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Developing a city-specific walkability index through a participatory approach

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Abstract. The extent to which the built environment encourages people to walk in public spaces, hence the quality of being walkable or 'walkability' has long been associated with positive outcomes on people's health. While various studies have developed indices to assess walkability, limited attention has been given to indices that reflect the influence of specific city characteristics on walkability. This study showcases the development of a city-specific walkability index through a participatory approach using Amsterdam as a case study. It explores the viewpoints of urban designers and policy-makers who work or reside in Amsterdam on what constitutes a walkable street and identifies the most significant walkability factors for Amsterdam. These factors are then quantified based on open-access datasets and integrated into a street-level weighted walkability index. The resulting walkability index underscores the importance of factors such as traffic and crime safety, quality of the pedestrian infrastructure, and proximity to public amenities in shaping residents' decisions to walk in specific public spaces. Finally, this research underscores the importance of involving individuals through participatory methods, considering subjective perspectives, and acknowledging shared experiences within particular groups and spaces when assessing walkability.

Keywords. Walkability, Active Mobility, Built Environment, Participatory, Q methodology

1 Introduction

The discourse on 'walkability,' defined as the degree to which public spaces are suitable and enjoyable for walking, has emerged with the challenges in the car-pedestrian conflict (Brambilla and Longo, 1977). It is supported by calls for creating livable streets (Appleyard and Gerson, 1981; Gehl, 2011) and enhancing public spaces with a focus on health and well-being (Lennard et al., 1987). Today, these perspectives shape urban policies, including efforts to promote a modal shift towards more sustainable public transport and active mobility, discouraging reliance on private vehicles (Troiano et al., 2008). Urban strategies also strive to foster active living environments, ensuring equal access to health-promoting resources (Tobin et al., 2022). Still, despite the growing interest and benefits of walking for the living environment and public health, there has been a decline in the popularity of walking in many cities over the past decades. Currently, a significant share of the population does not meet the recommended physical activity levels (World Health Organization, 2019).

These descriptive approaches that study the impact of the built environment on walkability go along with the analysis of its multidimensional assessable aspects. Discussions on what makes the built environment walkable widely vary. Whereas some highlight the enabling factors for walking, others focus on the outcomes and/or performance of walkable environments, and a third perspective emphasises walkability as a proxy to solve a wider variety of urban problems integrally (Forsyth, 2015).

To understand to what extent different types of built environments promote walking, several studies have focused on developing indicators to assess the walkability of public spaces and neighbourhoods. They are based principally on measurable urban environment characteristics (McCormack and Shiell, 2011), human perception (Ewing and 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). For example, WalkScore ®, one of the most popular walkability measuring tools in the United States considers factors such as density of retail, service and cultural destinations per square kilometre, route directness, and the presence of highways. Meanwhile, the walkability index developed by Lam et al.

(Lam et al., 2022) for the Dutch context considers the same factors as WalkScore ® plus spatial data on the amount of green space, public transport, and sidewalk density. Both indexes claim to measure walkability but each considers different factors. More so, neither one of the models aggregating geospatial data takes into account the subjective experience of the quality of being walkable or in essence being suitable for pedestrians of different kinds.

The promotion of public transport, liveability, physical activity, and health also influenced the policy, planning, and urban design in Amsterdam. While several public and private efforts are being made to improve walkability in public spaces (Gemeente Amsterdam, 2016, 2021a, b), a methodology for a context-specific, city-wide index of walkability is still missing here. An index enabling the walkability assessment of public spaces based on the points of view of residents of the urban area can incorporate specific indicators that account for its unique characteristics such as weather, topography, or local culture.

This paper proposes a set of interrelated methods to build a context-specific walkability index. It combines both quantitative and qualitative research methods, using a mix of general ontological and case-specific literature reviews, qualitative comparative analysis of individual perspectives, and quantitative geospatial data analysis. This mixed-methods approach involves gathering and analysing input addressing walkability and walkability indicators in a city-specific and participatory way. Given the complexity of the subjective and objective factors that influence the choice to walk in public space, different methods provide complementary information that is then used to build the final walkability index. Our findings show that the subjective factors, indicating characteristics that residents appreciate or dislike, relate to specific attributes of a public space, thus to identifiable geospatial data, which can be added to a walkability index that is context-specific across the city. Moreover, the opinions collected by making the process participatory, describe different ways in which the walkability factors influence the pedestrian experience. That is why, the resulting index summarises all the factors in an overall score but is also disaggregated into several sub-indexes that account for specific components of the pedestrian experience.

The subsequent sections of this paper are organized as follows. First, we introduce our methodology, delineating the interrelated methods and illustrating how each step utilizes the outputs of preceding steps to progressively construct the walkability index. We purposefully propose a broad methodology that can be applied to any urban area, in cities that would like to prioritise pedestrian-friendly, livable, and healthy environments and sustainable transportation options. Subsequently, we narrow our focus to apply our methodology in a case study. We outline our case study and provide details regarding the data sources we used and the experts who participated in our study. Then, we present the results of our empirical analysis. Next, we discuss the findings of our empirical analysis and the value and implications of the mixed methods approach for measuring walkability. The work concludes by presenting an overview of the main findings and limitations of our study and proposing recommendations for future research.

2 Method

The approach followed to build our city-specific walkability index is described in Figure 1. The interrelated methods are organised in three phases as follows:

- Phase A: Combining General Ontological and Case-Specific Literature Reviews to collect Walkability Factors
- Phase B: Qualitative Comparative Analysis of Individual Perspectives of Experts on Walkability through Q Methodology
- Phase C: Quantitative Geospatial Data Analysis to Measuring Walkability

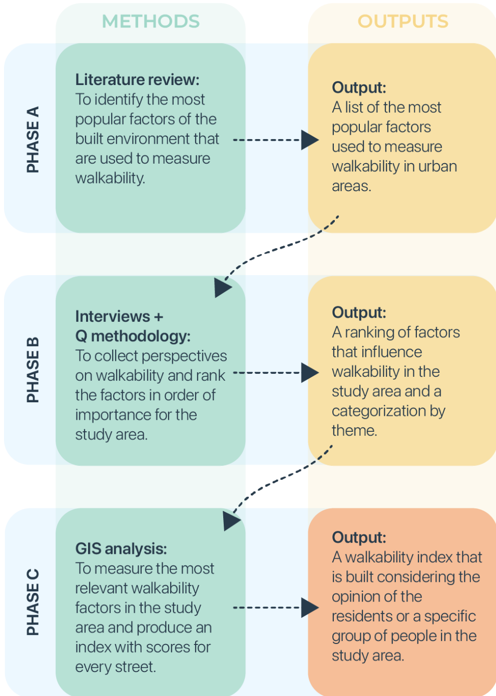

Figure 1. Overview of the methodology process and outcomes of each stage.

2.1 Phase A: Combining General Ontological and Case-Specific Literature Reviews to Collect Walkability Factors

In this phase, we uncover the factors that affect walkability by looking into the scientific literature for existing methods to measure it. For this purpose, we conduct a review of different studies on walkability factors and measurements in two rounds (Table 3). In the first round, to ensure that a broad range of commonly found factors is collected, we searched in Scopus all articles that appear under the combination of the keywords “walkability" and “measure" in the title, keywords, or abstract of an article. From the results we included in our review the five most cited articles. These articles are focused on general characteristics of the physical environment and not on how people perceive them. However, people’s perceptions of the urban environment could promote or discourage them from walking (Milias et al., 2023). Thus, we made a second round to include studies that accounted for either how people perceive the urban environment or that were specifically focused on cities of the Netherlands. In particular, we searched for terms such as “walkability" and “Netherlands" or “walkability" and “perceptions". Based on this second round, we included five more studies in our review.

The methods to measure walkability rely on the existence or absence of certain characteristics of the built environment as proxies for walkability. In this study, we call those walkability factors. Each time one of the factors is mentioned in one of the articles, we note in a matrix its name and the way of measuring it as described by the method.

We only took into account the factors used to measure walkability or mentioned as relevant by the authors of the studies. To facilitate the next phase of the study and obtain easily interpretable results, we grouped the factors by overarching category. For instance, factors related to the proximity to amenities such as land use mix, retail area, floor density, or recreation land use proximity are grouped under the same category. Through this process, we grouped the factors into a set of high-level factors that could be used in the next step (for the Q methodology).

2.2 Phase B: Comparison of experts’ perspectives on walkability

During phase B we collect and prioritise the subjective perceptions of how much the different factors what factors influence walkability. To this end, a tool to study subjective issues and points of view is required. To study and combine the different perspectives, we used the Q methodology to study subjectivity. The Q methodology was first introduced by William Stephenson in his study of behaviour. (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 (Foltỳnová et al., 2020). 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 (Millar et al., 2022). The theory on Q methodology sustains that even small participant samples can provide meaningful generalisations about the nature of human behaviour (Stephenson, 1953). In this phase, our objective is to efficiently gather opinions that reflect the factors that impact walkability in a given city. To do so, we gather opinions from experts in the field of walkability who work or reside in this city. This allows us to collect the necessary information within a reasonable timeframe and cost.

To collect perspectives on walkability that represent an integral view of the city’s opinions, the participants are chosen from a heterogeneous spectrum of backgrounds, all working on topics related to walkability in the studied urban area. This includes public servers, urban designers, advocates for walkability, and researchers on sustainable transportation.

To begin, the participants are confronted with a series of cards (printed or on a virtual board), each with a drawing and a short text describing one of the summarised walkability factors from the literature. Then, we asked them to organise the cards in an inverted pyramid distribution with the most important factors for them when walking in a public space to the left and the less important ones to the right as shown in Figure 2.

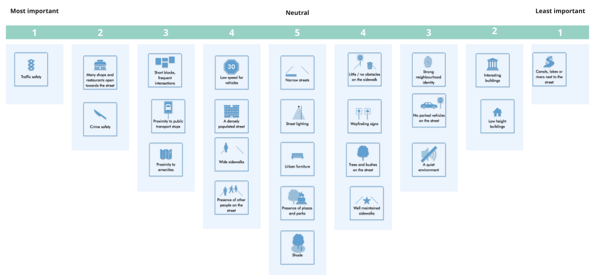

Figure 2. Example of a card sort by a participant of the study.

This distribution forces the participants to choose one factor as the most important and one as the least important. In the middle of the pyramid, they can insert more factors, being the central “neutral” column the one that allows the most factors. The reasoning behind this strategy is that the participants are forced to make choices and reflect on their walking experiences and the street characteristics they appreciate the most (Brown, 2004).

Once the card sorting exercise is completed, we conduct a post-sorting interview where participants are asked to explain the reasoning behind their choices. The information collected in these interviews is useful to identify groups of factors that influence different aspects of the pedestrian experience. These factors encompass elements such as feelings of safety from crime, the quality of the landscape, and the proximity of amenities within a walkable distance.

Finally, the collection of all the card sorts is organised as a matrix where the position of the card in the pyramid is translated into a score from 0 to 8 (0 for the least important column and 8 for the most important column). This matrix is then processed using a Principal Component Analysis (PCA) to find the component that describes best the overall choices of the participants. The PCA provides several possible factor rankings that fit the points of view of different groups of participants. To obtain a single index reflecting the average of the participants' preferences, we performed a PCA where we kept only one centroid factor for rotation. This procedure allows us to average all the answers and obtain a ranking of factors that is optimized in terms of correlation to all the participants' answers. Thus, the analysis provides a single factor that is as correlated as possible to all the entries of the dataset.

The PCA 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 and Pascual, 2016).

2.3 Phase C: Data Analysis to Measure Walkability

To score the walkability in each public space, we first identify datasets that contain information describing the walkability factors that emerged as the most important from the Q methodology (e.g., number of trees, traffic level). Figure 3 presents an overview of the process, data sources, and tools for developing the walkability index based on the results of the Q methodology. The process begins with the collection of the data sources for walkability factors. This data is then integrated into the street network of the urban area. In the case of data reflecting quantitative characteristics such as the number of shops and restaurants, the amount of public lights, or the number of obstacles, we normalised by street-segment length to obtain a measure of the number of features per meter of street using Eq. (1). Then, all the factors are normalised using min-max scaling to facilitate comparison as shown in Eq. (2). When the data describes characteristics that are seen as negative by the interviewees or the literature (e.g. road accidents, crime rates, etc) the value resulting from the normalisation is inverted (Eq. 3). Finally, to obtain the weighted walkability index, each scaled factor value is multiplied by its weighting factor (the one resulting from the z-scores) and added to the final score (Eq. 4). The results are presented as maps and can be also explored using the open-access interactive web tool CTstreets Map [1].

$$\text{Length-Normalised Factor} = \frac{\text{Feature Count}}{\text{Segment Length}} \quad (1)$$

$$\text{Scale-Normalised Factor} = \frac{\text{Factor} - \text{Min(Factor)}}{\text{Max(Factor)} - \text{Min(Factor)}} \quad (2)$$

$$\text{Inverted Factor} = 1 \text{ - Scale-Normalised Factor} \quad (3)$$

$$\text{Walkability Score} = \sum_{i=1}^{n} (\text{Normalised Factor}_i \times \text{Weight}_i) \quad (4)$$

[1] CTstreets: https://miliasv.github.io/CTstreets/info_page/

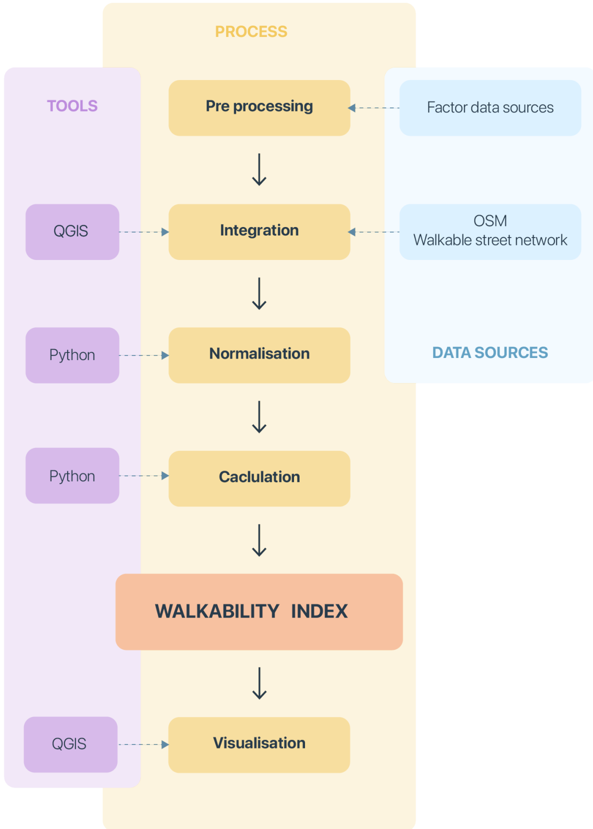

Figure 3. Process, data sources, and tools for developing the walkability index based on the results of the Q methodology.

3 Data

This section describes the inputs for the application of the methodology in the case study of Amsterdam. We first describe the study area, then we introduce the participants of the study and finally, we present the data sources we used to measure the walkability.

3.1 Study area

We applied this methodology in the urban area of Amsterdam, The Netherlands, as defined by the 2019 municipal boundaries. The method considered 114.117 street segments (of 50m or less each) and accounted only for the streets and spaces that are included in the street network of OpenStreetMap and are tagged as walkable.

3.2 Participants

The participants of our study were selected based on two main criteria. First, their expertise should be in the areas of urban design or policy-making. Second, they should be working or living in Amsterdam to be able to contextualize their input based on the needs and preferences of the citizens of Amsterdam. Based on these criteria the sample of the 10 experts who participated in our study consists of decision-makers and walkability advocates working or living in Amsterdam (Table 1). The participants were selected using a theoretical approach, meaning that they were chosen based on their relevance to the goals of this study (Newman and Ramlo, 2010). Each participant was assigned a code to keep the anonymity, and they were grouped into different categories depending on their function and affiliation.

Code	Function	Affiliation
GA1	Researcher on active mobility	Municipality
GA2	Assistant public space designer	
UC1	Urban development consultant	Private design firms
UC2	Urban development consultant	
UC3	Project Manager	
UC4	Urban Planner	
AW1	Secretary	Advocacy organisations
AW2	Chairman	
AW3	Chairwoman	
RM1	Program developer for urban mobility	Research institutes

Table 1. Code, function, and affiliation of the participants of our study.

Factor	Dataset	Source	Detail level
Traffic safety	Pedestrian accidents	BRON (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 - roads	AOD (2023)	Street
Proximity to amenities	Points of interest	OSM (2023)	Street
Crime safety	Amsterdam Safety Index	AOD (2021)	Neigh.
Proximity to public transport	Public transport stops	OV API (2023)	Street
Well-maintained sidewalks	Sidewalk maintenance survey	AOD (2021)	Neigh.
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/BGT (2023)	Street
No parked vehicles	Parking pressure	AOD (2023)	Street
Trees and bushes	Green map of The Netherlands	RIVM (2020)	Street
Short blocks, frequent intersec.	Walkable street network	OSM (2023)	Street

Table 2. Data sources for every walkability factor with their corresponding year and detail level

3.3 Data and software availability

The data sources used in this study are presented in Table 2 and are openly available. In particular, the data sources used are the following: OpenStreetMap (2023) (OSM), Rijksinstituut voor Volksgezondheid en Milieu (2020) (RIVM), Ministerie van Binnenlandse Zaken en Koninkrijksrelaties (2023) (BGT), Gemeente Amsterdam (2020) (AOD), Rijkswaterstaat Ministerie van Infrastructuur en Waterstaat (2022) (BRON), OVapi B.V. (2023) (OV-API). For the data processing, we used Quantum GIS and Python. The PCA was made with the help of the software package Ken-Q from Banasick (2023). All software used is open-source and publicly available. The dataset, which includes the processed street-level walkability scores from this study, is publicly accessible and shared through a data portal (Cardoso, 2023). The data can also be explored through the open-access interactive web tool CTstreets Map.

4 Results

This section reports the results of each step of our analysis for the urban area of Amsterdam, building up towards the final walkability index.

Phase A: Literature review. The literature review included the five most cited studies in the Scopus database as well as other studies mentioned in the base literature for this study or relevant to the context of Amsterdam. The studies are presented in Table 3. The review offered a comprehensive overview of the most popular factors associated with walkability. Table 4, presents the factors grouped by similarity. The literature review indicates that the proximity to destinations is the most popular walkability factor, followed by ease of navigation of the area and its aesthetics. This review revealed that factors at the neighbourhood scale, such as the percentage of retail land use or street density, are in general more popular than those assessing street-level characteristics like sidewalk width or the presence of urban furniture. The review also revealed that some approaches to measuring walkability consider city-specific factors such as slope or the presence of fences around gardens which are not relevant for the context of Amsterdam. Those factors were grouped under the label "Non-relevant for case study area".

Code	Study reference	Category
T1	(Frank et al., 2005)	Top cited articles in Scopus when searching the terms “walkability” + “measure”
T2	(Ewing and Handy, 2009)	
T3	(McCormack and Shiell, 2011)	
T4	(Leslie et al., 2007)	
T5	(Duncan et al., 2011)	
R1	(Cerin et al., 2009)	Top cited articles in Scopus when searching the terms “walkability” + “perceptions”
R2	(Forsyth, 2015)	
R3	(Millstein et al., 2013)	
R4	(Ortega et al., 2021)	
D1	” (Lam et al., 2022)	Relevant studies for the Dutch context. Found by searching “walkability” + “Netherlands”

Table 3. Studies included in the literature review.

Phase B: Comparison of experts’ perspectives on walkability. When applied to the participants in Amsterdam, the Q methodology revealed three main points of view on walkability. The first group of participants, which was also the largest, prioritised the quality of the infrastructure, traffic, and crime safety. The second group prioritised the availability of amenities with the secondary priority being proximity to public transport stops and a sense of security. Finally, the third and smallest group focused on having good infrastructure and landscape factors that make walk-

Walkability factor groups	Literature mentions
Proximity to destinations	16
Ease of navigation	13
Aesthetics	12
Presence of Sidewalks	6
Green areas	6
Population density	6
Active fronts	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 street	1
Parked Vehicles	1
Shade	1
Street width	1
Water bodies	1
Neighborhood identity	1
Wayfinding signs	1
Non-relevant for case study area	2

Table 4. Summary of the walkability factors found during the literature review.

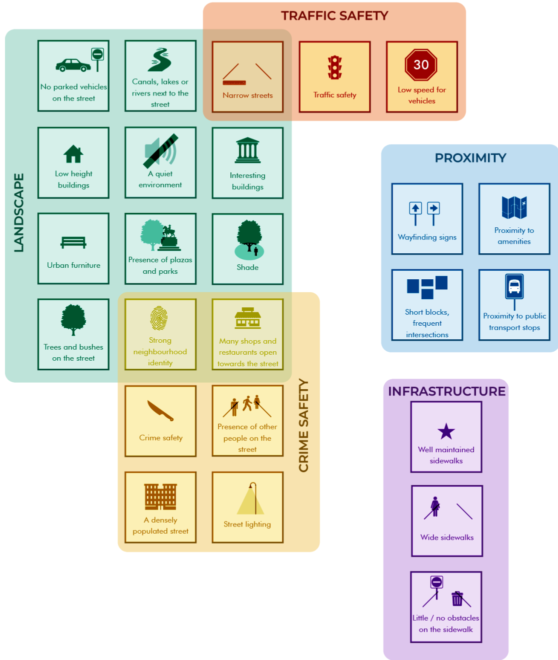

Figure 4. Factor groups as obtained from the interview comments.

ing enjoyable. Notably, a considerable overlap between the three groups was observed. This overlap is reflected in the final ranking of factors that resulted from the first principal component of the PCA analysis, accounting for an average of 61% of the variance present across the spectrum of individual card sorts. The existence of various perspectives on walkability in Amsterdam supports other research affirming that walking is not only influenced by the built environment but also by a series of personal factors (Methorst, 2021).

When we grouped the factors, based on the results of the interviews that followed the Q methodology card sorting, we identified five overarching groups of factors that are related to different aspects of what influences how walkable the public spaces in Amsterdam are considered. These groups are *Landscape*, *Traffic Safety*, *Crime Safety*, *Proximity* and *Infrastructure*. The factors related to each of the groups can be seen in Fig. 4. Some factors such as the street width and the amount of amenities open towards the street simultaneously contribute to two aspects.

Phase C: Data analysis to measure walkability. The results of the Q methodology allowed us to identify and prioritize the factors that influence walkability in Amsterdam. To measure these factors we researched to what degree openly available datasets contain data that reflect the needed information. Based on the data availability and excluding factors that received a low ranking from the experts and would therefore not impact the overall walkability score, we included 15 factors, presented in Table 5.

To develop the walkability index, we collected data from publicly available databases including OpenStreetMap (OSM) from OpenStreetMap (2023), the Dutch Basic

Statement	Inclusion / Exclusion	Weight
Traffic safety	Included	0.094
No obstacles	Included	0.093
Wide Sidewalks	Included	0.086
Presence of others	Excluded, no data	0
Street lighting	Included	0.074
Low speed	Included	0.073
Proximity to amenities	Included	0.073
Crime safety	Included	0.071
Proximity to PT	Included	0.068
Sidewalk maintenance	Included	0.065
Shops and restaurants	Included	0.059
Urban furniture	Included	0.056
Plazas and parks	Included	0.056
No parked vehicles	Included	0.053
Trees and bushes	Included	0.048
Shade	Excluded, no data	0
Frequent intersections	Included	0.031
Narrow streets	Excluded, low z-score	0
Wayfinding signs	Excluded, low z-score	0
Population density	Excluded, low z-score	0
Canals, lakes or rivers	Excluded, low z-score	0
A quiet environment	Excluded, low z-score	0
Neighborhood identity	Excluded, low z-score	0
Interesting buildings	Excluded, low z-score	0
Low height buildings	Excluded, low z-score	0

Table 5. Factors included in (or excluded from) the score calculation accompanied by their weights according to how the experts ranked them.

Registration of Large-Scale Topography (BGT) from the Ministerie van Binnenlandse Zaken en Koninkrijksrelaties (2023), the Open Data portal from the municipality (AOD) from Gemeente Amsterdam (2020), the Road Safety and Accident figures (BRON) from Rijkswaterstaat Ministerie van Infrastructuur en Waterstaat (2022), the General Transit Feed Specification file of the Netherlands (OV API) from OVapi B.V. (2023) and the Dutch Green Map (RIVM) from Rijksinstituut voor Volksgezondheid en Milieu (2020). The aim was to obtain only data for the year

2021, however, in some cases, older or newer data was the only option available. A complete list of the data sources and years is presented in Table 2. Most data was readily available to be integrated into the index. However, some factors such as the width of the sidewalks needed to be extracted from the 3d model of the BGT or required simplification and cleaning before normalisation.

The results of the overall walkability index for Amsterdam are depicted in Fig. 5. As observed, the overall walkability scores indicate that areas such as the city centre, parks, and the surroundings of train stations usually present higher walkability scores. 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 generally lower in the periphery of the city. The districts of Nieuw West, Noord, or Zuidoost obtained lower walkability scores. This reflects its lower density of amenities as well as the presence of higher-speed roads and higher criminality scores. The landscape sub-index in Fig. 6 gives the highest scores to areas containing considerable amounts of green, especially parks. The crime safety sub-index in Fig. 7 shows that areas in the periphery of the city have higher crime rates. Interestingly, the parks that received high scores in the landscape index received very negative crime safety scores, especially due to their lack of public lighting. The traffic safety sub-index in Fig. 8 shows that most of the city has high pedestrian safety standards. Parks and other pedestrian areas got the higher scores of this sub-index while dangerous crossings where accidents involving pedestrians have happened got the lowest. Areas with a high density of amenities received the best scores in the proximity sub-index depicted in Fig. 9, where especially the city centre and smaller dense areas stand out. Finally, the infrastructure sub-index presented in Fig. 10 presents a heterogeneous mix of high and low scores distributed throughout the city. Main roads and tourist areas received the highest scores due to their constant maintenance and wider sidewalks.

5 Discussion

Section 5 introduces the ramifications that derive from the results presented in the previous section. We first present two different approaches to the validation of the results, then we dive into the implications of this specific method to measure walkability, followed by the limitations of this approach and recommendations for future research.

5.1 Validation

We validate our approach in two ways. First, we compare our index with an existing walkability index provided by the municipality of Amsterdam. Second, we select a sample of 10 streets, two from each score-based quantile, ask participants who live in Amsterdam to rank the walkability of these streets, and measure how correlated the participants ranking is with our walkability index. These methods of validation aim to enable the identification of potential flaws in the research design or execution and to provide valuable insights for future research by indicating the reliability of the results.

Comparison with existing walkability indexes. We validate our walkability index by comparing it with the index results of another walkability index created by the municipality of Amsterdam. The municipality's index extent is limited to the city centre and is solely based 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. The Pearson correlation between the scores of the two indexes is found to be close to zero. This outcome suggests that both indexes highly differ in the scores given to the public spaces. The definition of walkability has considerable implications for the evaluation and design of urban transport networks, streets, and other public spaces (Lo, 2009). 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 that are city-specific and based on the opinions people who live and experience a certain city, such as the one proposed by this study, could assist in the identification of contextually relevant walkability factors and in the development of indices that better reflect what residents consider walkable.

Comparison by surveying walkability perceptions. The second validation method seeks to compare the scores calculated by the index with the scores given by a sample of respondents living in Amsterdam. This allows us to evaluate how the index performs in terms of estimating people's perceptions about the walkability of the street as an exemplary public space in a specific urban area. A randomly selected sample of 10 streets (two corresponding to each of the five quantiles of the final scores) is used for this method. The participants were asked to fill in a survey containing images of every street segment together with the name of the neighbourhood the street is located in. 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 was selected. The answers from the survey had a strong correlation of 0.86 (P=0.001) with the scores calculated in the index. Fig. 11 shows the results of this validation method and the individual scores obtained by each street segment. As expected, the streets that had lower scores in attributes that can not be directly inferred from the pictures such as Crime Safety and Proximity to amenities had the biggest differences between estimated and actual scores. Meanwhile, streets where the overall score was predominantly influenced by directly observable characteristics such as good infrastructure, green, or the presence of parks and plazas, presented more accurate estimated scores.

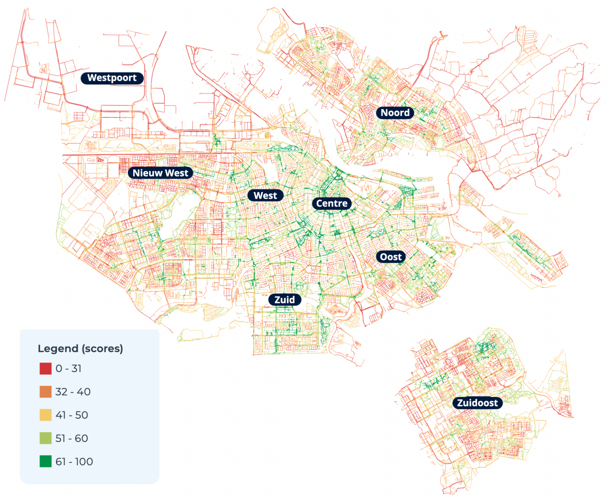

Figure 5. Overall walkability index, estimated for the street segments of Amsterdam.

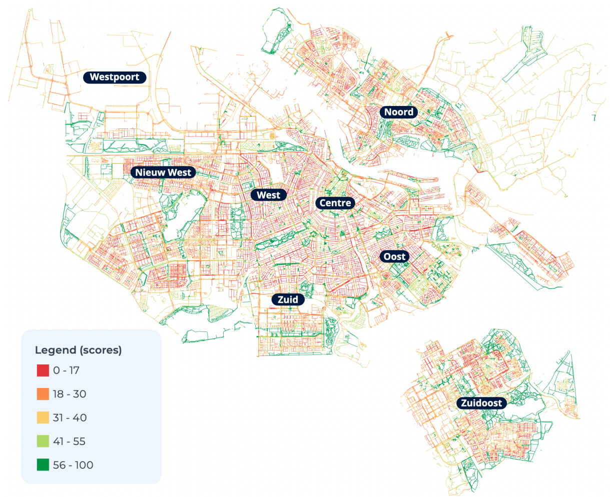

Figure 6. Landscape sub-index, estimated for the street segments of Amsterdam.

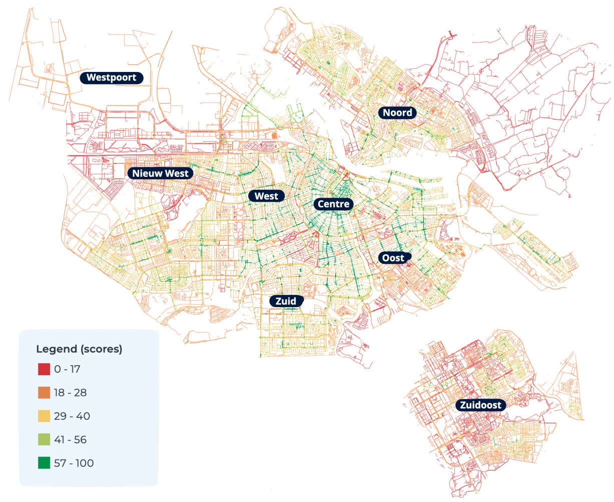

Figure 7. Crime safety sub-index, estimated for the street segments of Amsterdam.

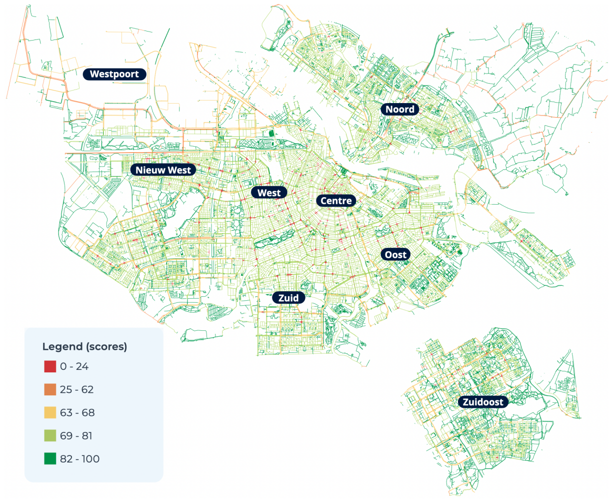

Figure 8. Traffic safety sub-index, estimated for the street segments of Amsterdam.

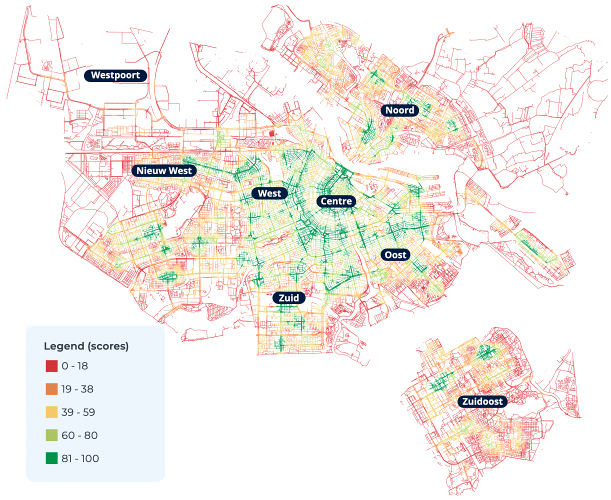

Figure 9. Proximity sub-index, estimated for the street segments of Amsterdam.

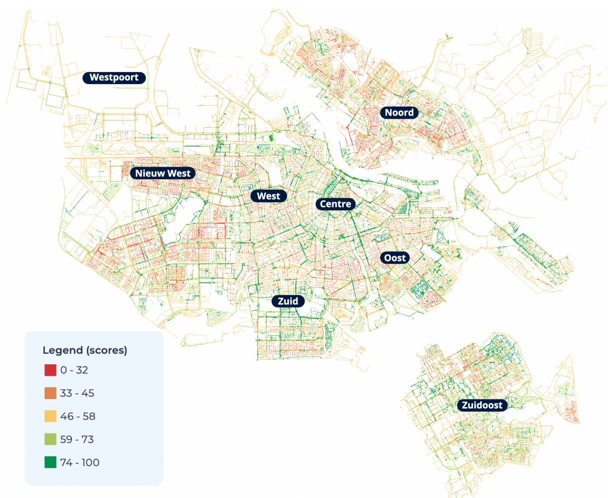

Figure 10. Infrastructure sub-index, estimated for the street segments of Amsterdam.

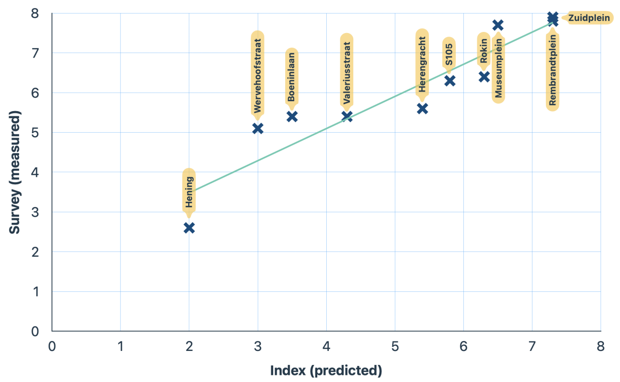

Figure 11. Comparison of the validation survey results and the estimated scores.

5.2 Implications

Mixed methods approach. By developing a context-specific walkability index we are enabled to account for the particularities of an urban area and measure what the 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 and Handy, 2009) and pedestrian streetscape factors (Millstein et al., 2013) become more relevant.

The combination of Q methodology and GIS analysis showcased in this study aims to ensure that the resulting index reflects the characteristics that are relevant to the citizens and particularities of a specific city. 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 in assigning 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 could unveil new insights into how the decision to walk in an area is made.

Scoring paradox. The disaggregated findings suggest that different areas in the city serve distinct functions. For instance, the pedestrian paths in Vondelpark (Fig. 12) overall exhibit a high walkability score. However, a closer examination of the thematic sub-indexes reveals that this high score is primarily attributed to positive factors related to landscape and traffic safety. Conversely, the same paths score poorly in terms of proximity to amenities and crime safety. Similar patterns are observed in other areas of the city, with the most negative correlation identified between landscape and crime safety. This arises from the inherent trade-offs, as no public space in Amsterdam can achieve the maximum score in all factors. Some factors become mutually exclusive after reaching a 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.

Identifying other views on walkability. Although this study 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 changes 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. Extending the application of this approach to participants from diverse demographic groups or various city areas can enhance our comprehension of local perspectives on walkability and place them in the broader context of Amsterdam's overarching objectives.

Walkability scores as a proxy for reality. The collection of walkability factors from the literature followed by the ranking based on a group of stakeholders who are familiar with 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. However, 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, before drawing conclusions from this data, an in-situ 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.

5.3 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 tem-

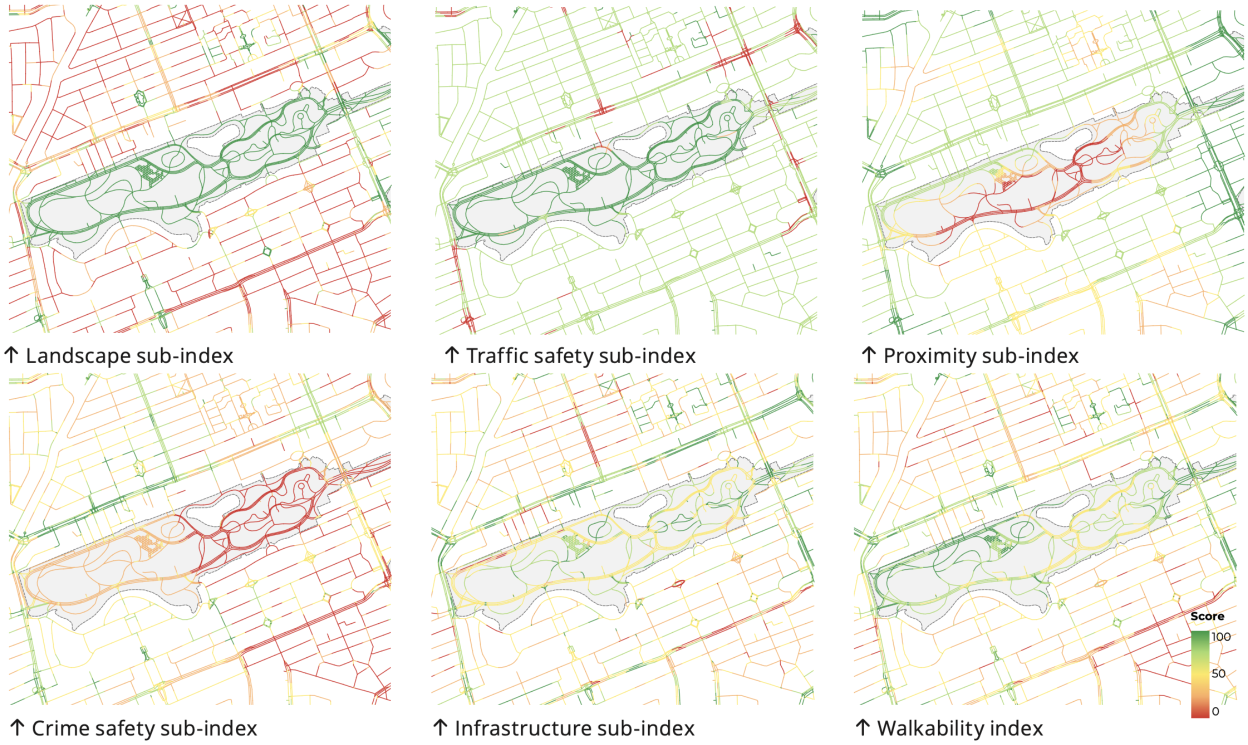

Figure 12. Scores of the different sub-indexes for the Vondelpark.

porary 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 weather. The walkability index presented in this research is indeed static and does not take into account dynamic factors. These factors can vary over time, making it challenging to capture their impact on walkability consistently. Better ways to obtain up-to-date information about the situation in public spaces could improve the accuracy of the index.

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, however, the information the index provides can still be valuable for urban planners and designers to explore walkability by area and individual street.

Another important limitation is that this study does not differentiate between different types of pedestrians that could have different needs such as the ones walking for leisure or to reach a destination.

Furthermore, it is essential to recognize that the validation process in this study does not directly engage with individuals in public space. 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. In future editions of this work, validation in situ is highly recommended.

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.

5.4 Recommendations

Drawing from the limitations explored in the previous section, further research is needed to create more accurate and up-to-date datasets that feed the index. 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. Engaging pedestrians directly in understanding preferences and behaviours could complement the engagement of stakeholders in providing qualitative insights and context. Furthermore, measuring and understanding common points of view between a diverse range of participants as well as comparing and finding correlations between different pre-existing indexes can improve the accuracy of the results.

6 Conclusion

Walkability, or the extent to which urban environments encourage people to walk has been firmly associated with positive health outcomes. To effectively improve walkability, decision-makers need a clear understanding of the factors that influence the walking experience and how to measure them.

This study introduces a participatory approach for developing a walkability index tailored to the context of a specific city. To comprehensively assess walkability, we employed a mixed-methods approach involving interviews, Q methodology, and geospatial analysis. This approach led to the development of a street-level walkability index. The study unfolds in three phases: the first two phases concentrate on collecting qualitative insights regarding the factors that impact walkability both in a general context and specifically within the designated study area. The third phase is dedicated to the collection and analysis of quantitative data to measure walkability based on the factors uncovered in the preceding phases.

The results of our empirical analysis indicate that walkability is significantly influenced by a mix of neighbourhood and street-level factors. While the criteria to consider public spaces walkable varies from one individual to another, 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 suggests that our approach can be used to provide valuable insights into the walkability of different areas while accounting for the particularities of a specific city.

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