased or decreased based on the area's requirements. They are designed as modules that can be seamlessly integrated with other amenities, allowing for flexible and efficient use of limited space while ensuring a robust and comprehensive planning process.

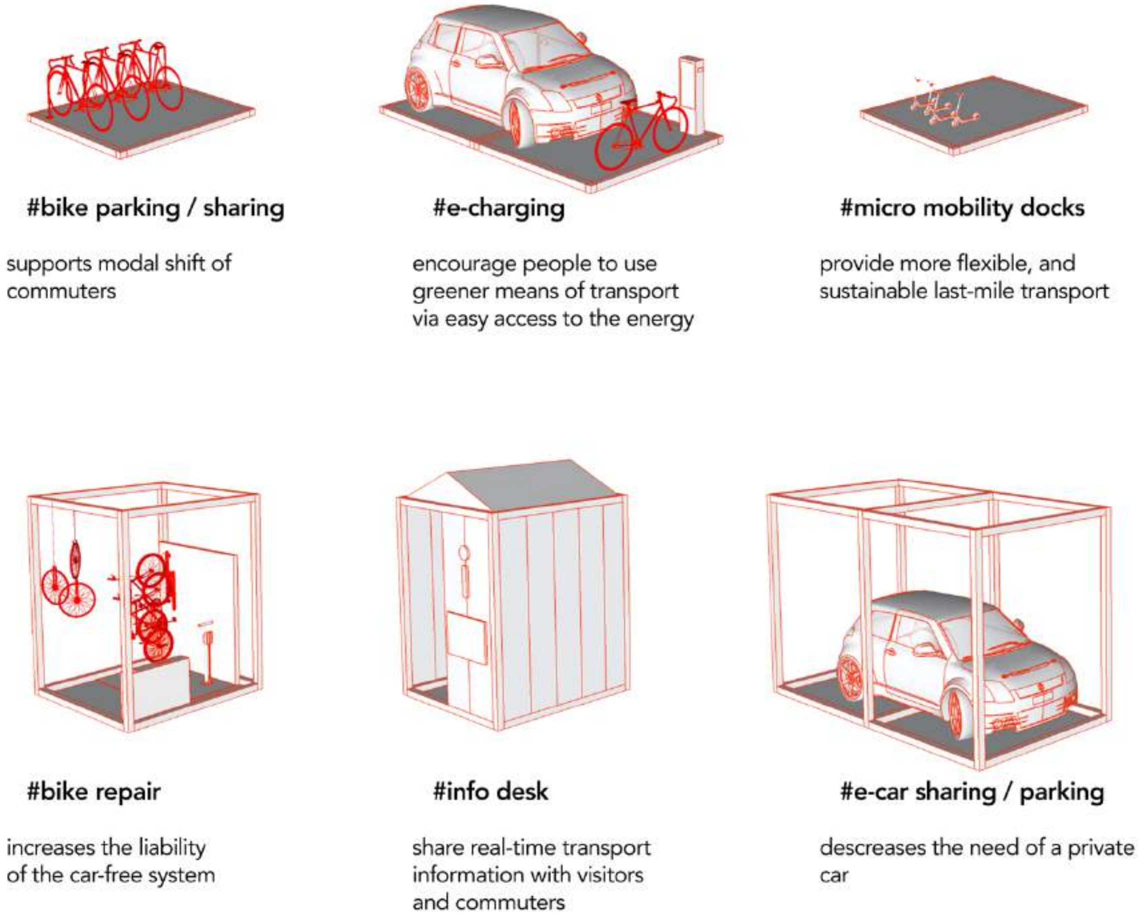


Figure 48: Suggested micro mobility functions and their primary design

By incorporating these micro-mobility elements, the car-free Schiphol Centrum aims to provide diverse and user-friendly transportation options, such as bike-sharing systems, e-scooter facilities, pedestrian walkways, and improved public transit connections. These elements are strategically placed to foster ease of movement for residents and visitors alike, reducing the need for private car usage.

Moreover, the modular design approach allows for scalability and adaptability, ensuring that the car-free Schiphol Centrum can evolve over time and accommodate changing transportation needs and preferences. The inclusion of micro-mobility elements enhances the overall accessibility, sustainability, and attractiveness of the development, contributing to a thriving and pedestrian-centric urban environment. Table 7 shows the numeric results of selected indicators for mobility contributions.

Table 7: Applied results for per indicator in Schiphol Centrum

Indicators /	Current condition	Phase 1 - Limited car-free development	Phase 2 - Car-free Schiphol Centrum
Car Parking (%)	0.018 per m^2 100%	0.014 per m^2 74%	0.013 per m^2 73%
Bike Parking (%)	0.003 per m^2 25%	0.01 per m^2 75%	0.013 per m^2 100%
Bike Parks (nr)	5	10	17
Micromobility hubs (nr)	1 (Schiphol Plaza)	8	15

Secondly, new amenities introduced to the area to design pedestrian friendly Schiphol Centrum. These amenities were chosen to the daily needs of people. For instance, a place to have a lunch break, coffee moment, resting, shopping, grocery, open work space etc. Figure 49 visualize the pre-chosen amenities and their primary design. These amenities can be increased by number and variety after getting the future walkability data and anayleses of car-free Schiphol Centrum.

Figure 49: Suggested amenities and their primary design

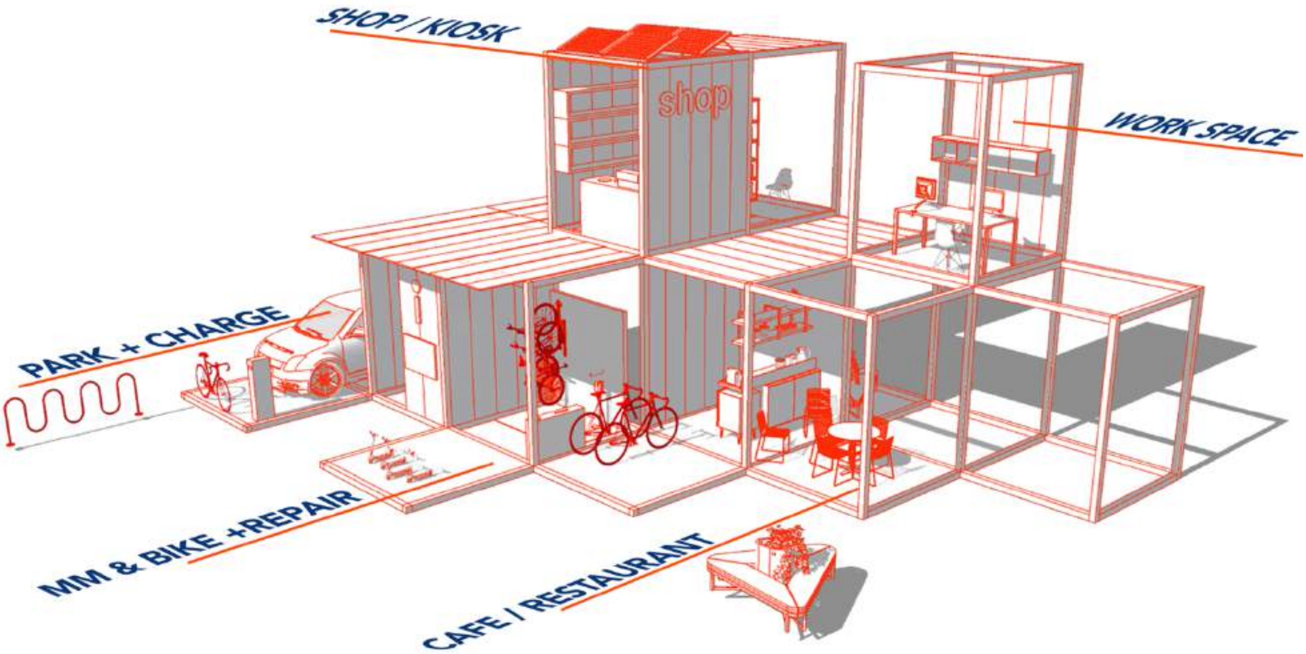
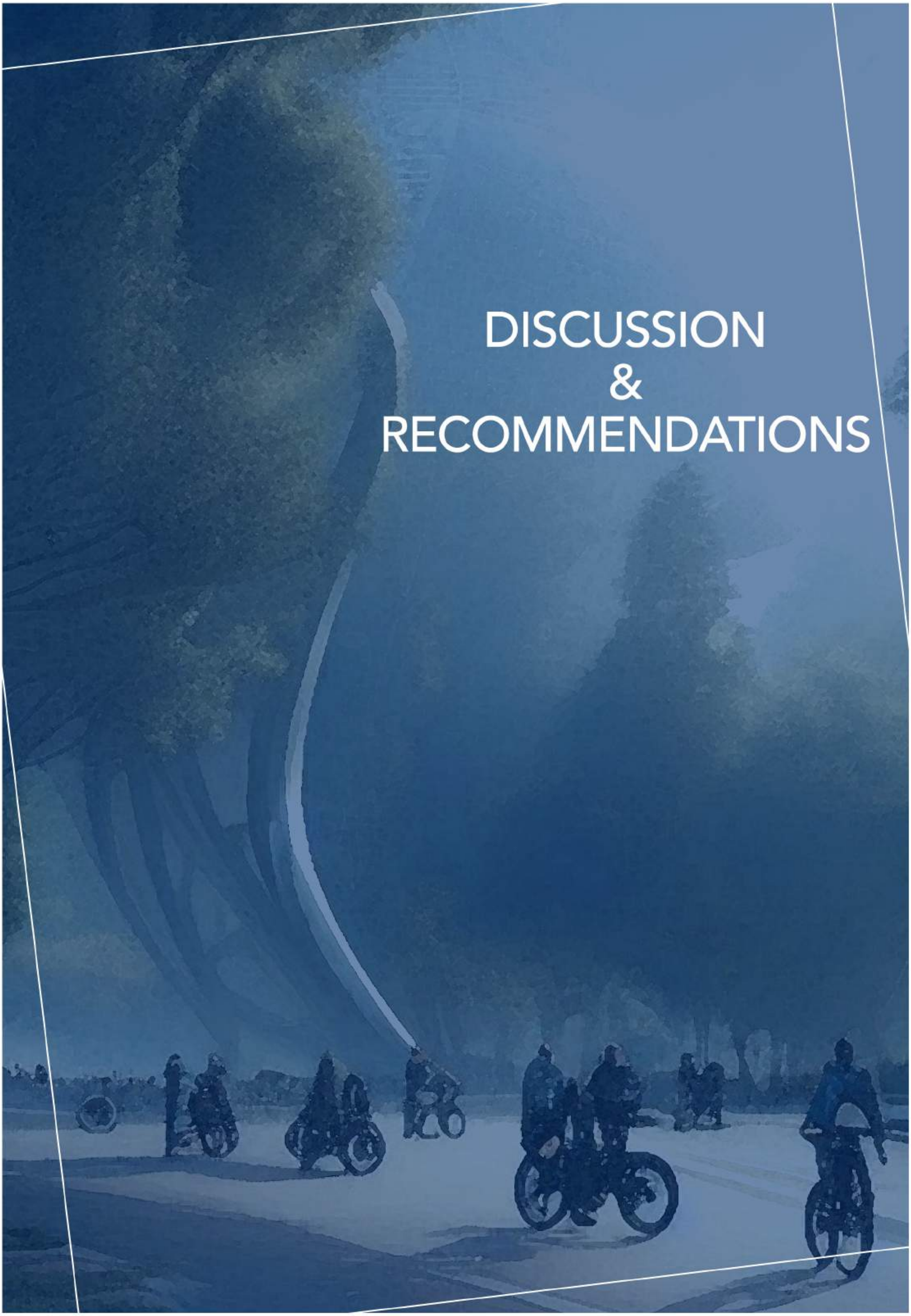


Figure 50: A model of a micro mobility hub design

*Table 8: Applied methodology results per indicator in Schiphol Centrum (*Schiphol Plaza amenities are not included in the "groceries" and "cafe and restaurants" calculation in the table.)*

Indicators /	Current condition	Phase 1 - Limited car-free development	Phase 2 - Car-free Schiphol Centrum
Walk Score	51	89 (70%▲)	93 (82%▲)
Green Area (m^2)	19, 800 m^2	75, 480 m^2 (377%▲)	165, 000 (820%▲)
Car-free area size	NA	311, 000 m^2	457, 238 m^2 + 331, 232 m^2 (restricted)
Access to the car-free area (nr)	NA	7	15
Groceries (nr)	0	1	2
Cafe/Restaurant (nr)	1	8	15

Overall, the results chapter indicates the successful implementation of the car-free Schiphol Centrum project. The expansion of car-free areas, the inclusion of necessary amenities, and the incorporation of micro-mobility elements have contributed to creating a pedestrian-friendly and sustainable environment. The Walk Score methodology has been applied to assess the feasibility and walkability of the area, resulting in positive outcomes. The addition of micro-mobility hubs and new functionalities, such as bike-sharing systems and improved public transit connections, has further enhanced accessibility and reduced the reliance on private cars. The modular design approach ensures scalability and adaptability for future transportation needs.



DISCUSSION & RECOMMENDATIONS

7. DISCUSSION & RECOMMENDATIONS

In the discussion chapter, the findings of the study are analyzed and interpreted. Building upon the conceptual framework established in the second chapter (Figure 18), it is important to develop an operational guideline for achieving CFD. The roadmap below (Figure 51) can serve as a guideline for stakeholders and practitioners, directing their attention toward holistic considerations in designing a possible future car-free area around the Schiphol Centrum.

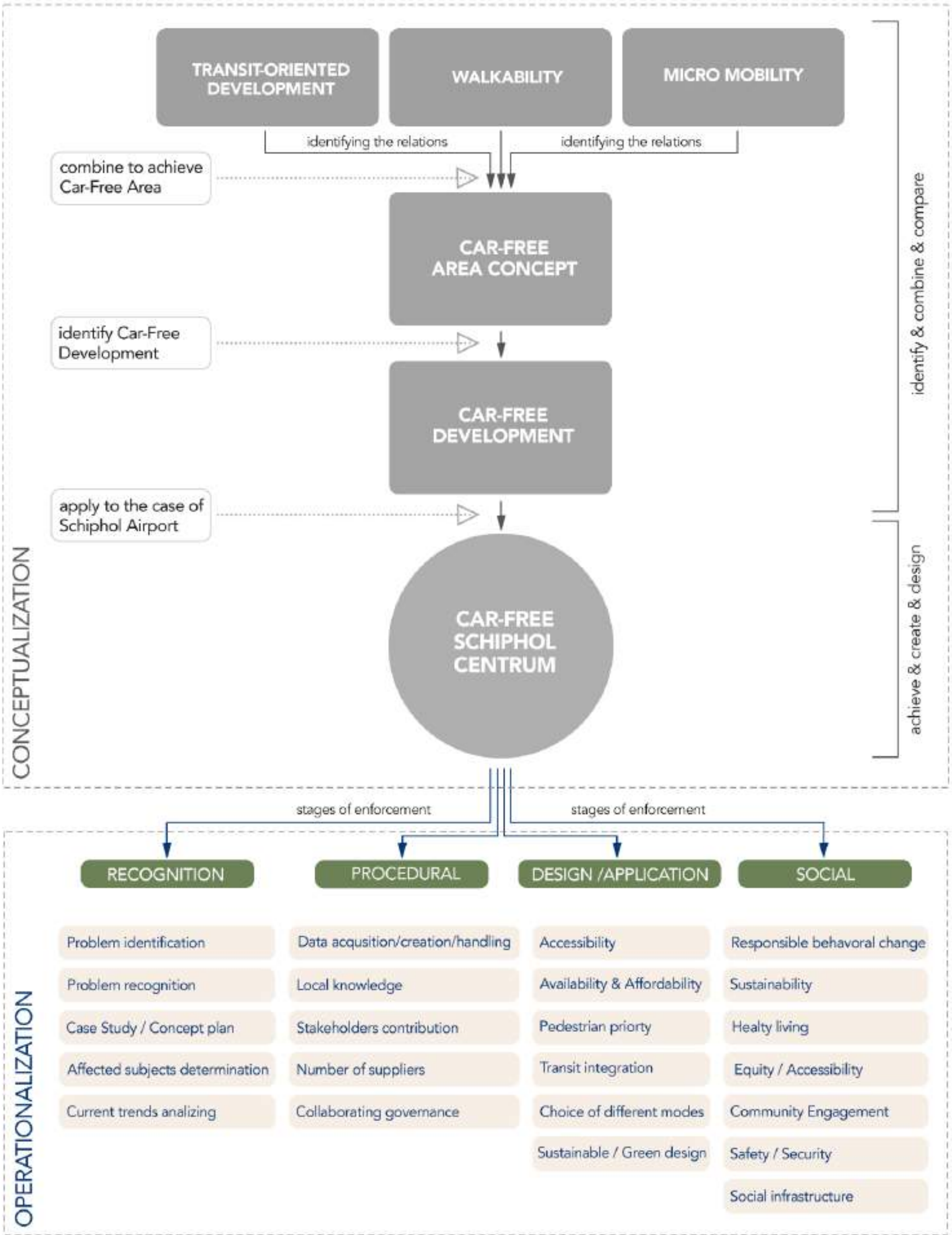


Figure 51: A generic operational guideline for exploring new research subjects and application domains

The roadmap provides a structured approach for addressing key challenges and opportunities in implementing car-free initiatives in airports or any form of city planning. It outlines the necessary steps and considerations to create a sustainable and efficient transportation system.

The first step in the roadmap is to conduct a comprehensive assessment and recognition of the present state, define a functional procedural process, design and apply guidelines, and considers measure contributing to social well-being.

Based on this assessment, the next step can be to develop a tailored strategy for creating a decision-making tool and promoting sustainable alternatives. This may involve implementing new policies, increasing the availability and accessibility of public transit options by offering new e-bus line (ring), incentivizing the use of non-motorized modes (such as bicycles, e-scooters, e-bikes, shuttles), and creating an urban space that commuters prefer over cars to/from Schiphol Airport.

Figure 52 illustrates the systematic difference between the door-to-door approach for private car transport and public transit (the goal). The provided figure serves as a visual representation that effectively highlights the methodological contrast between two transportation approaches: the door-to-door model for private car travel and the objective of public transit.

The illustrated contrast can use as a versatile strategic tool. It empowers stakeholders to comprehend the strategic significance of transitioning towards sustainable transportation modes. This need of transform aids urban planners, and policymakers in crafting targeted strategies to bridge the gap between current transportation systems and desired goals.

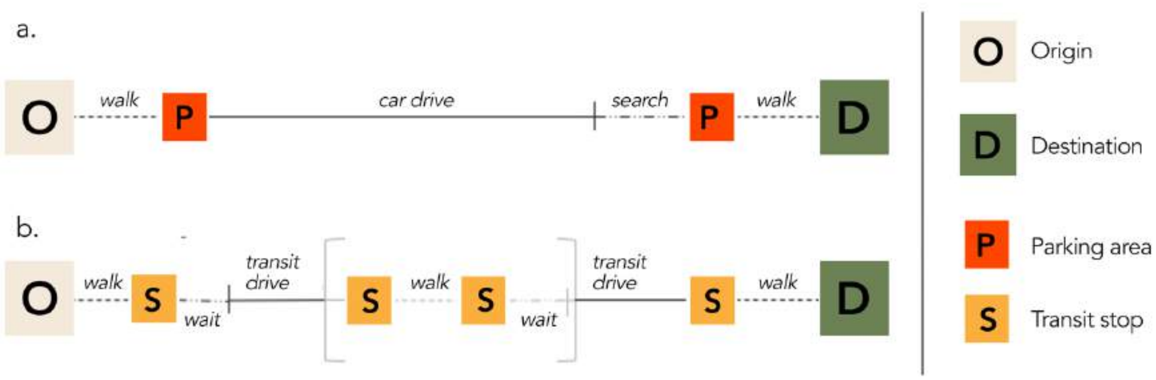


Figure 52: A door-to-door approach for private car transport (a) and public transit (b) (the goal) (Adopted from (Salonen & Toivonen, 2013))

According to the presented results, the scenario design of CFD and improved connectivity of public transportation systems can help achieve the goal of "Car-free Schiphol Centrum". The micro mobility solutions and Walk Score methodology enable pedestrian accessibility and provide insights into the effectiveness of policies promoting sustainable transportation modes.

A flow diagram was created to further think about the benefits of these two approaches (Figure 53). The diagram presents the proposed solutions for "quantifying new modalities" using the micro-mobility method within the car-free zone and the suggested areas for utilizing the Walk Score to assess walkability effectiveness. This helps to connect the CFD concept to the application of micro mobility and walkability in the designated area as well as further project planning.

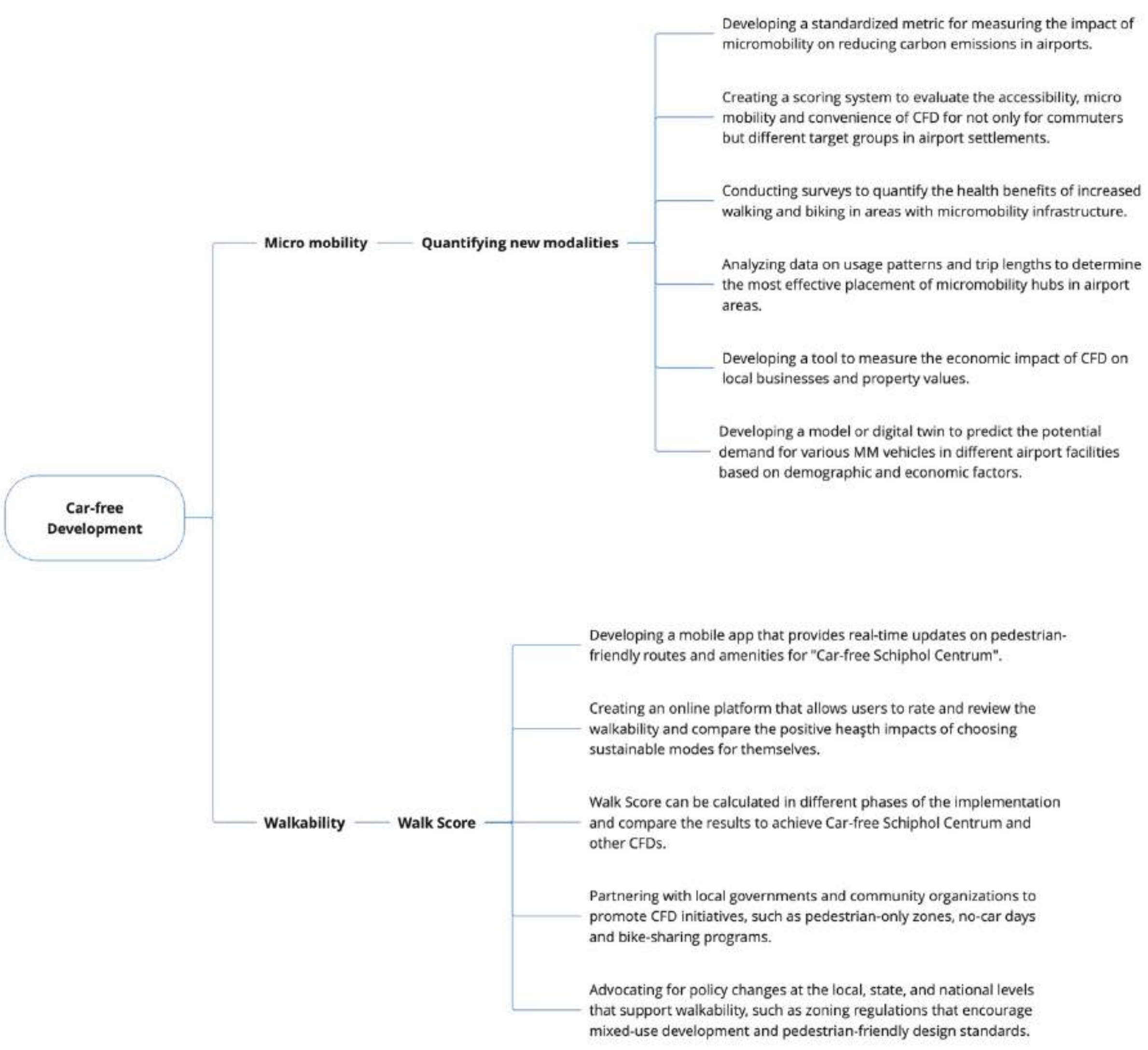


Figure 53: The potential recommendations in the scope of applied methods

The walkability analyses, in particular, highlight a clear distinction and results that can be achieved in the two phases, i.e. limited car-free and complete car-free Schiphol Centrum (Tables 7 and 8).

The estimated amount of green area that can be potentially added to public space in the Schiphol Centrum. The findings obtained through the WalkScore method emphasize the potential of increasing public amenities and green areas by more than 3 times (in phase 1) and even by 8 times by full CFD implementation. This is an important addition to the area and should be considered in future planning to create a more pleasant and sustainable environment.

The possibility of introducing other amenities, such as groceries and cafes or restaurants, would enhance the walkability of the area, leading to the reduction of car use, particularly by commuters. Notably, the transformation of the current industrial-looking area into pedestrian-friendly spaces proves to be highly encouraging from an environmental sustainability perspective.

By creating limited or complete CFD and by introducing the micro mobility facilities and hubs, we show how many new traveling options can be introduced to the area. For instance, covered bicycle parking facilities, micro-mobility charging docks, and the introduction of 8 to 15 new micro mobility hubs in the area reveal the potential to use the space in an efficient way to move away from car dependency. These can encourage people (specifically commuters and airport business visitors) to use sustainable transportation modes and help reduce car usage, which will result in reduced congestion and emissions.

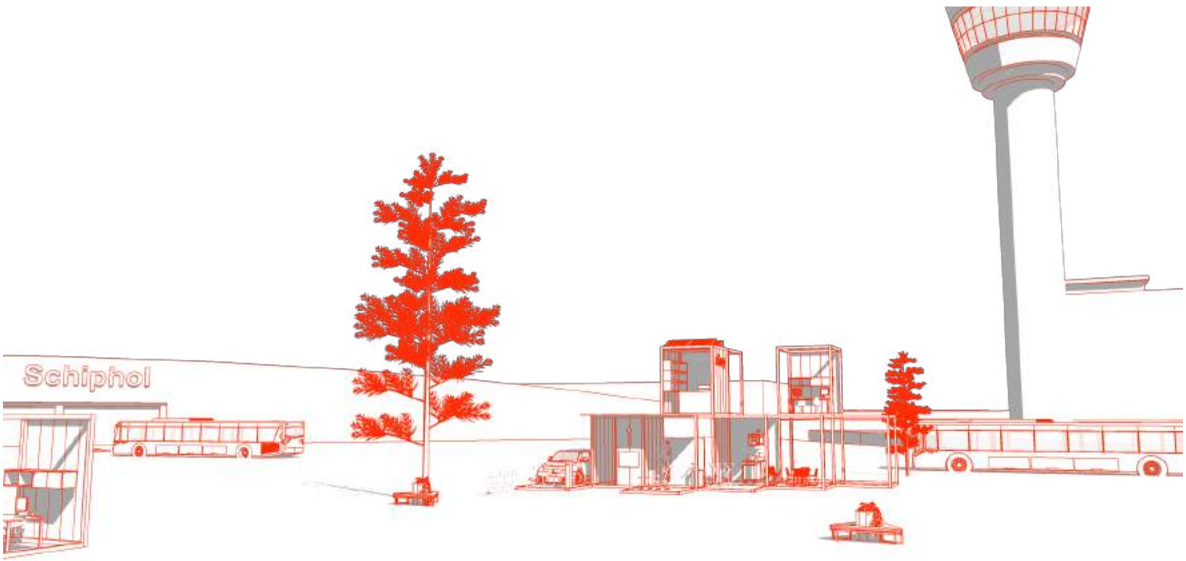


Figure 54: A potential design illustration of the amenities structure in Schiphol Centrum

The micro mobility adoption by commuters can be further enhanced or reinforced by implementing the proposed e-bus line between the north and south entrance of Schiphol Centrum and efficiently connecting them to the proposed micro mobility hubs. This is achievable by repurposing/relocating certain parking areas and prioritizing new infrastructure developments for sustainable transportation modes (such as micro mobility hubs, bike repairing units, and charging docks).

First of all, policymakers could benefit from this study's findings and recommendations to inform their decision-making process regarding sustainable transportation and urban design in airport areas.

From the finding of this study, we can provide several recommendations for airport designers and decision-making for achieving CFD goals:

- Traffic Congestion Reduction: Offering e-bikes, e-scooters, bike sharing, e-bus ring and improved walkability infrastructure with all amenities helps to alleviate traffic congestion by reducing the number of cars on the road with improved public transit systems at airports.
- Improved Public Health: Highlighting the positive impact of reduced car usage on public health by creating walkable and bike-friendly spaces, policymakers can encourage physical activity and reduce the adverse health effects of air pollution and sedentary lifestyles. For example, Schiphol Group can take a leading role in advising commuters and introducing more attractive transport options.
- Economic Benefits: The studies can demonstrate how investing in public transportation and creating pedestrian-friendly spaces can attract businesses and stimulate economic growth in the long run. The pedestrianized streets and improved green areas will uplift the liveliness of the Schiphol Centrum with added amenities.
- Social Equity: By focusing on improved accessibility for all users, including those who cannot afford cars or have mobility challenges. By incorporating these principles into their policies, policymakers can create more inclusive and equitable airport communities by adding micro mobility and e-shuttle services for the elderly, enabled, or physically lacking commuters. For those who cannot afford these new modes, Schiphol Group can offer discounts to accelerate sustainable transport for all commuters and visitors.

Overall, car-free development studies provide valuable insights and evidence-based solutions for policymakers to create more sustainable, livable, and environmentally friendly cities and communities.

Secondly, scholars can use this to further study their research on sustainable transportation and urban design in airport areas. The findings and recommendations can serve as a starting point for exploring new ideas and conducting in-depth studies in various ways:

- Research Opportunities: Providing a rich area for academic research, to explore topics related to simultaneously studying urban planning, transportation, sustainability, public health, and social equity, in a multidisciplinary context.

    - *Due to the lack of comprehensive studies on car-free airport settlements, investigating the practical, social, and economic impacts of CFD on other airport facilities around the world to compare the results.*

    - *Analyze the effective measures limiting car use, such as priced/rationed parking or added fees to dissuade commuting to airport via car.*

    - *Explore more on the relationship between TOD principles and the success of CFD in airports.*

    - *Evaluate the potential challenges and barriers to implementing CFD in different airport contexts.*

    - *Investigate and compare the benefits and drawbacks of different micro mobility solutions in car-free airport environments rather than applying limited mobility options. For example, shared bikes could be designed along with train/bus stops in the car-free airport areas to complement each other and enable various options to choose first and last-mile transportation for commuters.*

    - *The relationship between car-free developments and social equity can be explored more. This helps to understand the travel behavior of airport commuters and create CFDs with more engaging policies.*

- Interdisciplinary Collaboration & Real-World Applications: CFD studies often involve multiple disciplines (likewise the case study of the thesis), such as urban planning, environmental science, sociology, engineering, and other related fields. Academia can foster interdisciplinary collaboration, encouraging researchers from different fields to contribute their expertise to address complex urban challenges like airport and/or transit areas. The main stakeholders of "Car-free Schiphol Centrum" (SG, EGD, Transportation Ministry, Amsterdam, and Haarlemmermeer Municipalities) could be pioneers in bringing experts to the same table.

- Policy Influence: Academia's involvement in CFD studies can carry weight in policy discussions. Research findings and academic expertise can influence policymakers' decisions, ensuring that policies are evidence-based and aligned with sustainability goals. Policymakers could benefit from the given thesis report to reach a holistic car-free Schiphol attempt and benefit from current trends in transportation.

- Community Engagement & Public Awareness: Academia can collaborate and/or seek advice from local communities to conduct car-free studies. Additionally, this study can raise public awareness about the importance of sustainable urban planning and transportation choices. Engaging with community members allows researchers to better understand their needs, preferences, and concerns, ensuring that academic studies address the real-life challenges of commuters/residents. SG can run surveys to examine the existing situation of mode choices, accessibility pleasure, travel time/cost etc.

- Global Impact: Car-free development is a pressing global issue. A comprehensive academic research can contribute to the international dialogue on different sustainable urban development in airport facilities and inform policies in various regions worldwide.

Lastly, practitioners in different fields can utilize the insights from this study to inform their decision-making process when designing and developing car free areas in general, not specific for airport specific development purposes. The recommendations regarding repurposing parking areas, prioritizing amenities for sustainable transportation modes, and creating pedestrian-friendly environments can guide the planning and development of future car free projects in overall places in urban areas, for instance:

- Improved Urban Planning: This study offers insights into designing a conceptual pedestrian-friendly space as it is seen in the result section (Tables 7 and 8), creating mixed-use developments, and optimizing land use (look Phase 2 in Figure 42). Practitioners can use this knowledge to plan new airport facilities, prioritizing people over cars, resulting in more vibrant, accessible, and well-connected environments.
- Social and Environmental Sustainability: By adopting CFD principles, TOD strategies (Figure 26) and sustainable means of transport, practitioners can contribute to social equity and environmental sustainability. They can design inclusive communities that cater to various socioeconomic backgrounds while retrieving the harmful effects of the urban heat island GGE.
- Regulatory Support: The applied methods can provide practitioners with evidence-based data to support the implementation of supportive regulations and policies. The given case study showed the current status and the changes that would happen in case of implementing the mentioned "Phases 1 and 2" (Tables 7 and 8).

In conclusion, Schiphol Airport has the potential to become a leader in sustainable aviation by implementing car-free developments and promoting sustainable transportation modes. One of the main conclusions is that there is a significant role played by commuters using cars to go to their offices and redundant parking lots in the airport due to each domain having its primary parking area.

The scenario design, together with micro mobility applications and Walk Score methodology, can provide a comprehensive outlook on how sustainable transportation system for employees and passengers can be achieved. By addressing the challenges of parking and congestion, Schiphol Airport can improve air quality and reduce GGE and turn into a global, transit, and sustainable transport hub.

CONCLUSION

8. CONCLUSION

This thesis provides an overview of the research on sustainable last-mile transportation to/from Schiphol Airport. The study analyzed the impact of car-free developments, public transit options, and infrastructure like bicycle parking facilities and micro-mobility hubs. The Walk Score methodology was applied to assess pedestrian accessibility and identify areas for improvement. The study recommends impleme snting car-free zones, building more bicycle parking facilities, and expanding public transit options to reduce congestion and emissions. By addressing these challenges, Schiphol Airport can take the lead in sustainable aviation and support global efforts.

The research conducted in this study emphasizes the significance of implementing last-mile transport solutions specifically focusing on Schiphol Airport. By adopting sustainable transportation modes such as cycling, walking, micro mobility, and public transit, Schiphol Airport can pave the way for a more environmentally-friendly and efficient transportation system for all users.

To this point, Schiphol Group can lead the way by implementing sustainable transportation modes like cycling, walking, micro mobility, and public transit and become an example for other airports. The study recommends a complete car-free Schiphol Centrum in such high-traffic areas like busy airports, with introduction of micro mobility and light-electric vehicles, re-purposing existing streets with new amenities, more covered bicycle parking facilities, and expansion of public transit.

Reminding the questions constituted at the beginning of the thesis would be beneficial for the final conclusions chapter to present the overall and essential findings.

Sub-question 1:

- *How do the TOD principles help to convert Schiphol Centrum into a car-free development?*

In the thesis, the first sub-question was answered by discussing the TOD principles in transforming Schiphol Centrum into a car-free development. The findings highlighted how TOD is closely related and essential to achieving CFD at Schiphol. By designing the new boundaries of the motorways and car-free area as well as the major improvements such as re-locating parking lots and K&R, it can be clearly seen CFD+TOD literature-based frameworks worked well to achieve the obtained results.

The following was taken into consideration to achieve the transformation of Schiphol Centrum into a car-free development with the support of Transit-Oriented Development (TOD) principles.

- Identifying strategic locations within Schiphol Centrum to establish transit nodes, such as micro mobility and bus stops. These nodes will serve as focal points for efficient public transportation connections.
- Redesigning the urban layout of Schiphol Centrum to prioritize accessibility to and from the transit nodes. Ensure that pedestrian pathways and bike lanes lead to and from directly the transit hubs, making it easy for users to access public transportation.
- Introducing mixed-use development around the transit nodes, integrating commercial and recreational spaces. This approach encourages people to work, engage, rest, and access essential services within walking distance, reducing the need for car travel.
- Implementing comprehensive cycling infrastructure with seamless connectivity, including bike lanes, secure bike parking, e-bike charging docks, and bike-sharing systems. Encourage cycling as an alternative and eco-friendly mode of transport within the car-free Schiphol Centrum.

Overall, the research underscores the positive impact of TOD principles on developing car-free areas and emphasizes the need for their integration into urban planning.

Sub-question 2:

- What are the literature-recommended strategies to facilitate sustainable modes of transport and reduce reliance on private cars?

To address the second problem, extensive research examined car-free policies, academic literature, and existing car-free examples in various cities and similar airports. The aim was to identify the most effective strategies for transforming Schiphol Airport into a car-free environment.

After careful consideration and analysis, it was concluded that providing a successful modal shift is essential to make Schiphol airport car-free. Instead of relying heavily on private cars, the focus should be on promoting alternative modes of transportation. Enhancing walkability within the airport premises and providing micro mobility vehicles emerged as key strategies to facilitate this transformation. By encouraging pedestrians and utilizing micro mobility options, Schiphol Airport can reach a sustainable and accessible car-free transport system.

Additionally, the implementation of park-and-ride facilities (that can be provided in P3, P30, P40) outside Schiphol Centrum can also help reduce reliance on private cars. These facilities would provide convenient parking for travelers who use public transportation to access the airport. This strategy encourages a shift towards sustainable modes of transport while still accommodating the needs of commuters.

Lastly, it is important to create a supportive policy framework for the theoretical contributors incentivizing sustainable transportation choices. This can be done through various measures, such as providing subsidies for public transportation fares, promoting carpooling and ride-sharing initiatives, and offering tax incentives to purchase electric vehicles.

In conclusion, the literature-recommended strategies to facilitate sustainable modes of transport and reduce reliance on private cars at Schiphol airport include:

- Providing micro mobility options
- Enhancing walkability
- Implementing new facilities
- Creating a supportive policy framework
- Enhance livability

By implementing these strategies, Schiphol Airport can successfully transition into a car-free environment that prioritizes sustainable transportation choices and improves overall accessibility for passengers and visitors.

Sub-question 3:

- *How does micro-mobility affect the modal shift in commuters' first and last-mile travel in Schiphol Airport?*

Micro mobility plays a crucial role in influencing the modal shift for commuters' first and last-mile travel in Schiphol Airport. First and last-mile travel between a person's origin or destination and a major transportation hub, such as an airport.

Micro mobility options, such as e-scooters, bicycles, and electric bikes, provided commuters to travel short distances with convenient and accessible modes which is perfect to have in the Schiphol Centrum area. Users can easily cover their journey's first and last mile, bridging the gap between the terminal stations and their final destinations.

Micro mobility vehicles allow commuters to navigate through Schiphol Airport facilities and nearby areas swiftly and efficiently. This efficiency can motivate individuals to choose micro mobility, especially during peak travel times when traffic congestion is expected. These options can complement existing public transportation services by providing efficient connectivity to and from transit stations. This integration creates a seamless and user-friendly travel experience, encouraging commuters to incorporate micro mobility into their multimodal journey. This also reduces car dependence and lower carbon emissions in Schiphol directly.

Furthermore, micro mobility options are often cost-effective compared to private car usage or even some public transportation modes. This cost advantage can attract commuters to opt for micro mobility vehicles, leading to a modal shift away from more expensive transportation options.

By incorporating micro-mobility options into the transportation ecosystem at Schiphol Airport, commuters are more likely to shift from car-dependent travel to sustainable and efficient modes. Also, replacing the K&R on the border of the car-free zone encourages the travellers to shift their transport mode. Overall, it is expected that micro mobility options offer Schiphol commuters' flexibility and freedom in choosing their travel routes and timing to reach their offices after they leave from the Schiphol Plaza.

Sub-question 4:

- *How should pedestrian-friendly/walkable streets be conceived at the Schiphol Centrum area?*

The scenario design and Walk Score methodology provide a comprehensive and sustainable transportation system for employees, passengers, and visitors. By addressing parking and congestion challenges, Schiphol Airport can improve many urban challenges by targeting this one problem.

With the TOD strategies and micro mobility services, walkability brings a pedestrian-friendly environment to the Schiphol Centrum area. Still, there are some critical considerations for conceiving pedestrian-friendly streets at Schiphol:

Designing streets with wide sidewalks that allow for comfortable pedestrian movement would also help commuters' modal shift. Moreover, ensuring the presence of assisting directory signs would make it easy for any user to navigate and helps to create a safer environment at intersections to prioritize pedestrian safety.

Street design via installing benches, seating areas, and public spaces along the streets to provide resting spots for pedestrians will ameliorate user satisfaction. Therefore adding shading structures, trees, and greenery to create a pleasant walking experience should be considered in a repurposed industrial area such as Schiphol Centrum.

Lastly, future planning should consider incorporating green areas and public spaces to enhance the overall quality and sustainability of the airport. By prioritizing green spaces, Schiphol Airport can provide its stakeholders with a more pleasant and environmentally-conscious atmosphere.

This report contributes methodologically to the academic sphere by introducing an innovative approach. The methodological innovation of the thesis lies in incorporating micro mobility hubs within the amenity category as a substitute for traditional banks. The integration of micro mobility hubs underscores the acknowledgment of the rising prominence of online banking services. This shift from banks to micro mobility hubs is designed to align with evolving traveler preferences and requirements.

In this vein, each amenity category is assigned a weight determined by its significance in enhancing walkability, a metric substantiated by an extensive review of existing literature. To illustrate, the combined weight attributed to grocery stores and restaurants/bars is 3, while that of shopping and coffee shops is 2. This methodology is corroborated by precedent research and surveys exploring the concepts of walkability and accessibility.

The distance decay function is employed to ascertain the score distribution for each amenity category based on its proximity to the origin point. This function apportions a fraction of the total score to each category contingent on its spatial distance from the starting point. By integrating micro mobility features into the methodology, the overarching objective is to create a more comprehensive and inclusive evaluative framework. This enriched framework not only considers diverse transportation modes but also fosters walkability across the entirety of the project area.

The methodological contribution of incorporating micro mobility as a distinct category within the Walk Score methodology is two-fold: it reflects a responsive adjustment to contemporary urban dynamics. It enriches walkability assessment by accommodating evolving transportation trends. This addition augments the holistic understanding of walkability while enhancing the tool's accuracy in assessing urban accessibility.

The inclusion of micro mobility within the Walk Score framework primarily acknowledges the expanding influence of micro mobility options, such as e-scooters and shared bicycles, in urban mobility patterns. Traditional walkability assessments often focus solely on pedestrian infrastructure and proximity to amenities, disregarding the emerging trend of micro mobility solutions. By introducing a dedicated category for micro mobility hubs, the methodology acknowledges and quantifies the accessibility benefits these options provide.

Secondly, this methodological expansion reflects the responsiveness of the Walk Score framework to the evolving needs and preferences of contemporary urban dwellers. With the proliferation of online services, including banking and grocery shopping, and the shift towards sustainable transportation options, the inclusion of micro mobility becomes pertinent. It allows the methodology to encapsulate a broader spectrum of factors influencing people's choices in navigating the urban environment.

In practical terms, this methodological addition involves defining criteria and weightings specific to micro mobility hubs. These criteria could encompass the density and accessibility of micro mobility pick-up and drop-off points, the coverage of these hubs within the urban fabric, and their connectivity with other modes of transportation. Assigning appropriate weights to this category ensures that the tool accurately reflects the impact of micro mobility on overall urban accessibility. This makes the methodology more comprehensive and enhances its applicability and relevance in assessing walkability in modern urban contexts.

In addressing the relevance of Schiphol Airport's sustainable transportation goals, the study aims to give a comprehensive perspective. By highlighting the value of the research's insights and recommendations, it effectively underscores the thesis's contribution to the airport's overarching sustainability objectives. The report summarizes the multi-dimensional impact of the strategies within the research framework, showcasing a keen awareness of sustainable transportation paradigms.

Moreover, progressing from the initial reference to micro mobility alternatives, pedestrian enhancement, park-and-ride facilities, and policy frameworks to their integrative role signifies a coherent flow of ideas. The self-evaluation elucidates how each strategy melts into a cohesive, transformative trajectory for Schiphol Airport. This demonstrates a proficient grasp of the subject matter and an adeptness at articulating the co-working of diverse strategies within a larger sustainability framework.

Furthermore, the self-evaluation incorporates future-oriented thinking by characterizing micro mobility as a reflection of contemporary traveler preferences. This dimension attests to an awareness of the evolving nature of transportation trends and an aptitude for situating strategies within a broader socio-cultural context.This reveals the strategic significance of sustainable transportation practices in fostering the airport's standing as a modern, eco-conscious institution.

Finally, this thesis report holds significant relevance because it can furnish profound insights and astute recommendations concerning sustainable transportation and heightened accessibility at Schiphol Airport. The strategies outlined within this study, encompassing the integration of micro mobility alternatives, the augmentation of pedestrian-friendliness, the re-purposing the existing infrastructure, and the cultivation of an enabling policy matrix, collectively form a coherent roadmap towards curtailing car dependency and mitigating carbon emissions within the airport's precincts.

Collectively, these measures align with contemporary imperatives for sustainability, elevating Schiphol Airport's status as an exemplar of modern, eco-conscious transportation hubs worldwide. As this research culminates in actionable insights, it effectively equips Schiphol Airport with the requisite tools to embrace a more sustainable trajectory, better poised to cater to the evolving needs of both passengers and the planet.

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