Using Students pedestrian perceptions of the built environment to asses street-level walkability in Groningen.

Abstract

This research assesses walkability through both objective and subjective measures. Pedestrian perceptions are used as subjective weights for the calculation of a street-level walkability index specifically measured for students. Building on previous research, this study recreates an index that is both on micro- and meso-level, factoring in specific build environment components at street-level. This research has been carried out in the inner city of Groningen. The results show that the students rated *road safety* as more important than *pedestrian infrastructure robustness, personal security* and *comfort.* Moreover, the walkability index for students shows a growing score for street-segments closer to the centre of the inner city. However, a contradictive result can be found in the highest changes of the walkability scores through the perception of the students. The combination of a walkability index tailored for a specific group together with street-level characteristics makes this walkability index highly interpretable and thus suitable for policy-making and identifying vulnerable street segments and clusters. Thus, it is worth studying even further into the possibilities of this subjective walkability index and furthermore research the validity of this street-level index at other cities.

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Table of content

Background

Active transport such as cycling and walking, supports health through physical activity. Research of Yin et al. (2020) shows that increased physical activity through active commuting results in a positive effect on both Body Mass Index and life satisfaction. Furthermore, the physical activity of walking inhibits chances for depression and drug abuse and increases sociability (Southworth, 2005)(Appolloni et al. 2019). Together with factors such as safety (Jacobs, 1984) and global warming, planning policies are shifting towards the use of the concept walkability (Abley & Hill, 2005).

The concept of walkability and the consideration of what is a walkable place, varies among different city planners. In order to understand what is meant with walkability, Forsyth (2015) phrased walkability comprehensibly as: "being a combination of path condition and closeness with safety as a core". Walkability is often measured on meso- or macro-level (Guzman, Arellana & Castro, 2022)(Frank et al., 2010). In fact, it is easier to compose an index on meso- or macro-level because the data is more accessible. However, for a city more detailed walkability indexes are useful for the use of new policies. For this reason, Guzman, Arellana and Castro (2022) studied the walkability of Bogotá, the capital city of Colombia, on micro-level using the streets as spatial units.

Their index is based on five non-observable categories stated in the 'hierarchy of the walking needs' model of Alfonzo (2005). *Pedestrian infrastructure robustness; Road safety; personal security; Destination access and comfort*. For each of these non-observable categories there is a set of observable components. However, the perception of the built environment varies between socio-demographic differences. The research of Guzman, Arellana and Castro (2022) used age, gender and income as independent variables to create different sets of perceptions of the BE. These perceptions were collected by performing a ranking-questionnaire for pedestrians for both the observable- and non-observable components together with the socio-demographic information. Thereafter, perceptions of the built environment were used as weights for the walkability index to create multiple indexes for the independent variables.

Research problem

It can be argued that in dense cities, where amenities are spread amongst the people, and jobs are often close by, it is important to support walking in a city. Therefore, understanding the factors that influence walkability and whether the components are driven by different pedestrian characteristics is crucial for supportive active transport policies. This research will recreate part of the research of Guzman, Arellana and Castro (2022) in the inner city of Groningen using the same components based on the model of Alonzo (2005). However, new weights for the walkability index will be computed using the perceptions of students currently living in the city of Groningen. Although the city of Groningen and Bogotá come across many pedestrians, the reason differs. Bogotá has many low-income areas in which people walk because it is the cheapest or only option, whereas in Groningen people tend to walk for multiple reasons such as for leisure activity. The socio-demographic differences between Bogotá and Groningen ensures a shift in perceptions of the built environment and makes it necessary to recreate the research of Guzman, Arellana and Castro (2022) in an environment such as Groningen. It also gives the chance to enlarge the opportunity and the possible use of the walkability index for urban planning and institutional policies for the city of Groningen. Furthermore, the sample group for this research will be students due to a lack of samples with other occupations. Additionally, the sheer size of the research is

not feasible for this research. To include sub-variables such as gender, age and income would mean that it would be difficult to obtain a reasonable sample size for the perceptions of students. For this reason the independent variables will consist out of the non-observable and observable components without the consideration of different socio-demographics.
The main question that this research will try to answer is:

- How do the pedestrian perceptions of students reflect street-level walkability in the inner city of Groningen?

The following sub-question needs to be explained:

- Which factors of walkability are perceived important by students for the built environment of the inner city of Groningen?

To answer the main question, it is essential to know which factors of walkability are perceived as important by students because the importance of the factors will shape the pedestrian perceptions. Singh (2016) researched important factors for walkability through activity mapping and public surveys in New Delhi, India. Singh found that the most important factor for walkable streets is a sense of safety and control over the street. The translation of sense of control in this research was that people tend to walk at places with built fabric meaning optimal enclosure and smaller block lengths. Although these components can be found directly within the set of components for this research, the translation of sense of control and safety could differ between New Delhi and Groningen. For this reason it could be argued that for the non-observable components, it is expected that *personal security* and *road safety* are the most important components. However, the sense of safety and control in Groningen could well be differently percepted through different observable components. For this reason the hypothesis for this research is that personal security and road safety are the most important components.

Theoretical framework & conceptual model

Walkability Index Score

Walkability can be measured at different scales. Most often meso-scale measures are used to score walkability, being for example: blocks, districts or neighbourhoods. This is because of the ease of objective available data on this level. A well-known meso-scale measurement of walkability in urban areas is the 5D's model (Diversity, Design, Density, Destination accessibility and Distance to transit) of Ewing and Cervero (2010). Diversity of urban space indicates the mix of land-use. The more land-use is mixed, the more walking trips are to appear. Design of infrastructure is measured as road connectivity, being the number of roads connecting with each other. Walking trips become increasingly common as infrastructure connectivity improves. Density of urban areas can be measured as residential, commercial or institutional density. Residential density is the number of houses per square meter. Shops fall under commercial density and institutional buildings can be either offices, banks or other institutional buildings. Overall, a positive correlation is found between density of urban areas and walking trips. Destination accessibility is often measured as an aggregation of the number of service-areas per square meter. Distance to transit is referred to as the shortest possible way to the nearest transit stop. Another common way to measure this is to aggregate the number of stops per region. The closer the transit stops or the more stops per region, the more walking trips show.

By aggregating the data, the results assume homogeneity within the spatial units. This means for example, that within a block, all street segments are ought to be the same. Thus the model fails to include street-level characteristics into the index. Guzman, Arellana, and Castro (2020) built a walkability index at both meso- and micro-level, incorporating the street-level characteristics and therefore also enabling the use of perceptions of pedestrians. Their index is based on the 'hierarchy of walking needs' which contains five categories (Alfonzo, 2005): *Pedestrian infrastructure robustness; road safety; personal security; destination access and comfort.* For each of the categories there are observable components.

Conceptual model

The walkability index of this research is also based on the five non-observable components, from Alfonzo (2005). For each of these five non-observable components, there is a set of five observable components. These are components which can be either measured on micro- or meso-level. However, for the walkability-index the different components are weighted based on the perception of the built environment. Figure 1 shows the conceptual model including the non-observable and observable components together with the perception of the built environment.

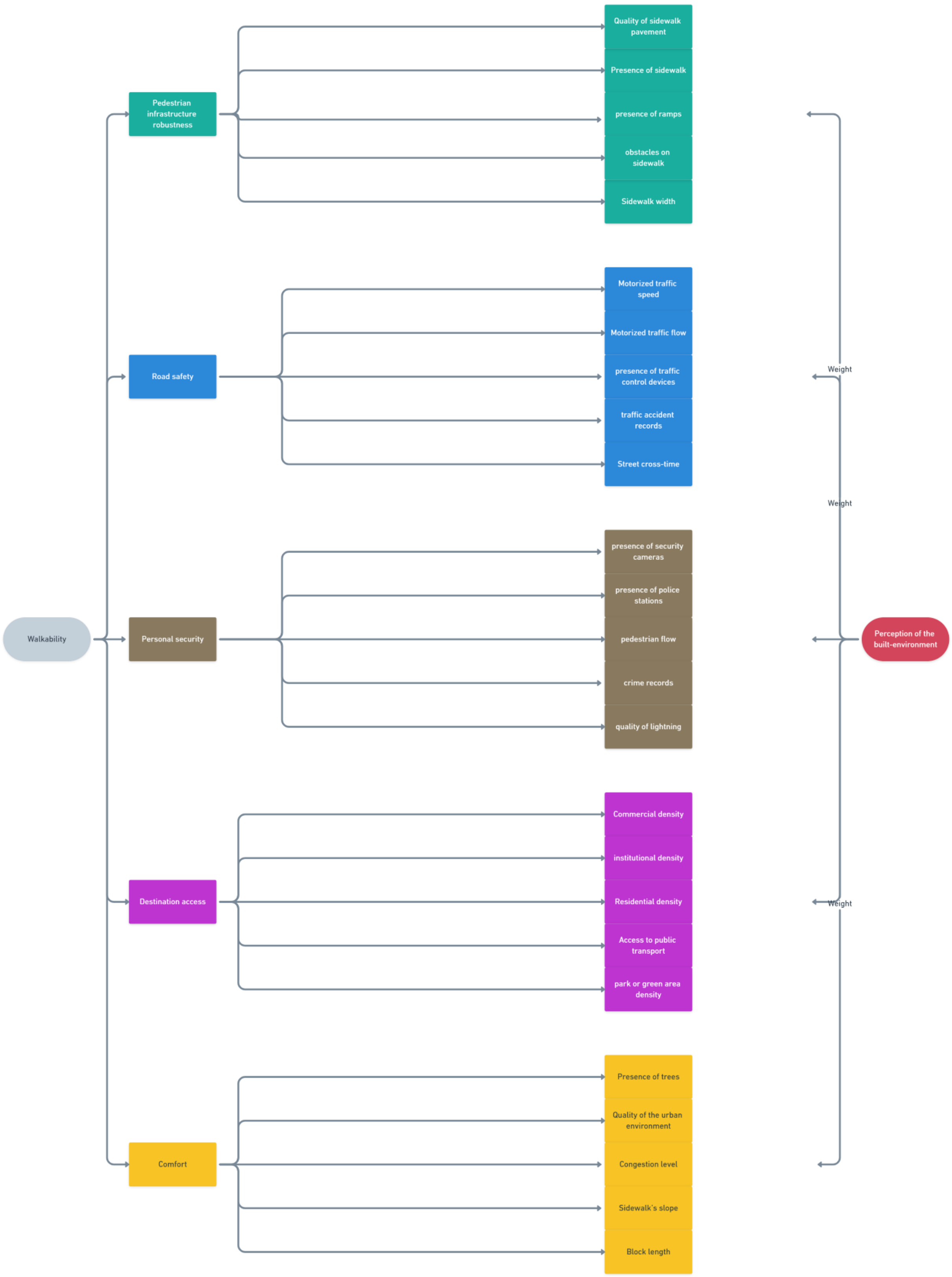


Figure 1: conceptual model of the relationships between the components of Walkability and the perception of the built environment.

Methodology

data collection

The data collection of this research will contain out of two parts. One part will be used to obtain the perception of the built environment of students living in Groningen and the other part of the data will be used to create a street-level walkability index. The data of the perception of the built environment will be applied to weight the importance of both the non-observable and observable components. With the combination of the data, a walkability index can be created which emphasises the perception of the students in Groningen.

data collection of the perception of the built environment

To measure the perception of the built environment, a survey is conducted for 76 students currently living in the city of Groningen. In the survey, students needed to fill in two parts: one where they needed to rank the non-observable and observable components and a second part in which they were asked to guess an average of both their number of pedestrian trips per week and the duration of these trips. Furthermore they were asked to fill in their gender, age and neighbourhood. For the first part of the survey, students were asked to rank the five non-observable components from one to five. one being the most important component and five being the least important. After the non-observable components, students were asked to rank the observable components per non-observable component. This means that in total students were asked six times to rank a set of five components. One time for the non-observable components and five times for the observable components.

The survey was distributed online via social platforms such as Facebook, Surveyswapp and WhatsApp. Because the survey was distributed online, the respondents are spatially spread amongst thirty-five different neighbourhoods. Out of these students, 44.7% is female and 55.3% is male.

data collection of the non-observable and observable components

This research is trying to regenerate a walkability-index earlier created by Guzman, Arellana and Castro (2022) in Bogotá, Colombia. Their walkability-index is based on the hierarchy of walking needs of Alfonzo (2005) and consists out of five components which cannot be directly observed. In order to create the walkability-index, Guzman, Arellana and Castro (2022) divined a set of five components per non-observable component which can be observed. They based these observable components on literature review, a pilot survey and experts' opinions. Each of these 25 observable components is either micro-level, which can be directly linked spatially to street-segments, or macro-level, which can be indirectly linked to street-segments by using aggregates from neighbourhoods. Other than in Bogotá, this research will not perform a walkability-index for the entire city, but will only create a walkability-index for the inner city. This is because of the duration of the process to create a walkability index on street-level and thus to enhance the feasibility of this research. Because some of the components are distance-based, some facilities or other features just outside the inner city can still impact walkability within the inner city. For this reason, the study area is the inner city plus a buffer of 400 meters. This is the distance that is known as the switching point of choice between walking and other transport also known as the pedestrian shed (Azmi, Karim & Amin, 2012). Figure 2 shows the study-area.

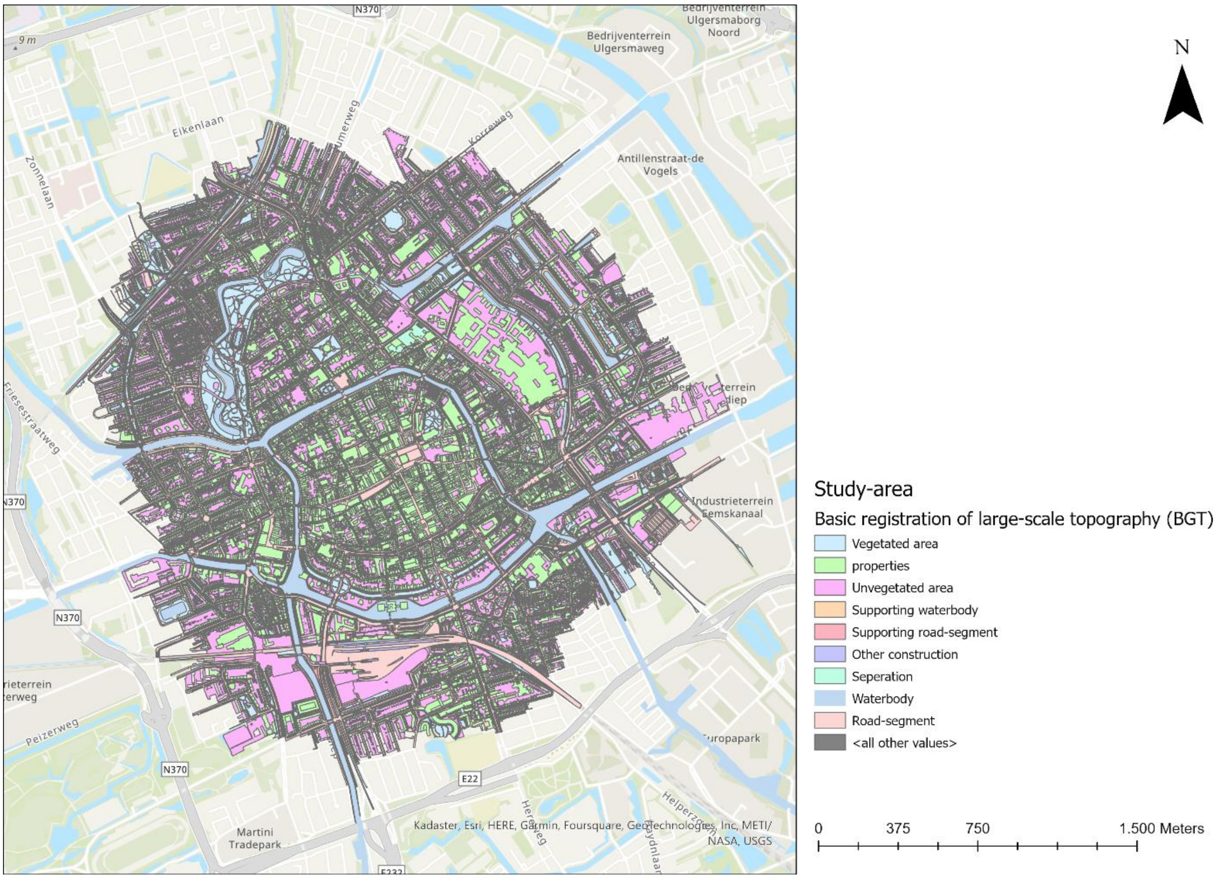


Figure 2: Study-area for the walkability index of the innercity of Groningen

The research of Guzman, Arellana and Castro (2022) used available city data for the observable components. However, for the city of Groningen some of the data is not readily available. For those components, that do not have suitable data in either micro or meso-level, the observable component is left out in the walkability index. This is the case for seven of the observable components: *Presence of ramps, street cross-time, presence of security cameras, pedestrian flow, congestion level, sidewalk's slope* and *block length*. To clarify, these components are also coloured red in table 1. All observable components are standardized to a measured value between 0 and 1. The lower the value, the lower the walkability-score for that particular component and the higher the value, the higher the walkability-score. For all of the components a brief summary of the measurement, variable, range-values, scale and source is given below in table 1. The scales are either on micro- or meso-level. Components on micro-level are measured at street-segments as spatial units, whereas meso-level components use neighbourhoods as spatial units.

Non-observable component	Observable component	Measurement	Variable	Range values	Scale	Source
Pedestrian infra-structure robustness	Presence of sidewalk	Presence of sidewalk segment on the city network	Width ≥ 2.0 m Width < 2.0 m	1 0	Micro-scale	BGT
	Sidewalk width	Sidewalk width in meters	Standardized field (0-1)	-	Micro-scale	BGT
	Quality of sidewalk pavement	Type of sidewalk pavement	Asphalt, concrete element, concrete paving stones, cement concrete, baked bricks and tiles Gravel, shells and unknown values Tree bark and ornamental pavement	1 0.6 0.3	Micro-scale	BGT
	Presence of ramps (handicap people)	No data available	City average		Macro-scale	No data
	Obstacles on sidewalk	Number of disruptions of street-segment per square meter	Standardized field (0-1)	-	Micro-scale	BGT
Road safety	Motorized traffic speed	Average traffic speed (in km/h)	Standardized field (0-1)	-	Meso-scale	OpenStreetMap
	Motorized traffic flow	Distance to vehicular traffic (in meters)	Standardized field (0-1)	-	Meso-scale	OpenStreetMap
	Presence of traffic control devices	There are traffic control devices in the neighbourhood	Yes No	1 0	Meso-scale	OpenStreetMap
	Traffic accident records	There are traffic accident records in the neighbourhood	Yes No	1 0	Meso-scale	BRON
	Street cross-time	Walking time from sidewalk to sidewalk (in seconds)	Standardized field (0-1)		Macro-scale	No data
Personal security	Presence of security cameras	No data available	City average		Macro-scale	No data
	Presence of police stations	Distance to police stations	Standardized field (0-1)	-	Meso-scale	OpenStreetMap
	Pedestrian flow	No data available	City average		Macro-scale	No data
	Crime records	Numbers of robberies and crimes per neighbourhood divided by hectares	Standardized field (0-1)	-	Meso-scale	CBS/Politie
	Quality of lightning	Night lightning presence		1	Micro-scale	OpenStreetMap

Non-observable component	Observable component	Measurement	Variable	Range values	Scale	Source
			Lightning within two meters Lightning within 4 meters Lightning within 6 meters No public lightning	0,6 0,3 0		
Destination access	Commercial density	The density of commercial establishments	Standardized field (0-1)	-	Meso-scale	Gemeente Groningen
	Institutional density	The density of institutional establishments	Standardized field (0-1)	-	Meso-scale	OpenStreetMap
	Residential density	Population density	Standardized field (0-1)	-	Meso-scale	Gemeente Groningen
	Access to public transport	Distance to public transport stops and stations	Standardized field (0-1)	-	Micro-scale	OpenOV
	Parks or green areas density	The density of parks and green areas per neighbourhood	Standardized field (0-1)	-	Meso-scale	BGT
Comfort	Presence of trees	Trees presence	Trees within two meters of segment No trees within two meters of segment	1 0	Micro-scale	BGT
	Quality of the urban environment	Assessment based on level of SES	High SES Middle SES Low SES	1 0,5 0	Meso-scale	CBS
	Congestion level	No data available	City average		Macro-scale	No data
	Sidewalk's slope	No data available	City average		Macro-scale	No data
	Block length	Average block length	Standardize field (0-1)		Macro-scale	No data

Table 1: Non-observable factors, observable factors, measurement of variables and range

Weight estimation

The ranking scores consists out of two layers. The main layer consists out of the five non-observable main components. The second layer consists out of five times five observable components which can be compared per non-observable component. In the main layer, the five non-observable components are compared by their mean. In the research of Guzman, Arellana and Castro (2022), these differences are weighted by performing a multinomial logistic regression. With this test a probability can be calculated that one of the components is chosen as most important component. However, in this research the sample size is about 5% of their sample size, yet still has around 25 independent variables. Because of the lack of respondents, a multinomial logistic regression is not a possibility. Because the data consists out of ranking data, the total of the components adds up to fifteen. For this reason other logistic regressions will leave out one of the components which makes it unfeasible to compose weights for five components at the same time. For this reason the differences between the components is calculated by using a one-sample T-test with a test value of 3. The mean of all components together equals three. This is because the ranking scores vary from one to five. By comparing the means of all non-observable components with the average, a difference in importance between the components can be calculated. A weight (W) of a non-observable component (I) can be calculated by subtracting the mean (X) from 5 and divide it by the total of 5 minus the means (formula 1). The mean is subtracted from 5 because the scores need to be reversed. Thus the lower a mean, the more important the component is.

$$W^I = (5 - X^I)/\sum_{I=1}^{n}(5 - X^I)$$ *(formula 1)*

$$w^i = (5 - x^i)/\sum_{Ii=1}^{n}(5 - x^i)$$ *(formula 2)*

The second layer, consisting out of the observable components, is weighted per non-observable component. For each non-observable component the set of five accompanying observable components are similarly tested by using a one-sample T-test with a test-value of 3. The weights of the observable component (w^i) is calculated in the same way as the non-observable components, only for these components they are only compared with the other components from the same non-observable component. For some of the observable components, no data is available which means that these observable components need to be excluded from the equation. The effect of the omission of the components is that the remaining components become more representable for the non-observable component and will have higher weights.

With the two formulas the main layer of the ranking scores adds up to one and the second layer combines five sets of observable components in a total of five. However, for this research both layers need to be connected so that there is a relation between importance of the non-observable and observable factors. In practice, this means that the observable componants of the most important non-observable components should weight more than the less important components. Therefore, the weights of the observable components (w^i) are multiplied by the accompanying weight of the non-observable component (W^I).

$$w^{Ii} = w^i \times W^I$$ *(formula 3)*

The new sum of the weights (w^{Ii}) of the observable components will now end up in one and further include the connection between both the layers of the ranking scores. These weights can be entered into GIS using a new field value. This value can now be used to project the perception of the built environment onto the map. The value can be calculated by using the formulas above. Furthermore an extra field will be created which gives all components the same weight. This can be used to look into the difference of the walkability index with and without perceptions of students in segments of the city-centre.

Results

The results will be divided into two sections. One section will discuss the results of the survey questions by interpreting the T-test results for the perception of the students. Furthermore this section will discuss the outcome of the weights of the components. The second section shows the results of the weights into the walkability index. In this section the walkability index will be shown for different parts where the difference between the perception and the non-weighted walkability index is the biggest.

test results

For both the non-observable components and the observable components, T-tests are conducted to compare the means to the test-value being the average score. The test is once conducted for the five non-observable components and furthermore five times executed for the five matching sets of observable components. The test result for the five non-observable components is demonstrated in table 2. At the heading 'Mean Difference' the distance to the average is indicated. A negative number corresponds with a mean below the average of three. The more negative a score, the more important the non-observable component is. Likewise, a lower mean corresponds with a higher weight, and thus a higher mean results in a lower weight. Furthermore, this test shows the significant difference from the test-value being three. Finally, the confidence interval for the components is indicated in the last column and can be used to identify significant differences between components. A more detailed table for the confidence intervals of the non-observable components is shown in table 3. The tests outcomes together with the corresponding confidence intervals can be found in the appendix.

One-Sample Test

	Test Value = 3						
			Significance			95% Confidence Interval of the Difference	
	t	df	One-Sided p	Two-Sided p	Mean Difference	Lower	Upper
Destination access	-,747	69	,229	,458	-,114	-,42	,19
Road safety	-3,455	69	<,001	<,001	-,486	-,77	-,21
Personal Security	1,095	69	,139	,277	,200	-,16	,56
Pedestrian Infrastructure Robustness	,973	69	,167	,334	,171	-,18	,52
Comfort	1,279	69	,103	,205	,229	-,13	,59

Table 2: one-sample T-test for the non-observable components

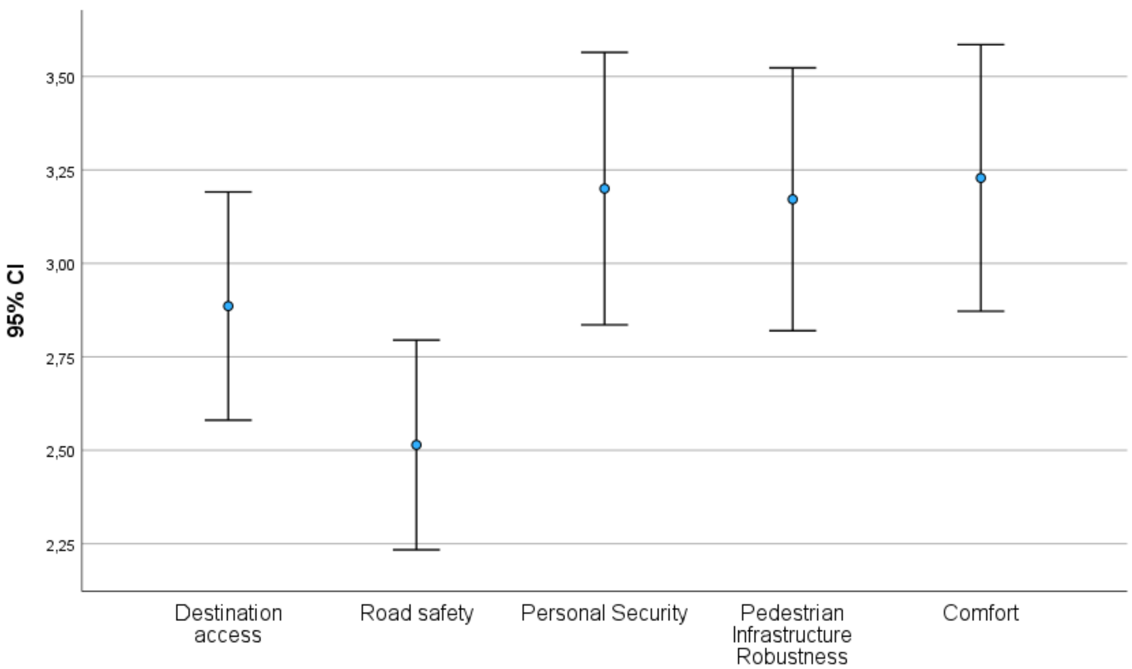
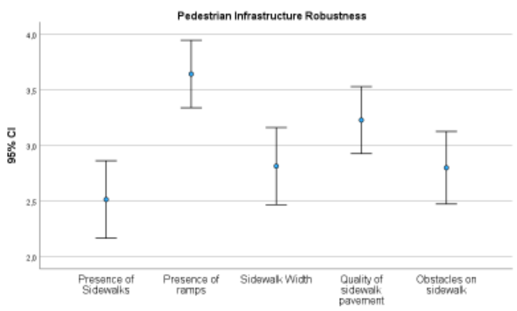
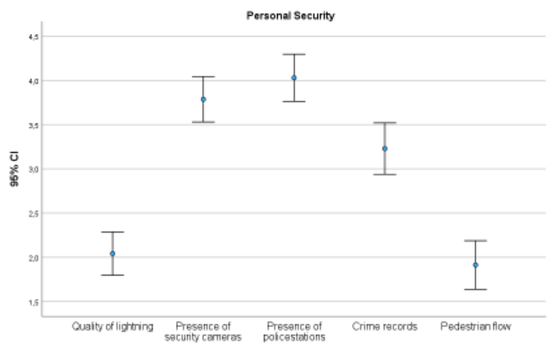


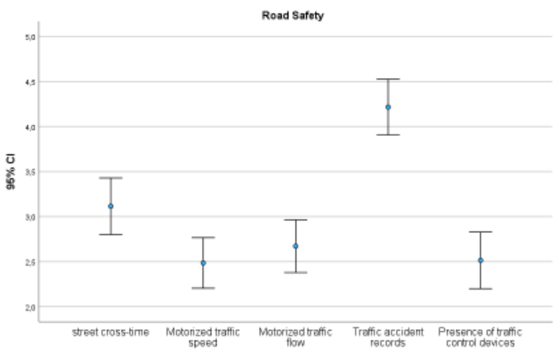
Table 3: confidence intervals for thev non-observable components

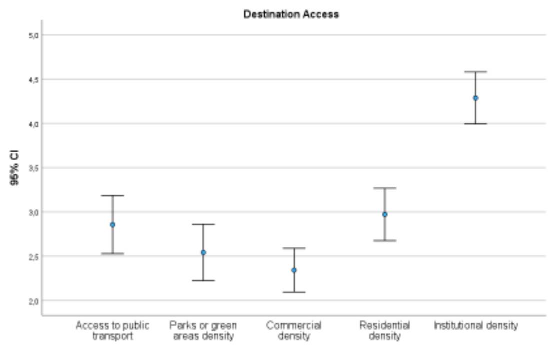
Given the results shown in table 2 and 3 the following statements can be made:
In this research no significant difference is found between *destination access, personal security, pedestrian infrastructure robustness* and *comfort*. Furthermore, no significant difference is found between *road safety* and *destination access*. However, a significant difference is found between *road safety* and the three non-observable components: *personal security, pedestrian infrastructure* and *comfort*. Although *road safety* has the lowest mean and is therefore given the highest weight, it can not be said that *road safety* is the most important factor, since the difference with *destination access* is not significantly. Still the results show that *road safety* is perceived by students in Groningen as more important than *Personal security, Pedestrian infrastructure* and *Comfort*. The fact that *road safety* is significantly more important than *pedestrian infrastructure robustness* and *comfort* is in line with the hypothesis derived from the research of Singh (2016). Moreover it was expected that *personal security* would also be an important factor. However in this research it is one of the least important factors. This is also not in line with the outcome of Guzman, Arellana and Castro (2022) which showed that in Bogotá the most important factors are: *pedestrian infrastructure robustness, personal security* and *road safety*. An explanation for this unexpected result is that students are less concerned with safety. Another explanation can be found in the difference in cities. People in New Delhi and Bogotá have other habits of life which can endanger the external validity of these researches.

For *Pedestrian infrastructure robustness, Presence of sidewalks* is perceived as significantly more important than both the *quality of the sidewalk pavement* and *presence of ramps* (table 4). Furthermore, *sidewalk width* and *obstacles on the sidewalk* are perceived as more important components than *presence of ramps*. Although no component is either significantly the least or most important component *for pedestrian infrastructure robustness, presence of sidewalk* has the lowest mean and thus the highest weight and *presence of ramps* has the highest mean and thus the lowest weight. This result is obvious since the absence of sidewalks would make it impossible to look for the width and quality of pavements, obstacles and ramps.









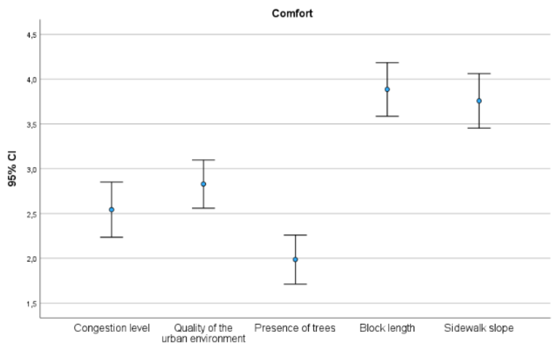


Table 4: Confidence intervals of the observable components

For *personal security*, *pedestrian flow* and *quality of lightning* are significantly more important components than *presence of security cameras, presence of police stations* and *crime records.* Additionally the component *crime records* is perceived as more important than *presence of security cameras* and *presence of police stations*. For *personal security* no observable component is significantly either most important or least important. *Pedestrian flow* has the lowest mean and *presence of police stations* has the highest mean. The results are in line with Jacobs (1984) thoughts about street safety. She argued that in order to maintain a safe and lively street, it is vital that there are enough eyes on the street, which fits the description of *pedestrian flow*. The number of police stations and cameras in the city of Groningen is generally low in comparison with other cities. For that reason it is not surprising that these components scored lower on importance.

For *road safety, traffic accident records* has a significantly higher mean than all the other components which means that this component is least important. Furthermore, *motorized traffic speed* is significantly more important than *street cross time,* has the lowest mean, but does not have a significant difference with *motorized traffic flow* and *presence of traffic control devices.*

For *destination access, Institutional density* has a significantly higher mean than all the other components which means that this component is least important. Additionally, *commercial density* has the lowest mean but does not differ significantly with *parks or green area density* and *access to public transport.* However it does have a significant difference with *residential density.* The result for *destination access* is somewhat in line with the idea that people are willing to walk as long as the destination is in short distance. Here you can find a connection between having a walk to either shops, parks or a nearby bus stop. *Institutional density* is also linked to the same idea, however people are less likely to travel to institutions.

For *comfort, block length* and *sidewalk slope* are perceived as least important components. On the other side of the spectrum, *presence of trees* has the lowest mean and is significantly more important than all other components except *congestion level.*

Although not all the components differ significantly in the scores, this research uses the mean score as start to compute the weights for the components. Following the calculations from formula 1, table 5 displays the weights for the non-observable components. The table shows that *road safety has the highest weight* and *personal security* has the lowest weight. Together with the data for the observable components and following the calculations from formulas 2 and 3, the outcome of the weights of the observable components are presented in table 6. In this table the estimated weights is given per observable component per non-observable component. To easily find the difference in weights, figure 3 ranks all the observable components by there weight. Overall, *presence of trees, quality of lightning* and *motorized traffic speed* are perceived as most important components. Two sidenotes need to be made here. First, although these weights are the highest, it does not mean that these components are significantly more important than the other components. Secondly, because some of the components are left out of the walkability index, some of the non-observable components are represented by fewer observable components. This makes these observable components more representable and thus results in higher weights. For example: *presence of trees* is one of two components representing *comfort.* Therefore*, presence of trees* is more likely to be found on the left side of figure 3 and in this case is actually the component with the highest weight.

Non-observable component	Estimated weight (W^I)
Pedestrian infrastructure robustness	0.183
Road safety	0.249
Personal security	0.180
Destination access	0.211
Comfort	0.177

Table 5: estimated weights for the non-observable components

Non-observable component	Observable component	Estimated weight (w^{Ii})
Pedestrian infrastructure robustness	Presence of sidewalk	0.053
	Sidewalk width	0.046
	Quality of sidewalk pavement	0.038
	Obstacles on sidewalk	0.046
Road safety	Motorized traffic speed	0.077
	Motorized traffic flow	0.071
	Presence of traffic control devices	0.076
	Traffic accident records	0.025
Personal security	Presence of police stations	0.037
	Crime records	0.053
	Quality of lightning	0.090
Destination access	Commercial density	0.056
	Institutional density	0.015
	Residential density	0.043
	Access to public transport	0.045
	Park or green areas density	0.052
Comfort	Presence of trees	0.103
	Quality of the urban environment	0.074

Table 6: Estimated weights for the observable components

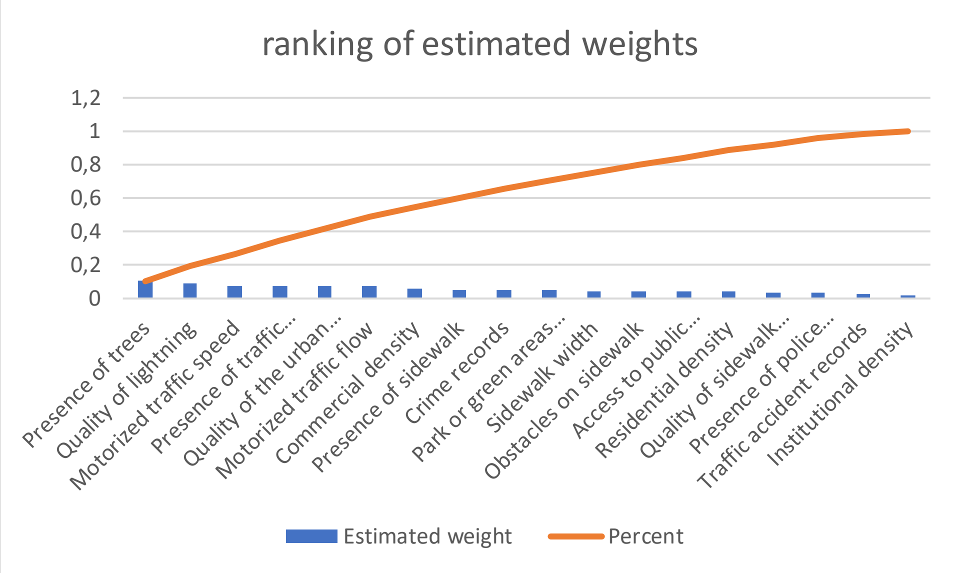


Figure 3: ranking of the estimated weights of the observable components

street-level walkability index

With a total of 18 observable components measured and weighted in GIS, the street-level walkability index for the inner city of Groningen is computed based on the pedestrian perceptions of students. The results are shown in figures 4 to 9. Figure 4 shows the final street-level walkability index for the inner city of Groningen based on the perceptions of the students. Walkability is scored from 0 to 1 and furthermore grouped into four categories. Red segments have the lowest walkability and blue segments have the highest walkability. Figure 6 shows the distribution of the walkability scores of the segments. With a total of 1491 segments this figure (6) shows a normal distribution. Furthermore the index is checked on spatial autocorrelation. This measures the null hypothesis that the features in the index exhibit a spatially random pattern. The outcome of the test gives a z-score of 21.696 which means that there is a less than 1% likelihood that the clustered patterns could be the result of random chance. Additionally the spatial patterns are mapped in figure 5 which shows both clusters with high and low walkability. The main result from this figure (figure 5) is the high-high cluster at 'de Grote Markt' and the adjacent streets. This means that this area has an overall high score for walkability for students. Another noticeable result in figure 5 is that the clusters for low walkability are mostly located outside the canals of the inner city. Finally figure 4 and 5 both show a pattern which might indicate that the walkability score for students gets higher the closer to the centre of the city.

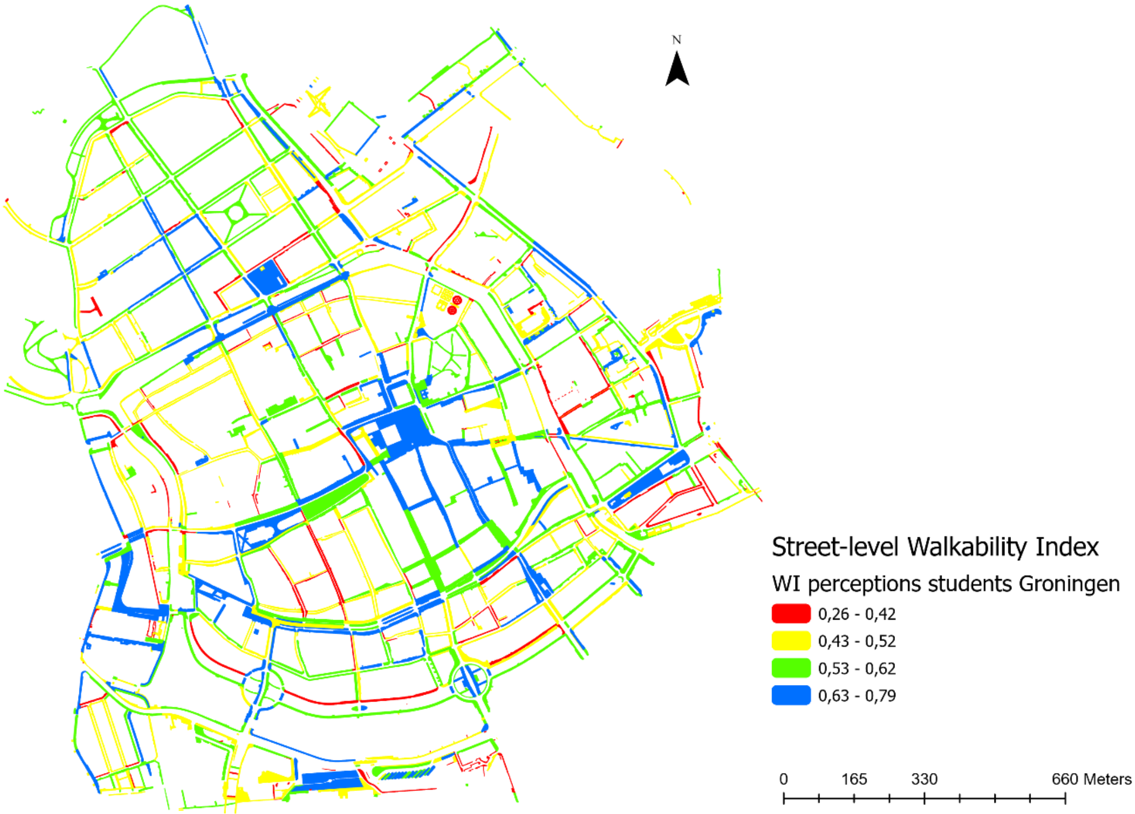


Figure 4: Walkability index for the inner city of Groningen with the perception of students

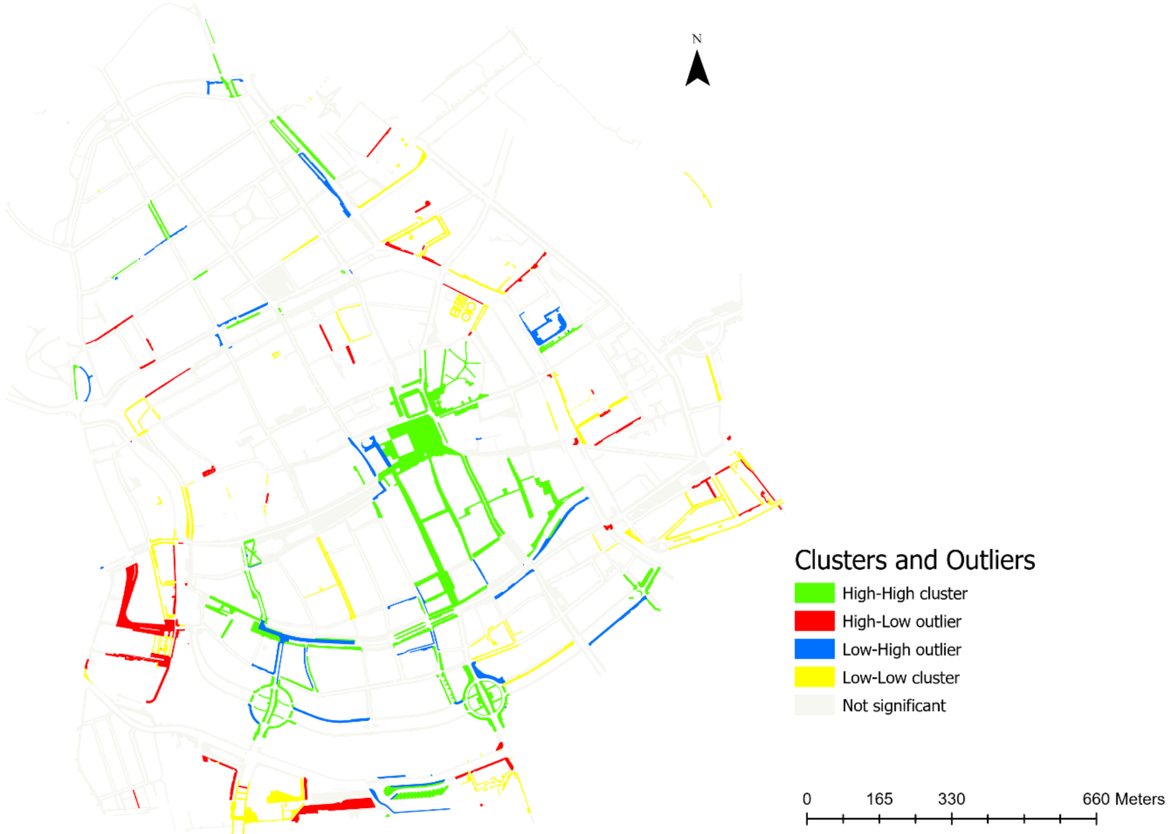


Figure 5: Clusters of the Walkability index for the inner city of Groningen with the perception of students

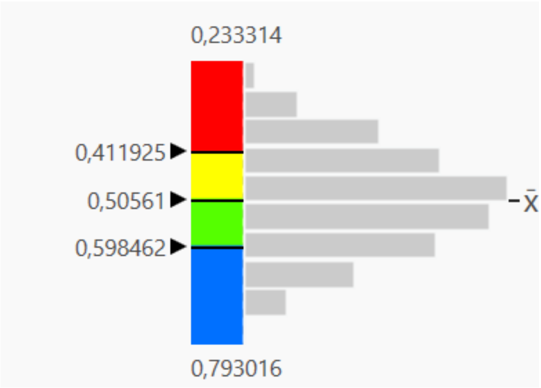


Figure 6: distribution of the segments from the Walkability index

Whilst the walkability index for students is a result in itself, more clarity can be obtained by comparing the results of the walkability index for students with a walkability index which has not been weighted and thus treats the components as equally important. The result of this walkability index without perceptions is shown in figure 7. This index looks similar to the index with the perceptions. However, a general difference can be found. The overall score of the walkability index for students seems to be slightly higher than the one without perceptions. To check this claim, another index is created which displays the difference between the first two indexes by dividing the Walkability index of the students by the objective walkability index (figure 8). Figure 9 is the corresponding distribution of the index and clearly shows a skewed distribution to the negative scores. This is consistent with the claim that the walkability index without perceptions is higher than the walkability index with the perceptions of students. Additionally, figure 8 seems to shows that the walkability index of the students is particularly lower in the centre of the inner city, yet higher at the outskirts of the inner city. To confirm this claim, a test for spatial correlation is conducted and shown in figure 10. This figure clearly shows the difference between the outskirts and the centre. A reason for this difference is the impact of the observable components with the highest weights. These are: *presence of trees, quality of lightning* and *motorized traffic speed.* In the north-east of the map from figure 10 a noticeable cluster of positive change can be seen. This indicates that this piece of segments improved by adding the weights for students. This piece of segment is 'de Noorderplantsoen' and adjacent streets, which makes sense because there are many trees and only slow traffic. Thus by adding the perception of the students, the walkability in the outskirts improves, and the walkability in the centre of the inner city decreases. However, as shown in figure 4 and 5, overall the segments closer to the centre of the inner city have higher scores for walkability.

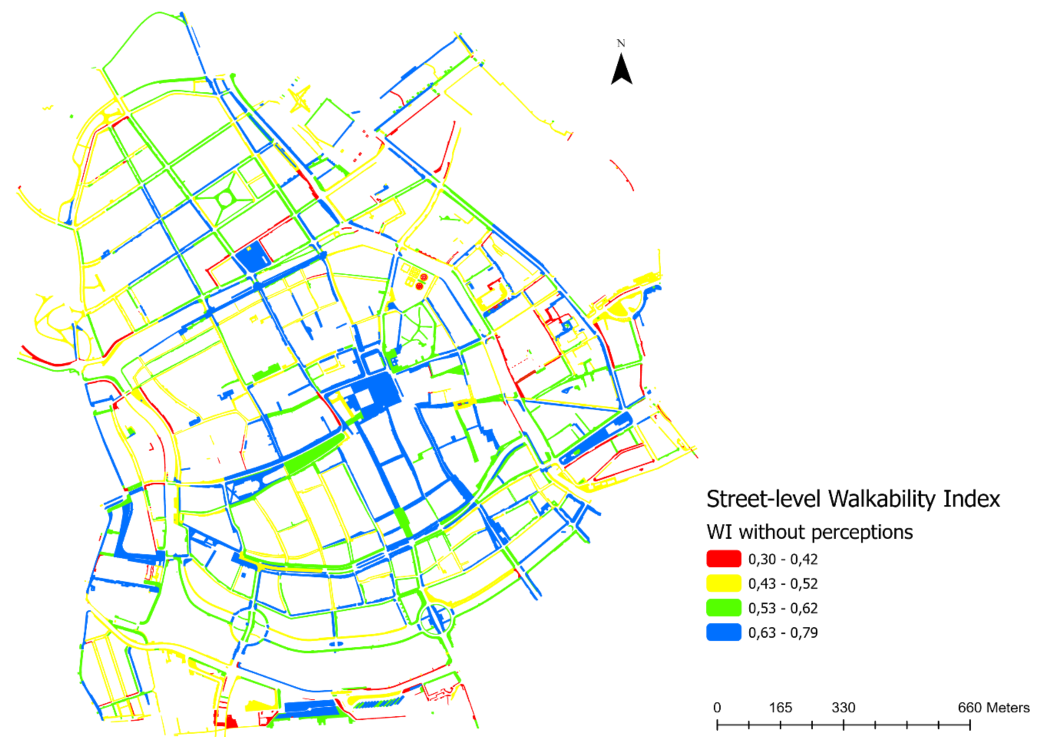


Figure 7: Walkability index for the inner city of Groningen without the perception of students

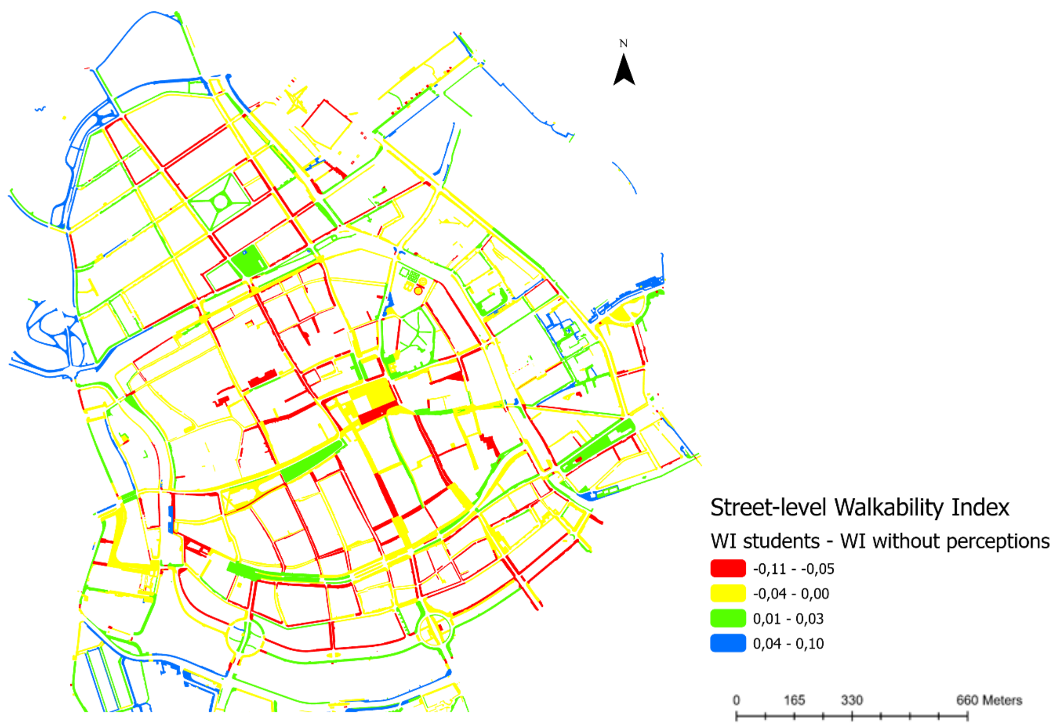


Figure 8: Differences of the Walkability index for the inner city of Groningen with and without the perception of students

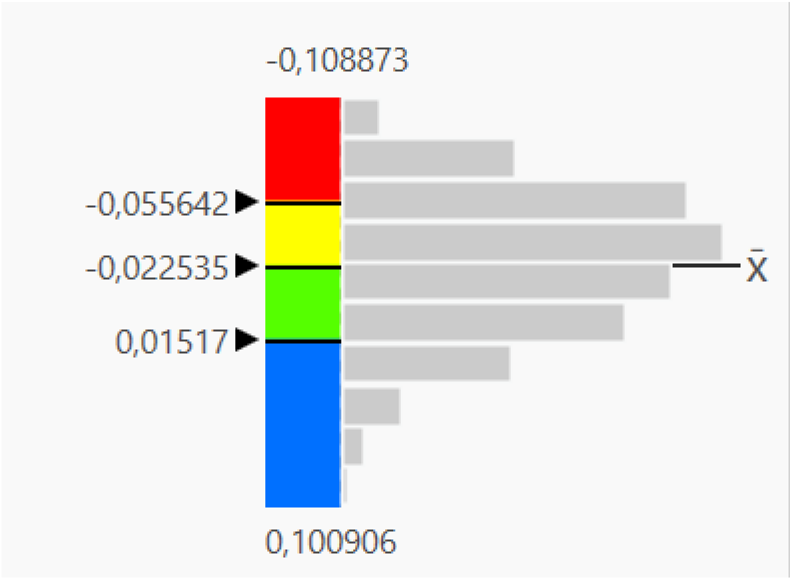


Figure 9: distribution of the difference

Figure 10: Clusters of the differences in Walkability indexes

conclusions

To promote active transport within cities it is vital to know the factors that guide towards walkability. By understanding the most important components, a city can embody these factors into their plans to improve the built environment. This research approached these factors as a combination of objective and subjective methods, creating a walkability index fitting for the inner city of Groningen. Other than the previous research (Guzman, Arellana & Castro, 2022) this study focussed merely on students without looking at other socio-demographics. Together with the fact that some data of the components was not available in this study area, the resulting walkability indexes cannot be compared between cities. Additionally it cannot even be said that a segment scoring high on walkability is per definition a very walkable segment in the eyes of students. However, within the city the walkability index gives a strong idea of what students within Groningen find important in walkability. Furthermore a walkability index like this, is a robust tool to use for policies and consulting, since it contains the subjective perceptions of the inhabitants of the city. Additionally in further research, other focus groups can be added, and different socio-demographic variables can be obtained to broaden the walkability index.

For the city-centre of Groningen a few important claims can be made based on the results of this research. First, the students rated *road safety* as more important than *pedestrian infrastructure robustness, personal security* and *comfort.* This is different than in the research of Guzman, Arellana and Castro (2022), which is not strange since it is expected that the perceptions differ between cultures. However, the result is somewhat in line with the research of Singh (2016) which stated that the most important factors are sense of safety and control.

When looking at the resulting walkability index the following statement can be made for the inner city of Groningen: For the perception of students we see that walkability improves as segments are located closer to the centre of the inner city (figure 4 & 5). However, the same result can be found within an objective walkability index of the city. When looking at the difference between the subjective and objective indexes, the results show an improvement in walkability in the outskirts, and decrease of walkability in the centre of the inner city (figure 8 & 10).

The street-segment walkability index has been recreated from the research of Guzman, Arellana and Castro (2022) which in Bogotá lead to other results in perceptions of pedestrians. However, the structure and set up of the index is still sound and properly recreated in this research. Therefore, it is recommended to use this walkability index on street-level including both micro- and meso-level data and furthermore incorporating the subjective perceptions within the objective index. For this research proved that this index can be translated to an entire different city and with the perceptions of the inhabitants there, create a walkability index suiting for that city.

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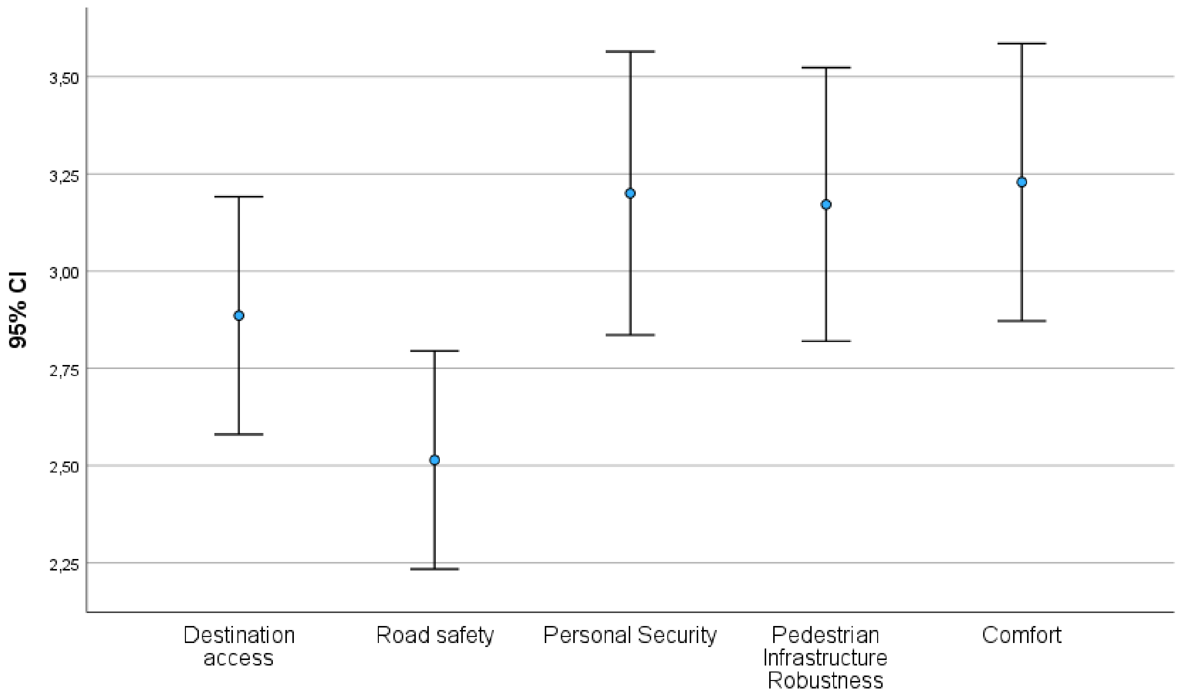
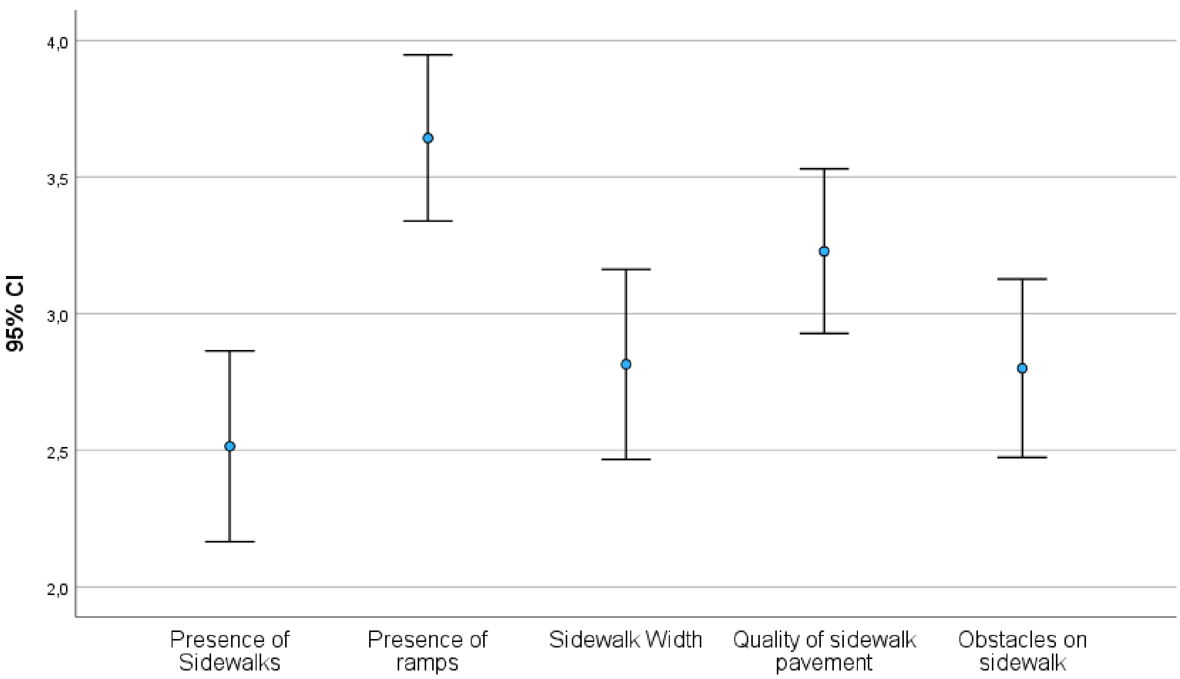
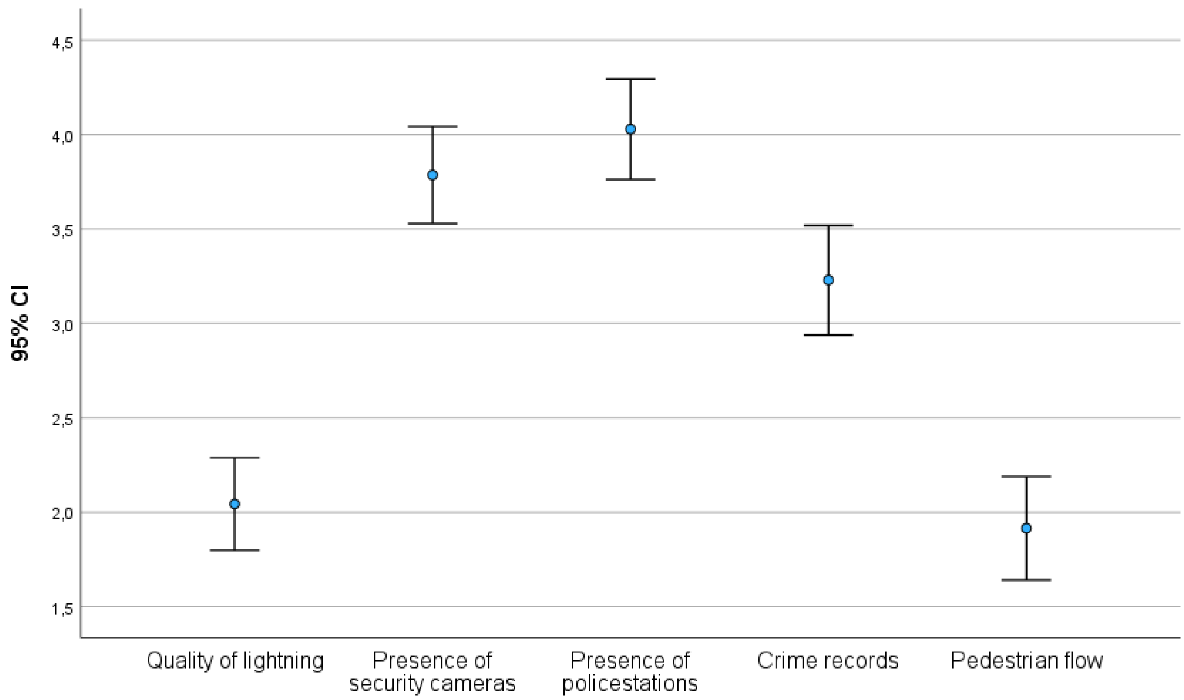
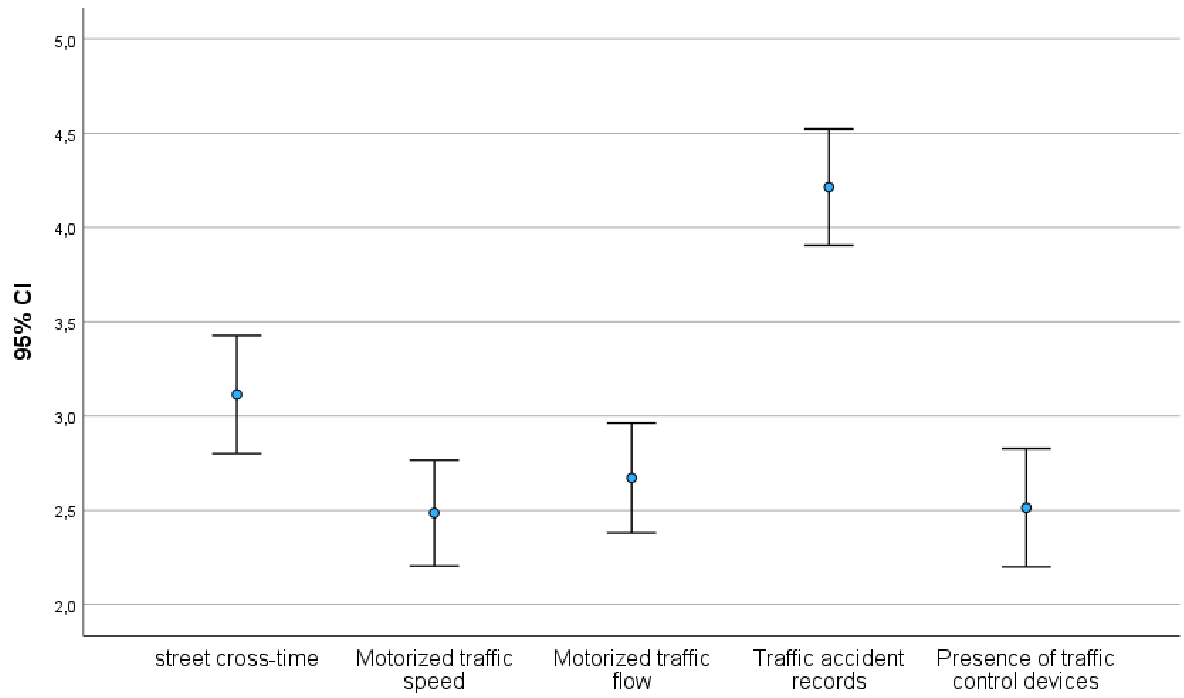
Appendix


95% CI
3,50
3,25
3,00
2,75
2,50
2,25
Destination access
Road safety
Personal Security
Pedestrian Infrastructure Robustness
Comfort

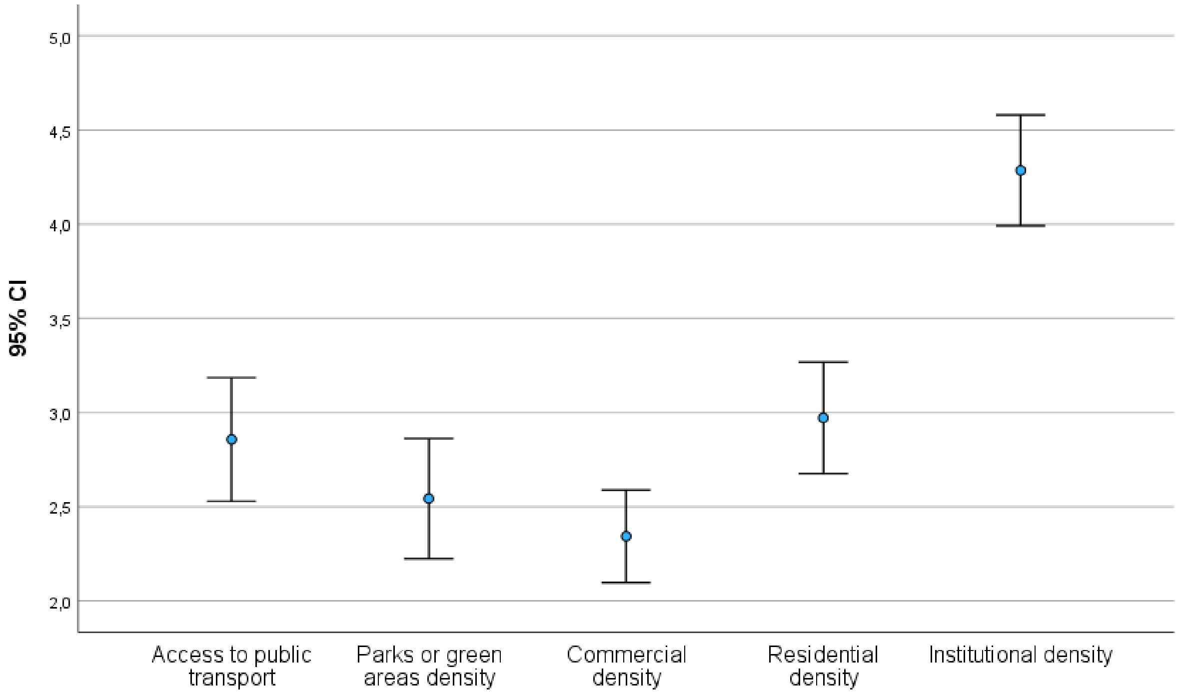

95% CI
4,0
3,5
3,0
2,5
2,0
Presence of Sidewalks
Presence of ramps
Sidewalk Width
Quality of sidewalk pavement
Obstacles on sidewalk



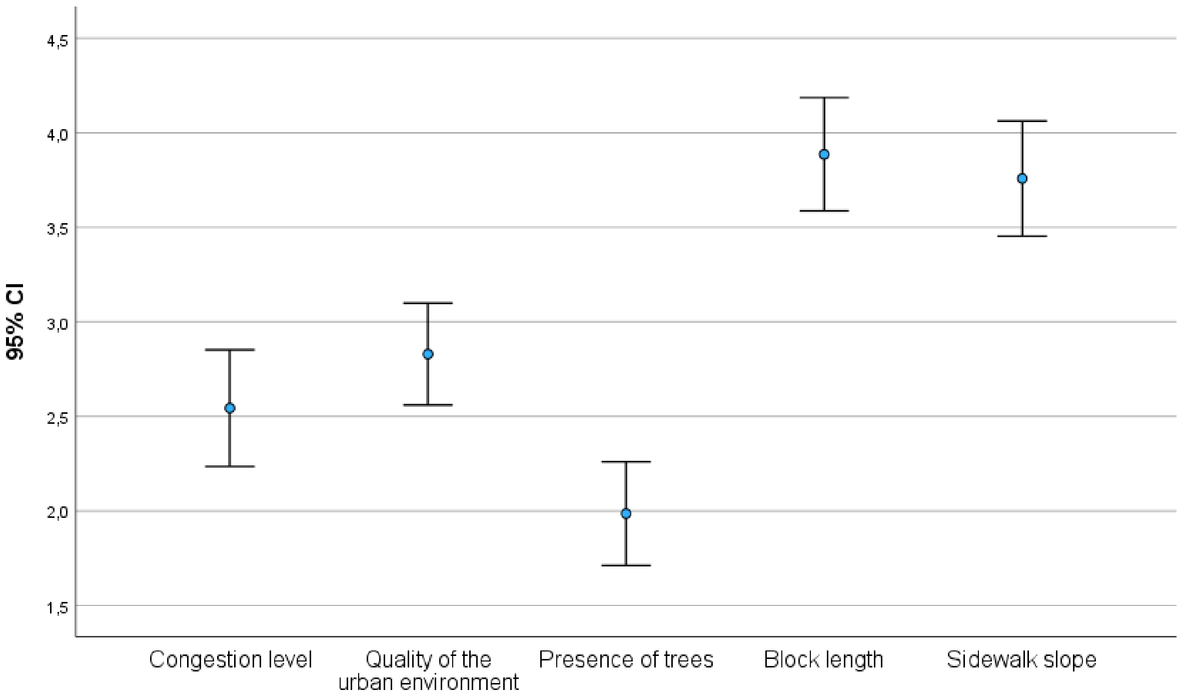
4,5
4,0
3,5
3,0
2,5
2,0
1,5
95% CI
Quality of lightning
Presence of security cameras
Presence of policestations
Crime records
Pedestrian flow



5,0
4,5
4,0
3,5
3,0
2,5
2,0
95% CI
street cross-time
Motorized traffic speed
Motorized traffic flow
Traffic accident records
Presence of traffic control devices



95% CI
5,0
4,5
4,0
3,5
3,0
2,5
2,0
Access to public transport
Parks or green areas density
Commercial density
Residential density
Institutional density



95% CI
4,5
4,0
3,5
3,0
2,5
2,0
1,5
Congestion level
Quality of the urban environment
Presence of trees
Block length
Sidewalk slope

One-Sample Test

	Test Value = 3						
	t	df	Significance One-Sided p	Significance Two-Sided p	Mean Difference	95% Confidence Interval of the Difference Lower	95% Confidence Interval of the Difference Upper
Destination access	-,747	69	,229	,458	-,114	-,42	,19
Road safety	-3,455	69	<,001	<,001	-,486	-,77	-,21
Personal Security	1,095	69	,139	,277	,200	-,16	,56
Pedestrian Infrastructure Robustness	,973	69	,167	,334	,171	-,18	,52
Comfort	1,279	69	,103	,205	,229	-,13	,59

One-Sample Test

	Test Value = 3						
	t	df	Significance One-Sided p	Significance Two-Sided p	Mean Difference	95% Confidence Interval of the Difference Lower	95% Confidence Interval of the Difference Upper
Presence of Sidewalks	-2,780	69	,004	,007	-,486	-,83	-,14
Presence of ramps	4,220	69	<,001	<,001	,643	,34	,95
Sidewalk Width	-1,066	69	,145	,290	-,186	-,53	,16
Quality of sidewalk pavement	1,512	69	,068	,135	,229	-,07	,53
Obstacles on sidewalk	-1,223	69	,113	,226	-,200	-,53	,13

One-Sample Test

	Test Value = 3						
	t	df	Significance One-Sided p	Significance Two-Sided p	Mean Difference	95% Confidence Interval of the Difference Lower	95% Confidence Interval of the Difference Upper
Quality of lightning	-7,792	69	<,001	<,001	-,957	-1,20	-,71
Presence of security cameras	6,113	69	<,001	<,001	,786	,53	1,04
Presence of policestations	7,711	69	<,001	<,001	1,029	,76	1,29
Crime records	1,570	69	,060	,121	,229	-,06	,52
Pedestrian flow	-7,889	69	<,001	<,001	-1,086	-1,36	-,81

One-Sample Test

	Test Value = 3						
	t	df	Significance One-Sided p	Significance Two-Sided p	Mean Difference	95% Confidence Interval of the Difference Lower	95% Confidence Interval of the Difference Upper
street cross-time	,728	69	,235	,469	,114	-,20	,43
Motorized traffic speed	-3,658	69	<,001	<,001	-,514	-,79	-,23
Motorized traffic flow	-2,245	69	,014	,028	-,329	-,62	-,04
Traffic accident records	7,843	69	<,001	<,001	1,214	,91	1,52
Presence of traffic control devices	-3,088	69	,001	,003	-,486	-,80	-,17

One-Sample Test

	Test Value = 3						
	t	df	Significance One-Sided p	Significance Two-Sided p	Mean Difference	95% Confidence Interval of the Difference Lower	95% Confidence Interval of the Difference Upper
Access to public transport	-,869	69	,194	,388	-,143	-,47	,19
Parks or green areas density	-2,860	69	,003	,006	-,457	-,78	-,14
Commercial density	-5,317	69	<,001	<,001	-,657	-,90	-,41
Residential density	-,193	69	,424	,848	-,029	-,32	,27
Institutional density	8,750	69	<,001	<,001	1,286	,99	1,58

One-Sample Test

	Test Value = 3						
	t	df	Significance		Mean Difference	95% Confidence Interval of the Difference	
			One-Sided p	Two-Sided p		Lower	Upper
Congestion level	-2,958	69	,002	,004	-,457	-,77	-,15
Quality of the urban environment	-1,270	69	,104	,208	-,171	-,44	,10
Presence of trees	-7,390	69	<,001	<,001	-1,014	-1,29	-,74
Block length	5,894	69	<,001	<,001	,886	,59	1,19
Sidewalk slope	4,953	69	<,001	<,001	,757	,45	1,06