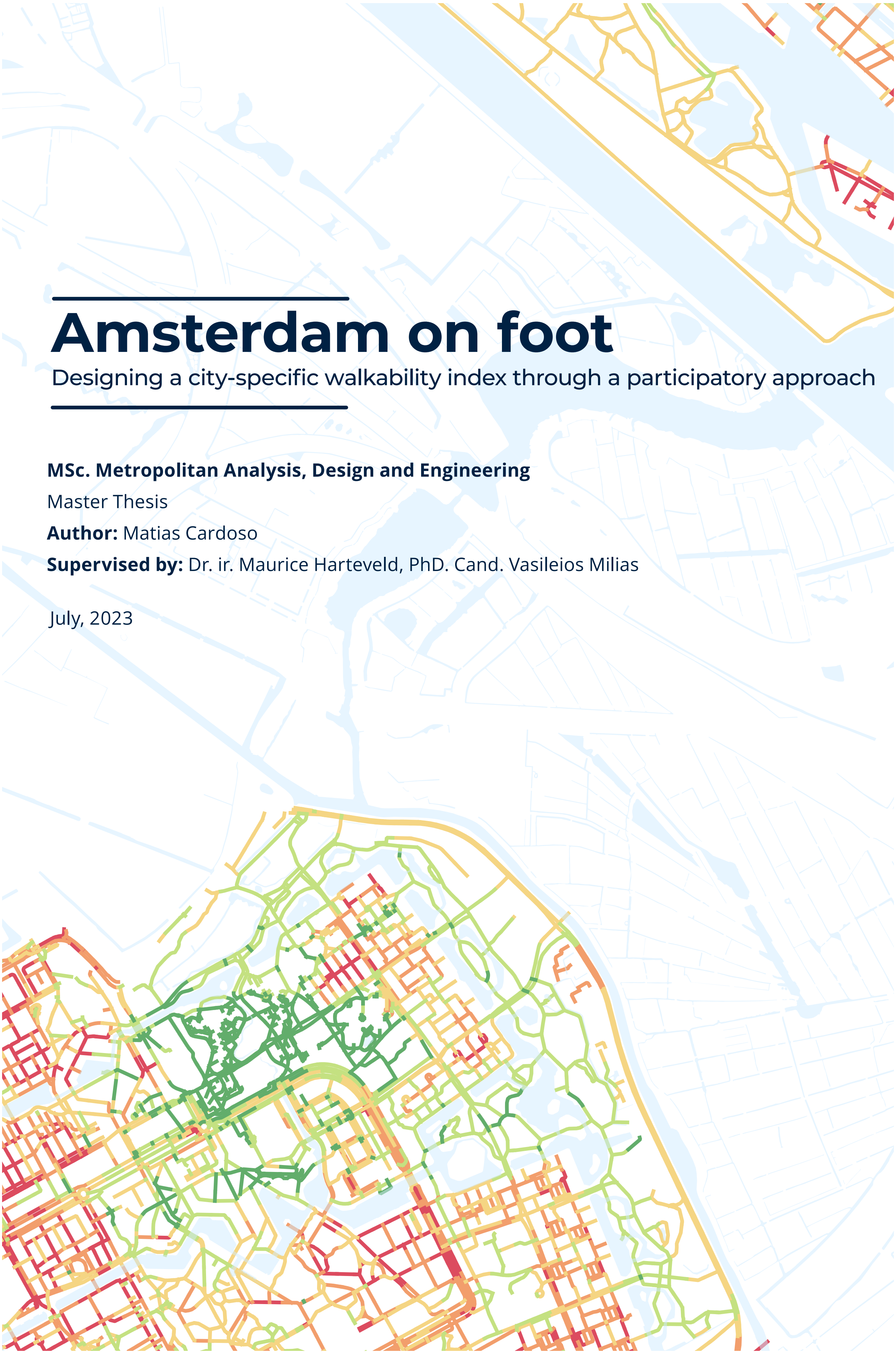

Amsterdam on foot

Designing a city-specific walkability index through a participatory approach

MSc. Metropolitan Analysis, Design and Engineering

Master Thesis

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Abstract

Walkability, which refers to the extent to which the built environment encourages walking, has been linked to increased physical activity and improved health. While various studies have developed indicators to assess walkability, limited attention has been given to the influence of specific city characteristics on residents' perceptions of walkability. Therefore, this study proposes the development of a context-specific walkability index for Amsterdam. Through a mixed methods approach, the study explores subjective viewpoints on what defines a walkable street and identifies the most significant walkability factors for this particular urban region. These factors are then incorporated into a weighted walkability index, which provides street-level scores.

The findings emphasize that walkability in Amsterdam is not a uniform concept, as individual walking behaviour is influenced not only by the environment but also by personal factors. The resulting walkability index underscores the importance of factors such as traffic safety, crime safety, pedestrian infrastructure, and proximity to amenities in shaping residents' decisions to walk on specific streets.

This study highlights the significance of participatory approaches and the inclusion of individuals' subjective views when evaluating walkability. By considering both objective indicators and subjective viewpoints, cities can develop more meaningful strategies to enhance walkability and create environments that promote active and healthy lifestyles.

Keywords: Walkability, Active Mobility, Built Environment, Participatory.

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1. Introduction

1.1 Background

An urban environment that promotes walking and other forms of active mobility can significantly contribute to better health outcomes and improved quality of life. Walkability, or the extent to which the built environment promotes walking, has been found to be associated with physical activity and improved health (Tobin et al., 2022). Furthermore, as many cities shift from private vehicles to public transport oriented mobility, walking becomes an important part of the multimodal chain of trips and is especially relevant for first and last mile mobility to overcome short distances. Walking has shown to be accessible, sustainable and promote overall health (Learnihan et al., 2011; Rhoads et al., 2023).

Despite all the benefits, in many cities including Amsterdam, the popularity of walking has decreased in the last decades and significant shares of the population do not meet the recommended physical activity levels (Gemeente Amsterdam, 2016; World Health Organization, 2018).

In recent decades, the city of Amsterdam has focused its urban development policies on promoting active mobility, a term that encompasses all non-motorized means of transport including walking. The municipality has been working on upgrading the urban environment to make it inviting and attractive to cycle and walk in the hopes of promoting a lifestyle behaviour change. The health principles that guide the city development dictate that mixed facilities should be easily accessible by foot or cycling in any neighbourhood (Gemeente Amsterdam, 2021). Furthermore, the Amsterdamse Beweeglogica (2016) states that one of its goals is to organise the city in such a way that all residents are consciously and unconsciously invited to move. Special attention is paid to residents that live in neighbourhoods with lower scores of physical activity and where the layout of the public space does not invite to walk (Gemeente Amsterdam, 2016). This goes in line with the efforts to overcome inequality of access and movement in certain areas of the city (Gemeente Amsterdam, 2023).

To understand to which extent different types of built environments promote walking, several studies have focused on developing indicators to assess the walkability of the urban environment. They are based principally on measurable urban environment characteristics (McCormack & Shiell, 2011), human perception (Ewing & Handy, 2009), or a combination of both (Millstein et al., 2013). However, the applicability of such indicators cannot be universally replicated as the influence of certain factors varies greatly based on the particular characteristics of each urban area (Horak et al., 2022).

Walking is healthy and brings a series of benefits to urban areas. In order to build a city where everyone is invited to walk, the municipality of Amsterdam needs to know where the less walkable streets are located and why they are less walkable.

1.2 Problem statement

While there are several municipal and private efforts being made in Amsterdam to improve the walkability and pedestrian accessibility to public spaces (Gemeente Amsterdam, 2016, 2021, 2023), a context-specific, city-wide index to assess walkability is still missing. Such an index would enable the assessment of the streets based on the decision-makers standards for pedestrian access and should incorporate tailor-made indicators that account for the particular characteristics of the city.

Currently, no such index exists. This thesis aims to address this problem by showcasing the development of a context-specific walkability index for Amsterdam's streets, measuring the most significant factors for walkability as identified by decision-makers, researchers, advocates, and experts in the field of active mobility.

1.3 Societal & scientific relevance

By 2030, more than 80% of the European population will live and interact with a complex urban environment (Vlaanderen et al., 2021). Previous research has been established that the urban environment, and walkability in particular, plays a relevant role in the health outcome of its inhabitants (Tobin et al., 2022). This study, contributes a novel approach towards identifying and measuring factors that impact the walkability of particular urban areas. The outcomes can give decision makers the necessary information to address walkability problems, facilitate active mobility and foster a walking culture.

The overarching scientific and societal relevance of this study stems from its innovative mixed methods approach to measure walkability. This approach allows taking into account the particular characteristics of the urban area and the opinion of the experts working on it. The information such an index could reveal has the potential to shape urban policies that have an impact in the overall health of the population.

1.4 Research aim & objectives

The main objective of this research is to develop a mixed methods approach that allows the co-design of a walkability index customised to the context of Amsterdam. This will be achieved through the combination of publicly available data with the insights from experts, advocates and decision makers working on walkability within the city.

The qualitative component of this research aims to understand how to explore the walkability factors that are important according to recent scientific literature and contrast that information with the perspectives of experts. This analysis will provide insights into the factors that are particularly important for Amsterdam and reveal clusters of shared opinions. By capturing this opinions, a ranking of the factors will be created.

The quantitative aspect of the research aims explore how to build a walkability index based on the outcomes of the qualitative research. Using publicly available data, the walkability will be measured at a street level.

1.5 Research questions

The context of this research established the importance of walkability in the health and quality of life of the urban population. Therefore, policymakers and urban designers need to be aware of the factors that affect walkability in a particular urban area. Nowadays, the municipality of Amsterdam is implementing walkability measures in renovations and new developments. However, there is still a lack of methods and tools that allow to measure walkability in a city wide scale to identify the areas that are most and least walkable.

Despite efforts made abroad to measure walkability, a context-specific walkability index for Amsterdam is still missing. Therefore, the main research question is:

> **MRQ:** What approaches and methods help create a walkability index for Amsterdam that considers the particularities of the city and the opinion of its decision makers?
>
> The creation of such an index requires research on the following intermediate sub-questions:
>
> **RSQ 1:** What are the most common factors that influence walkability in urban areas?
>
> **RSQ 2:** What are the most influential factors for pedestrians in Amsterdam, as identified by experts and advocates for walkability?
>
> **RSQ 3:** What is the current condition of walkability in the streets of Amsterdam?

1.6 Scope

This research, conducted over a 7 month period, focuses on the municipality of Amsterdam as defined by its 2021 boundaries (before the annexation of Weesp) to better understand the walkability situation and provide a measuring tool that reflects the views of decision-makers.

In this study, walkability is understood as the series of factors that make walking in the public space (e.g. a street) feasible, accessible, safe, convenient, comfortable, and attractive as defined by Methorst (2021). Further explanation on the definition can be found in the theoretical framework.

This research recognises that other factors affect walkability, such as individual or household factors, but these extend beyond the scope of this study.

It is not the intention nor aim of this research to mislead or exaggerate the ability of the resulting walkability index to define what a walkable street is in Amsterdam. The resulting index aims to help decision-makers understand how the measured factors influence walkability in certain streets but no further assumptions should be made out of the results.

2. Theoretical framework

The theoretical perspectives that will be used to answer the research questions and inform the discussion are explained in this section.

2.1 Walkability

The definition of walkability has considerable implications for the evaluation and design of urban transport networks, streets and other public spaces (Lo, 2009). While some researchers focus on the means and conditions for walkability, others propose that walkability is about the outcomes and the performance of an area (Forsyth, 2015). According to Forsyth (2015), many urban design theories assume that physical features will make people want to talk. However, theories of behaviour change used in health research suggest that personal characteristics, social contexts and individual behaviours might also play a role in choosing whether to walk in a given environment or not (Baranowski et al., 2003). Currently, there is no agreement on the conceptual definition of walkability (Tobin et al., 2022).

The theories of behaviour change tell us that the concept of walkability might differ depending on the target group. Tobin (2022), proposed a revised definition of walkability which is the one that will be taken as a reference for this study: the emergent natural, built, and social properties of neighbourhoods that promote physical activity and health and allow for equitable access to health-enhancing resources.

2.2 Walkability dimensions (perspectives)

Although there is a discussion on the conceptual definition of walkability, Forsyth (2015) has classified the most popular definitions of walkability into three main categories and established several dimensions for each. Figure 1 presents the three different definition groups of walkability with their dimensions.

Means: Enabling walkability

These definitions include themes related to the built environment that are usually perceived as walkability-inducing factors. This is the extent to which the environment promotes walking and exercise.

Outcomes: Perceived consequences of walkability

This group relates to the outcomes that are usually associated with successfully walkable places such as more people walking in the public space, environmental preservation or access to sustainable transport options. These outcomes are sometimes used to measure walkability.

Multidimensional terms: Walkability as a proxy for better design

Often walkability is used as an indicator of better design. For instance, some researchers like Lo (2009), have created walkability definitions based on indicators of liveability or sustainable development.

While according to Forsyth (2015), there is no consensus on the use of these indicators as definitely for walkability but they have been included on the list because of their popularity among researchers. This list of walkability dimensions can be organised as a hierarchy if the means are considered preconditions for the outcomes and these two categories can be combined in multidimensional terms as shown in Figure 1.

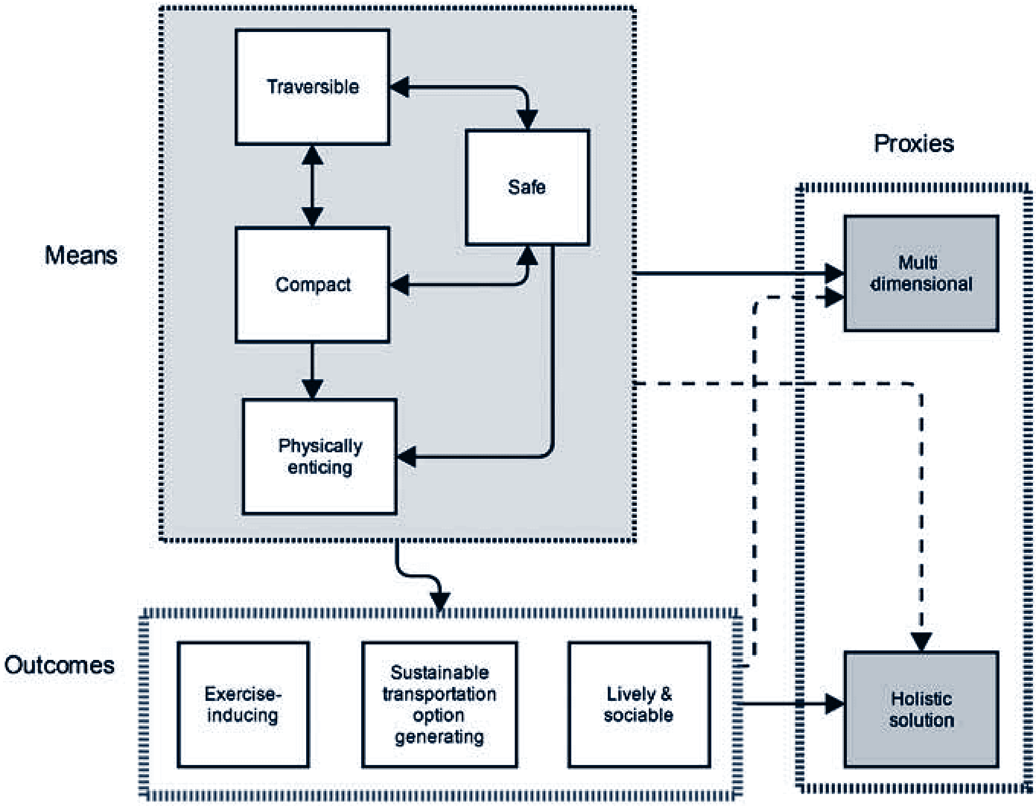


Figure 1: Walkability Dimensions (Forsyth, 2015)

2.3 Walking needs

Alfonzo M. (2005) proposed the "Hierarchy of Walking Needs" as a way to understand the factors that might influence people's decision to walk. According to this theory, the factors are organised in a hierarchical order, with the ones at the base of the pyramid being the most essential and becoming satisfiers while moving up in the pyramid (Figure 2). Alfonzo also talks about how a person's life circumstances and individual factors might influence the relationship between these factors and the outcome of choosing to walk or not. The factors, from most to least influential, are the following (Alfonzo, 2005):

Feasibility: This is the most basic level of needs in the hierarchy of walking needs. It refers to the feasibility of a walking trip, in other words, can I go there by foot? Distance, child care responsibilities in the household, physical disability and time might affect the choice of travel mode.

Accessibility: Alfonzo proposes that, if feasibility has been established, the person then considers accessibility. Accessibility encompasses the distribution of activities present in the walking area and the connectivity between them. Accessibility also includes the presence of sidewalks, actual or perceived barriers, the perception of distance to a particular destination or the integration of various uses in an area (Alfonzo, 2005).

Safety: In this case, the author refers to the feelings of safety towards the threats of crime. Feelings of safety may be influenced by the presence of certain land uses (bars, liquor stores, pawnshops), litter, graffiti, or poorly maintained housing (Alfonzo, 2005).

Comfort: Once feasibility, accessibility and safety needs are met, a person may consider comfort, or the level of ease and convenience of walking. The qualities that may affect comfort include the infrastructure which influences the relationship between the pedestrian and motorised traffic, the condition of the walkway system, weather protection features (e.g. trees and arcades) and features that improve the overall walking experience (e.g. street benches, drinking fountains and other street furniture) (Alfonzo, 2005).

Pleasurability: If all four previous levels are met, a person may consider the level of appeal of the walking surrounding. Features that affect pleasurability are the ones related to how enjoyable and interesting an area is for walking. For example, the presence of trees, architectural diversity, other people or the diversity of uses (Alfonzo, 2005).

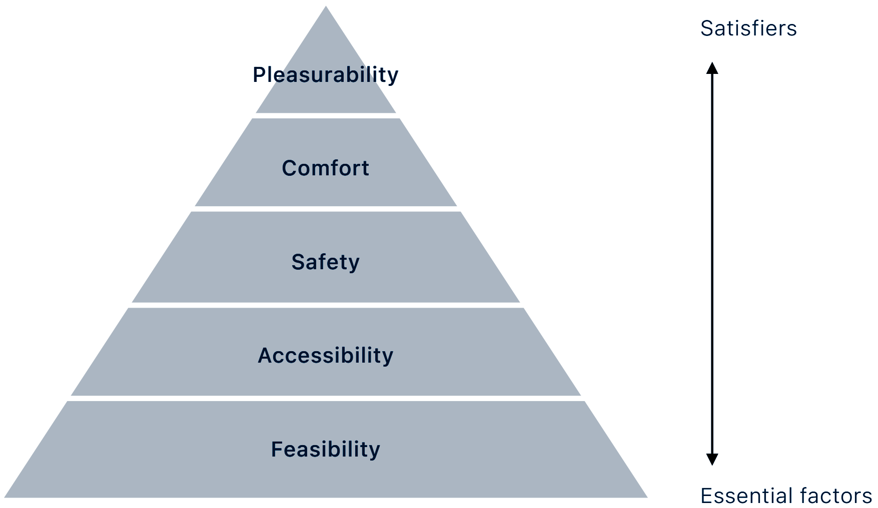


Figure 2: Pyramid of walking needs (Adapted from Alfonzo, 2005)

The pyramid of walking needs was further developed by Methorst (2021), into a conceptual model for walking and sojourning that puts in context the environmental and personal factors that affect walkability. The conceptual model proposed by Methorst can be seen in Figure 3.

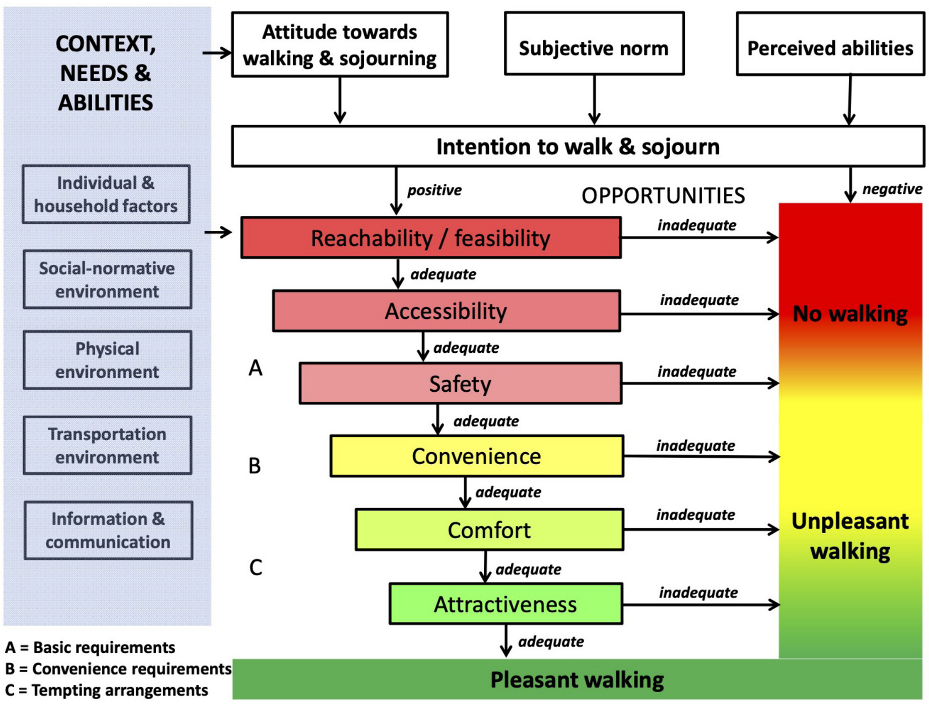


Figure 3: Conceptual model for Walking and Sojourning (Methorst, 2021)

2.4 Measuring walkability:

There are several methodological proposals on how to measure to which degree the built environment influences the choice to walk (McCormack & Shiell, 2011). These different approaches use physical or perceived characteristics of the city to measure walkability.

Through physical qualities of the built environment:

The relationship between several built environment factors and physical activity has been established in multiple reviews (Gebel et al., 2007; Van Cauwenberg et al., 2011). Prior studies have shown that the presence of certain characteristics such as proximity to amenities, pedestrian infrastructure or a high population density can be correlated with higher chances of people walking on that area and increased physical activity (Frank et al., 2005).

Through the human perception of the built environment:

Ewing & Handy (2009) argue that physical features of the built environment may not tell the complete story about the experience of walking on a street, therefore the subjective qualities of the built environment need to be assessed as well. Some examples of these subjective qualities that can be found on a street are: enclosure, legibility, human scale, complexity, etc (Ewing & Handy, 2009).

Through a combination of physical and perceived qualities:

Millstein (2013) proposes measuring walkability considering not only spatial and built environment attributes but also the streetscape features that can influence people's perceptions of their neighbourhoods suitability for walking. Some examples of the walkability factors proposed by Millstein are land uses, aesthetics of the street, the presence of graffiti, perceived noise, or the width and height of the sidewalks (Millstein et al., 2013).

3. Research design and structure

3.1 Mixed methods approach

This research uses a mixed methods approach in order to leverage the strengths of various methodologies. Using a combination of literature review, qualitative analysis and geospatial quantitative analysis, this research aims to address the task of assessing walkability in Amsterdam. Given the complexity of the subjective and objective factors that influence the choice to walk on a street, different methods provide complementary information that then is used to build the final index.

3.2 Research framework

The research framework explains how the different methods complement each other in order to obtain a context-specific walkability index. This is the overarching structure that will guide the research phases and provide the links between methods (Figure 4).

A. Collecting walkability factors
B. Capturing the perspectives on walkability
C. Measuring walkability

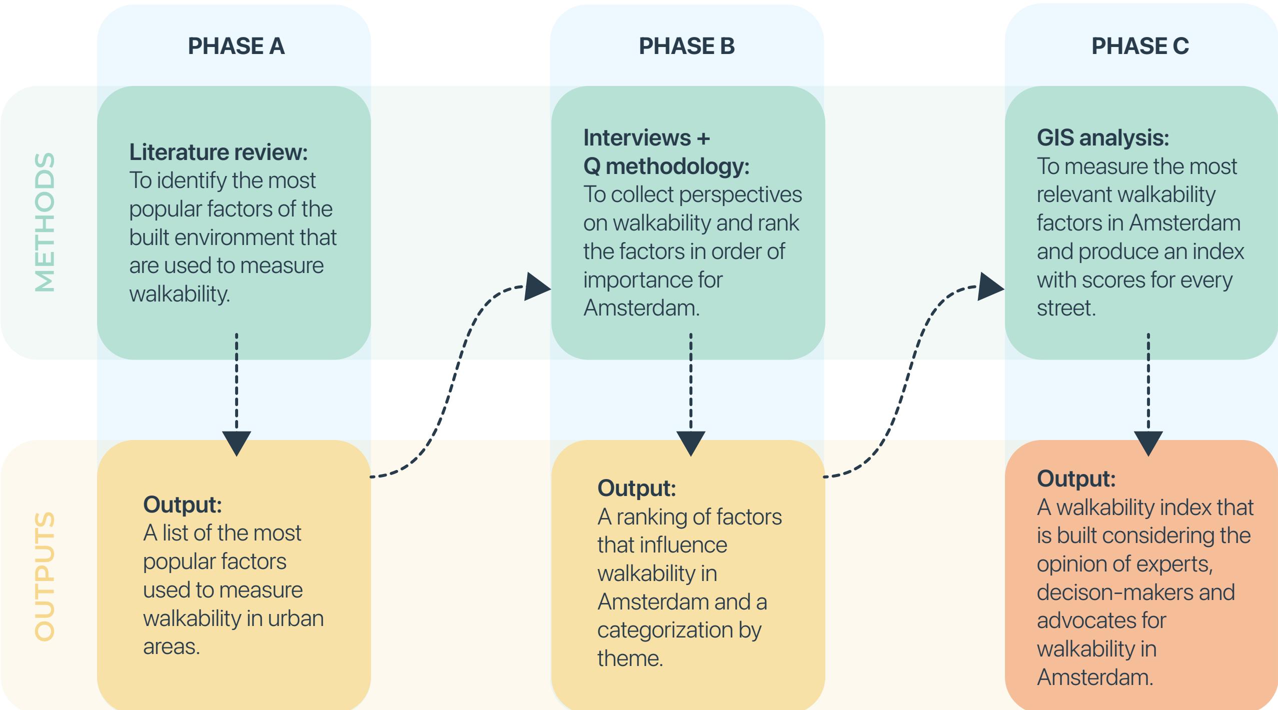


Figure 4: Research phases

A. Collecting walkability factors

Phase A of this research addresses the research sub question 1: What are the most common factors that influence walkability in urban areas? To find out what are the most common factors influencing walkability, a literature review will be conducted. Using the SCOPUS scientific paper database, the most popular walkability assessment methods will be reviewed as well as methods that are relevant for the Dutch context. From this review, a collection of walkability factors will be harvested and the results will inform the next phase which consists in the grouping and ranking of these factors to find out the most important ones for walkability in the specific context of Amsterdam.

B. Capturing the perspectives on walkability

Phase B of this research addresses the research sub question 2: What are the main groups of factors influencing walkability in Amsterdam? This question deals with subjective perceptions of what is walkable and why. Therefore, to address this question, a methodology to study subjective issues and points of view is required. To study and combine the different perspectives, the Q methodology to study subjectivity is used. This study focuses on gathering the point of view of experts and decision-makers, that is why, the participant sample will be limited to this group. The Q methodology was first introduced by (Stephenson, 1953). Its goal is to reveal shared viewpoints on a particular topic in society. It has been used in a variety of research fields such as medicine (Maniam et al., 2022) and more recently, transport (Brůhová Foltýnová et al., 2020). The Q methodology combines qualitative and quantitative techniques to study subjective points of view. During a typical Q study, participants are confronted with a series of statements that they are asked to sort on a grid according to the level of importance or agreement. This process is followed by statistical analysis with the potential to reveal clusters of shared viewpoints (Duncan Millar et al., 2022).

Since the Q methodology is a core part of this study, the steps it proposes are described in the following paragraphs.

Creation of a sample of statements

Using the literature review explained in the previous step of the research framework, the universe of walkability factors will be analysed and simplified in order to build a sample of factors. This means, the walkability factors will be grouped by similarities to reduce the number of factors to around 25, this is what the Q methodology calls the Q sample. Newman & Ramlo (2015) define a Q sample as:

> *"Ideally, Q samples are composed of statements that are "natural" in the language of the parties to the concourse and "comprehensive" in their representation of the subjective phenomena and viewpoints possibly implicated."*
>
> Newman & Ramlo, 2015

As a simplification of a broader universe of walkability factors, Q samples do not include all the possibilities of the universe but rather an approximation of the main topics surrounding the walkability issue.

Participant sample

Even though the primary focus of the Q methodology is given to the Q samples, the selection of the participants is also important. According to Newman & Ramlo (2015), the Q method emphasises using a small number of participants because the theory behind it (Stephenson, 1953) sustains that even small participant samples can provide meaningful generalisations about the nature of human behaviour.

Sorting the set of Q samples

A set of Q samples is known as a Q set, and the sorted Q set is known as a Q sort. The sorting of such a set is an operation in which a person sorts the different statements (the ones summarising the literature review) in a grid from most to less important according to a given instruction. This process of making decisions about the relative importance or unimportance of the different Q samples has the potential to reveal the subjective points of view of the participants.

According to Newman & Ramlo (2015), the sorting process is also a synthesising operation. No item is evaluated in isolation and its positioning is related to the contextual positioning of all other cards.

The grid will limit the number of Q samples that a participant can add to every column. This is called a forced distribution. A forced distribution is recommended for less sensitive topics because it allows for more legible comparisons between Q sorts.

Post Sorting interview - Factor grouping

Once the sorting is completed, a post-sorting interview will be conducted where participants will be asked to explain the reasoning behind their choices. The information collected in this interviews will be useful to identify groups of factors that influence different aspects of the pedestrian experience.

Statistical analysis

Statistical analysis in the Q methodology involves the application of two different statistical procedures:

• **Correlation:** Q sorts are correlated to each other using the Pearson product-moment correlation. Other types of correlation can be used as well but previous experiences have shown that the results have little variance despite the chosen correlation technique (Brown, 2004). This analysis is performed one time for every possible combination of two Q sorts producing a matrix where all Q sorts are correlated to each other.

• **Factor analysis:** Factor analysis comprises the statistical means by which the respondents are grouped according to their Q sorts. For this purpose, there are several software solutions available such as KenQ (Banasick, 2019) or Q-sortware (Pruneddu & Zentner, 2011). The factor analysis clusters the individual viewpoints that every Q sort portrays into shared perspectives on the topic. When combining all perspectives into one, the factor analysis provides a single perspective that groups all answers. This is the technique used to obtain a ranking of walkability factors that will inform the creation of the index in the next step.

C. Measuring walkability

Phase C of this research addresses the research sub question 3: What is the current condition of walkability in the streets of Amsterdam? This phase continues from phase B and aims to find publicly available data that allows to measure the most important walkability factors obtained from phase B. The data will be collected or generated from a variety of publicly available sources such as OpenStreetMap, the Dutch BGT (Basisregistratie Grootschalige Topografie) or the Open Data Portal from the municipality of Amsterdam. Once all the data is obtained, it will be processed using QGIS to add all the characteristics of the urban environment to the Walkable Street Network that will be obtained from OpenStreetMap. Once all factors are added to the Walkable Street Network layer, Python will be used to group normalise the dataset, add intervals of interest and calculate the final weighted scores for every street segment. A simplification of the above described process can be seen in Figure 5.

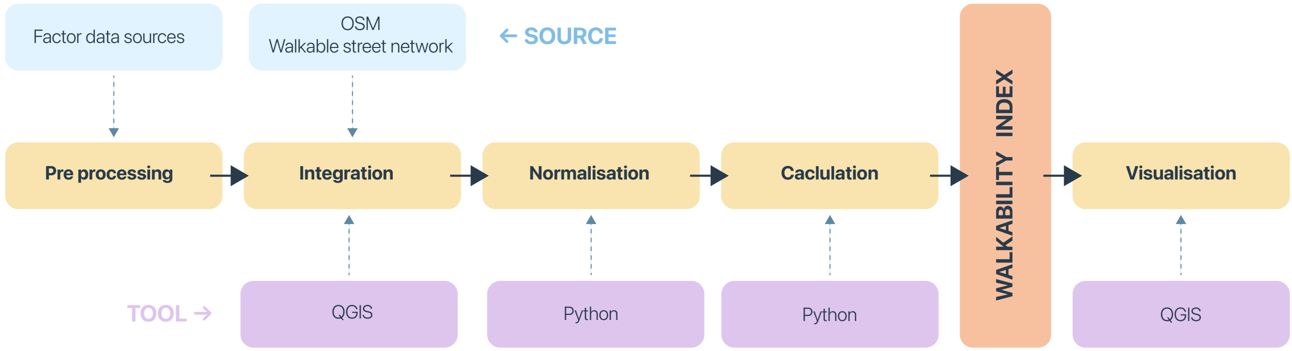


Figure 5: Workflow for measuring walkability.

3.3 Thesis outline

This study is structured in three phases: (A) Collecting walkability factors, (B) Capturing the perspectives on walkability and (C) Measuring Walkability. This structure follows the phases described in the research framework section.

After conducting all research activities of every phase, a short summary of the results is presented. Once all the steps of the methodology have been executed, there results are displayed in the form of different walkability maps and showcasing some street-level examples of the best, worst and average scored streets. The discussion section takes a critical look on the insights, dives into the limitations, reliability and replicability of this study and outlines possible future lines of research. Finally, the conclusion chapter draws general insights and findings obtained from the research process. A summary of this thesis outline can be seen in Table 1.

Chapter		Related Sub Research Questions
Chapter 1	Introduction	
Chapter 2	Theoretical Framework	
Chapter 3	Research Framework	
Chapter 4	Collecting walkability factors	SRQ1: What are the most common factors that influence walkability in urban areas?
Chapter 5	Capturing the perspectives on walkability	SRQ2: What are the most influential factors for pedestrians in Amsterdam, as identified by experts and advocates for walkability?
Chapter 6	Measuring walkability	SRQ3: What is the current condition of walkability in the streets of Amsterdam?
Chapter 7	Results	
Chapter 8	Discussion and Reflection	
Chapter 9	Conclusion	

Table 1: Thesis outline and sub-research questions.

4. Collecting walkability factors

This chapter tackles sub research question 1: What are the most common factors that influence walkability in urban areas?

4.1 Literature review setup

The factors that affect walkability can be uncovered by looking into different ways to measure walkability in the scientific literature. This approach assumes that the authors of the reviewed articles included different factors that have proved to be proxies for walkability. For this purpose, a review of different studies on walkability factors and measurements is conducted. To ensure that a broad range of factors is collected, this review includes the 5 most cited articles in Scopus that appear under the combination of the keywords “Walkability” and “Measure” when looking for these words in the title, keywords and abstract of the article. Additionally, 5 other relevant studies that propose novel ways of measuring walkability are included in the review to add diversity and include an approach to the Dutch context.

The methods to measure walkability found in the literature rely on the existence or absence of certain characteristics of the built environment. Each time one of the characteristics is mentioned, the name and way to measure it is collected into a matrix.

Table 2 provides an overview of the selected articles along with the reasons for their inclusion in the review.

Code	Study reference	Indexing Tool Name	Reason for inclusion in the review
T1	Frank et al., 2005	-	Top 5 cited articles in Scopus when searching for “Walkability” and “Measure”
T2	Ewing & Handy, 2009	-	
T3	McCormack & Shiell, 2011	-	
T4	Leslie et al., 2007	PLACE	
T5	Duncan et al., 2011	Walk Score	
R1	Cerin et al., 2009	NEWS	Other relevant studies / measuring methods mentioned in literature
R2	Forsyth, 2015	-	
R3	Millstein et al., 2013	MAPS	
R4	Ortega et al., 2021	-	
D1	Lam et al., 2022	Walkability index for the Netherlands	Relevant for the Dutch context

Table 2: Literature included in the review.

4.2 Literature synthesis

From the literature review, a universe of 57 factors influencing the walkability of a street is found. Only the factors used to measure walkability or mentioned as relevant by the authors are taken into account. To facilitate the next phase of the study and have easily interpretable results, the factors are grouped by similarity. This process synthesises the 57 factors into a set of 26. Table 3 presents the factors from each study and the categories used to group them.

Study code →	T1	T2	T3	T4	T5	R1	R2	R3	R4	D1
QS 1. Sidewalks / Pedestrian infrastructure										
Walking infrastructure						x	x			
Sidewalk width							x		x	
Presence of sidewalks/pedestrian paths			x							
Pedestrian streets									x	
QS 2. Proximity to destinations										
Land use mix	x		x	x				x		x
Proximity to amenities					x	x		x	x	
Non-Recreation land use proximity			x							
Recreation land use proximity			x							
Retail area floor density								x		x
Net area retail				x						
Retail density										x
QS 3. Traffic safety										
Traffic safety						x	x			x
QS 4. Obstacles										
Obstacles on the sidewalk								x	x	
QS 5. Presence of other people										
Presence of other people		x					x			
QS 6. Crime safety										
Crime safety						x	x			
QS 7. Proximity to public transport										
Public transport density									x	x
Distance to public transport			x							
QS 8. Sidewalk Maintenance										
Sidewalk maintenance							x			
QS 9.Active fronts / Eyes on the street										
Active fronts		x					x	x		
Proportion of first floor windows		x								
Proportion street-wall		x								
Presence of outdoor dining		x								
QS 10. Street lighting										
Pedestrian lighting							x			

Study code →	T1	T2	T3	T4	T5	R1	R2	R3	R4	D1
QS 11. Slow / low traffic										
Traffic calming measures							x			
QS 12. Green areas										
Vegetation		x					x		x	x
Trees							x		x	
QS 13. Plazas and parks										
Parks and plazas		x	x						x	
QS 14. Urban furniture										
Street furniture		x	x				x		x	
QS 15. Ease of navigation										
Street connectivity / intersection density	x		x	x	x	x		x	x	x
Sidewalk density										x
Compactness					x		x			
Block length					x					
Long sight lines		x								
QS 16. Parked Vehicles										
Vehicle parking									x	
QS 17. Shade										
Shade									x	
QS 18. Population density										
Population density	x			x	x	x		x		x
Employment - job density			x							
QS 19. Street width										
Street width									x	
QS 20. Aesthetics										
Positive aesthetics						x	x			x
Tourist attractions									x	
Historic buildings		x								
Buildings with non-rectangular shapes		x								
Major landscape features		x								
Dominant building colours		x								
Buildings with identifiers		x								
Accent colours on buildings		x								
Public art		x								
Aesthetics diversity			x							
QS 21. Noise										
Noise		x							x	
Traffic intensity			x						x	

Study code →	T1	T2	T3	T4	T5	R1	R2	R3	R4	D1
QS 22. Water bodies										
Presence of water										x
QS 23. Neighbourhood identity										
Sense of belonging							x			
QS 24. Street scale										
Building heights		x							x	
Proportion of sky		x								
QS 25. Wayfinding signs										
Wayfinding signs							x			
QS 26. Others										
Fences									x	
Slope									x	

Table 3: Literature synthesis.

4.3 Chapter summary

The literature review offered a comprehensive overview of the most popular factors associated to walkability. In Table 4, the factors are grouped by similarity to facilitate their interpretation. The proximity to destinations is the most popular walkability factor, followed by ease of navigation of the area and its aesthetics. This review shows that neighbourhood-scale factors are in general more popular than the ones measuring the street-level characteristics.

Walkability factor groups	Number of mentions in the literature
Proximity to destinations	16
Ease of navigation	13
Aesthetics	12
Sidewalks / Pedestrian infrastructure	6
Green areas	6
Population density	6
Active fronts / Eyes on the street	5
Urban furniture	4
Noise	4
Traffic safety	3
Proximity to public transport	3
Plazas and parks	3
Street scale	3
Presence of other people	2
Crime safety	2
Discarded items	2
Obstacles	1
Sidewalk Maintenance	1
Street lighting	1
Slow / low traffic	1
Parked Vehicles	1
Shade	1
Street width	1
Water bodies	1
Neighbourhood identity	1
Wayfinding signs	1
Other	2

Table 4: Factors found in the literature grouped by topic.

5. Capturing the perspectives on walkability

This chapter tackles sub research question 2: What are the most influential factors for pedestrians in Amsterdam, as identified by experts and advocates for walkability?

5.1 Application of the Q Methodology

This section shows the procedure followed to apply the Q methodology and obtain the shared perspectives on walkability in Amsterdam. The perspectives are then merged to obtain a single factor ranking that averages all points of view.

The Q methodology and interviews are used to answer sub-research question 2. The Q methodology provides the ranking of the factors and the main clusters of perspectives on walkability. The interviews complement the rankings and perspectives with information on why certain factors are more important and the relationship of the choices with the particular context of Amsterdam. As described in the research framework, the Q methodology starts with the creation of a sample of statements that will be ranked by the participants.

Creation of a sample of statements

Drawing from the conclusions of the literature review, 25 groups of factors that were relevant for the context of Amsterdam were turned into cards with statements. In order to improve the clarity of the sorting exercise, the statements were rephrased positively, meaning that factors such as "Sidewalk width" were phrased as "Wide sidewalks". Each card depicts in an icon the idea or general meaning of the statement it represents. As mentioned in the research framework, Q samples do not include all the possibilities of the universe but rather an approximation of the main topics surrounding a given issue. Its purpose is to provide a comprehensive and manageable representation of the universe of factors (Newman & Ramlo, 2015). That is why for some factors, the sorting cards are not a direct representation.

Figure 6 (in the next page) displays the 25 cards created and used in the interviews.

Figure 6: Statement cards used for the Q-methodology activities

Participant sample

The sample of 10 participants focused on decision-makers and walkability advocates working in the Randstad or preferably in Amsterdam. The participants are selected using a theoretical approach, meaning that they were chosen based on their relevance to the goals of this study (Newman & Ramlo, 2015).

Table 5 shows the participant names, functions, affiliations and relevance to the study:

Code	Function	Affiliation	Group
GA1	Mobility researcher	Municipality of Amsterdam	Municipality workers
GA2	Assistant designer of public space	Municipality of Amsterdam	
PC1	Consultant on urban development	Kickstad	Private advisors working on public space and area development projects
PC2	Consultant on sustainable urban development	AM Gebiedsontwikkeling	
PC3	Project Manager	Goedopweg	
PC4	Urban Planner & co founder of Humankind	Humankind	
AW1	Secretary of MENSenSTRAAT	MENSenSTRAAT	Advocates for walkability
AW2	Chairman of MENSenSTRAAT	MENSenSTRAAT	
AW3	Chairwoman of the pedestrian association of the Netherlands	Pedestrian association of The Netherlands	
RM1	Programme developer on urban mobility	AMS Institute	Researcher on urban mobility

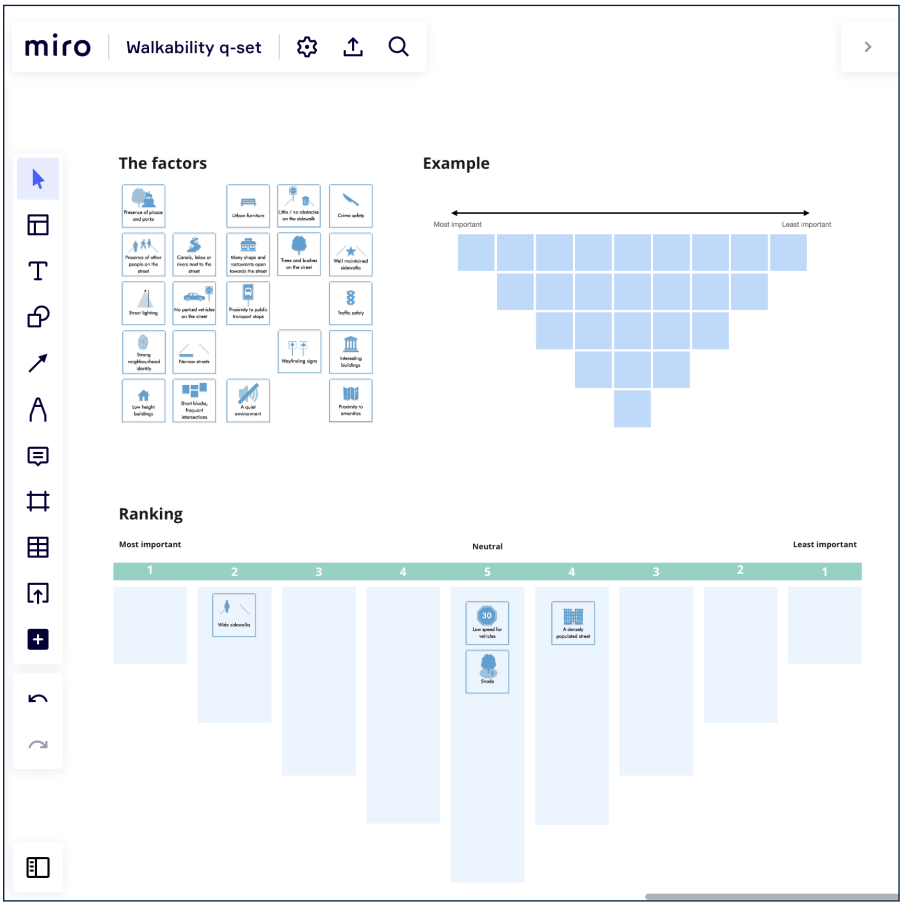
Table 5: Participant sample.

Card Sorting

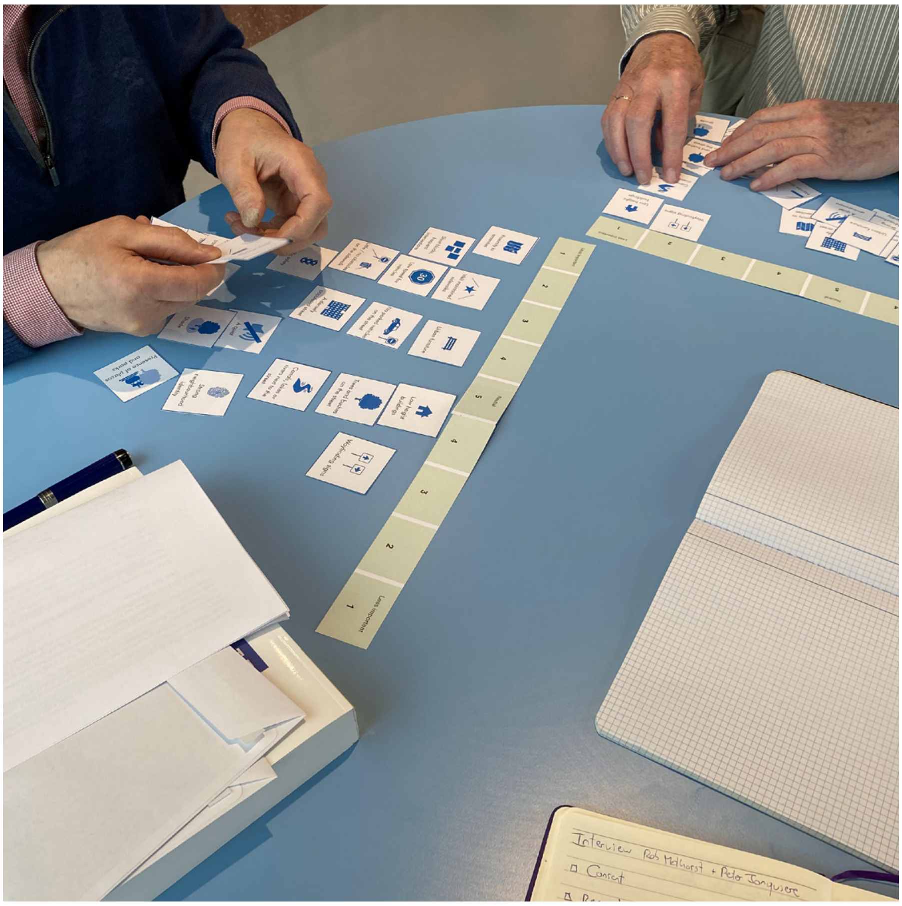
Sorting the statements requires sufficient space to work with the cards or, alternatively, an online tool to make the sorting possible. Both options are developed since interviews are planned to take place in person and online. The set of cards and a scale are prepared in the Miro platform to perform the sorting activity online (Figure 7). Meanwhile, for the in-person interviews, the same cards and scale are printed (Figure 8).

The interviews start with "warming up" questions aiming to understand more about the participant's background and connection to walkability in Amsterdam. Then they are asked to participate in the Q methodology activity under the following instruction: "You are advising the municipality of Amsterdam on how to design a street that maximises walkability, which factors are the ones that you would prioritise as most important?". With this guideline, the activity continues as follows:

1. The participant gets familiar with the Q sample items and asks clarifying questions if needed.
2. As this happens, the participant can arrange the items in three piles: most important, neutral, and less important.
3. The participant sorts the items in the grid from most to least important and keeping in mind that all items placed under the same column have the same importance value.
4. The participant reviews and adjusts the sort to finalise it.
5. A post-sort interview is conducted where participants are asked to explain some of their choices and the rationale behind them, especially for the Q samples at the extreme ends of the grid.
6. Finally, the participants are asked if there is something missing in the grid and how would they rank the missing factor(s).



←Figure 7: Participants sorting the statements for the Q methodology online.



←Figure 8: Participants sorting the statements for the Q methodology in person.

5.2 Processing the Q sorts to obtain groups of shared perspectives

In the Q methodology, the participants are the variables that are being studied (M. Brown, 2004). Therefore, the goal is to find correlations and common viewpoints. The most prominent viewpoints were extracted through a principal component analysis and then subjected to Varimax rotation to ensure a high factor loading. For this purpose the KenQ software is used (Banasick, 2019).

Correlation Matrix

The Q methodology analysis begins with the creation of a correlation Matrix. In this case, the Pearson correlation formula is used, resulting in the matrix presented in Table 6. It is worth noting that, as stated by Brown (1993), the choice of correlation method, be it Pearson or any other commonly used method, does not significantly impact the analysis (S. R. Brown, 1993). Nevertheless, to follow the common practice on this field, Pearson correlation is selected for this study (M. Brown, 2004).

The resulting matrix shows that there is some degree of correlation between the importance of the walkability factors among the advocates for walkability (AW group). The other participants have an average correlation factor of 31%, meaning that, on average, they agree at least with one-third of the viewpoints of each other.

	GA1	GA2	PC1	PC2	PC3	PC4	AW1	AW2	AW3	RM1
GA1		40	17	27	1	36	44	29	15	34
GA2	40		48	27	-20	15	24	52	48	31
PC1	17	48		38	5	49	34	47	49	42
PC2	27	27	38		6	18	33	13	33	28
PC3	1	-20	5	6		23	28	15	1	0
PC4	36	15	49	18	23		62	52	35	15
AW1	44	24	34	33	28	62		58	55	28
AW2	29	52	47	13	15	52	58		68	39
AW3	15	48	49	33	1	35	55	68		56
RM1	34	31	42	28	0	15	28	39	56	

Table 6: Pearson correlation matrix showing the correlation level between participants and groups.

Obtaining the shared perspectives - Do urban experts and advocates agree?

The Q methodology proposes the use of a factor analysis to obtain the shared perspectives. As explained by McKeown & Thomas (2013), the type of factor analysis used in the Q methodology has little influence on the results. To follow the convention in the field (M. Brown, 2004), a Principal Component Analysis (PCA) is performed. The PCA allows to reduce the number of dimensions in large datasets to increase the interpretability of the data while preserving the maximum amount of details (Newman & Ramlo, 2015).

Participant	Comp. 1	Comp. 2	Comp. 3
GA1	0.0946	0.1509	0.8721
GA2	0.6719	-0.2413	0.3869
PC1	0.7042	0.1621	0.1807
PC2	0.2309	0.0485	0.6193
PC3	-0.1333	0.7721	-0.0949
PC4	0.341	0.6918	0.2572
AW1	0.4051	0.6569	0.3857
AW2	0.774	0.3874	0.0647
AW3	0.8667	0.1683	0.0608
RM1	0.6174	-0.0456	0.287

Table 7: Level of variance explained by each perspective.

In the first analysis, the PCA revealed three meaningful components which in the Q methodology are interpreted as shared points of view or perspectives on walkability. Table 7 shows the level of variance that every component explains for each individual answer and highlights in blue the answers that contribute to each perspective. In this case, the variance can be understood as the extent to which the individual point of view of the participant matches the shared perspective. Each shared perspective on walkability that results from the PCA entails a different walkability factor ranking that can be found in the Appendix 1.

Interpretation of the perspectives on walkability in Amsterdam:
As proposed by Maniam et al. (2022), the shared perspectives can be interpreted to draw conclusions about each group of respondents.

Perspective 1 - Feasible and safe walking: 5 participants fall under this common point of view with a correlation of 61% or more with this order of walkability factors. This perspective prioritises the qualities of the pedestrian infrastructure (no obstacles, wide sidewalks) and factors such as traffic and crime safety. The reachability of amenities or public transport has median importance and in the last place they rank factors that have to do with an improved environment for walking such as a strong neighbourhood identity, low height buildings or a quiet environment but also the population density of the area and the navigability of the neighbourhood.

Perspective 2 - Walking with a purpose: 3 participants have a correlation of 65% or more with this point of view. This perspective prioritises the reachability of amenities and the ease of navigation of the environment. Traffic and crime safety are also important concerns for them. Factors concerning the quality of the walking infrastructure have a median importance for this group. Lastly, in a similar fashion than in perspective 1, factors that make the walking experience enjoyable are ranked as the least important.

Perspective 3 - Feasible and enjoyable walking: 2 participants fall into this perspective with a correlation of 61% or more. The priority for this group is the quality of the walking infrastructure, and the proximity to amenities but they also rank among the top 5 factors the presence of vegetation and shops or horeca establishments on the street. In the middle part of the ranking, we can find factors such as traffic safety such and low speed for vehicles. Interestingly, this group ranks crime safety (a highly ranked factor in the other two perspectives) as not so important.

5.3 Linking the Q-methodology with the factor ranking for a walkability index

The presence of three main perspectives on walkability, as found in the PCA, indicates that there is no single way to understand walkability in Amsterdam. However, in order to create an index, a single ranking of factors considering all perspectives is required. To find the final factor ranking, the three main perspectives on walkability are combined into one where all individual views contribute. To achieve this, a new PCA is conducted to calculate one single principal component that collects all perspectives. This common point of view is able to explain at least 48% of the variance of all the Q sorts except for one which had a correlation of 14%. The correlation scores of the common point of view with the individual views can be seen in Table 8.

Participant	Exp. Variance
GA1	0.53
GA2	0.63
PC1	0.71
PC2	0.49
PC3	0.14
PC4	0.65
AW1	0.75
AW2	0.80
AW3	0.79
RM1	0.61

Table 8: Level of variance explained by the unified perspective.

The PCA analysis also results in Z-scores that account for the number of standard deviations by which the value is above or below the mean score of all factors (Zabala & Pascual, 2016). Table 9 presents the factor final factor ranking with the correspondent Z-scores. The factors prioritised in this combined ranking have to do with traffic safety and pedestrian infrastructure, street lighting and the presence of other people (which in the interviews appeared as a proxy for crime safety) are also highly ranked. Then come the factors about proximity to amenities and public transport as well as having shops and restaurants open toward the street. Lower on the ranking are the factors that make walking enjoyable such as the presence of plazas and parks, urban green and shadow. Finally, a quiet environment and factors relating to the architecture of the street are ranked the lowest.

Rank	Factor	Z-Score
1	Traffic safety	1.53
2	Little / no obstacles	1.49
3	Wide Sidewalks	1.28
4	Presence of others	0.94
5	Street lighting	0.88
6	Low speed	0.83
7	Proximity to amenities	0.82
8	Crime safety	0.77
9	Proximity to public transport	0.66
10	Well maintained sidewalks	0.55
11	Many shops and restaurants	0.37
12	Urban furniture	0.27
13	Presence of plazas and parks	0.27
14	No parked vehicles	0.17
15	Trees and bushes	-0.01
16	Shade	-0.48
17	Short blocks, frequent intersec.	-0.56
18	Narrow streets	-0.68
19	Wayfinding signs	-0.98
20	A densely populated street	-1.02
21	Canals, lakes or rivers	-1.24
22	A quiet environment	-1.36
23	Strong neighbourhood identity	-1.42
24	Interesting buildings	-1.49
25	Low height buildings	-1.60

Table 9: Final factor ranking and Z-scores.

5.4 Interviews summary

Alongside the Q sorting activity, a short interview is performed with the participants to better understand the reasoning behind their sorting choices and collect comments about the factors. The participants are asked to elaborate on the reasoning of their choices and give a short comment on how they perceive each factor. This section displays a summary of the comments made about every factor.

Traffic safety

Traffic safety was ranked as the most important factor by some of the interviewees, they commented that it is closely related to the speed of the vehicles on the street but also to pedestrian infrastructure characteristics such as having wide sidewalks. Traffic safety was seen not only as the number of accidents on a street but also as the feeling of safety towards the vehicles which can be reached by having adequate infrastructure and speed limits.

Wide sidewalks

Interviewees usually judged this factor as very important and many pointed out that in places like the city centre of Amsterdam, sidewalk width is below the recommended minimum. This factor was associated with making walking a feasible option. One of the interviewees working for the municipality explained that currently, there is no policy for sidewalk width design. This person argues that the sidewalk is usually given the remaining space after fitting the car and bike lanes in the street space because the last two have minimum width requirements established in the policies.

Proximity to amenities

When explaining the importance of the proximity to amenities, the comment "I am more prone to walk if my destination is close by" was frequent. This factor was often associated with the accessibility to services and walking with a purpose instead of recreational or touristic walking.

Little or no obstacles

The absence of obstacles was associated with accessible and feasible walking. The distinction was made between temporary and permanent obstacles being the first the bigger problem in the city of Amsterdam. Parked bikes, old furniture and trash were mentioned as examples of obstacles that are difficult to measure. About the number of parked bikes, one of the municipality workers mentioned that the data on the parking pressure of bikes or the location of the bike racks is limited to a few areas of the city.

Presence of others

The presence of others in the street was associated with social safety but also to liveability and vibrancy of the street. Several interviewees mentioned that even though in most cases the presence of other people is positive, it can also negatively affect the walkability of the area if it becomes too crowded. Places such as the city centre and the surroundings of the Bijlmer ArenA were mentioned as examples of places where the excessive presence of people becomes a nuisance and affects walkability.

Crime safety

Safety from crime was ranked either very high or very low by different interviewees. The group that ranked it very high explained that for them it is essential to feel safe in a place in order to decide to walk. Several interviewees argued that they placed crime safety very high because of personal experiences and that it is associated with the presence of others on the street and street lighting. On the other hand, the interviewees ranking it very low argued that the Netherlands is in general a safe country, therefore, they don't think about crime safety before choosing to walk in an area.

Proximity to public transport
In a similar fashion as with proximity to amenities, this factor was associated with accessibility and walking with a purpose. The importance of walking as a first and last-mile option for public transport was highlighted by several interviewees.

Well maintained sidewalks
The notion of maintenance was associated with accessibility and the absence of obstacles . Some of the interviewees also mentioned that a well-maintained sidewalk could also inspire feelings of safety because they would have the impression of walking in an area with higher social control.

Many shops and restaurants open toward the street
This factor was related by the interviews to the principle of "Eyes on the Street" first mentioned by Jane Jacobs in 1961. Some commented that the presence of see-thru façades provided social safety but also made the walking experience more interesting and engaging.

Street lighting
Highly associated with crime safety, this factor was mentioned to be especially important in winter. Some interviewees also mentioned that this factor is essential in the evenings making walkability feasible in areas that are properly lit.

Low speed
Low speed for vehicles was associated with traffic safety, it was mentioned that lowering the speed of vehicles in certain streets could encourage people to drive less and walk more.

Trees and bushes
Even though it was frequently mentioned as an important factor for the enjoyment of the walking experience, the presence of trees and bushes was usually ranked in the middle and lower tiers of the sort. When asked about it, many participants acknowledged the importance of greenery but stated that it is not a factor that makes walking more feasible, therefore they placed it after factors that make walking feasible such as having proper infrastructure or traffic safety.

Presence of parks and plazas
Parks and Plazas were associated with making the walking experience enjoyable and inviting. Other interviewees mentioned their importance as pockets of green in the city and areas where recreational walking can occur.

Urban furniture
Associated especially with the elderly and enjoyment of the public space, the presence of urban furniture was seen as a matter of accessibility for older or disabled groups by providing places to rest during the walk. Some interviewees shared their concerns about the removal of benches from public spaces in Amsterdam as a strategy to discourage the presence of homeless people or other social groups traditionally considered problematic.

Short blocks, frequent intersections
This factor was usually associated with the ease of navigation of the area to easily reach a destination. It was also associated with having a human scale and an interesting route to walk on. Most participants did not consider this as an important factor, the few that ranked this factor in the top tier did so because they consider the ease of navigation important.

No parked vehicles on the street

Most participants did not consider parked vehicles as a problem for walkability. The general comment was that the absence of parked vehicles makes the walking experience more pleasant but the presence of them does not hinder their ability or willingness to walk.

Shade

Shade was considered important for some of the participants as a way to make the walking experience more pleasant especially in the summer. Some participants pointed out that shade can also affect walkability in cold days when people would prefer to be under the sun. This factor was associated with the presence of trees and bushes on the street and was deemed to make the walking experience more enjoyable.

A densely populated street

Most participants considered this factor as one of the least important. The most common explanation was that they do not care about how many people lived in the street if they can not see them (as happens with the presence of other people on the street). On the other hand, participants that ranked this factor as higher in the pyramid explained that densely populated areas attract businesses and therefore are related to the proximity to jobs and amenities.

Narrow streets

Most participants did not consider the width of the street as an important factor. The usual explanation was that they don't mind walking next to a wide street as long as the sidewalk is spacious and in good condition. The participants that ranked this factor higher in the list explained that it is related to having lower speed, traffic safety and more enjoyable environments to walk on.

Interesting buildings

The presence of interesting buildings in the street was one of the lowest ranked factors. Participants explained that even though it might make the walking experience more interesting and enjoyable, their absence won't hinder their ability to walk on the street.

A quiet environment

This factor was usually considered positive and related to low traffic and more enjoyable walking experiences. Some of the participants commented that if the environment is too quiet it can be considered unsafe and lacking vibrancy which could hinder the walking experience.

Canals, lakes or rivers

Canals lakes and rivers were judged to be positive additions to the landscape but not essential, and were ranked in general in a lower place than the presence of trees and bushes.

Strong neighbourhood identity

The neighbourhood identity was ,in general, not considered an important factor influencing the walkability of an area. Some interviewees stated that a strong neighbourhood identity might help improve feelings of safety and enjoyment in pedestrians.

Low height buildings

The height of the buildings was associated with having a landscape with "human scale". The presence of low rise buildings was not considered a significant factor for walkability by most of the interviewees with explanations such as "tall buildings can also make the walking experience enjoyable and more interesting".

Wayfinding signs

The presence of way-finding signs was considered important but only in touristic areas such as the city centre. Some participants explained that they do not consider this an important factor because they rely on their phones for navigation.

5.5 Factor groups

Based on the comments retrieved in the interviews, the type of influence of the walkability factors is identified in Figure 9. These groups of factors show different aspects of the pedestrian experience in Amsterdam, some factors have influence in more than one group. This information will be used to enrich the final walkability index and give insights into the final scores.

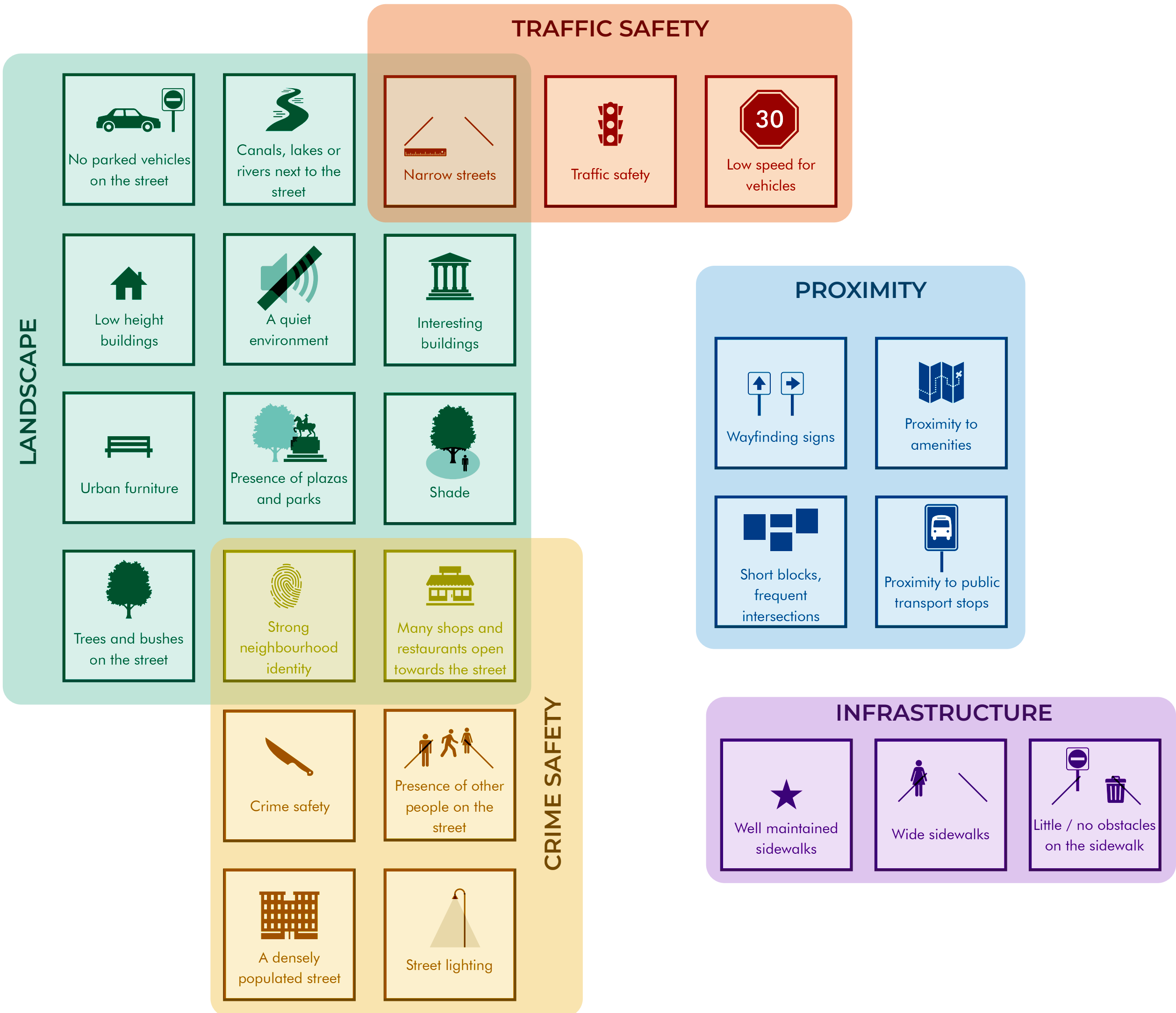


Figure 9: Factor gorups as obtained from the interview comments.

5.6 Chapter Summary

The Q methodology unveiled three shared perspectives on walkability from the participants sample. In order to create an index, these perspectives were combined into a single factor ranking by running a new PCA. This single factor ranking shows that traffic and crime safety, and the quality of the pedestrian infrastructure are considered very influential for walkability. The interviews gave insights into how people perceive different factors and what aspects of walkability they influence. Drawing from this information, the walkability factors were organised into 5 categories that will be used to create thematic sub-indexes.

6. Measuring Walkability

This chapter tackles sub research question 3: What is the current condition of walkability in the streets of Amsterdam?

6.1 Calculating the factor weights

The PCA analysis performed in the Q methodology facilitates the calculation of a ranking of factors based on its total scores. From the scores, a metric called Z-score can be calculated. The Z-score is the number of standard deviations by which the value is above or below the mean score of all factors (Zabala & Pascual, 2016). The Z-score provides further insight into the ranking by showing the distance between factors , thus, allowing the calculation of weights.

To understand the relative importance of the factors and generate weights for every item, the Z-scores of the included factors are normalised with min-max normalisation into a value ranging from 0 to 1. Then they are compared to the sum of all the normalised scores to obtain the percentage of importance of the factor. It was decided to include only the factors with a Z score higher than -0.6. Since no data is available for all the factors, the weights are only calculated for the ones that have data available and can be included in the processing of the index. These normalised values are the final factor weights as can be seen in Table 10.

Rank	Factor	Z-Score	Inclusion / Exclusion	Calculated weight
1	Traffic safety	1.53	Included	**0.094**
2	Little / no obstacles	1.49	Included	**0.093**
3	Wide Sidewalks	1.28	Included	**0.086**
4	Presence of others	0.94	Excluded - No data available	**-**
5	Street lighting	0.88	Included	**0.074**
6	Low speed	0.83	Included	**0.073**
7	Proximity to amenities	0.82	Included	**0.073**
8	Crime safety	0.77	Included	**0.071**
9	Proximity to public transport	0.66	Included	**0.068**
10	Well maintained sidewalks	0.55	Included	**0.065**
11	Many shops and restaurants	0.37	Included	**0.059**
12	Urban furniture	0.27	Included	**0.056**
13	Presence of plazas and parks	0.27	Included	**0.056**
14	No parked vehicles	0.17	Included	**0.053**
15	Trees and bushes	-0.01	Included	**0.048**
16	Shade	-0.48	Excluded - No data available	**-**

Rank	Factor	Z-Score	Inclusion / Exclusion	Calculated weight
17	Short blocks, frequent intersec.	-0.56	Included	**0.031**
18	Narrow streets	-0.68	Excluded due to low ranking	-
19	Wayfinding signs	-0.98	Excluded due to low ranking	-
20	A densely populated street	-1.02	Excluded due to low ranking	-
21	Canals, lakes or rivers	-1.24	Excluded due to low ranking	-
22	A quiet environment	-1.36	Excluded due to low ranking	-
23	Strong neighbourhood identity	-1.42	Excluded due to low ranking	-
24	Interesting buildings	-1.49	Excluded due to low ranking	-
25	Low height buildings	-1.60	Excluded due to low ranking	-

Table 10: Calculation of final factor weights.

6.2 Data gathering

To begin the construction of the index, data is collected from different publicly available databases such as OpenStreetMap, the Dutch BGT (Basisregistratie Grootschalige Topografie) and the Open Data portal from the municipality of Amsterdam. The identified databases provide information for 21 out of 25 indicators. The aim is to obtain only data for the year 2023, however, in some cases, older data is the only option available. A complete list of the data sources and years can be seen in Table 11.

Most criteria are readily available or need light processing to be integrated into an index, however, some other factors need to be calculated from the 3D model of the BGT or require some kind of simplification and cleaning to be ready for normalisation.

Factor	Dataset	Source	Detail level
Traffic safety	Pedestrian accidents	Rijkswaterstaat (2021)	Street
Little / no obstacles	Street objects	BGT (2021)	Street
Wide Sidewalks	Sidewalk polygons	BGT (2021)	Street
Street lighting	Location of public lights	AOD (2023)	Street
Low speed	Maximum speed in roads	AOD (2023)	Street
Proximity to amenities	Points of interest	OSM (2023)	Street
Crime safety	Amsterdam Safety Index	AOD (2021)	Neighbourhood
Proximity to public transport	Public transport stops	OV API (2023)	Street
Well maintained sidewalks	Sidewalk maintenance survey	AOD (2021)	Neighbourhood
Many shops and restaurants	Shops and restaurants location	OSM (2023)	Street
Urban furniture	Benches location	OSM (2023)	Street
Presence of plazas and parks	Parks + pedestrian areas location	AOD (2023)+ BGT (2023)	Street
No parked vehicles	Parking pressure	AOD (2023)	Street
Trees and bushes	Green map of The Netherlands	RIVM (2023)	Street
Short blocks, frequent intersec.	Walkable street network	OSM (2023)	Street

AOD = Amsterdam Open Data
BGT = Basisregistratie Grootschalige Topografie
OSM = OpenStreetMap
RIVM = Rijksinstituut voor Volksgezondheid en Milieu

Table 11: Data sources used to measure the qualities of every factor.

6.3 Data pre-processing

The data describing each one of the factors is prepared and added to the walkable network layer in order to create the index. Different methods are used to pre-process and add the information to the network layer depending on the detail level and type of dataset. The four methods used to integrate the data are described in Figure 10.

THE 4 GIS METHODS TO INTEGRATE DATA TO THE WALKABLE NETWORK LAYER

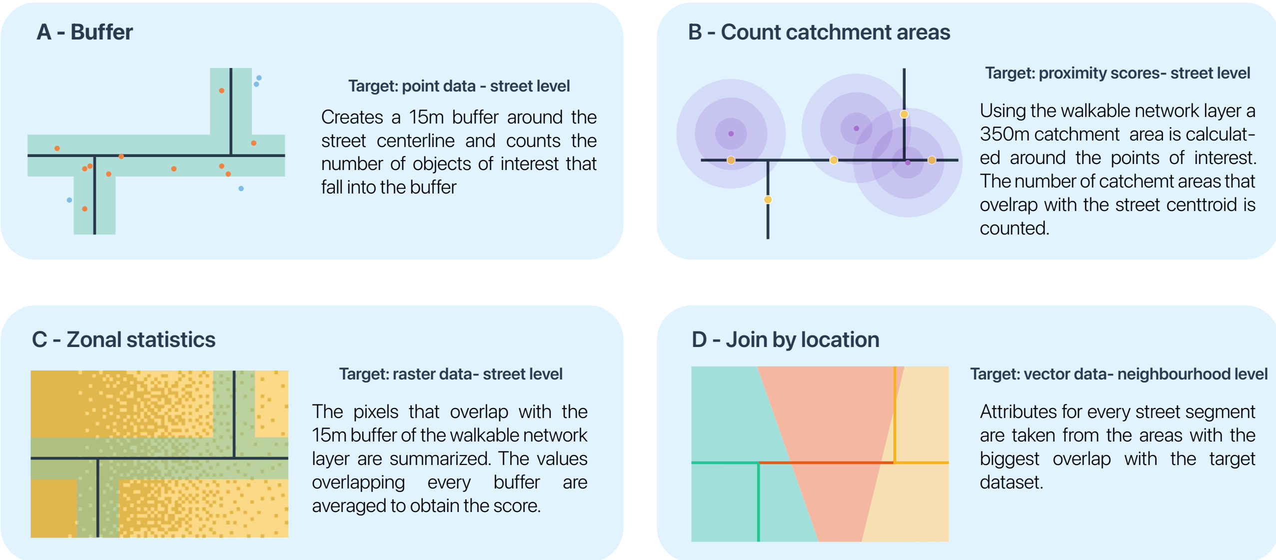


Figure 10: GIS methods to integrate information to the walkable network.

Walkable Network

The pedestrian network of the municipality of Amsterdam (from now on: walkable network layer) is downloaded from OpenStreetMap using the OSMnx plugin (Boeing, 2017) in Python. Since there are street segments that vary greatly in length, the lines are segmented every 50 meters and the parts measuring less than 1 meter are disregarded. The pedestrian network is therefore comprised of 114.003 segments that measure less than 50 metres and more than 1 metre.

Traffic safety

Traffic safety is measured through the collection of road accidents involving pedestrians in 2019, 2020 and 2021. The count of accident points is associated with every street segment making it possible to identify areas where more accidents occur. The information on accidents is collected from the Rijkswaterstaat website. GIS method A is used to add this information to the walkable network layer.

Obstacles

Obstacles data is obtained from several sources such as the BGT and OpenStreetMap. The location of mailboxes, light posts, bollards, electricity closets, trash cans, bus stops, trees, urban furniture, etc is collected from the BGT. Meanwhile, the location of terraces is obtained from the Open Data portal of the municipality of Amsterdam and the location of public furniture from OpenStreetMap. The points are combined into a single layer and filtered to obtain only the ones that fall inside the geometry of the sidewalks. For this factor, elements that can bring positive qualities in other factors (e.g. trees, benches) are also considered obstacles if they occupy sidewalk space because they make the effective walking space smaller. GIS method A is used to add this information to the walkable network layer. Finally, the number of obstacles in the sidewalk is normalised by dividing it by the street segment length and added to the network shape file.

Wide sidewalks

Information on sidewalk width is calculated from the shape files containing the geometry of all pedestrian paths and areas in the city in 2021. A series of QGIS tools are combined into a model that first skeletonizes the sidewalk geometries to obtain the centerlines and then measures the distance from the centreline to the edges of the sidewalk every meter. The different width measures are averaged in every street and the information is added to the corresponding segment of the walkable network using GIS method A. This method is inspired by the sidewalk width tool developed by Harvey (2021) for the city of New York.

Street lighting

Street light locations are obtained from the Open Data portal of the municipality of Amsterdam. To begin, lights that are less than 1 meter from each other were grouped into a single point. Then, a 10 meters buffer representing the average area covered by a street light is drawn. Finally, the number of buffers that every street segment touches is counted and the value is normalised by dividing it by the segment length. GIS method A is used to add this information to the walkable network layer.

Low speed

The maximum speed of the roads of Amsterdam is collected from the Open Data portal of the municipality. The speed information is then added to the walkable network shape file through a location-based join as described in the GIS method D.

Proximity to amenities

The location of popular amenities such as supermarkets, shops, schools, general practitioners, markets, churches, etc. is downloaded from the OpenStreetMap database. According to the KIM Institute for Transport Analysis (2019), the acceptable walking distance to shops is between 300 and 1000 meters. Therefore, a catchment area of 350 meters around every amenity is calculated using the pedestrian network. Finally, the number of amenities accessible from the centroid of every street segment is counted and the information is added to the walkable network layer as described in the GIS method B.

Crime safety

Crime safety indicators for 2021 are obtained from a study made by the municipality of Amsterdam and reflect the perceived safety in every neighbourhood. The scores ranging from 0 to 10 were added to the walkable network layer using a location-based join in QGIS as described in the GIS method D.

Proximity to public transport

Public transport stops locations are downloaded from the open GTFS service of the Netherlands (OV API, 2023). According to the KIM Institute for Transport Analysis (2019), the acceptable walking distance to public transport stops is 350 meters. Therefore, a catchment area of 350 meters around every point is calculated using the pedestrian network. Finally, the number of stops accessible from the centroid of every street segment is counted and the information is added to the walkable network layer as described in the GIS method B.

Well maintained sidewalks

Sidewalk maintenance data is partially available through the municipality Open Data portal. The data for 2021 stems from the study “Wonen in Amsterdam” commissioned by the municipality of Amsterdam (Gemeente Amsterdam, 2021b). The data reflects the average score that residents give in response to the question: How do you assess the state of maintenance of the streets and sidewalks in your neighbourhood? (1 = more than unsatisfactory, 10 = more than satisfactory).

Answers are available only for neighbourhoods with at least 20 respondents reported. Because of the study design, 353 out of 514 neighbourhoods report a score. For the neighbourhoods that miss a score, the average score of 6,7 is assigned. The average is used in this case because the available data shows a standard deviation of 0.5 which is considered moderate (Barde, 2012). Finally, the scores ranging from 0 to 10 were added to the walkable network layer using a location-based join in QGIS (GIS method D).

Many shops and restaurants open on the street

This measure is different to the proximity to amenities because it only counts land uses that are on the street and usually have an inside-outside visual connection. Therefore, schools, churches, general practitioners, etc are not included in this metric. The rest of the amenity points facing the street (e.g. shops and restaurants) are counted using GIS method A, and the resulting value is normalised by dividing it by the length of the street segment. Then, the information is added to the walkable network layer.

Urban furniture

Urban furniture location is obtained from OpenStreetMap. The number of benches in every street segment is counted using GIS method A and the resulting value is normalised by dividing it by the length segment. Then, the information is added to the walkable network layer.

Presence of parks and plazas

Information on parks and plazas is available in the Open Data portal from the municipality of Amsterdam. The information on the presence of parks and plazas next to a street is added to the walkable network layer using a location-based join (GIS method D). Only segments at 15 or less meters from the park or plaza edges are marked as close to parks and plazas.

No parked vehicles on the street

The municipality of Amsterdam offers a dataset containing the "Parking Pressure" of every street in the city. This term refers to what percentage of the parking capacity is occupied during the performance of the parking study. When there are 100 parking spaces within an area and 70 parking of them are occupied, the parking pressure is 70% at that time (4-traffic.nl, 2021). The parking pressure information is added to the walkable network layer using a location-based join (GIS method D).

Trees and bushes

Data on the presence of greenery is obtained from the "Groenkaart van Nederland" available on the RIVM (National Institute for Public Health and the Environment) website. The map shows the percentage of green contained in every square of a 10x10 meters grid. This information is added to the walkable network layer using zonal statistics that calculated the average green percentage of every street segment and a buffer area of 15 meters around it as described in GIS method C.

Short blocks, frequent intersections

This measure refers to having good connectivity and is usually measured by the intersection or street density of the neighbourhood (Hajrasouliha & Yin, 2015). Since a distance of 350 meters is already used as an "acceptable walking distance" for public transport stops and amenities ((KiM Netherlands Institute for Transport Policy Analysis, 2019), a line density analysis is performed in QGIS using a 350-meter radius. The line density analysis shows how many street segments exist in a certain area and it is considered a proxy measure for connectivity and ease of navigation (Hajrasouliha & Yin, 2015). The line density analysis output is a raster grid of 10x10 meters that contains the number of lines counted in a 350-meter radius around that cell. This information is added to the walkable network layer using a zonal statistics (GIS method C) that calculated the average line density of every street segment and a buffer area of 15 meters around it.

6.4 Intervals of Interest

To avoid skewing the index with outliers, seven factors showing skewed data toward higher values are capped between 0 and a fixed value representing the new maximum possible score. Table 12 shows the intervals that are used and the reasoning behind them. This allows for easier comparison between streets. However, it is only applied where necessary as it has the potential to bias the results in the index.

Factor	Min/Max. Value
Street lighting	Max = 1 light per meter
Shops and restaurants open toward the street	Max = 1 amenity per 10 meters
Furniture	Max = 1 bench per meter
Obstacles	Max = 1 obstacle per meter
Proximity to public transport	Max = 10 reachable public transport stops
Sidewalk width	Min = 0.9m , Max = 3.6m (according to Ruimte voor de Voetganger, 2023)
Parking pressure	Min = 0% , Max=100%

Table 12: Factors for which an interval of interest is assigned.

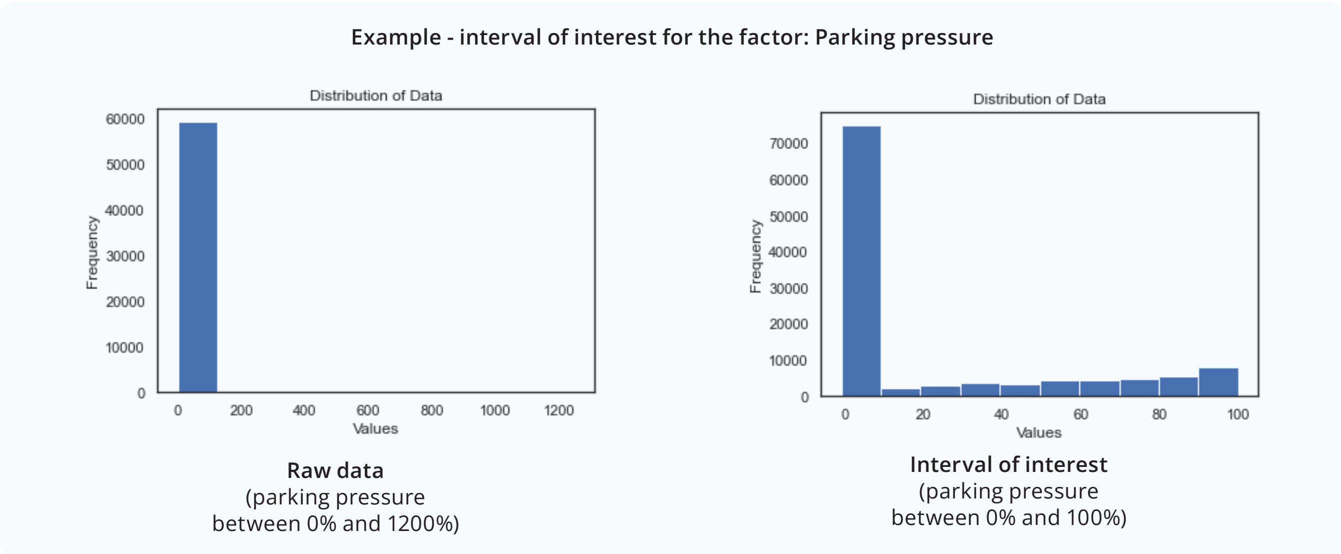


Figure 11: Example of the application of an interval of interest.

6.5 Normalisation

To be able to compare the different street walkability criteria, the scales of the data need to be normalised. To this end, all columns of the dataset containing the street qualities information are normalised using the Min-Max function of the scikit-learn package (Pedregosa et al., 2011) in Python. This min-max normalisation process distributes the data along a scale of 0 to 1. This technique of normalisation is preferred as it retains the proportions between values in the same column and allows for easier comparison and interpretation of the results.

6.6 Transformation

In some cases, the qualities that are being reflected by the dataset are considered negative for walkability. For example, the more vehicles parked on the street, the lower the walkability. To reflect this relationship, the normalised score is transformed to reflect the complement of the value in the interval from 0 to 1. For example, if a street segment has a score of 0.8 in obstacles after normalisation, its complement would be 0.2 (1 - 0.8 = 0.2). This can be understood as "flipping" the scores to match the relationship with walkability. This transformation is performed for: maximum speed, number of accidents involving pedestrians, crime, parking pressure and number of obstacles.

Example - Normalisation and transformation for the factor: Parking pressure

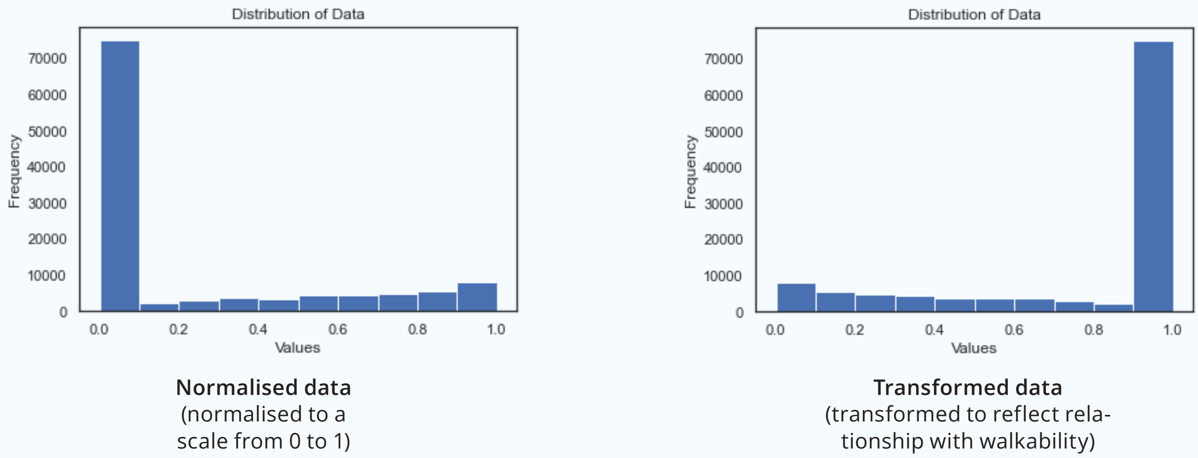


Figure 12: Example of data normalisation and transformation.

6.7 Index Calculation

To obtain the final walkability score, the normalised factor data are multiplied by their weights as obtained from the Z-scores of the Q methodology. Thematic sub-indexes for the categories discovered in the interviews are also calculated maintaining the weights of the general index. As mentioned in the interview results (Section 5.5) some factors contribute to more than one sub-index. Figure 13 (in the next page) displays the influence of each factor in the general index and the factors that are combined to create the thematic sub-indexes. To calculate the index, the normalised score of each factor is multiplied by its weight, the addition of this values conforms the final walkability score. It is worth noting that even though one factor contributes to two different sub-indexes, it only contributes once to the general index. The thematic sub-indexes are calculated by multiplying the factors of the corresponding factor group by the weight and then normalising the result to obtain a score between 0 and 100.

6.8 Chapter summary

Using the Z-scores calculated in the Q methodology, weights are calculated for the factors that are relevant and for which data is available. The GIS methods allow to integrate different types of information to the walkable network layer of Amsterdam. Finally, the information is normalised and transformed to make it comparable and facilitate the calculation of final scores. Six different scores are calculated for every street segment, five describing different groups of characteristics as found in the interviews (Section 5.5) and one general walkability index that reflects the combination of all the scores.

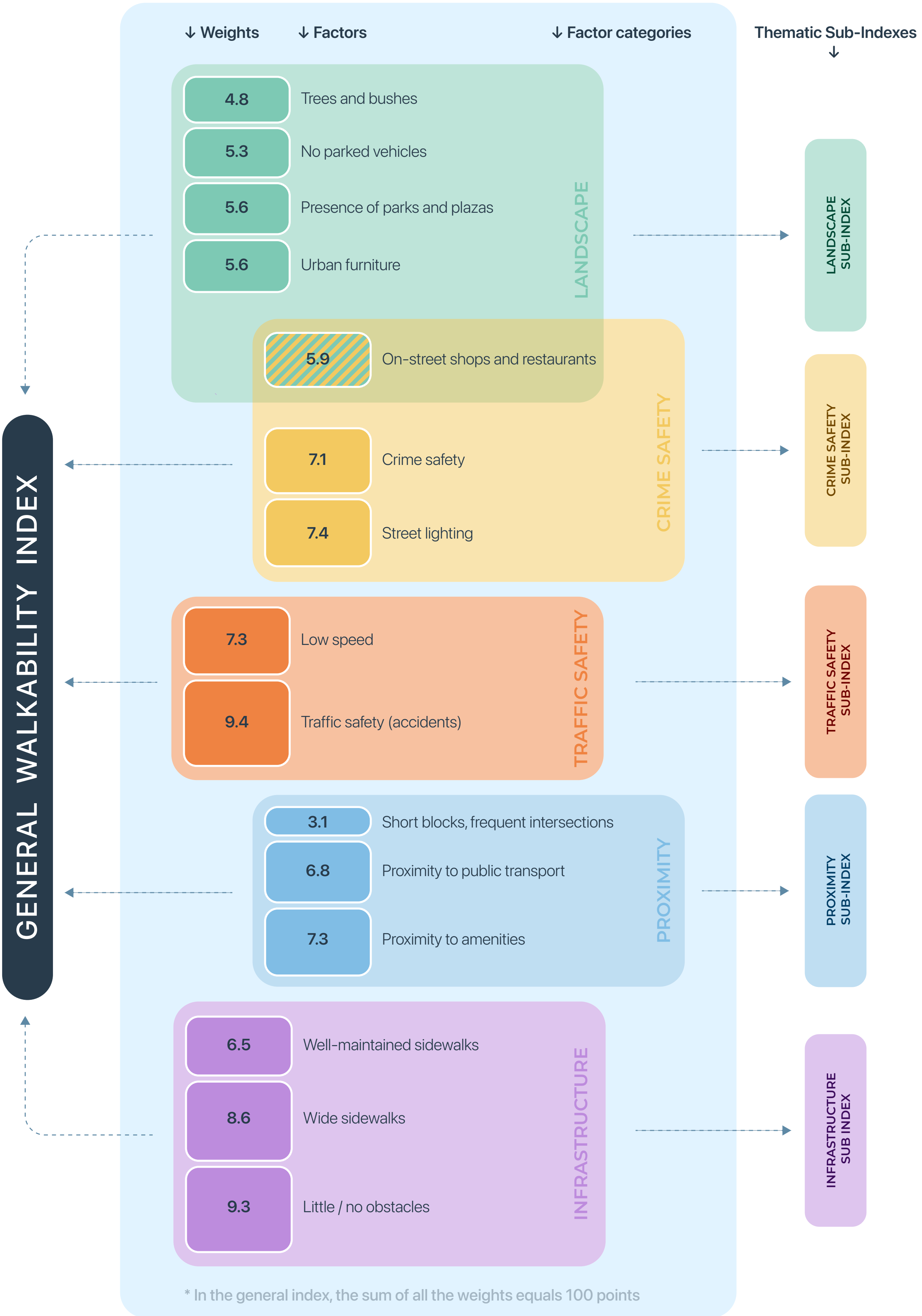


Figure 13: Index calculation scheme.

7. Results

7.1 Introduction to the results

This chapter presents the results of the walkability analysis made for Amsterdam. By focusing on the use of maps to visualise and understand the spatial distribution of the different walkability factors, valuable insights can be obtained for different areas of the city. Some examples with radar charts of the street level scores are also included to highlight how the sub-indexes help to understand why certain streets obtain higher or lower scores.

The Jenks clustering method, a well-established classification technique for maps data (Tortum & Atalay, 2015), is employed to classify the walkability data into distinct categories that correspond to the colour scale of the maps. This method minimizes the variation within each category while maximizing the differences between them, resulting in visually distinct and meaningful groupings. Thanks to this approach, the maps presented in this chapter allow for an easier understanding of the varying levels of walkability across different areas.

In some cases, the maps showcased in this chapter highlight specific areas that display notable walkability characteristics. This showcases how the maps can be used to gain valuable insights into the dynamics that contribute to either high or low levels of walkability, thus providing a deeper understanding of the urban environment.

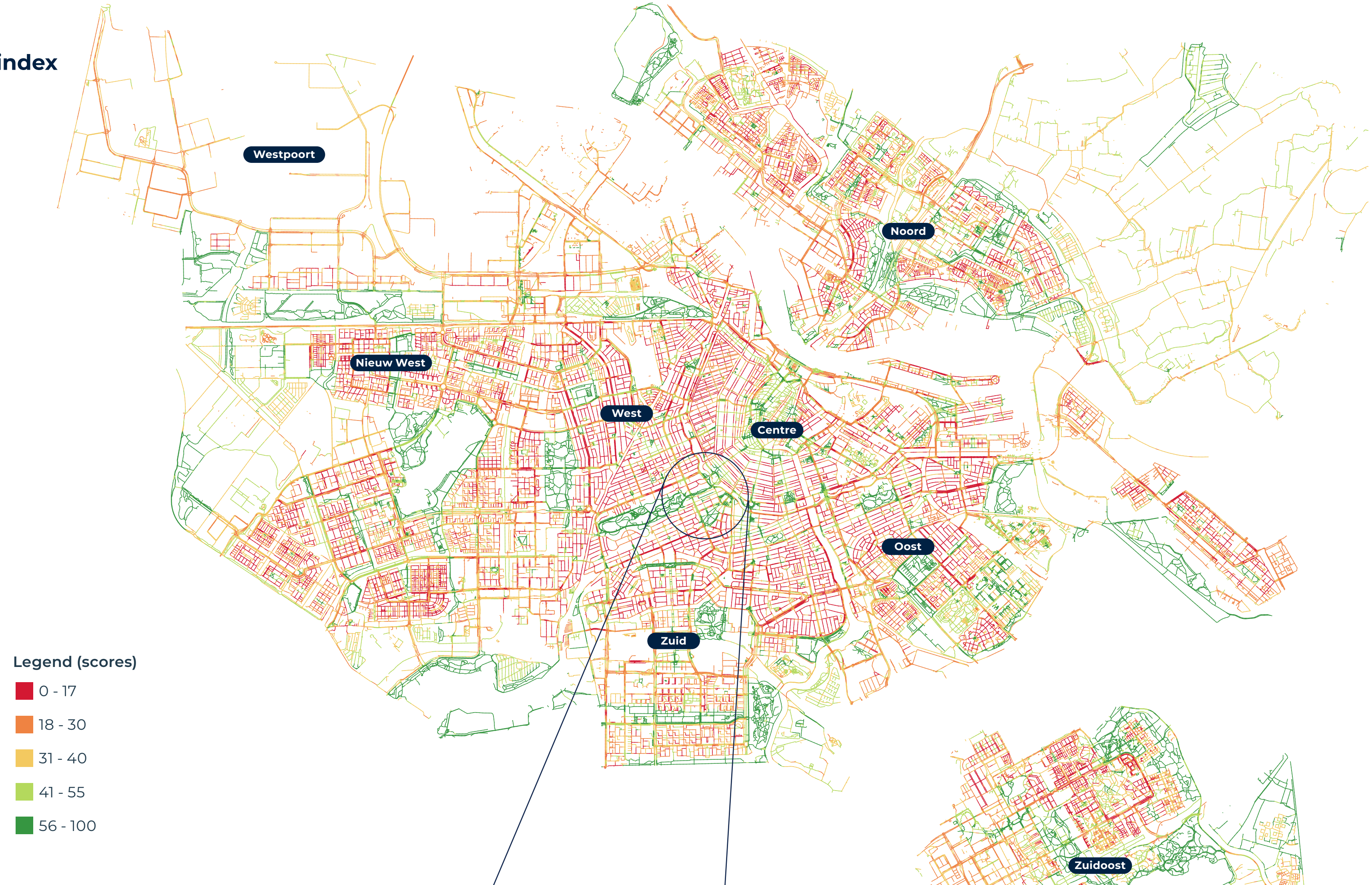
This chapter presents first the sub-indexes that reflect different groups of qualities of the urban environment. This builds up to the general walkability index map which displays the final scores. Finally, the street level examples are shown.

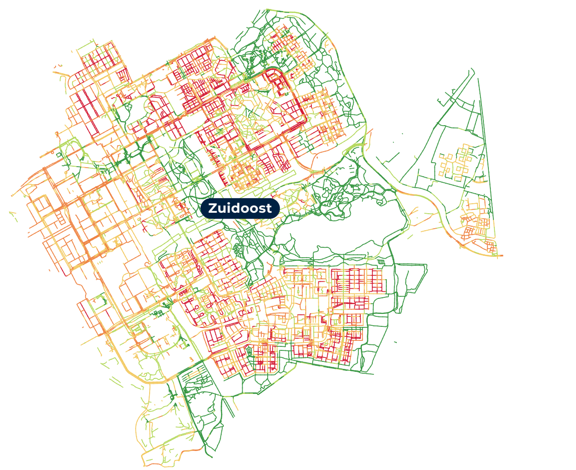
By providing an overview of the spatial distribution of walkability factors, this chapter sets the stage for further analysis and discussion.

7.2 Landscape sub-index

Factors considered in this sub-index

- Trees and bushes on the street
- Presence of plazas and parks
- No parked vehicles on the street
- Urban furniture
- Many shops and restaurants open towards the street



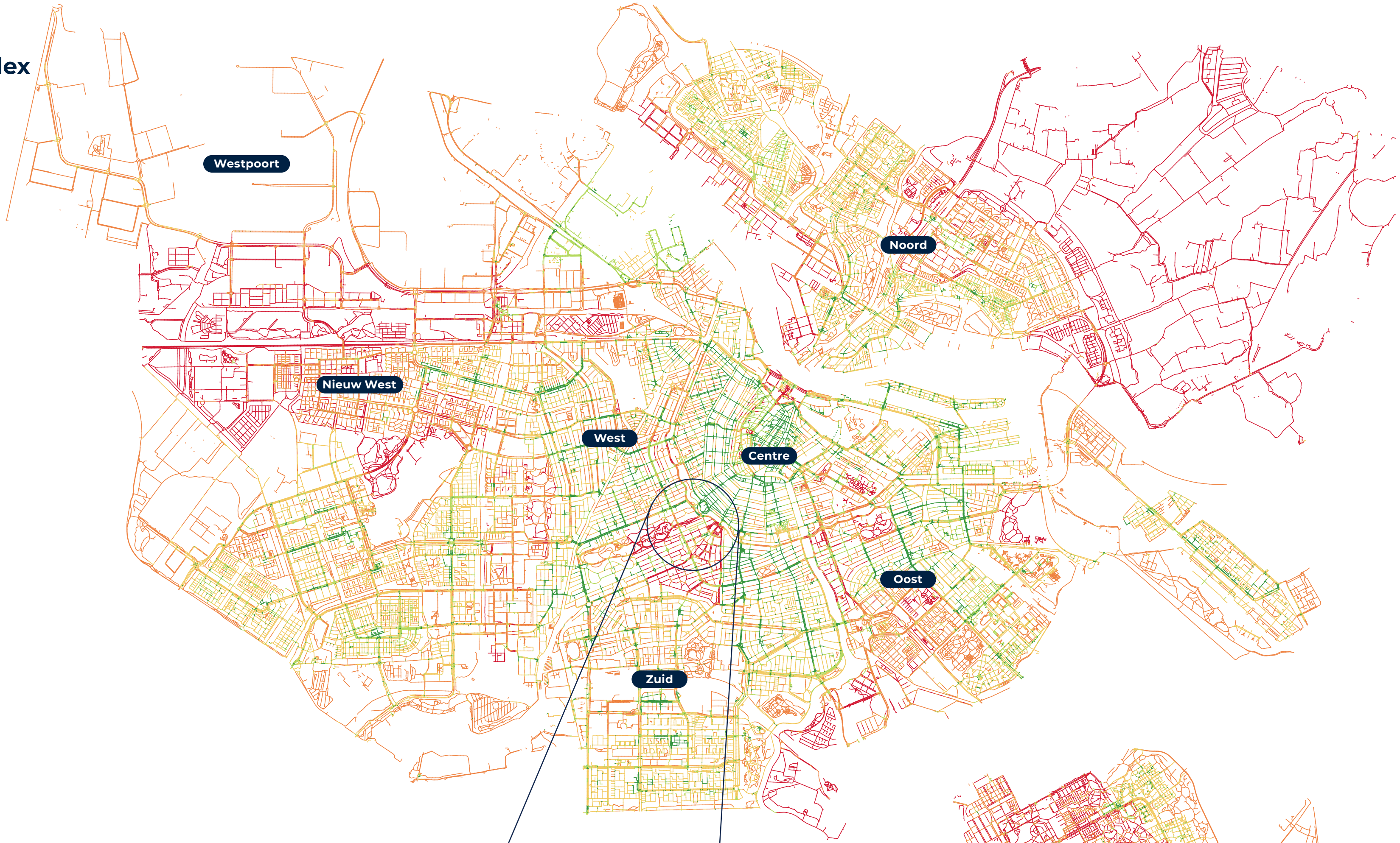


Description

The landscape sub-index reflects the qualities of the built environment that are described as positive for the enjoyment of the walking experience. Parks and other green areas are highly ranked in this index as well as the city centre because of the high density of amenities.

Example
Vondelpark receives high scores because of the high number of trees and benches it contains. Some streets around that area are also highly ranked because they have lots of shops and restaurants open.

7.3 Crime Safety sub-index



Factors considered in this sub-index ↓

- Crime safety
- Street lighting
- Many shops and restaurants open towards the street

Legend (scores)

- 0 - 17
- 18 - 28
- 29 - 40
- 41 - 56
- 57 - 100

Description

The Crime Safety sub-index identifies streets that lay in neighbourhoods that are considered less safe and considers also the amount of street lighting as well as shops and restaurants open towards the street. Streets in the city centre score in general higher while Nieuw West, Noord and Zuidoost have streets with lower scores.

Example

In contrast to the landscape index, parks like Vondelpark receive lower crime safety scores due to reduced public lighting to preserve wildlife.

7.4 Traffic Safety sub-index

Factors considered in this sub-index

- Traffic safety
- Low speed for vehicles

Legend (scores)

- 0 - 24
- 25 - 62
- 63 - 68
- 69 - 81
- 82 - 100

Description

The Traffic Safety sub-index reflects the speed of the streets and identifies areas where accidents involving pedestrians have happened. This sub-index is especially useful to identify intersections and streets that have a record of unsafe interactions between pedestrians and vehicles.

Example

Parks receive the highest scores because of their absence of cars. Intersections where accidents involving pedestrians have happened receive the lowest scores.

7.5 Proximity sub-index

Factors considered in this sub-index

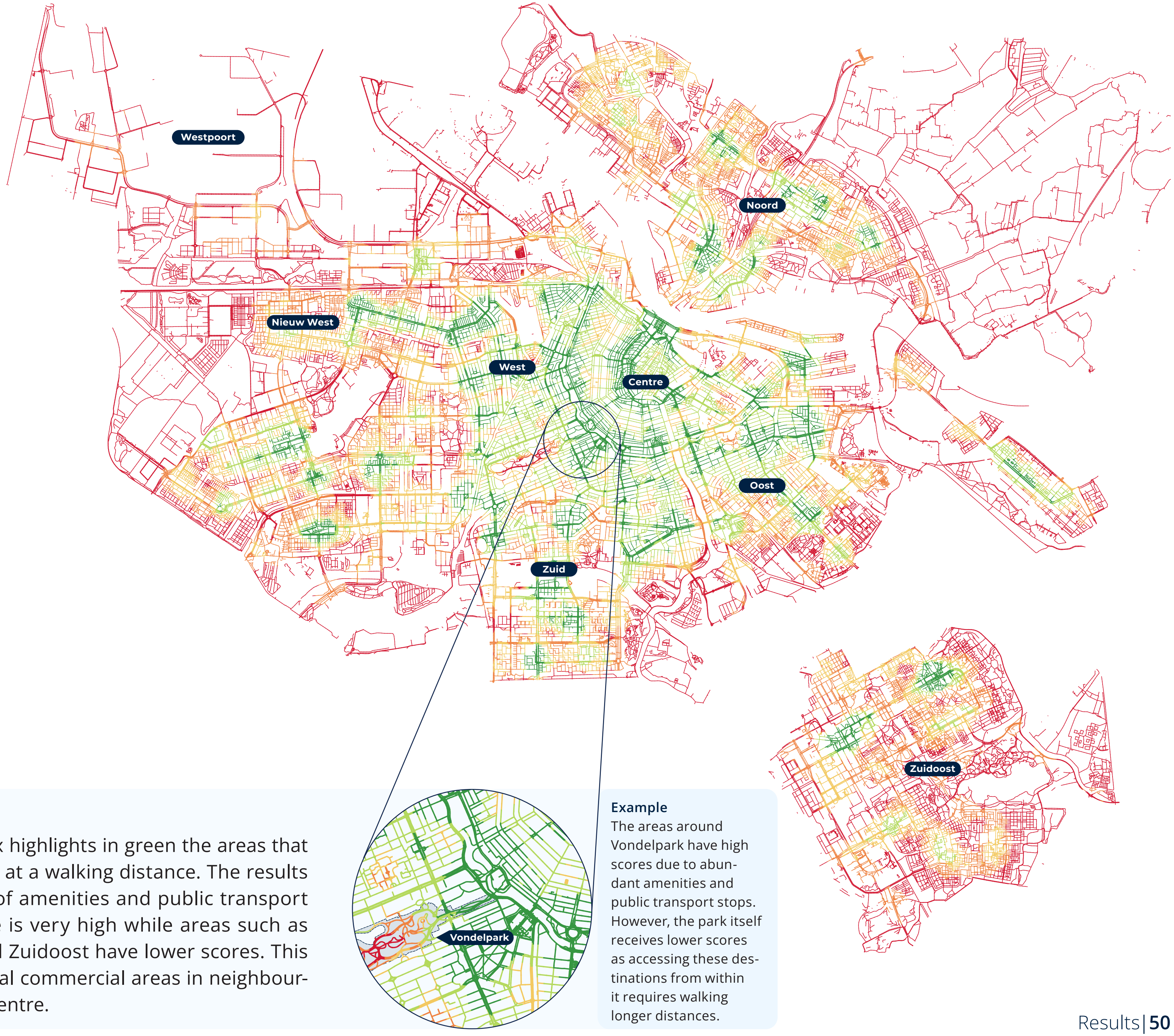
Proximity to amenities

Proximity to public transport stops

Short blocks, frequent intersections

Legend (scores)

- 0 - 18
- 19 - 38
- 39 - 59
- 60 - 80
- 81 - 100



Description

The Proximity sub-index highlights in green the areas that have more destinations at a walking distance. The results show that the density of amenities and public transport stops in the city centre is very high while areas such as Noord, Nieuw West and Zuidoost have lower scores. This index also identifies local commercial areas in neighbourhoods outside the city centre.

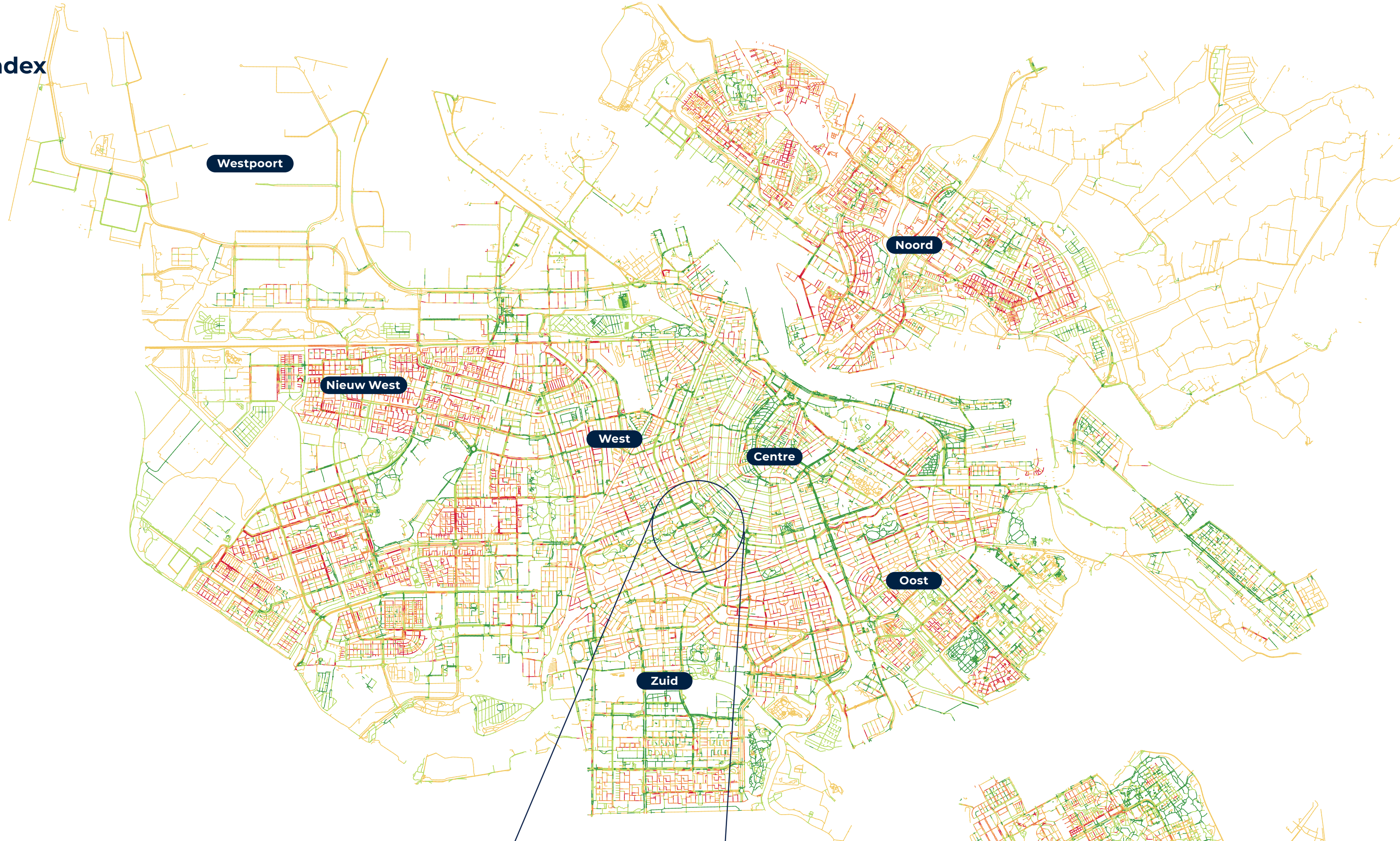
Example

The areas around Vondelpark have high scores due to abundant amenities and public transport stops. However, the park itself receives lower scores as accessing these destinations from within it requires walking longer distances.

7.6 Infrastructure sub-index

Factors considered in this sub-index ↓

- Wide sidewalks
- Little / no obstacles on the sidewalk
- Well maintained sidewalks



Legend (scores)

- 0 - 32
- 33 - 45
- 46 - 58
- 59 - 73
- 74 - 100

Description

The Infrastructure sub-index pinpoints streets with narrow sidewalks, lots of obstacles, low maintenance levels, or a combination of the three. Because of the level of detail and the street-by-street specificity of the factors it considers, the results of this sub-index are difficult to read in a general level but can inform targeted street-level analysis and interventions.

Example

In this case, the Vondelpark receives mixed scores. Some of its segments are wide and free of obstacles but in other places there can be high numbers of bollards and other barriers combined with narrow paths.

7.7 General Walkability Index

General index process

LANDSCAPE SUB-INDEX

+

CRIME SAFETY SUB-INDEX

+

TRAFFIC SAFETY SUB-INDEX

+

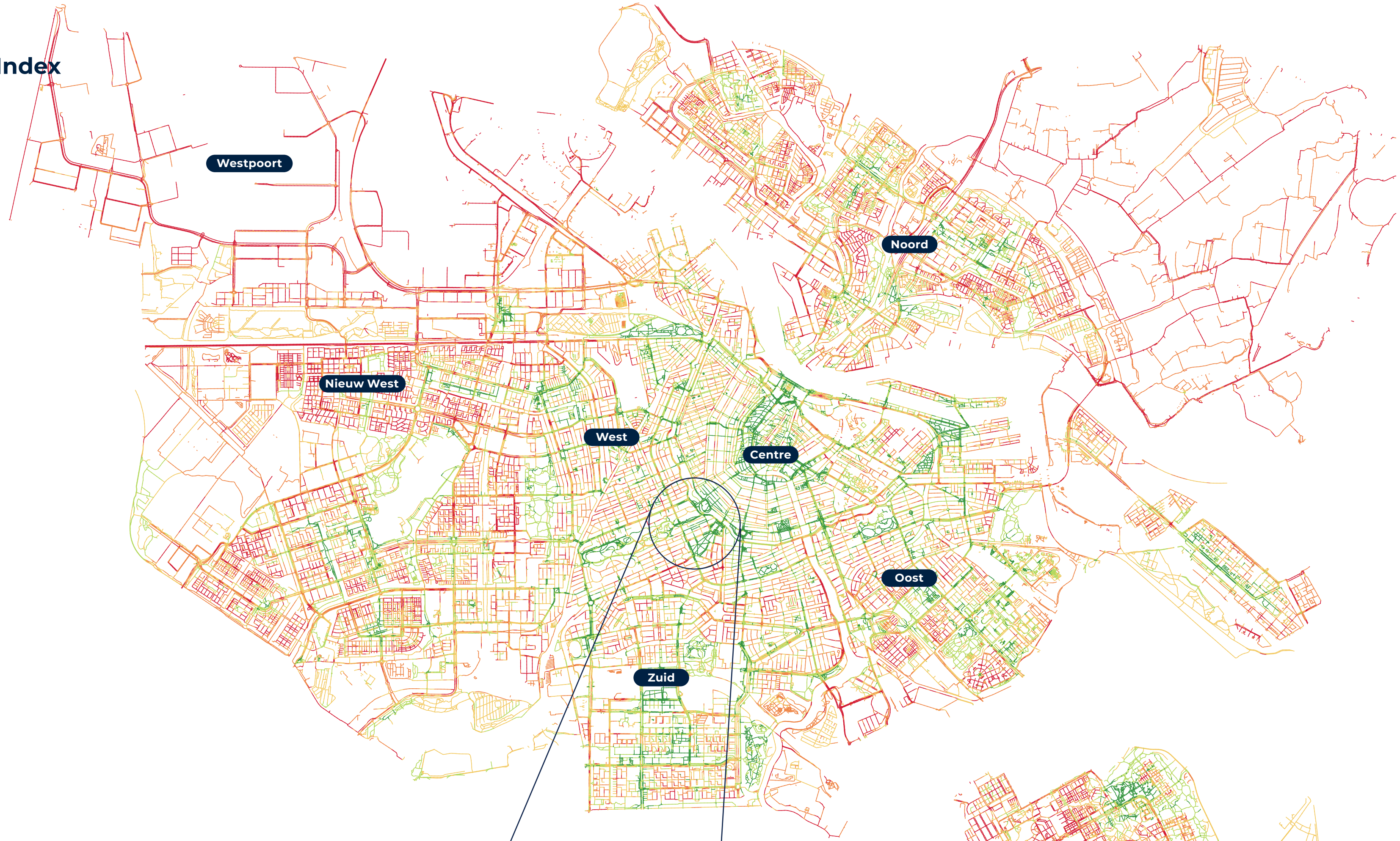
PROXIMITY SUB-INDEX

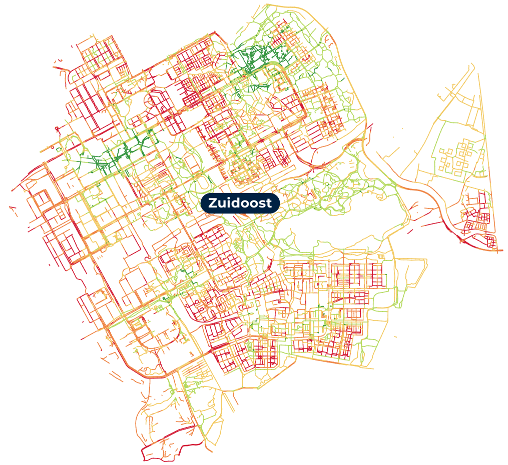
+

INFRASTRUCTURE SUB INDEX

↓

WALKABILITY INDEX





Legend (scores)

- 0 - 31
- 32 - 40
- 41 - 50
- 51 - 60
- 61 - 100

Description

The general walkability index map displays the final scores obtained by the street segments and highlights in green areas that obtained high scores in many of the thematic sub-indexes. This index helps identify areas that -because of their micro and macro characteristics- can be considered more walkable.

Example

The Vondelpark and its surroundings show relatively high scores. This score is mainly due to the high proximity to destinations, positive landscape qualities and good pedestrian infrastructure.

7.8 Street level examples

The value of this index lies also on its street-level disaggregated scores. These give insights into the situation of any particular street segment of Amsterdam and how it compares to the rest of streets. This section displays some examples where streets with high, average and low scores.

Location of the streets showcased in this section

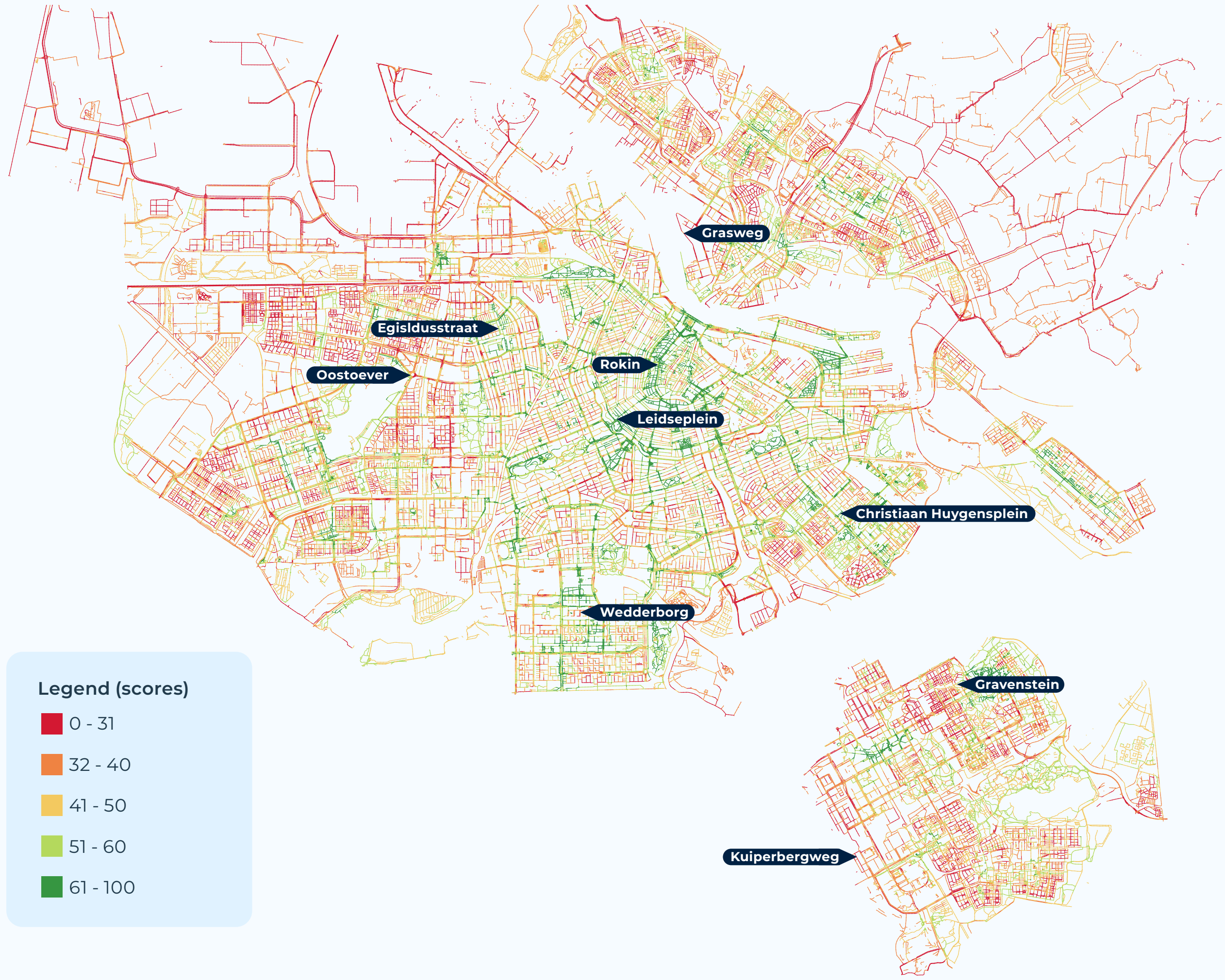
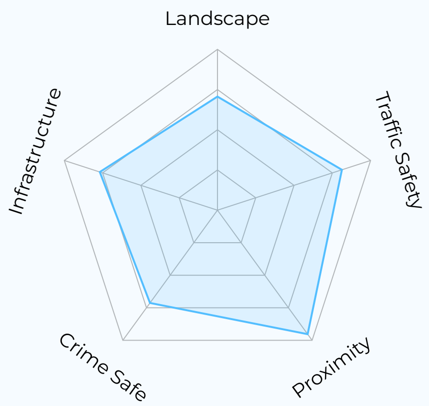


Figure 20: Location of the street-level examples.

Street-level examples (from highest to lowest walkability score)

Leidseplein

Walkability score: 73/100



Insights
Leideplein scores high in all categories, especially in proximity because of the high density of amenities in the area.

Rokin

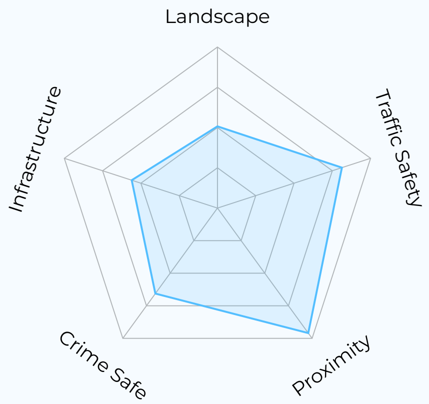
Walkability score: 64/100

Credit: Google Street View, 2023

Insights
Lack of greenery and a negative crime perception make Rokin's landscape and crime safety scores low. In general it still receives a good walkability score.

Christiaan Huygensplein

Walkability score: 63/100

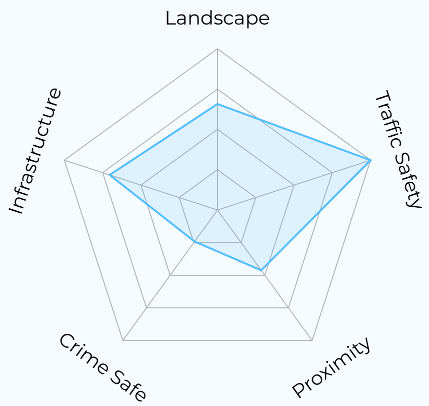



Credit: Google Street View, 2023

Insights
The presence of obstacles in the sidewalks makes this street's score lower in infrastructure while the proximity to amenities is very high.

Vondelpark

Walkability score: 62/100

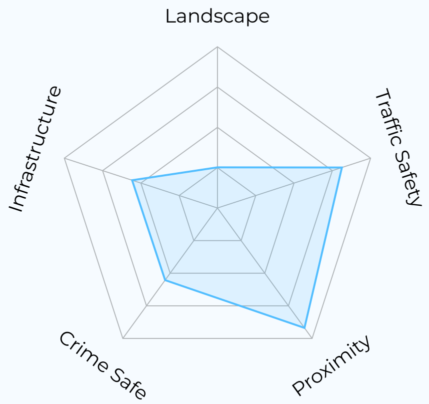



Credit: Google Street View, 2023

Insights
This path in the Vondelpark scores low in crime safety due to the absence of public lighting and shops or other amenities.

Egisldusstraat

Walkability score: 55/100

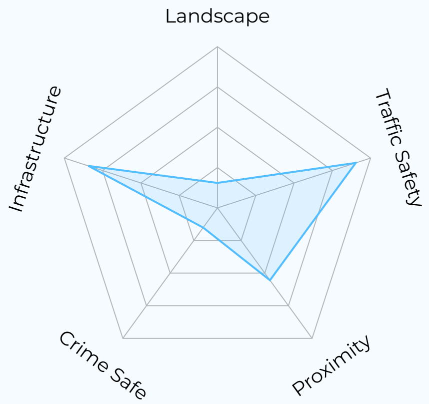


Credit: Google Street View, 2023

Insights
Few trees, lots of parked vehicles, and lots of obstacles on the streets make this streets scores in landscape and infrastructure low.

Gravenstein

Walkability score: 47/100

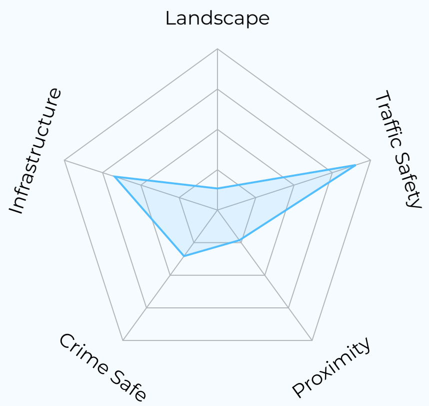


Credit: Google Street View, 2023

Insights
Lots of parked vehicles and a negative crime safety perception combined with the lack of amenities on the street make the scores of Gravenstein low.

Wedderborg

Walkability score: 41/100

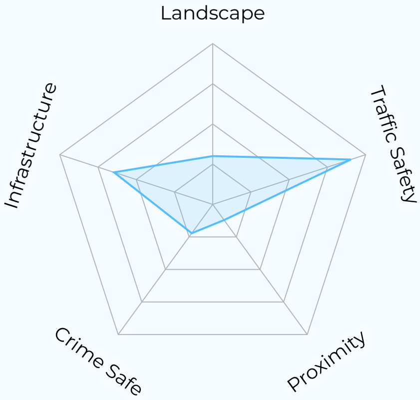


Credit: Google Street View, 2023

Insights
Similar to Gravenstein, lots of parked vehicles and a negative crime safety perception make scores go down. In this case there are less amenities close by.

Kuiperbergweg

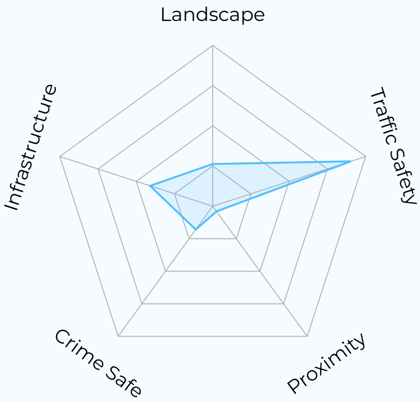
Walkability score: 39/100



Insights
Narrow sidewalks, parked vehicles, lack of amenities or public transport close by, and a negative crime perception make this street's score low in general.

Grasweg

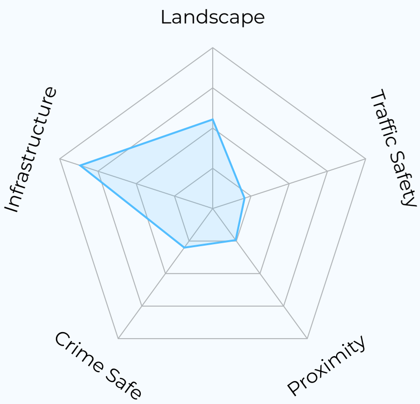
Walkability score: 32/100



Insights
All categories but one receive low scores indicating a low walkability. Traffic safety remains high due to the 30 km/h speed limit in this street.

Oostoever

Walkability score: 28/100



Insights
While infrastructure scores high in this street, all other categories score low. Traffic safety is low because of previous accidents and high speed limits.

Figure 21: Street level examples.

7.9 Validation

To understand if the proposed method is effective enough to address the research question and provide reliable results, two ways of validating the outcomes are explored. This allows to identify the potential flaws in the research design or execution and provides valuable information for future research by indicating the reliability of the results.

Validation by comparison with other walkability indexes

The first method is comparing the index results with another walkability index created by the municipality of Amsterdam. The municipality's index extent is limited to the city centre and bases the scores on the relationship between the effective walking space (remaining sidewalk width after considering the space taken by obstacles and parked bikes) and the pedestrian demand. When looking for Pearson correlation between the scores of both indexes, it was found to be close to zero. This outcome means that both indexes highly differ in the scores given to the streets. Lo (2009), explains that the definition of walkability has considerable implications for the evaluation and design of urban transport networks, streets and other public spaces. The low correlation found through this validation method can indicate that the indexes are based on different definitions of walkability and therefore focus on measuring different characteristics of the public space. Approaches such as the one proposed by this study help in the identification of the relevant factors to measure so the resulting index can better reflect what people consider walkable.

Validation by surveying walkability perceptions

The second validation method seeks to compare the scores obtained by the index with the scores given by a sample of respondents. This allows to evaluate how the index performs in terms of estimating people's perceptions about the walkability of the street. A randomly selected sample of 10 streets (2 corresponding to each of the 5 quantiles of the final scores) is used for this method. The participants were asked to fill in a survey containing images from every street segment and the name of the neighbourhood, with this information in mind, they were asked to rank the walkability of the street guided by the following question: How inviting do you find this street for walking? Given the limited time and resources of this study, a convenience sample of 26 participants is selected. This gives an indication of how accurate the index can be but it is not representative of the broader population of Amsterdam. The answers from the survey had a strong correlation of 0.86 (P=0.001) with the scores calculated in the index. Figure 17 shows the results of this validation method and the individual scores obtained by each street segment.

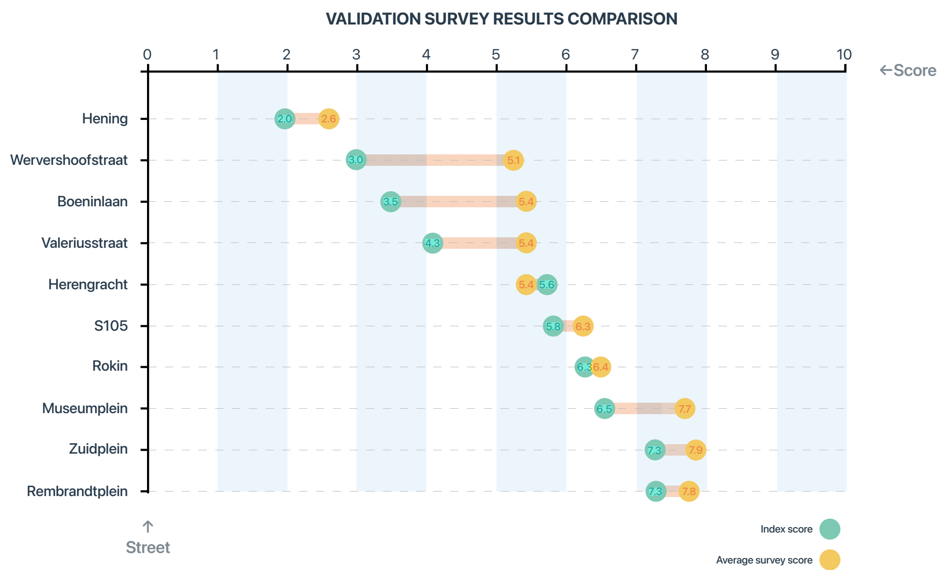


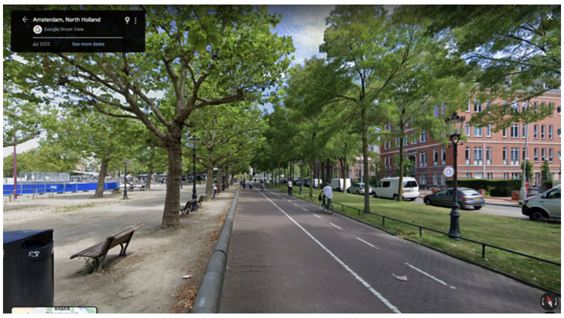
Figure 22: Comparison of the validation survey results and the estimated scores.

Interestingly, the streets that had lower scores in attributes that can not be directly inferred from the pictures had the highest differences between estimated and actual scores. Attributes such as proximity to destinations or crime and traffic safety are difficult to grasp from a picture (Figure 18) and that is reflected on the difference in scores.

↑ Boeninlaan (Google Street View, 2023)

↑ S105 (Google Street View, 2023)

↑ Herengracht (Google Street View, 2023)

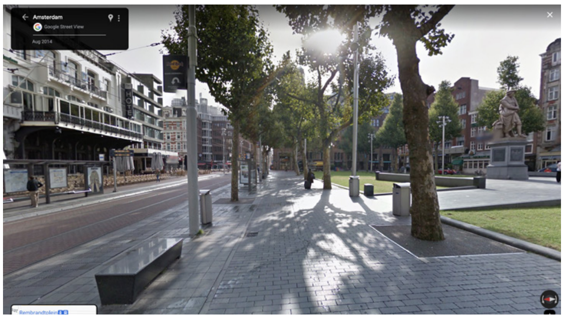


↑ Museumplein (Google Street View, 2023)

↑ Wervershoofstraat (Google Street View, 2023)

↑ Hening (Google Street View, 2023)

↑ Rokin (Google Street View, 2023)



↑ Rembrandtplein (Google Street View, 2023)

↑ Zuidplein (Google Street View, 2023)

↑ Valeriusstraat (Google Street View, 2023)

Figure 23: Street segments included in the validation survey (Google Street View, 2023).

Figure 24: Example of walkability factors in a street.

8. Discussion

8.1 Main findings

This section discusses the main research outputs of this thesis. The first one consists of the mixed methods approach that combines the collection of subjective points of view with GIS data processing to create a context-specific walkability index. The second output consists of the walkability scores obtained through the application of this method to the case study area of Amsterdam.

Mixed methods approach

This thesis began with the idea of exploring ways to create a context-specific walkability index. The benefit of creating a context-specific index is that it accounts for the particularities of an urban area and measures what its inhabitants consider most relevant. In contrast, generic indexing methods are not able to take into account particular characteristics of the city and usually assume a one-size-fits-all approach. This can be positive in some cases such as when comparing the walkability of different cities across the world or working with large geographical areas. But, when working on a smaller scale, the subjective views on the public space (Ewing & Handy, 2009) and pedestrian streetscape factors (Millstein et al., 2013) become more relevant.

The mixed methods approach allows the participatory creation of a context-specific walkability index. By departing from what other studies consider as relevant factors for walkability, the method proposes the creation of a universe of walkability factors that have the potential to be relevant for any given urban area. Then, using the factors discovered in the literature review, the Q methodology is applied to a group of relevant stakeholders that represent the views on what a street must contain to be considered walkable in the study area. Finally, by using publicly available datasets, the relevant factors are measured in GIS and a score is assigned to every street segment. Since the resulting score is conformed by the mix of several different factors with various weights, it can be difficult to understand why certain score is assigned. To give more digestible information, sub-indexes that measure specific groups of factors can also be calculated, giving a more in-depth perspective of the characteristics of a street segment. In some cases, the thematic sub-indexes can be more useful than the general index because of the legible and more detailed information they provide.

The innovative combination of Q-methodology and GIS analysis showcased in this study ensures that the resulting index relfects the characteristics that are actually relevant for the group of participants. The guiding assumption of the research was that the collection of perspectives from decision-makers and advocates can give an insight into the general perspectives around walkability in Amsterdam. By including other groups in the study, the relevant factors might change. This combination of methodologies proved to be especially useful to assign weights to the different factors in the index, giving more relevance to the characteristics that are appreciated the most by the participants. The direct connection between the weights obtained from the Q-methodology and the final index (and sub-indexes) gives an understanding of the city through the eyes of the participants and unveils new insights on how the decision to walk in an area is made. This kind of insights can give decision-makers a more in-depth understanding of the qualities of the built environment that citizens appreciate and where they are lacking. The main challenges this combination of methods poses is the simplification of the perspectives on walkability and the limited number of factors that can be ranked in a normal Q-methodology session. While the obtention of a combined view on walkability from all the individual perspectives allows the creation of an index, a certain amount of detail is lost in this simplification process. The different clusters of perspectives that are combined to create the index, provide by themselves rich details on what different groups of people value in their walking experiences. In the future, they can inform the creation of other types of sub-indexes, for example an index that measures positive qualities only for recreational or utilitarian walking.

As this study focuses on the development of a methodology and not on its refinement, many components of the walkability index are rudimentary. The data processing tools and the method chosen to link the Q methodology with the GIS process has still a range of possibilities for improvement, for example, other ways of translating the results of the Q methodology to weights for the index need to be explored. Furthermore, a large proportion of the steps taken to process the Q methodology results and to deal with the datasets for measuring walkability are not automated, which leads to a considerable manual effort for reapplication.

This methodology is built upon the assumption that high-quality datasets on all (or at least most) of the factors are publicly available. However, this is not often the case. Therefore, in future applications of this method, it might be relevant to first assess the factors for which data is available before collecting the perspectives on walkability.

Walkability Index

This section discusses the results of the application of the methodology to create a walkability index and the findings of every phase of the research.

The literature review indicated that proximity to destinations is usually considered the most popular predictor of walkability. In general, the qualities of the individual streets are less popular in other studies with most walkability measures focusing on neighbourhood-level metrics. This does not necessarily mean that these are less relevant, it can also be the case that street-level factors are more challenging to measure and process into an index. Millstein (2013), mentions the expense of data collection and the lack of well developed and accessible scoring systems as the main reasons why street-level factors are less often studied.

The Q methodology revealed three main points of view on walkability, with the biggest group being the one that prioritizes the quality of the infrastructure and general safety. The second group prioritised having amenities and public transport stops within walking distance but also feeling safe. Finally, the third and smallest group focused on having good infrastructure but also having factors that make walking enjoyable. A considerable overlap between the three groups was observed and that also reflected in the final ranking of factors, which was able to reflect at least 48% of the variability of all the individual opinions but one. The perspectives on walkability and the factor groups obtained from the interviews give an indication of what is important in order to make the streets more attractive for pedestrians. The existence of various perspectives on walkability in Amsterdam supports the theory explained by Methorst (2021), which affirms that walking is not only influenced by the built environment but also by a series of personal factors. The choice to apply the Q methodology to decision-makers and advocates means that the results reflect the views of that group in particular and can not be concluded that these are the only views on walkability in Amsterdam. It is likely that the results would greatly vary if the same method is applied to other groups such as the elderly, wheelchair users, children, etc.

The general walkability scores revealed that areas such as the city centre, certain parks or the surroundings of train stations usually present higher walkability scores as can be seen in Figure 20. This can be explained by the concentration of positive landscape attributes in parks and the high density of amenities and public transport that usually surrounds train stations in Amsterdam. Scores are in general lower in the periphery of the city starting from areas close to the A10 ring and outwards. Neighbourhoods like Nieuw West, Noord or Zuidoost obtain in general a lower walkability score. This can be attributed to a lower density of amenities in those neighbourhoods as well as the presence of higher-speed roads and higher criminality scores.

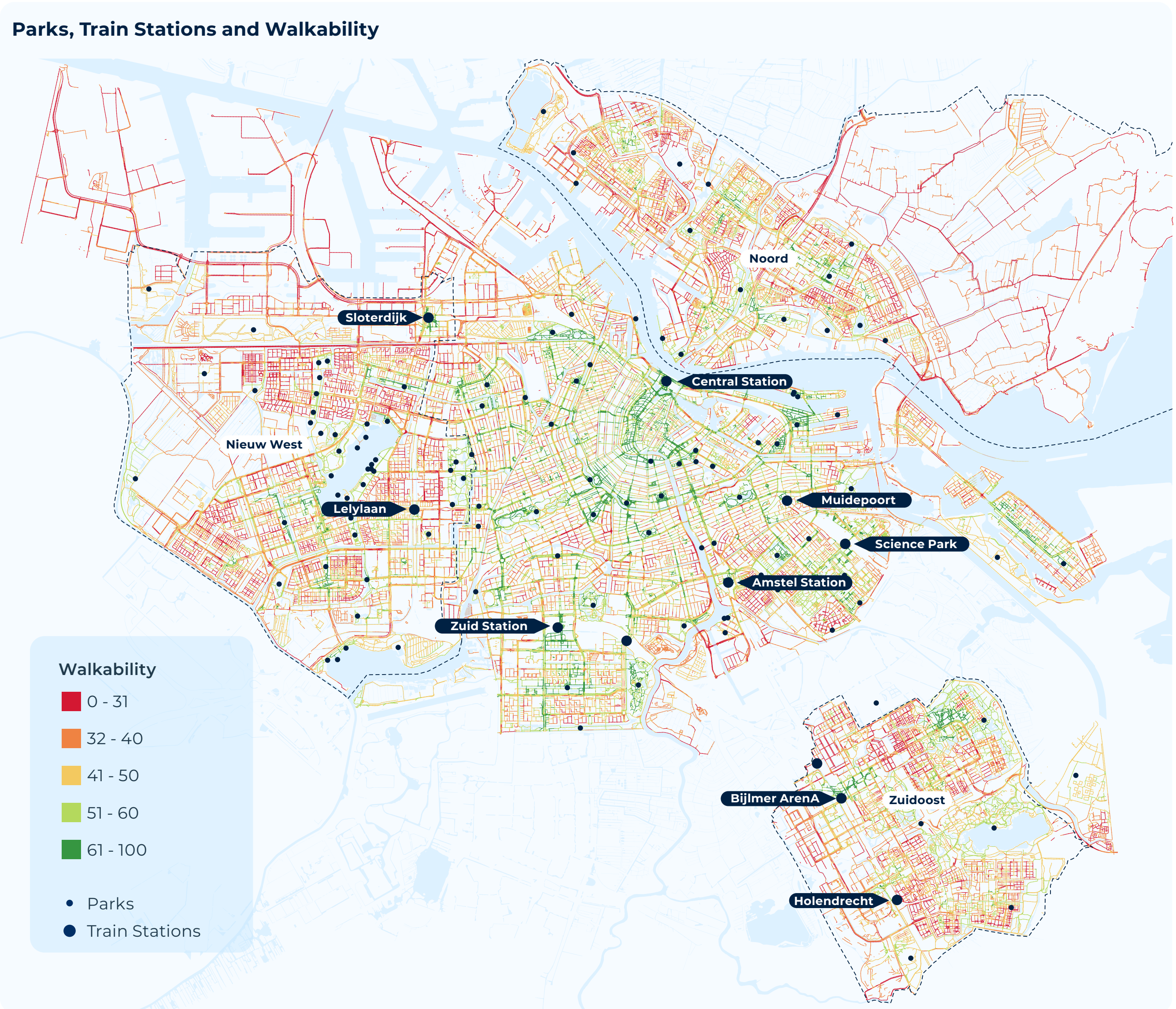


Figure 25: Walkability scores and their relationship to Train Stations and Parks.

To give further insights into why certain streets are perceived as less walkable, thematic sub-indexes were created. The 5 sub-indexes (landscape, crime safety, traffic safety, proximity, and infrastructure) are a result of a series of comments collected from the interviews and reflect specific qualities of the pedestrian space. For example, the sub-indexes can be used to explore how an area like Amsterdam Zuidoost can be made more attractive for pedestrians. The thematic sub-indexes indicate that the infrastructure, landscape and traffic safety are in general good in the area, however, the general score is severely affected by the crime safety perceptions and the low score on proximity to destinations such as amenities and public transport as can be seen in Figure 21. This example highlights the value of the sub-indexes as a tool to interpret why certain streets receive lower or higher scores in the general walkability index.

These maps offer decision makers valuable insights into neighbourhood and street-level requirements. In the case of Zuidoost, decision makers could create policy and interventions to increase the number of amenities in the area and address the negative crime safety perceptions. Similar analyses can be conducted for other Amsterdam areas, uncovering insights and revealing potential issues.

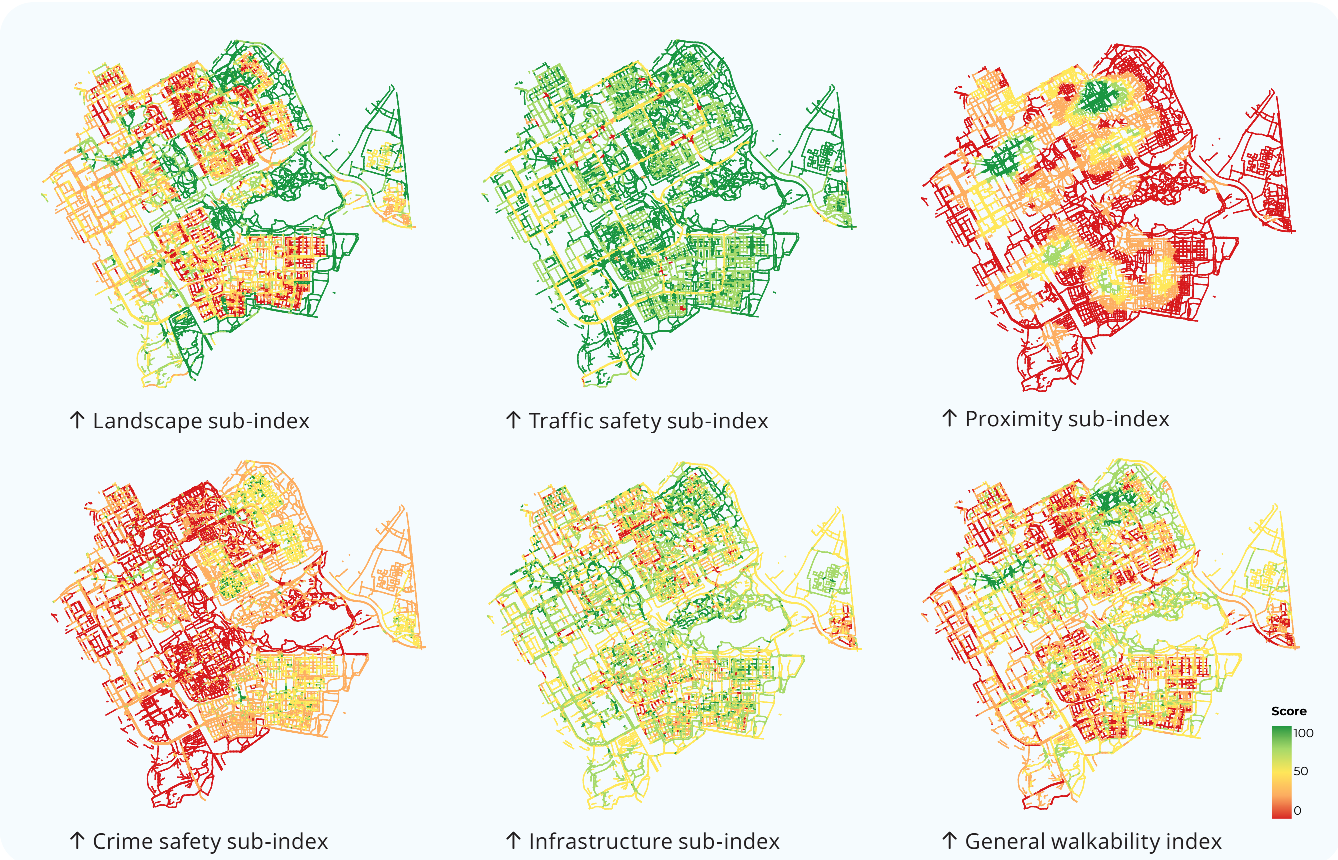


Figure 26: Disaggregated indexes for Amsterdam Zuidoost.

8.2 Interpretation

This section draws the concepts from the theoretical framework to relate some of the findings to the broader walkability discussion.

Factor categories in Amsterdam and general walking needs (Alfonzo, 2005; Methorst, 2021)

Alfonzo proposed the "Hierarchy of Walking Needs" as a way of understanding the factors that might influence people's decision to walk. According to this theory, the factors are organised in a hierarchical order, with the ones at the base of the pyramid being the most essential and becoming satisfiers while moving up in the pyramid. This research found that the factor groups drawn from the interview comments and used to create the thematic sub-indexes reflect some qualities of the groups outlined by Alfonzo, 2005. Adapted versions of this theory are used by the CROW knowledge platform for infrastructure, public space, traffic, and transport in the Netherlands.

As explained in the theoretical framework of this study, the factors proposed by Alfonzo are grouped by its influence on the decision of a person to walk. Figure 22 shows how the order of factors proposed by Alfonzo compares with the ranking and grouping that resulted from the Q methodology and the interviews. When a factor group is connected to a walking need it means that they refer to similar factors. For example, what Alfonzo calls "Accessibility", encompasses the distribution of activities present in the walking area and the connectivity between them. This definition fits with the factors included in the proximity group which refers to the number of amenities and public transport stops within walking distance.

The order of the pyramid of factor groups by average weight reflects the average weight of the factors included in that category in the general walkability index.

The similarity between the walking needs of Alfonzo and the factor groups from the interviews supports the validity of these categories and indicates that the hierarchy of walking needs can be a good starting point for future prioritisation of walkability factors. Interestingly, this research found that opinions on walkability in Amsterdam differ with what Alfonzo and Methorst propose especially in relation to crime safety and proximity, showing that in some cases, it might be more relevant to improve feelings of safety than to have all the possible amenities a person needs close by.

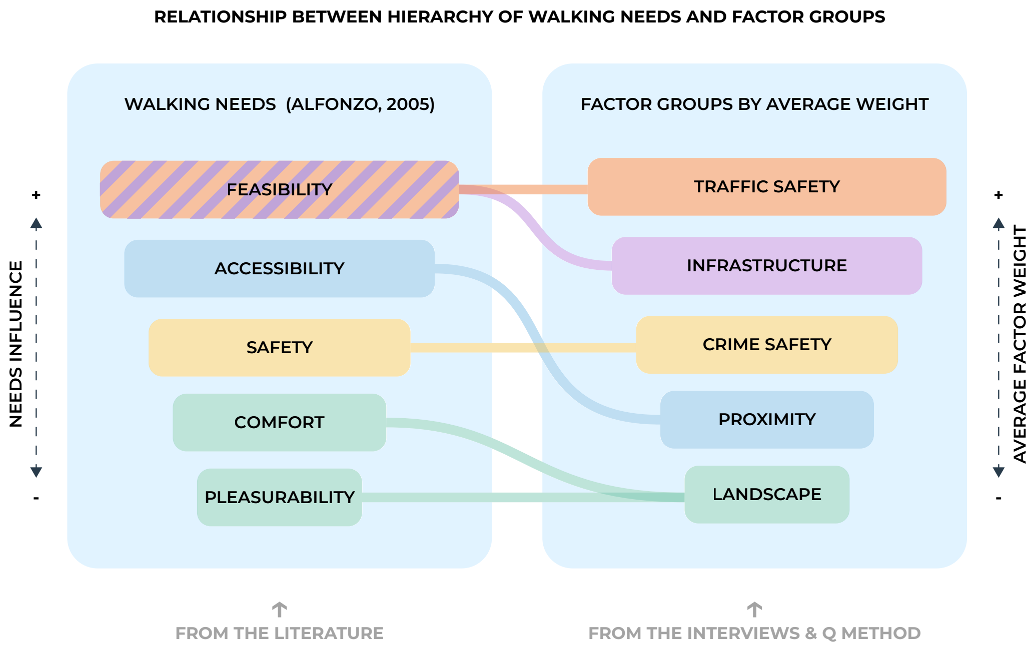


Figure 27: Relationship between the walking needs (Alfonzo, 2005) and the factor groups.

8.3 Discussion

This section builds upon the findings to draw certain insights about the methodology and the current walkability situation in Amsterdam related to the research questions. These reflections also touch upon some limitations and recommendations that will be further explained in the next sections.

The sidewalk as the space for public life

During the interviews, one of the repeating complaints about walkability in Amsterdam was the lack of a policy that regulates minimum sidewalk width and other basic infrastructure conditions such as the absence of obstacles that have shown to be very relevant for walkability. Even though walking is a transport mode accessible for almost everyone (Learnihan et al., 2011) and promotes overall health (Tobin et al., 2022), it often only receives marginal attention and resource allocation. Several advocates for walkability and experts mentioned that there are strict guidelines for the space needed for a car or a bike to move in the city, but when it comes to pedestrians they are usually allocated the remaining space on the street after satisfying the needs of other means of transport.

In addition to the lack of a policy defining minimal infrastructure requirements for pedestrians, pedestrian spaces are usually considered the “buffer” space for all activities that can not happen in a road or bike lane. These spaces often serve as gathering spots for conversations, children’s play, temporary parking of moving vans, or the placement of benches for residents to enjoy the sun. Unlike roads and bike lanes, sidewalks and other pedestrian spaces not only facilitate mobility but also contribute to social capital by fostering human interaction.

Considering that pedestrian spaces are vital for mobility as well as various urban dynamics, it is imperative for the municipality of Amsterdam to prioritize the design of these spaces and develop a clear policy framework. By doing so, the municipality can enhance walkability and address the broader needs of its citizens in a more comprehensive manner.

Figure 28: Examples of sidewalks fulfilling multiple functions beyond mobility.

Scoring paradox

The disaggregated findings suggest that different areas in the city fulfil different functions. For instance, the pedestrian paths in Vondelpark (Figure 24) have in general a high walkability score, but when looking at the thematic sub-indexes it becomes clear that this high score is especially due to its positive landscape and traffic safety attributes. On the other hand, it scores low in proximity to amenities and crime safety. Other areas of the city present similar situations with the highest negative correlation found between landscape and crime safety. This is due to the fact that no street in Amsterdam can have the maximum score in all the factors, some of them become mutually exclusive after reaching certain threshold. For example, if a street segment has as many trees as in the Vondelpark, it is unlikely that it will also have space to accommodate as many shops as some streets in the city centre. This also explains the fact that even though the index scores the streets in relation to each other, no street reaches the maximal or minimal scores. The highest score obtained in the general index is 87 while the lowest is 17 (Figure 31).

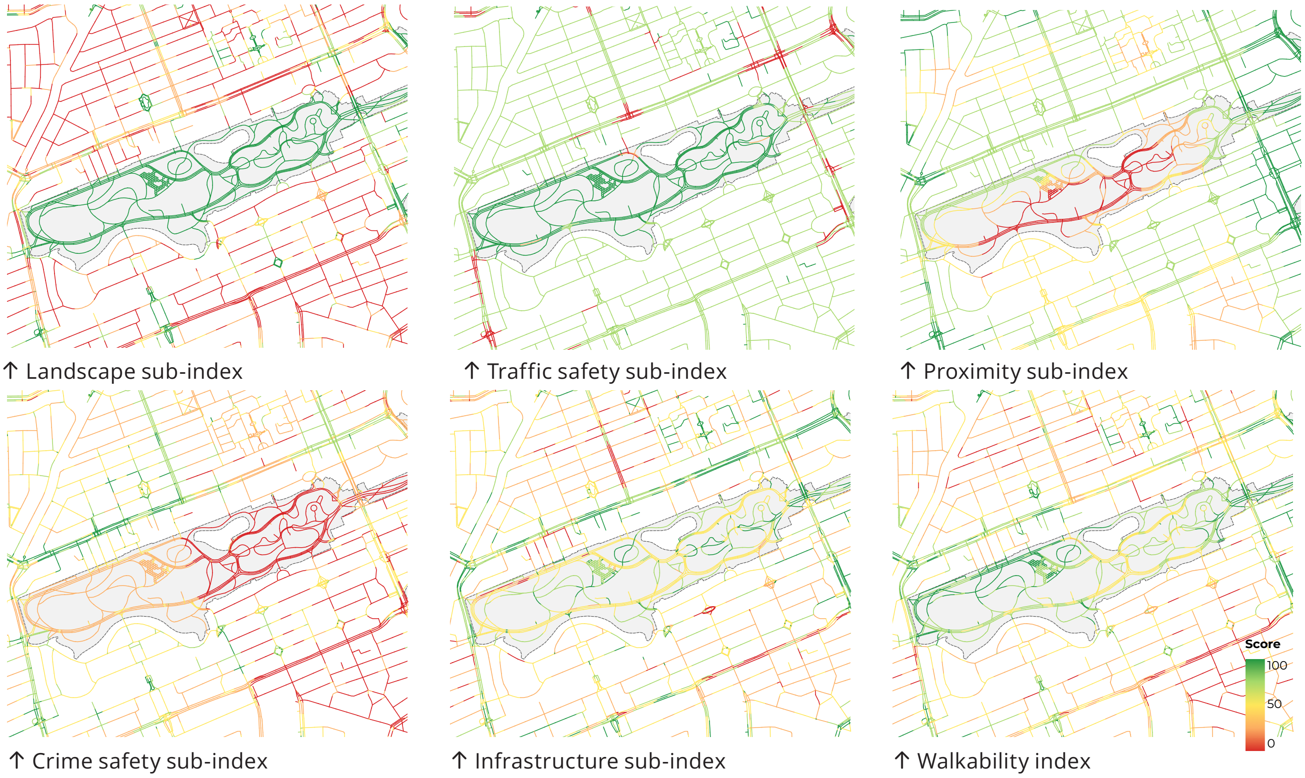


Figure 29: Scores of the different sub-indexes for the Vondelpark.

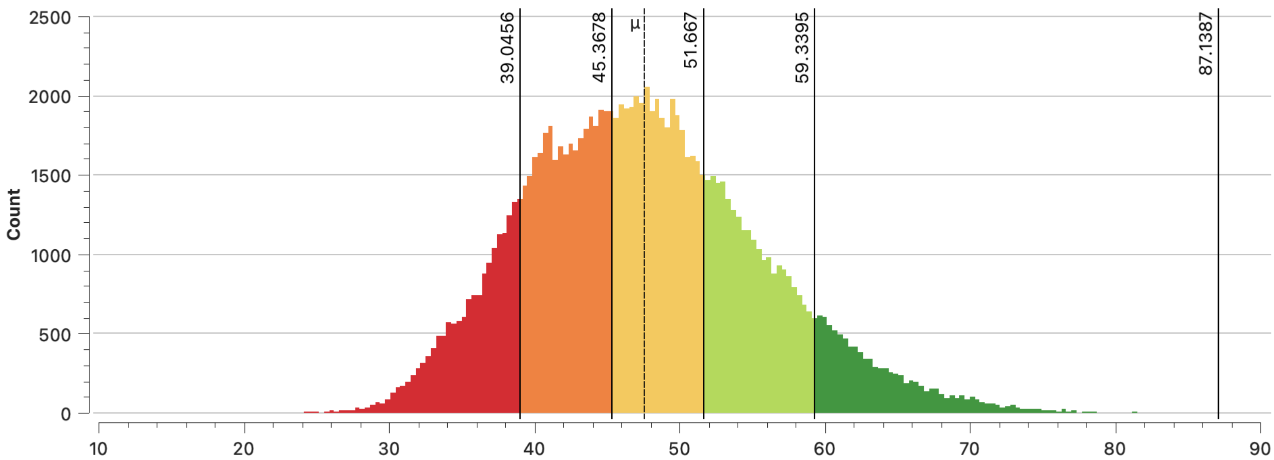


Figure 30: Histogram showing the distribution of the scores in the general walkability index.

Identifying other views on walkability

Although this thesis is based on identifying general levels of walkability, the results are bound to the participant sample considered for the Q methodology. The walkability score is calculated based on the importance attributed to each factor by this group of people and encoded as a weight. If the respondent sample would change drastically, the scores could also experience considerable changes. In the case where decision-makers or other target groups would change their views on walkability, the associated importance of the factors would give a different picture of walkability in Amsterdam, accounting for these new perspectives.

The reapplication of this method in different demographic groups or areas of the city can help in understanding local views on walkability to contextualise them within the larger goals of Amsterdam.

8.4 Implications

The showcased methodology and results for the city of Amsterdam can help inform new policy measures on the field of active mobility and walkability. The use of the Q methodology to understand the points of view from decision-makers can also help unveil the perspectives form other groups in the city that have special needs or come from a different background.

The walkability scores that have been calculated help identify areas where municipal interventions could improve walkability by indicating what is the problem and how relevant is it in the bigger picture of factors affecting the pedestrian experience.

Walkability scores as a proxy for reality

The collection of walkability factors from the literature and then the ranking by a group of stakeholders that is familiar with the situation of Amsterdam makes the index a simplified representation of reality. The walkability scores calculated in this research are especially valuable in a city or neighbourhood-wide analysis. Even though street level scores are calculated, these do not consider some relevant factors such as temporary obstacles or the crowdedness of the area. Therefore, prior to drawing conclusions from this data, an in-site analysis is recommended. For example, the crime sub-index in Vondelpark shows relatively low scores. This may suggest interventions such as adding more street lighting or installing amenities to attract more users. However, the score doesn't show that Vondelpark is already frequented by large groups of people and the lack of street lighting is a deliberate decision made to protect the biodiversity of the area.

8.5 Scalability and comparability

The proposed methodology focuses on street and neighbourhood-level indicators, therefore, it is weaker in terms of general applications to large geographical areas. However, the same approach can be applied to other urban areas to unveil their own relevant walkability factors and build a tailor-made walkability index. The methodology's flexibility enables its application with varying sets of factors and data sources, facilitating its replication in other urban areas where datasets on the most relevant factors are accessible. This adaptability allows for the study of walkability in different contexts, enhancing its applicability beyond the current study area. The data allows for street-by-street comparisons, but since the methodology focuses on unveiling walkability factors that are unique to every context, comparisons between cities are challenging.

8.6 Reproducibility

The steps undertaken in this study are fully reproducible; however, due to the subjective nature of human perspectives on walkability, it is possible that the results may vary slightly with each application.

8.7 Limitations

This study is subject to several limitations that should be taken into account when interpreting and discussing the findings.

One notable challenge is the difficulty in measuring certain factors that influence walkability. Elements like temporary obstacles and crowds present measurement challenges due to their dynamic nature. Other dynamic factors present the same challenges such as seasons, day/night or the climate. The walkability index presented in this research is indeed, static and can not take into account changing factors. These factors can vary over time, making it challenging to capture their impact on walkability consistently.

While this methodology can provide valuable insights into walkability, the datasets being used cannot capture the full range of activities happening on a sidewalk. They offer simplified representations of reality and cannot account for every nuance and complexity of real-world pedestrian interactions. As a result, the walkability index may not fully capture reality.

Furthermore, it is essential to recognize that the validation process in this study does not directly engage with individuals on the streets. This approach may overlook valuable insights and observations from pedestrians in real time. Without this street-level validation, there may be limitations in fully assessing the accuracy and relevance of the walkability index in capturing the true experiences of pedestrians.

These limitations underscore the need for future research to address these challenges. Enhancing the measurement of dynamic factors, incorporating diverse perspectives, having a more robust method for validating findings, and refining the methodology will contribute to more accurate and inclusive assessments of walkability in urban contexts.

8.8 Recommendations

For the re-application of the methodology

Drawing from the limitations explored in the previous section, further research is needed to establish improved ways of coupling the outputs of the Q methodology with quantitative spatial assessments of walkability.

Looking for ways of improving the datasets that feed the index and obtaining better data on factors that proved to be relevant such as temporary obstacles and crowdedness could also further improve the precision of the index.

Considering broader population ranges for the Q methodology could make the index more inclusive and help avoid bias. The inclusion of different population groups could mean that the walkability index is adapted to reflect how these groups perceive walkability and identify their most pressing needs. Furthermore, measuring and understanding common points of view between a diverse range of participants can make the final result more accurate.

For the walkability of Amsterdam

The results of the index suggest that areas outside of the A10 ring contain some of the lowest-scored streets. Specifically, Nieuw West, Zuidoost and Noord present low crime safety and proximity scores. This suggests the need for interventions to add more services to these areas and improve the residents' perceived safety.

The areas close to the city centre score low in the landscape and infrastructure factors, suggesting the need for better pedestrian infrastructure (interventions and policy) and more landscape factors such as green areas and benches.

Finally, drawing from the comments made in the interviews and the evaluation made on the infrastructure, the walkability in Amsterdam could be improved by building and enforcing a walkable streets policy framework that regulates the conditions of pedestrian infrastructure, accessibility and safety for pedestrians.

8.9 Future research

Future research is necessary to determine the accuracy of the proposed walkability index, this can be achieved by doing a more robust validation and including diverse population groups in the Q methodology. Additionally, further research should consider the role that personal factors play in the perspectives on walkability and how they influence the individual's walking priorities. Finally, the different perspectives unveiled by the Q methodology could be used in future studies to improve the accuracy of the walkability index or even create several indexes that reflect the priorities of different groups.

The approach taken by this research could be extended to other fields to measure other qualities of the urban areas that are strongly influenced by subjective factors and individual points of view such as cyclability, urban environment & safety or attractivity of public transport.

Figure 31: Examples of walkability factors on a street.

9. Conclusion

Walkability, or the extent to which a street invites people to walk on it has been linked to positive health outcomes in the population. Recently, the municipality of Amsterdam has unveiled a series of vision and policy documents that affirm the intention to improve walkability through policy and spatial interventions. To effectively improve walkability, decision-makers need a clear understanding of what influences the walking experience on the streets, and how to measure these influential factors.

This thesis proposes a city-specific method to measure walkability in Amsterdam at a street-level. The main research question of this study is "What approaches and methods help assess walkability in Amsterdam while considering the particularities of the city and the opinion of its decision-makers?". To understand and assess walkability in Amsterdam, a mixed-methods approach is adopted. Using a combination of interviews, Q methodology and GIS quantitative analysis, a street-level walkability index was built. The research was framed in three phases, each one addressing one sub-research question.

Phase 1 focused on understanding different approaches on measuring walkability in existing studies and collecting a set of influential characteristics of the urban environment for the experience of walking. A literature review identified common factors influencing walkability, and similar factors were grouped to create a representative summary. The findings revealed that neighbourhood-level factors such as population density and proximity to amenities are the most popular for measuring walkability whereas the characteristics of the individual streets such as sidewalk width or the number of obstacles are less popular.

In Phase 2, a ranking and grouping of the representative walkability factors was conducted to determine their relevance in Amsterdam. In this phase, the Q methodology proved to be useful to understand the subjective points of view on what makes a street walkable in Amsterdam and rank the factors by its level of influence. This study found that while perceptions of walkability may vary based on environmental and personal circumstances, the Q methodology effectively facilitates the creation of a factor ranking that aligned closely with the majority of opinions. Furthermore, the interviews conducted alongside the Q-methodology provided context on why the factors are relevant. This allowed grouping them in relation to their influence on the walking experience. The identified groups were: Landscape, Crime Safety, Traffic Safety, Proximity, and Infrastructure.

The third phase involved assessing the current condition of walkability in Amsterdam by creating a weighted walkability index based on the factor ranking from Phase 2. The index considered 15 different factors, generating street-by-street scores and sub-indexes. The results revealed variations in walkability across different areas of the city, with neighbourhoods like the City Centre, Zuidas, and the Museumkwartier scoring higher, while others like Nieuw West, Zuidoost, and Noord obtained lower scores.

This research has found that walkability is significantly influenced by a mix of neighbourhood and street-level factors. The criteria to consider a street walkable varies from one individual to another but, by making a detailed study of the perspectives on walkability, the factors can be ranked by popularity allowing the development of a walkability index. The validation of the resulting index by comparing it with the opinions about different streets suggested that it can accurately identify areas considered more inviting for pedestrians.

Based on the results of this research, there are two main recommendations for improving this index and using it to measure and improve walkability in Amsterdam or other urban areas. First, to further develop the walkability index by diversifying the group of participants involved and considering more factors for the final score calculation. And second, to analyse the disaggregated scores reflected in the sub-indexes at a street or neighbourhood level. This detailed examination can indicate underlying social or infrastructural problems and facilitate the development of targeted policies and physical interventions aimed at addressing the specific factors that hinder walkability in different areas.

The urban environment plays a crucial role in walkability, accessibility, and overall health. It is important for urban planners, municipalities, and academics to collectively understand and assess the key factors that influence walkability in cities. This research showcased a path to obtaining more accurate measurements and reliable metrics based on what the citizens consider important. By involving the population of a city in the creation of its assessment tools, it is possible to obtain more accurate metrics and effectively bring meaningful changes to the urban environment.

Figure 32: Examples of walkability factors on a street.

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Appendix

Appendix 1: Factor ranking for the three main perspectives unveiled by the Q-methodology.

	Ranking		
Statements	**Perspective 1**	**Perspective 2**	**Perspective 3**
Wide Sidewalks	6	6	1
Proximity to amenities	14	1	2
Traffic safety	2	5	15
Little / no obstacles	1	11	3
Presence of others	4	8	19
Crime safety	7	3	22
Proximity to public transport	11	9	6
Well maintained sidewalks	9	10	14
Many shops and restaurants	15	13	5
Street lighting	3	7	18
Low speed	5	12	12
Trees and bushes	13	14	4
Presence of plazas and parks	8	19	8
Urban furniture	12	17	10
Short blocks, frequent intersections	23	4	7
No parked vehicles	10	20	11
Shade	17	21	9
A densely populated street	24	2	17
Narrow streets	19	16	16
Interesting buildings	21	22	13
A quiet environment	20	15	25
Canals, lakes or rivers	18	25	21
Strong neighbourhood identity	22	23	20
Low height buildings	25	18	24

55%

"Feasible and safe walking"

30%

"Walking with a purpose"

15%

"Feasible and enjoyable walks "

Appendix 2: Code for calculating the scores of the index and sub-indexes.

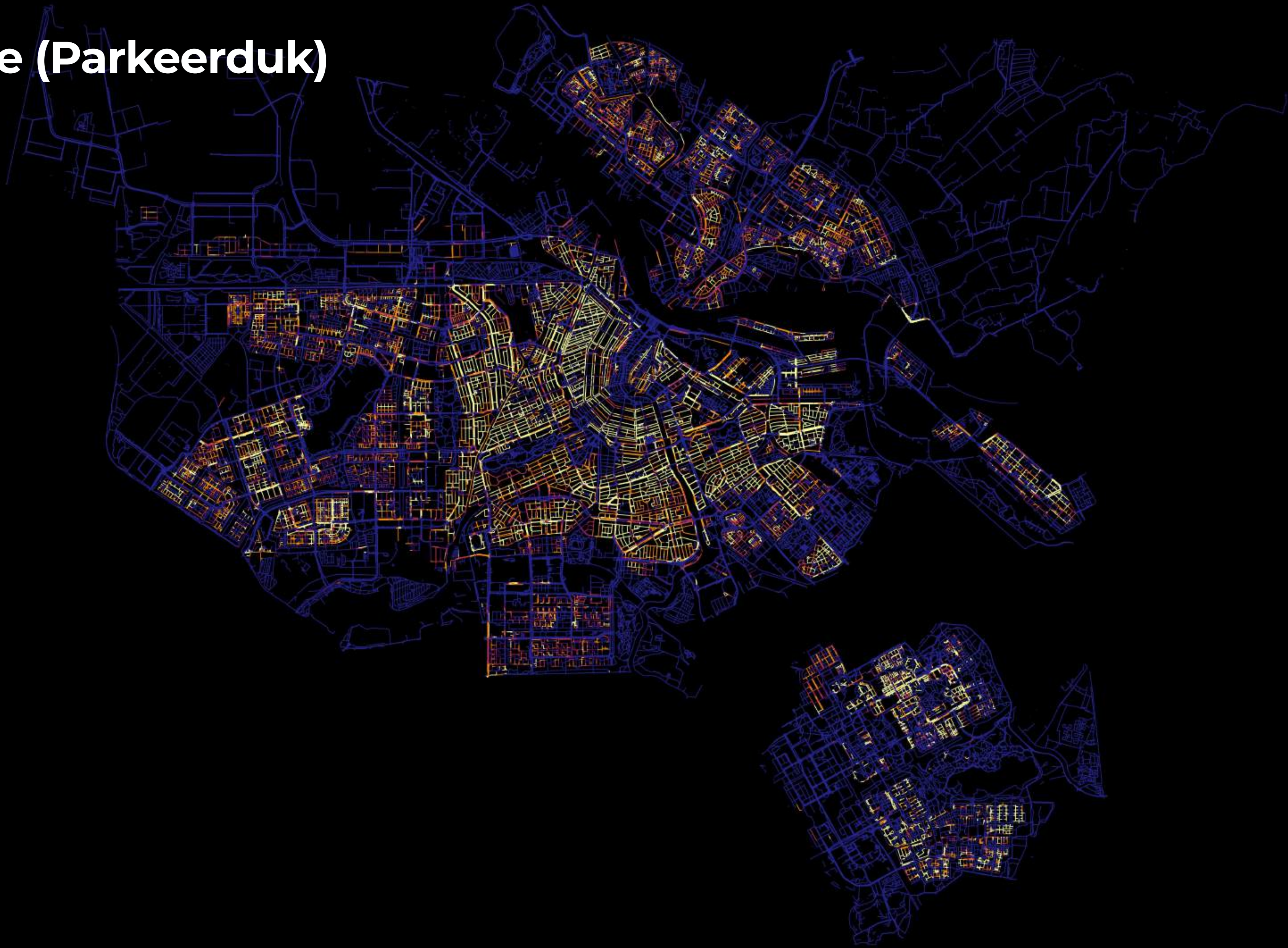
```
@author: matiascardoso
"""


#%% PACKAGES
# Basics
import numpy as np
from math import pi
import warnings
import pandas as pd

from datetime import datetime, timedelta
from pandas import DataFrame


IndexRaw = pd.read_csv('IndexRawV6.csv')

#%%Fill NULL
Indexv1 = IndexRaw.fillna(0)


#%% Adding intervals
Indexv1['SidewalkCo'].where(Indexv1['SidewalkCo'] <= 5, 5, inplace=True)
Indexv1['SidewalkCo'].where(Indexv1['SidewalkCo'] >= 0.9, 0, inplace=True)
Indexv1['CoAmenitie'].where(Indexv1['CoAmenitie'] <= 20, 20, inplace=True)
Indexv1['ParkinPres'].where(Indexv1['ParkinPres'] <= 100, 100, inplace=True)

#%%Remove segments of less than 1m length
Indexv2 = Indexv1[Indexv1['length'] > 1]

#%% Normalising fields

Indexv2 = Indexv2[['ID']].copy()

#Indexv2['N-Accidents'] = Indexv1['Accidents'] / Indexv1['length']
Indexv2['N-Furniture'] = Indexv1['Benches'] / Indexv1['length']
Indexv2['N-EyesOnStreet'] = Indexv1['AmenitiesO'] / Indexv1['length']
Indexv2['N-Obstacles'] = Indexv1['OBS'] / Indexv1['length']
Indexv2['N-Lighting'] = Indexv1['NewLights'] / Indexv1['length']

#Fields that don't require normalisation
Indexv2['N-RoadSafety'] = Indexv1['id_count'] #changed name
Indexv2['N-ProxAmenit'] = Indexv1['CoAmenitie'] #changed name
Indexv2['N-Crime'] = Indexv1['IntDens_me']
Indexv2['N-ShortBlocks'] = Indexv1['INDEX2021']
Indexv2['N-OV'] = Indexv1['OV-corr']
Indexv2['N-SidewalkWi'] = Indexv1['SidewalkCo']
Indexv2['N-MaxSpeed'] = Indexv1['MaxSpeed']
Indexv2['N-Green'] = Indexv1['Green']
Indexv2['N-ParkinPres'] = Indexv1['ParkinPres']
Indexv2['N-ParksPlaza'] = Indexv1['ParksPlaza']
Indexv2['N-Maintenance'] = Indexv1['Maintenanc']
Indexv2['W-Sidewalks'] = Indexv1['SidewalkCo']

#%% Adding intervals
Indexv2['N-Lighting'].where(Indexv2['N-Lighting'] <= 0.5, 0.5, inplace=True) #No more than 1 light per meter
Indexv2['N-EyesOnStreet'].where(Indexv2['N-EyesOnStreet'] <= 0.05, 0.05, inplace=True) #No more than 1 shop per 10m
Indexv2['N-Furniture'].where(Indexv2['N-Furniture'] <= 0.1, 0.1, inplace=True) #no more than one bench per meter
Indexv2['N-Obstacles'].where(Indexv2['N-Obstacles'] <= 0.1, 0.1, inplace=True) #No more than one obstacle per meter
Indexv2['N-RoadSafety'].where(Indexv2['N-RoadSafety'] <= 1, 1, inplace=True)
Indexv2['N-OV'].where(Indexv2['N-OV'] <= 10, 10, inplace=True)



#%% Min Max Normalisation

from sklearn.preprocessing import MinMaxScaler

scaler = MinMaxScaler()

Indexv3 = Indexv2
```

```
Indexv3[['N-RoadSafety','N-Furniture','N-EyesOnStreet','N-Obstacles','N-Lighting','N-ProxAmenit','N-Crime','N-ShortBlocks','N-OV','N-SidewalkWi','N-MaxSpeed','N-MaxSpeed','N-Green','N-ParkinPres','N-ParksPlaza','N-Maintenance']] = scaler.fit_transform(Indexv3[['N-RoadSafety','N-Furniture','N-EyesOnStreet','N-Obstacles','N-Lighting','N-ProxAmenit','N-Crime','N-ShortBlocks','N-OV','N-SidewalkWi','N-MaxSpeed','N-MaxSpeed','N-Green','N-ParkinPres','N-ParksPlaza','N-Maintenance']])


#%% Transformation (Flip columns)

Indexv3['N-MaxSpeed'] = 1 - Indexv3['N-MaxSpeed']
Indexv3['N-RoadSafety'] = 1 - Indexv3['N-RoadSafety']
Indexv3['N-Crime'] = 1 - Indexv3['N-Crime']
Indexv3['N-ParkinPres'] = 1 - Indexv3['N-ParkinPres']
Indexv3['N-Obstacles'] = 1 - Indexv3['N-Obstacles']


#%% Calculating the scores

Indexv4 = Indexv3
list(Indexv4)

Indexv4['I-Zscore'] = Indexv4["N-RoadSafety"]*0.094 +Indexv4["N-Obstacles"]*0.093 +Indexv4["N-SidewalkWi"]*0.086 +Indexv4["N-Lighting"]*0.074 +Indexv4["N-MaxSpeed"]*0.073  +Indexv4["N-ProxAmenit"]*0.073 +Indexv4["N-Crime"]*0.071 +Indexv4["N-OV"]*0.068 +Indexv4["N-Maintenance"]*0.065 +Indexv4["N-EyesOnStreet"]*0.059 +Indexv4["N-Furniture"]*0.056 +Indexv4["N-ParksPlaza"]*0.056 +Indexv4["N-ParkinPres"]*0.053 +Indexv4["N-Green"]*0.048  +Indexv4["N-ShortBlocks"]*0.031


#Sub indexes

Indexv5 = Indexv4

Indexv5['Landscape'] = Indexv4['N-Furniture']*0.056+Indexv4[ 'N-Green']*0.048+Indexv4[ 'N-ParksPlaza']*0.056+Indexv4[ 'N-ParkinPres']*0.059+Indexv4['N-EyesOnStreet']*0.053

Indexv5['Traffic Safety'] = Indexv4['N-RoadSafety']*0.094+Indexv4['N-MaxSpeed']*0.073

Indexv5['Proximity'] = Indexv4['N-ProxAmenit']*0.073+Indexv4['N-ShortBlocks']*0.031+Indexv4['N-OV']*0.068

Indexv5['Crime Safe'] = Indexv4['N-EyesOnStreet']*0.059+Indexv4['N-Crime']*0.071+Indexv4['N-Lighting']*0.074

Indexv5['Infrastructure'] = Indexv4['N-Obstacles']*0.093+Indexv4[ 'N-SidewalkWi']*0.086+Indexv4['N-Maintenance']*0.065


#%% Min Max Normalisation
scaler = MinMaxScaler()


Indexv5[['Landscape','Traffic Safety','Proximity','Crime Safe','Infrastructure']] = scaler.fit_transform(Indexv5[['Landscape','Traffic Safety','Proximity','Crime Safe','Infrastructure']])

#%% Save it
Indexv5.to_csv('WalkabilityIndex.csv', index = False)
```

Benches

Bench locations from OpenStreetMap

Parking Pressure (Parkeerduk)

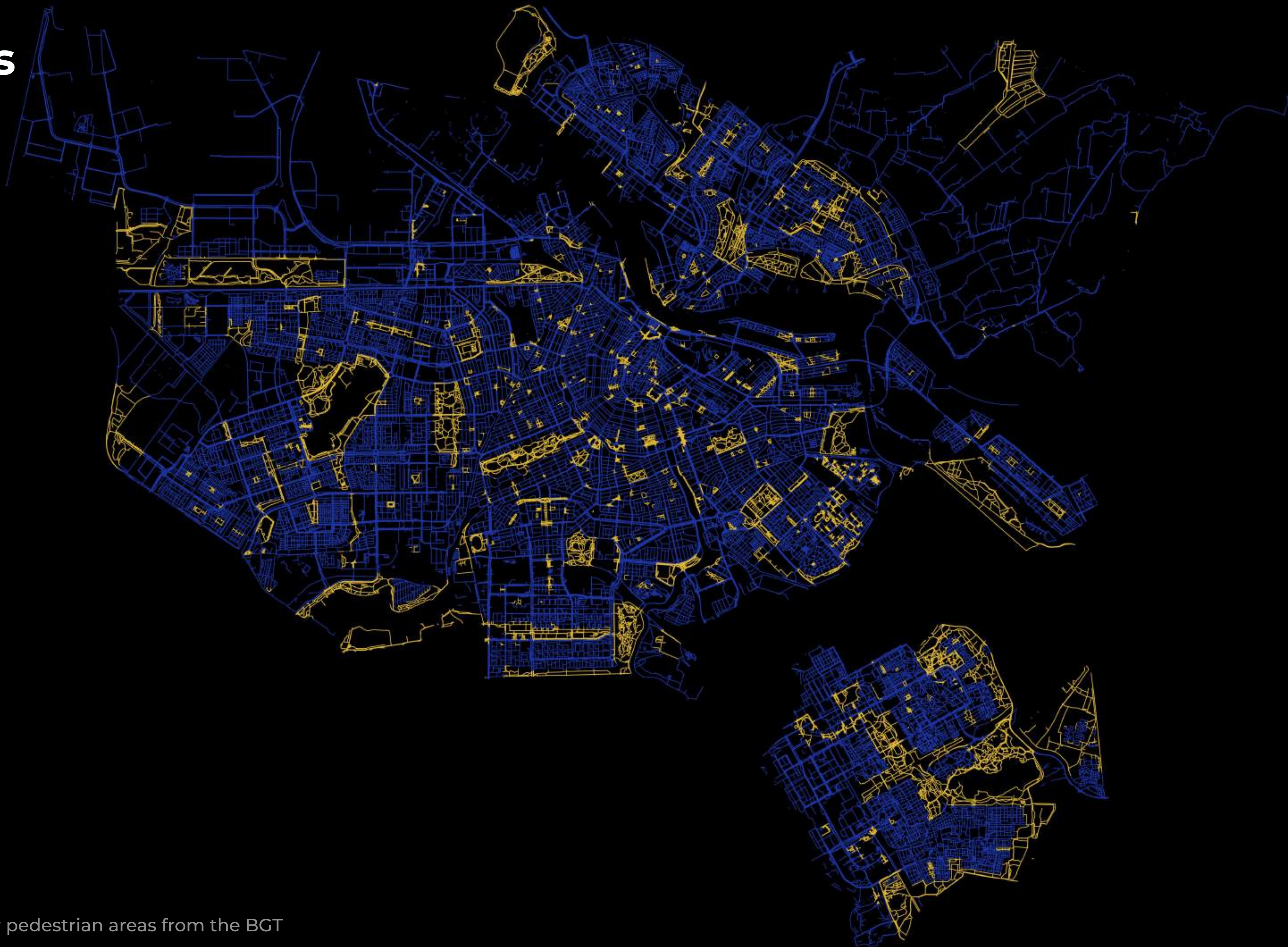


Data from: Amsterdam Open Data

Green

Data from: Groenkaart van Nederland

Parks and plazas



Parks from Amsterdam Open Data, other pedestrian areas from the BGT

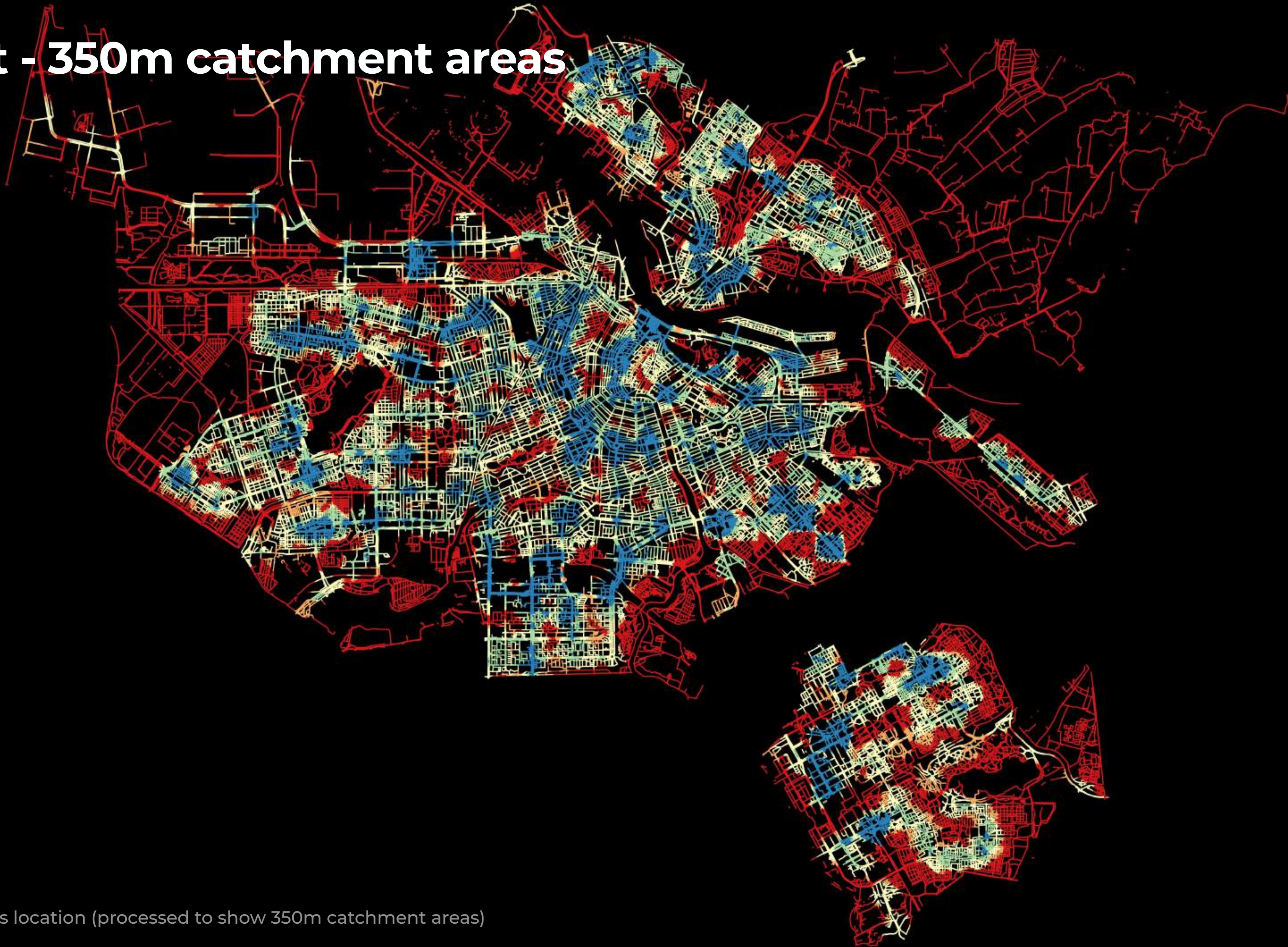
Amenities

Amenity locations from OpenStreetMap

Public Transport

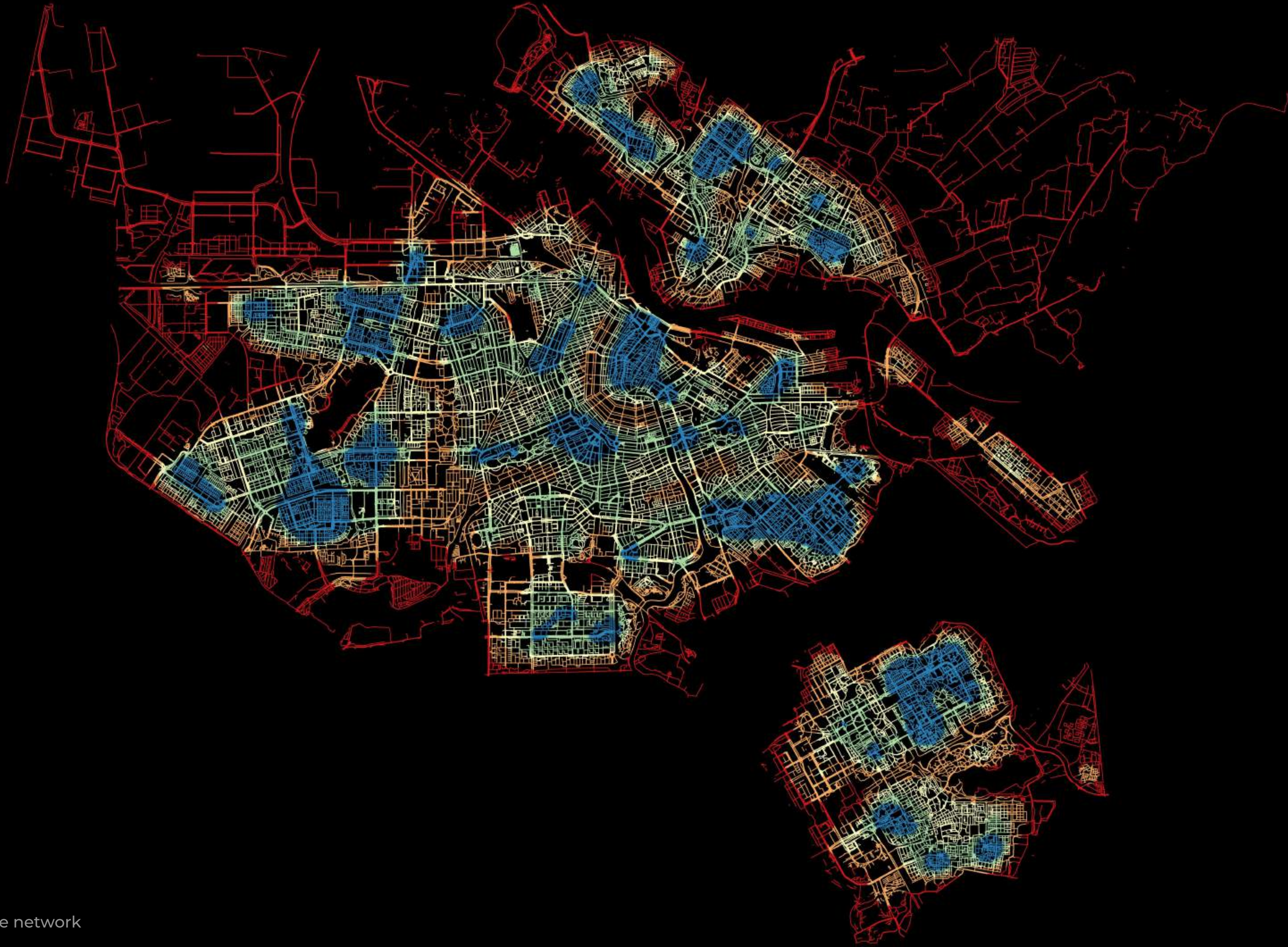
Data from OV-API - Public transport stops location

Public Transport - 350m catchment areas



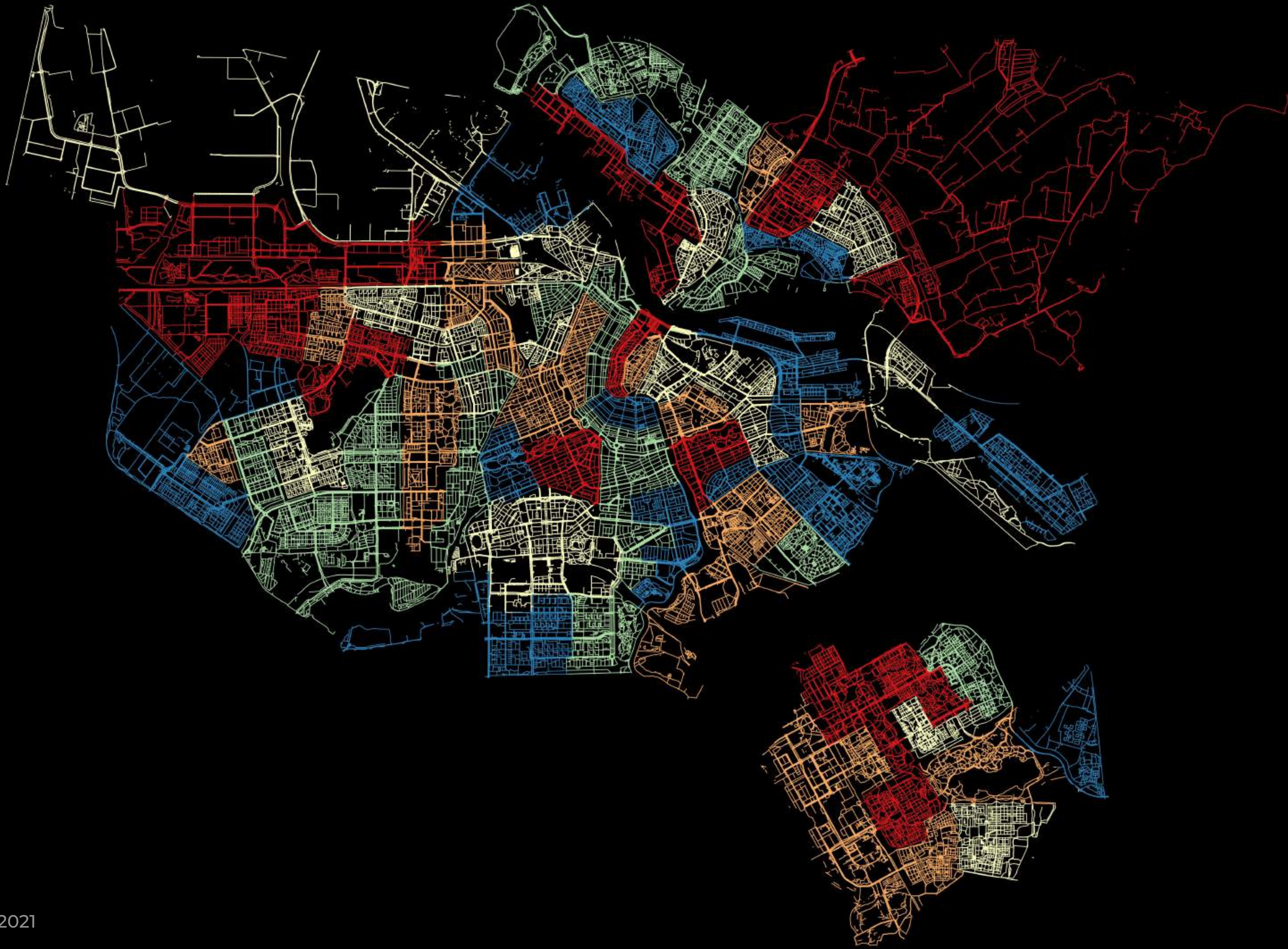
Data from OV-API - Public transport stops location (processed to show 350m catchment areas)

Street Density



Calculated from the OpenStreetMap walkable network

Crime



Data from: Veiligheidsindex Amsterdam 2021

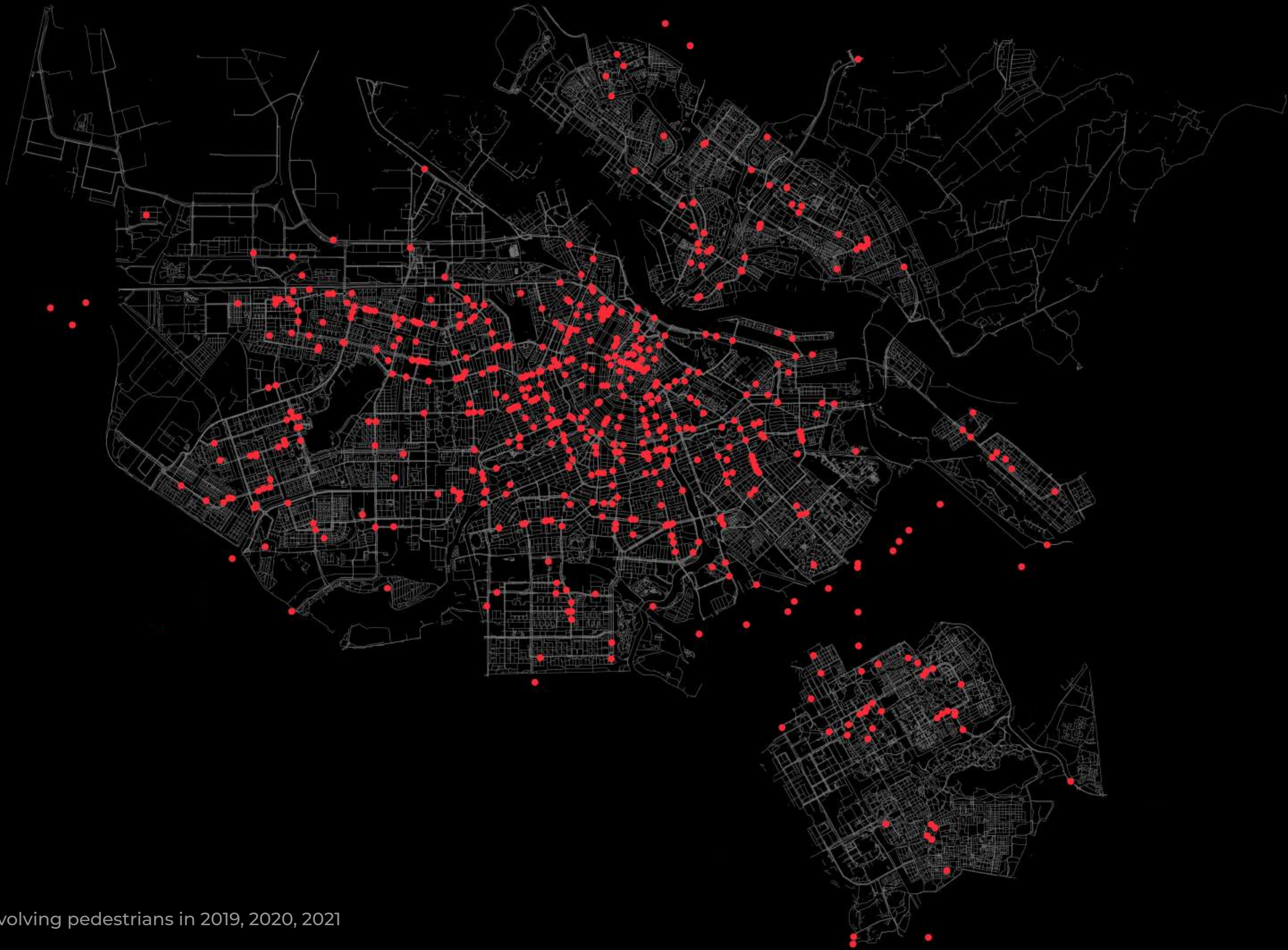
Open Fronts - Streets with shops or restaurants

Amenity locations from OpenStreetMap

Max. Speed

Data from: Amsterdam Open Data

Accidents

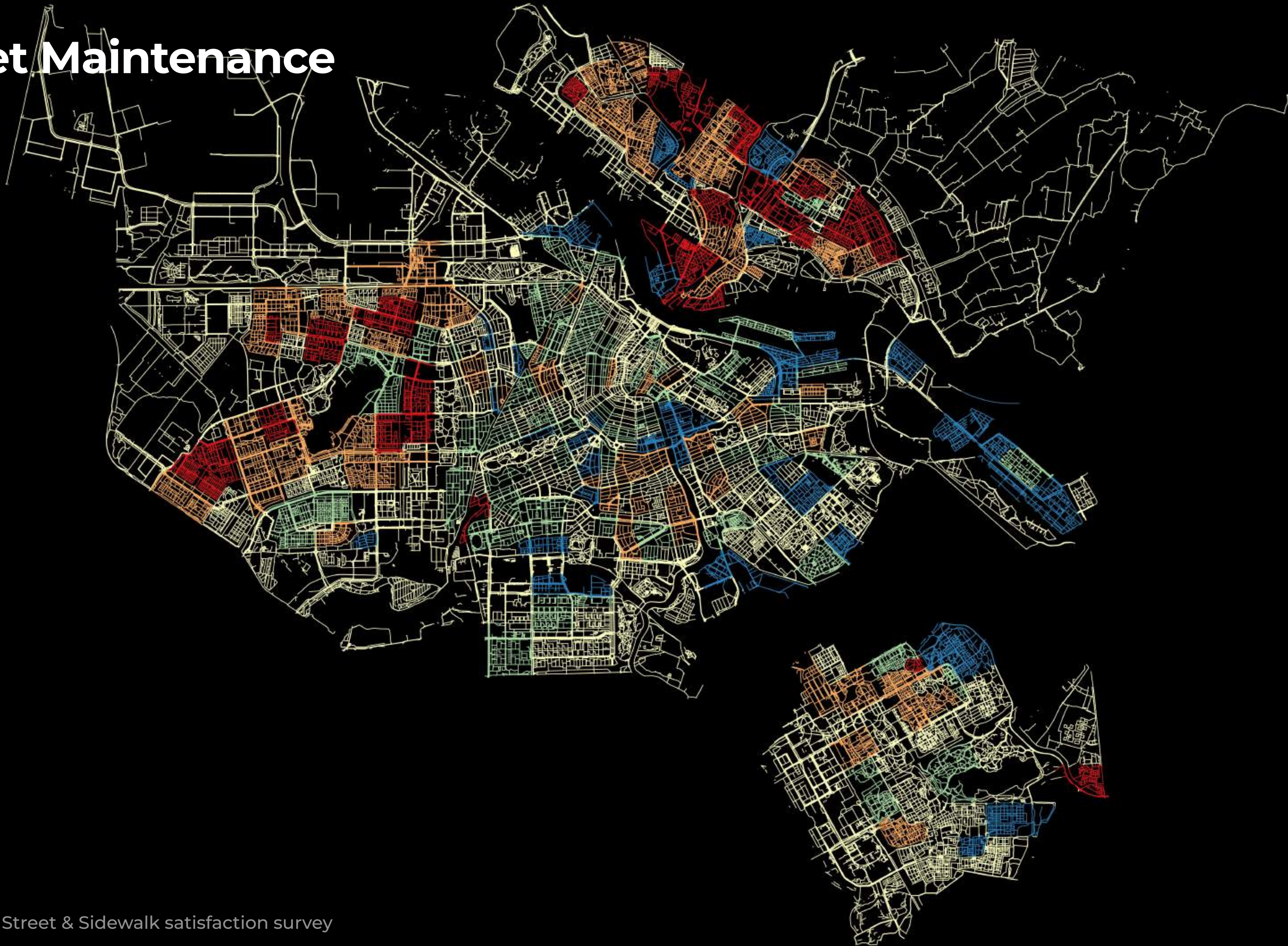


Data from: Rijkswaterstaat - Accidents involving pedestrians in 2019, 2020, 2021

Street lighting

Lights locations from Open Data Amsterdam

Sidewalk + Street Maintenance



Data from: Wonen in Amsterdam study - Street & Sidewalk satisfaction survey

Sidewalk Width

Calculated from: BGT - Sidewalk polygons

Obstacles

Obtained from BGT - filtered for objects in the sidewalks