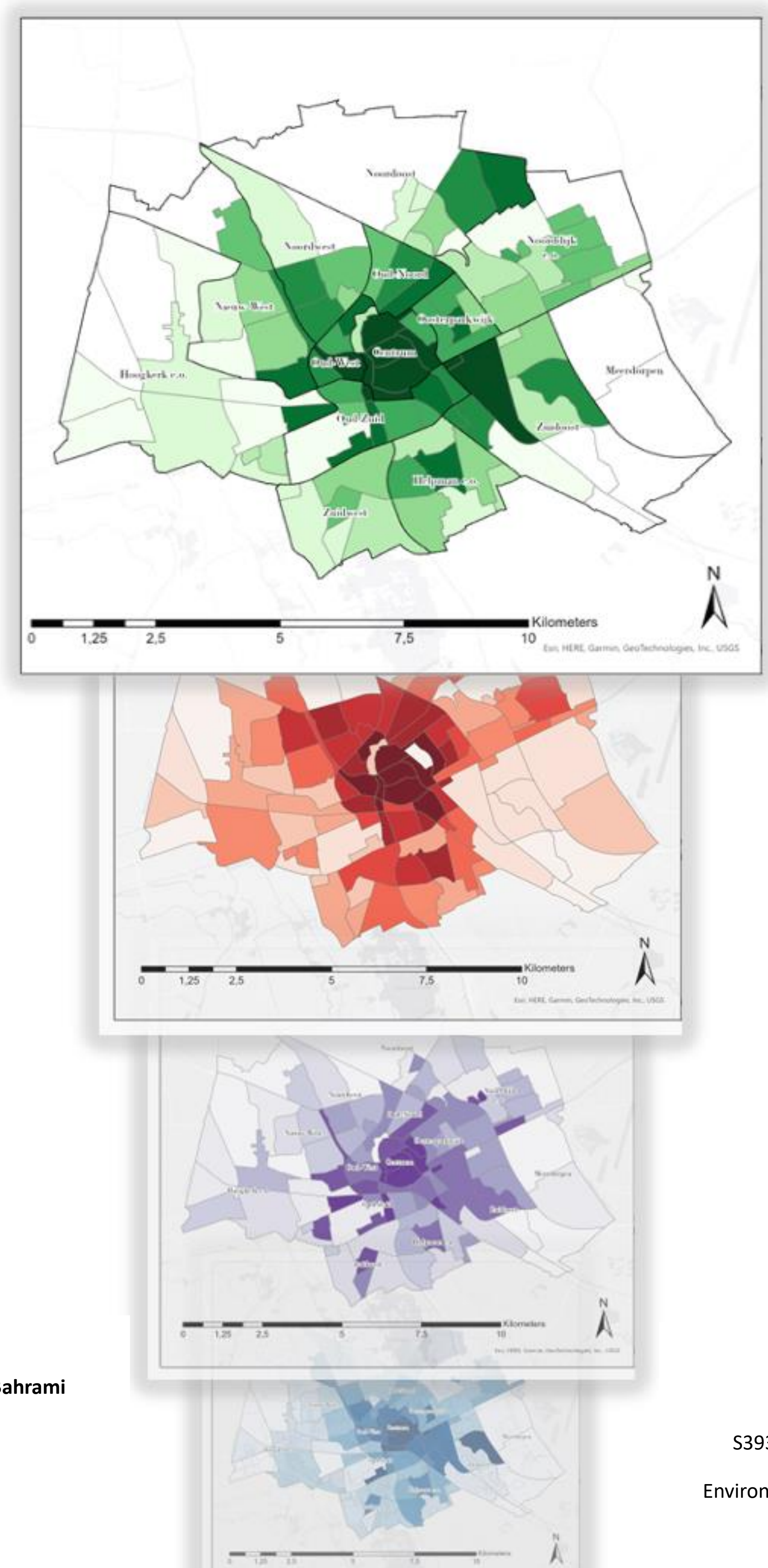
Assessing the alignment of objective and perceived walkability measures with reported favourite walking routes

A study of neighbourhoods in Groningen



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Abstract

Purpose: The study's purpose was to examine the extent to which the NEWS-CFA questionnaire and the Walkability Index (WAI) relate to residents' Reported Favourite Walking Routes (RFWR), the agreement between WAI and NEWS-CFA, the spatial distribution of high-scoring neighbourhoods based on WAI, NEWS-CFA, and residents' RFWR, and key contributing factors to high and low objective and perceived walkability. **Methods:** For 105 neighbourhoods the objective walkability was assessed, using Geographical Information Systems (GIS) to calculate the WAI. Perceived walkability was assessed using the NEWS-CFA and analysed using GIS. Secondary RFWR data were obtained and analysed using GIS. **Results:** The WAI showed a distinct radial pattern in which the neighbourhoods in which the top scoring WAI decile consisted of central neighbourhoods, whereas the lowest scoring WAI decile consisted of outer neighbourhoods. The NEWS-CFA showed a more dispersed pattern regarding scoring patterns, with only two neighbourhoods overlapping with the WAI in terms of high walkability. The RFWR showed a similar radial pattern to the WAI, and with four out of ten overlapping neighbourhoods in the highest decile, it showed alignment with the WAI. **Conclusions:** Objective and perceived walkability showed substantially different outcomes, in which the WAI showed the highest agreement with the RFWR, suggesting that the WAI can potentially be a useful tool for predicting the density of RFWR in neighbourhoods. **Key words:** Walkability; Perceived; Objective; GIS; Built environment.

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NEWS(-CFA/A): Neighbourhood Environment Walkability Scale (-Confirmatory Factor Analysis/ Abbreviated)

WAI: Walkability Index

RFWR: Reported Favourite Walking Routes

GIS: Geographical Information Systems

FAR: Floor Area Ratio

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1. Introduction

Inhabitants of modern-day societies are often living sedentary lifestyles, despite the well-established link between physical activity and health (Powell et al., 2011). Being physically inactive has been identified worldwide as one of the biggest risk factors for mortality (World Health Organization, 2009). In response, a growing body of research has emerged, exploring the relationship between physical activity and walkability (Fonseca et al., 2022). It has become evident that enhancing neighbourhood walkability can have a positive impact on residents' physical activity levels (Arvidsson et al., 2012; Nichani et al., 2019; Wang & Yang, 2019). Walkability refers to the extent to which the built environment is pedestrian-friendly and enables walking (Habibian & Hosseinzadeh, 2018; Taleai & Taheri Amiri, 2017). It can be influenced through urban planning as neighbourhood walkability is closely related to aspects of the built environment (Jacobs et al., 2021; Liao et al., 2020). However, besides the substantial health benefits, improving walkability and the amount of active transportation also has major environmental benefits (Ellis et al., 2015; Ewing & Cervero, 2010; Newman et al., 2011; Taleai & Taheri Amiri, 2017). Walking, as a sustainable transport mode, helps reduce the amount of emissions, noise and congestion associated with motorized vehicles (Ellis et al., 2015; Taleai & Taheri Amiri, 2017). Therefore, walkable neighbourhoods are crucial in creating low-carbon cities and facilitating climate change adaptation (Ewing & Cervero, 2010; Newman et al., 2011). Walkability can be assessed both objectively and subjectively (Fonseca et al., 2022; Frank et al., 2010; Saelens, Sallis, Black, et al., 2003). The latter way is based on the subjective experience in terms of the ease of walking in an area or to destinations and can be examined with the Neighbourhood Environment Walkability Scale (NEWS) survey (Cerin et al., 2009; De Vos et al., 2022; Saelens, Sallis, Black, et al., 2003). In contrast, objectively assessed walkability focuses on the built environment factors, such as residential density, land use mix, and street connectivity (Fonseca et al., 2022; Frank et al., 2005, 2010). Commonly used tools for objective walkability assessment include the Walkability Index (WAI) and the Walk Score, which are used to map highly walkable and less walkable areas using Geographic Information Systems (GIS) (Arvidsson et al., 2012; Duncan et al., 2011; Frank et al., 2010; Reyer et al., 2014).

Previous research has highlighted a misalignment between objectively assessed and perceived walkability, with approximately one-third of participants perceiving walkability differently from the objective measures (Arvidsson et al., 2012; Ding & Gebel, 2012). To overcome this discrepancy, it is argued that combining both perceived and objective measures is crucial, as they may have differential associations with walking preferences (Boehmer et al., 2006; McCormack et al., 2007; McGinn et al., 2007). Even though it is a well-researched topic, uncertainties regarding the meaning of walkability are evident (Dovey & Pafka, 2020). It is a multidimensional topic which requires multi-disciplinary approaches (Forsyth, 2015; Lo, 2009). Previous studies have compared the objective Walkability Index (WAI) and subjective Neighbourhood Environment Walkability Scale (NEWS) instruments to physical activity levels, through assessed self-reported walking questionnaires (IPAQ) or measured by vertical acceleration using accelerometers (Arvidsson et al., 2012; Ding & Gebel, 2012). However, no existing studies have compared these instruments to Reported Favourite Walking Routes (RFWR).

Thus, the following primary question emerges: To what extent do the NEWS-CFA questionnaire and the WAI relate to residents' RFWR in Groningen, the Netherlands? Besides, the level of agreement between objective walkability measures (WAI) and perceived walkability measures (NEWS-CFA) will be investigated. Subsequently, this research will examine the spatial distribution of high-scoring neighbourhoods based on objective walkability measures (WAI), perceived walkability measures (NEWS-CFA), and residents' RFWR. Lastly, the key factors of objective and perceived measures that contribute to high and low walkability scores in neighbourhoods will be analysed.

2. Theoretical framework

2.1 Active Transportation and walkability

Walking and cycling, as human-powered modes of transportation, are integral components of active transportation, which encompasses daily commuting and recreational purposes (Millward et al., 2013). Active transportation is widely recognized as an environmentally-friendly alternative to motorized vehicles by promoting physical activity, thereby contributing to healthier lifestyles and living environments (Millward et al., 2013; Sallis et al., 2004). In the realm of land-use and transportation planning, extensive research has been conducted to examine the relationship between walking activity and the built environment (Millward et al., 2013). These studies often inform policies aimed at increasing the prevalence of walking as a mode of transportation. One key concept explored in this research is the notion of "walkability", which emphasizes the influence of neighbourhood characteristics on walking behaviour (Millward et al., 2013). Walkability is a multidimensional concept that broadly refers to the extent to which the built environment is pedestrian-friendly and enables walking (Habibian & Hosseinzadeh, 2018; Taleai & Taheri Amiri, 2017). Furthermore, recent studies have highlighted the growing recognition of the built environment as a significant factor influencing walking behaviours and physical activity (Jacobs et al., 2021; Liao et al., 2020).

2.2 Influential Factors of the Built Environment

The built environment comprises the physical support of activities, services, and infrastructures found in urban spaces (Fonseca et al., 2022). Multiple attributes of the built environment have been identified as influential factors that shape walkability (Fonseca et al., 2022). In this section, the most commonly used attributes in walkability studies will be covered.

2.3 Density

Density, in the context of the built environment refers to the concentration of land uses, buildings, residents, and pedestrians within a given area (Dovey & Pafka, 2020; Fonseca et al., 2022). It is a multifaceted concept with various interpretations and measurements. Density can include the density of buildings, both in terms of net residential density on specific sites and gross density that considers other functions in public spaces (Dovey & Pafka, 2020). Existing literature states that high residential density is often significantly correlated with walking and physical activity (Clark et al., 2014; Huang et al., 2019). Therefore, density plays a crucial role in walkability by shortening distances and bringing more destinations within walkable distances (Bhadra et al., 2015; Dovey & Pafka, 2020; Fonseca et al., 2022).

2.4 Mixed Land use

Land use diversity, similarly called mixed land use, refers to the extent of mixing different land uses within a given area (Tsiompras & Photis, 2017). This diversity is commonly assessed through two primary attributes: land use mix and retail floor area (Fonseca et al., 2022). The measurement of land use mix often involves employing an entropy equation to determine the proportional distribution of specific land uses in the area (Fonseca et al., 2022). One widely used Walkability Index, proposed by Frank et al. (2010) incorporates five major land uses: residential, retail, recreational, office, and institutional. However, some studies used a number ranging from 3 to 17 land uses (Hanibuchi et al., 2012; Taleai & Yameqani, 2018). A range of studies conducted worldwide have consistently shown that areas with mixed land uses, incorporating non-residential activities such as shops, restaurants, offices, and banks, are associated with walkable environments and higher levels of physical activity (Frank et al., 2005; Kaczynski, 2010; Lovasi et al., 2011). Additionally, the retail floor area attribute reflects the amount of space available for parking. Areas with low retail density tend to have more parking space, while high retail density areas typically have less unused land and parking areas, making them more conducive to walking (Learnihan et al., 2011; Sehatzadeh et al., 2011).

2.5 Access

Accessibility in built environments is often measured by the proximity or distance to key amenities and public transportation (Cervero et al., 2009). Studies commonly assess accessibility by calculating the network distance between amenities and specific locations, such as residential areas and schools (Fonseca et al., 2022). Having easy access to amenities shows reduced sedentary lifestyles and higher levels of physical activity (Cerin et al., 2007; Oyeyemi et al., 2019). Research consistently highlights that shorter distances to public transportation stops are linked to increased walking activity and a higher likelihood of using public transport (Boulange et al., 2018; Riggs & Sethi, 2019). Furthermore, areas with a higher density of public transport stops have shown a positive correlation with walking behaviour (Buck et al., 2015; Kerr et al., 2014). Interestingly, the distance to car parks, city centres, and other urban attractions has received less attention in walkability studies (Fonseca et al., 2022). However, findings suggest that the distance to these destinations may not have a significant influence on walkability (Fonseca et al., 2022).

2.6 Street connectivity

Street network connectivity refers to the directness and availability of alternative routes between destinations, and it plays a crucial role in enhancing walkability (Ellis et al., 2015). A well-connected street network offers more potential routes for walking and reduces distances to destinations (Tsiompras & Photis, 2017). However, while there are various attributes used to describe street network connectivity, there is no standardized method for its assessment (Ellis et al., 2015). Nonetheless, intersection density is the most commonly used attribute to measure street network connectivity, representing the number of road intersections with three or more links within a given area (Fonseca et al., 2022). A multitude of studies have associated higher intersection density to increased physical activity and walking and it is regarded as the most supreme measure of street network connectivity (Buck et al., 2015; Cruise et al., 2017; Ellis et al., 2015; Frank et al., 2005). In addition to intersection density, other derived attributes are used, such as block length, link to node ratio, and cul-de-sac density. Among these, cul-de-sacs are recognized as hindering connectivity due to dead-ends (Sehatzadeh et al., 2011).

2.7 Objectively assessed walkability

Frank et al. (2005) introduced the WAI as an objective measurement tool based on the concepts of density, land-use mix, and connectivity as described above. This index aggregates the normalized scores of each walkability measure (Frank et al., 2005). Building upon this, (Frank et al., 2010) expanded its scope by incorporating the ratio of total commercial building floor area to the total commercially used land area (FAR). Notably, objective factors that were most often analysed in previous studies are the street network connectivity, land use density and land-use mix, intersection density, residential/population density to measure walkability (Fonseca et al., 2022).

2.8 Pedestrian facility and comfort

Within the pedestrian facility and comfort category, three attributes are considered: sidewalk characteristics, slopes, and environmental conditions at the street level (Fonseca et al., 2022). When it comes to sidewalk characteristics, existing studies emphasize the importance of sidewalks that are wide, unobstructed, and in good condition, designed to meet pedestrians' needs (Vargo et al., 2012; Y. Wang et al., 2016). The presence and percentage of sidewalks correlate positively with walking, while narrow sidewalks with obstacles hinder the ease of walking (Tsiompras & Photis, 2017; Vargo et al., 2012). However, poorly maintained sidewalks are considered a barrier to walking, particularly for older and impaired individuals (Larranaga et al., 2019; Moura et al., 2017). Furthermore, slopes, as another attribute in this category, negatively impact walkability as they influence walking speed, comfort, safety, as well as the energy and effort required for walking (Kerr et al., 2013; Taleai & Yameqani, 2018).

Lastly, environmental conditions at the street level also play a role. Street greenery, such as trees in particular, have been found to have positive associations with physical activity, promoting healthy pedestrian routes and creating more pleasant walkable areas (Herrmann et al., 2017; Lovasi et al., 2011; Taleai & Yameqani, 2018; Tamura et al., 2019).

2.9 Traffic safety and security

Traffic safety and security are also crucial aspects to consider in terms of walkability (Fonseca et al., 2022). Traffic safety relates to separating pedestrians from motorized traffic, while security relates to crime (Foster et al., 2021; Williams et al., 2018). On the one hand, traffic safety is often evaluated through various measures, such as the risk of accidents, exposure to vehicular traffic, and the implementation of traffic calming measures. Findings indicate that high traffic volume the risk of accidents act as a deterrent to walking (Lovasi et al., 2011; Moran et al., 2017). On the other hand, crime security is assessed through various factors of the built environment, such as street lighting, the presence of buildings with broken windows and graffiti, as well as indirect indicators like homicide rates and police presence (Fonseca et al., 2022). However, due to the challenges of obtaining crime security data, many researchers rely on qualitative methods to gather data on pedestrian perceptions of crime security (Fonseca et al., 2022). Recent studies reveal that higher perceived crime is associated with reduced physical activity and decreased walking to school (Esteban-Cornejo et al., 2016; Nichani et al., 2019).

2.10 Streetscape design

Finally, Streetscape design also has a strong relation to walkability and it refers to the detailed characteristics of the built environment at the street level, encompassing various perceptual qualities Streetscape design is commonly evaluated based on attributes such as aesthetics, human scale, enclosure, and complexity (Fonseca et al., 2022; Yin, 2017). The impact of streetscape design features on walking and the creation of comfortable walking environments, particularly in terms of aesthetics, has been widely acknowledged (Pelclová et al., 2013; Van Dyck et al., 2012; Yin, 2017). However, it is worth noting that obtaining streetscape design data can be challenging, as it often requires extensive fieldwork and audits (Al Shammas & Escobar, 2019; King & Clarke, 2015).

2.11 Subjectively assessed walkability

The NEWS is a widely used questionnaire developed by Saelens et al. (2003) to assess subjective perceptions of the neighbourhood environment. Over the past decade, NEWS has emerged as the most popular measure of perceived neighbourhood environment globally (Cerin et al., 2013). The questionnaire consists of 66 questions organized into eight subscales, which capture various aspects of walkability: residential density, land use mix, land use mix access, street connectivity, infrastructure for walking and cycling, aesthetics, traffic safety/hazards, and safety from crime (Almeida et al., 2021; Saelens et al., 2003). Later, the abbreviated version, the NEWS-A was developed, followed by an adapted version called the NEWS-CFA, in which certain items were recategorized (Cerin et al., 2009). Additionally, the questionnaire includes items that assess individual satisfaction with the neighbourhood (Almeida et al., 2021). Van Dyck et al. (2012) conducted a study in Ghent, Belgium, and found that perceived levels of density, land use mix, cycling safety, and walkability (measured using NEWS) positively influenced the frequency and duration of walking and cycling among 1166 adults. A comprehensive overview of the theory is provided in the conceptual model, visible in figure 1.

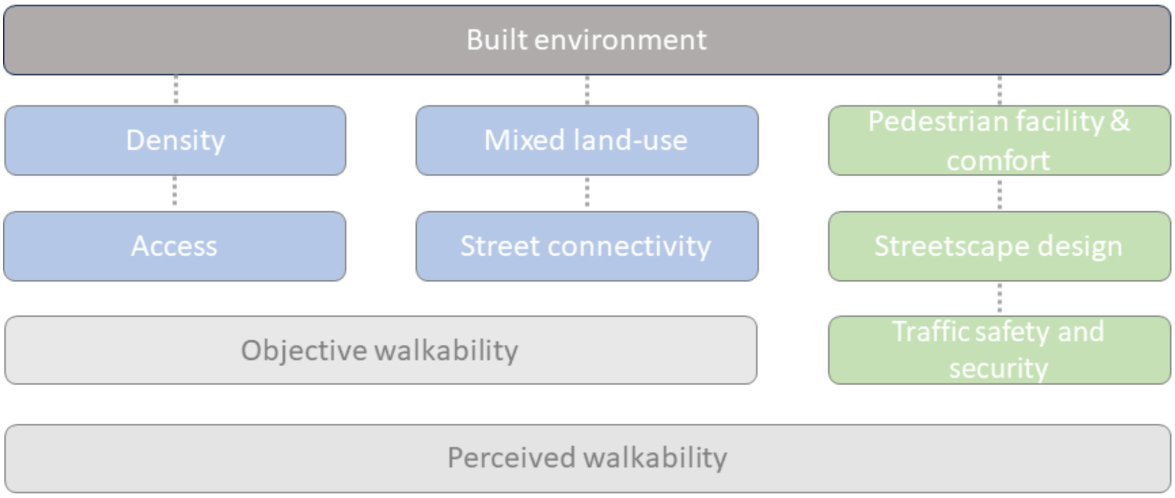

Figure 1: Conceptual model

2.12 Hypotheses

1. The NEWS-CFA will give similar neighbourhoods high scores as the RFWR as they are both more on the perception side. To elaborate. the NEWS-CFA assesses subjective perceptions of the neighbourhood environment, including factors such as streetscape design and safety (Saelens et al., 2003). Similarly, the RFWR encompasses residents' perceived favourite walking routes. Since both measurements emphasize perceptions and experiences, it is hypothesized that they will exhibit similar spatial distributions of higher scores.

2. Based on the theory it can be expected that the NEWS-CFA (which assesses perceived walkability) results and the outcome of the WAI (which assesses objective walkability) will not align in the context of Groningen. This hypothesis is based on earlier findings, indicating that one-third of the participants in previous studies perceived walkability differently from the objective walkability measured by instruments, such as the WAI (Arvidsson et al., 2012; Ding & Gebel, 2012).

3. Residential density, land use mix, and street connectivity will have the strongest effect on high walkability scores. This is hypothesized, due to the large body of research that based its walkability assessments on such objective factors, rather than subjective ones (Fonseca et al., 2022; Frank et al., 2005, 2010). However, there is no golden standard to walkability, nor is there a standard scale to measure it. If objective measures are favoured by the majority of researchers over subjective ones, it could be inferred that they are considered a more robust evaluation of walkability.

3. Methods

3.1 Neighbourhood selection

The selection of neighbourhoods for this study was based on the availability of RFWR data. Initially, neighbourhoods with RFWR data were identified as the core study area. To ensure a representative sample, additional neighbourhoods were included by expanding outward from the city centre. This expansion followed a somewhat radial approach, incorporating neighbourhoods within a similar distance from the centre. This strategy aimed to capture the variability in walkability across different parts of Groningen while maintaining geographic balance. By including neighbourhoods both proximate to the city centre and towards the periphery, the study sought to examine overall walkability patterns comprehensively.

3.2 Walkability Index

The Walkability Assessment Index (WAI) that was used in this study, developed by Frank et al. (2010), focuses on key built environment factors including density, land-use mix, connectivity, and the ratio of total commercial building floor area to total commercially used land area (FAR). The combination of these four indicators gives an indication of the objectively assessed walkability in a specific neighbourhood, which is in this case based on the city of Groningen, The Netherlands. Three of the indicators are calculated in ArcGIS Pro and one in QGIS, which are so-called geographic information systems. In a previous study by Reyer et al. (2014), the Walkability Toolbox, available online, was used for WAI calculations. However, during the course of this research, it was discovered that the Python scripts in the toolbox were outdated. Therefore, manual calculations were done by following the instructions provided in the scripts and adhering to the guidelines outlined by Frank et al. (2010). A comprehensive overview of the analysis steps in GIS is provided in appendix 2. The final WAI was calculated by first standardizing all four indicators using a z-score for comparability, and second, by implementing the resulting z-scores into the following formula:

$$WAI = (2 * conn) + ent + FAR + rdens$$

Where:

WAI	=	walkability index
conn	=	connectivity
ent	=	entropy
FAR	=	retail floor area ratio
rdens	=	residential density

In the creation of the WAI, a weighting factor of two was assigned to the street connectivity z score. This decision was based on previous research indicating the strong impact of street connectivity on walking distances and its influence on choosing active modes of transportation (Saelens, Sallis, & Frank, 2003). Furthermore, for each abovementioned variables, the data was divided into ten equal classes, ranging from the lowest to the highest outcome values. This process ensured that each class contained approximately ten percent of the data. To visualize the distribution on a map, a 'Graduated Colours' symbology was applied using the quantile method in ArcGIS Pro. This method created ten distinct colour categories, representing the different decile classes of the outcomes. These decile classes led to roughly ten displayed neighbourhoods per class due to the total number of 105 neighbourhoods. In the following sections, the calculation approach for each indicator will be covered. Furthermore, the data that were used for these analyses are presented in appendix 1.

3.2.1 Connectivity

To calculate the connectivity indicator, a network data set is required, showing all pedestrian pathways, including line features and crossings in the area of interest. This indicator assesses the intersection density of the pedestrian network (Frank et al., 2010). During the GIS analysis conducted for the connectivity indicator as part of the WAI, several steps were taken in ArcGIS Pro. Firstly, missing pedestrian paths were added by utilizing satellite views to accurately map out the entire network. Secondly, crossings were created using the Intersect tool, allowing for a precise representation of pedestrian intersections. In order to focus solely on sidewalks and pedestrian-friendly routes, roads and highways with speeds exceeding 80 km/h were removed, and any necessary corrections were made with the assistance of satellite imaging. Lastly, the calculation of junctions per square kilometre per neighbourhood was accomplished through the usage of spatial join and field calculator functions.

3.2.2 Entropy

The entropy focuses on the level of mixed land use, meaning, the amount of variety in land use in the area of interest. This requires a data set containing polygons showing different types of land use. For the analysis of the entropy indicator, calculations were performed using QGIS instead of ArcGIS Pro for convenience and suitability. The process involved the following: Firstly, the Intersect tool in QGIS was used to associate the land use polygons with their respective neighbourhood polygons. Afterwards, the land use categories in the following table 1 were used.

Category	Code
Living	L
Retail	R
Services	S
Industrial	I
Institutional	T
Recreational	R
Water	W

Table 1: Entropy land use categories

This allowed for the merging of all polygons of the same land use type within each neighbourhood using the dissolve tool. Next, the "Add geometry attributes" tool was applied to calculate the area of each land use type within the neighbourhood polygons. This information was then joined with the neighbourhood layer using the "Join Attributes by Field Value" tool. To determine the total number of land use types within each neighbourhood, the "Statistics by Categories" tool was used. This resulted in a new layer that was combined with the previous layer through a join operation. A new column was created in the attribute table to calculate the ratio logarithm (ratio_log) for each land use type using the field calculator. The sum of the ratio_log values based on land use types was obtained using the "Statistics by Categories" tool. The final step involved calculating the entropy index by applying the field calculator. The resulting entropy values were then joined with the original neighbourhoods layer to incorporate the entropy information.

3.2.3 Retail Floor Area Ratio (FAR)

To calculate the Floor Area Ratio (FAR) indicator, which measures the ratio of total retail building floor area to the total retail land-use area, certain steps were taken. Due to the unavailability of parcel-level data, the analysis was modified by using the total neighbourhood area instead of the land use assigned to retail functions. The process involved the following: Firstly, the features representing the land use category of "retail" were extracted from the land use layer. Next, the "summarize within" tool was used to calculate the total amount of retail area within each neighbourhood, aggregating the data accordingly. A new field was created to perform the calculation of retail floor space per square kilometre, divided by the neighbourhood area in square kilometres. It was assumed that the shops covered the entire base floor, even in cases where mixed functions were present, because this distinction was not visible within the dataset.

3.2.4 Residential Density

Finally, the indicator of residential density, which is the most straightforward to calculate, originally entails the net residential density according to Frank et al. (2010). It measures the ratio of residential units to the land area specifically designated for residential purposes within each block group (Frank et al., 2010). However, because block group data was not available, the gross residential density was calculated instead. The interpretability of the results will remain unaffected as the analysis primarily focuses on the neighbourhood scale. Thus, the amount of households was divided by the total land area of each neighbourhood in square kilometres. In order to do so, the following steps were taken:

Firstly, features corresponding to the land use function 'residential' were extracted from the land use layer. Next, the 'summarize within' tool was used to summarize the number of households within each neighbourhood, taking into account the spatial boundaries. A new field was created to calculate the number of households per square kilometre, by dividing the total number of households by the area of the neighbourhood in square kilometres.

3.3 Neighbourhood Environment Walkability Scale

3.3.1 Survey and Data Collection

The assessment of perceived walkability in participants' own neighbourhoods was conducted using the NEWS-CFA, adapted from the NEWS-A, originally developed by Cerin et al. (2009). The survey aimed to capture participants' perceptions of walkability in their specific neighbourhood context. In this study, several adaptations were made to the NEWS-CFA questionnaire for the context of Groningen. Categories related to hilliness and physical barriers to walking were removed, as they were not relevant to the flat terrain of Groningen. Additionally, since the assessed neighbourhoods in Groningen did not have significant physical barriers such as freeways, rivers, canyons, or hillsides, those aspects were excluded. Minor adaptations were made by merging similar sub questions within each category to streamline the questionnaire. Some adjustments were also made to align the land use categories with the context of Groningen. Additionally, the survey was provided in Dutch and English, to ensure a broad applicability. The full questionnaires are presented in Appendices 3 and 4.

The data collection procedure involved a five-day period during which 50 data collectors were stationed at ten different locations throughout the city. These locations were strategically chosen to cover a wide range of areas, including major shopping centres, cultural hotspots, the train station, and busy pedestrian areas in various neighbourhoods. Different time slots, including early morning, lunchtime, and late afternoon/early evening, were selected to capture a diverse range of participants. The selected locations had larger service areas to ensure representation from across the entire study area. There were no specific exclusion criteria based on age groups or genders, and participants were not restricted to specific neighbourhoods, allowing for a varied sample reflecting the city's population. It is important to note that the data collectors were informed about the data collection procedure and provided with detailed instructions during a single meeting. This ensured consistency in how the survey was administered and how responses were captured.

The survey was provided in a digital format through a QR code, which participants could scan, to fill in the survey on the spot or at a more convenient time using their own devices. They were first asked to fill in generic information, such as gender, age and their full postal code for the geographic positioning of the response. In total, 320 responses were gathered. However, some surveys were not usable due to incompletely or incorrectly written postal codes. After omitting these responses, 219 usable surveys were left, covering 41 out of 105 neighbourhoods in the study area.

3.3.2 NEWS-CFA GIS analysis

In order to calculate the mean NEWS-CFA score for each neighbourhood, a series of steps were carried out. Firstly, a Geocoder plugin for ArcGIS Pro was utilized to convert all postal codes into point data on the map. Next, the spatial join tool was applied to connect the neighbourhood names with the corresponding point data. Subsequently, the dissolve tool was employed based on the neighbourhood name, ensuring that each neighbourhood appeared only once. This process included a survey count and mean calculation for each subcategory of the NEWS. To generate the aggregated final NEWS-CFA score, a new field was created, and the field calculator was used, calculating the formula with the subcategories:

$$Mean\ NEWS - CFA = (B + C + D + E + F - G - H + I + J + N)/10$$

Where:

B	=	Land-use mix – diversity	*G*	=	Traffic hazards
C	=	Land-use mix – access	*H*	=	Crime
D	=	Street connectivity	*I*	=	Lack of parking
E	=	Infrastructure & walking safety	*J*	=	Lack of cul-de-sacs
F	=	Aesthetics	*N*	=	Social interaction while walking

In this formula, the subcategories of traffic hazards and crime are subtracted due to their negative impact on walkability. Noticeably, categories A, K, L and M were left out, which was done for specific reasons. Category A displayed perceived residential density, which gave an outcome in hundreds. Since the other categories show outcomes of up to 5, this would skew the results too much. The other factors that were left out, were assessing hilliness and cul-de-sacs. The author is familiar with the Groningen context and decided that such factors are not applicable. As such, they were not assessed.
Finally, these Mean NEWS-CFA scores are displayed on a map. To do so, a 'Graduated Colours' symbology was applied using the quantile method in ArcGIS Pro. Here, four distinct colour categories were used, representing the different quartile classes of the outcomes. Quartiles were chosen instead of deciles, in order to display 10 neighbourhoods per class for comparability to the other analyses.

3.4 Agreement between WAI and NEWS per neighbourhood

In order to assess the level of agreement between the WAI and the NEWS-CFA, a bivariate choropleth map was created in which both variables were set side by side in each neighbourhood.
A choropleth map shows the level of agreement between two variables. A high agreement shows when both variables show a high or low score within the same neighbourhood. A low agreement shows when one variable is high and the other low, and vice versa.

The bivariate choropleth map was created by, first classifying both variables with 3 classes representing three quantiles, thus 33% of the data for each variable. These classes are labelled as low, middle and high outcome scores. Second, both classifications were combined into one variable which represents all the nine combinations between the two.
Lastly, the map was symbolized using the combined variable, matching colours from the labelled palette to each class. As a result, the relationship between both NEWS-CGA and WAI variables become visible.

3.4 Reported Favourite Walking Routes

The RFWR were utilized as a means to compare the outcomes of the NEWS-CFA and the WAI. These routes were obtained through a secondary survey conducted in the city of Groningen, where 173 participants used Maptionnaire to draw their preferred walking paths on a map of the city. The resulting line features, representing the RFWR, were then exported and analysed using ArcGIS Pro. Each individual route was represented as a polyline feature, capturing the spatial information of the paths chosen by the respondents. To assess the density of RWFR for each neighbourhood, the total length of all line features within neighbourhoods was divided by the land area of those neighbourhoods (km/km2). This calculation was based on the assumption that higher resulting favourite walking route density values indicate a more walkable neighbourhood. To visualize the distribution, the same 'Graduated Colours' symbology as in the WAI was applied using the quantile method in ArcGIS Pro. Finally, the outcomes of the WAI and NEWS were compared to the RFWR to identify any similarities or differences between the two measures of walkability. This comparison offers valuable insights into the level of agreement or divergence between the objectively assessed WAI and the subjective perceptions of residents, as captured by the NEWS, based on their RFWR. By examining the relationship between these two measures, we can better understand the alignment between objective indicators of walkability and the individual experiences and preferences of residents when it comes to their walking choices.

3.5 Ethical Considerations

Prior to participating in the surveys, participants were provided with clear and comprehensive information about the purpose of the study, the nature of their involvement, and the potential risks and benefits. They were assured that their participation was voluntary, and they had the freedom to decline or withdraw from the survey at any time without facing any consequences.
Measures were taken to ensure the anonymity and confidentiality of the participants. All responses and personal identifying information were kept strictly confidential and were accessible only to the research team. Participants were assured that their individual responses would be aggregated and reported in a manner that would not allow identification of individual participants. By maintaining confidentiality, the research team aimed to protect the privacy and identity of the participants throughout the study.

4. Results

4.1 Walkability Index

As it was explained in the methods section, the WAI is an aggregation of its four indices, in which the numbers represent z-scores. These z-scores indicate the amount of standard deviations from the mean, which allows us to make meaningful comparisons (the mean for z-scores is zero). The analysis of the WAI, using ArcGIS Pro, reveals interesting patterns regarding the neighbourhoods that ranked in the highest and lowest decile of WAI out of the total of 105 neighbourhoods. These deciles represent the ten percent of neighbourhoods with the highest and lowest walkability scores. Furthermore, the overall pattern of objective walkability in Groningen is covered.

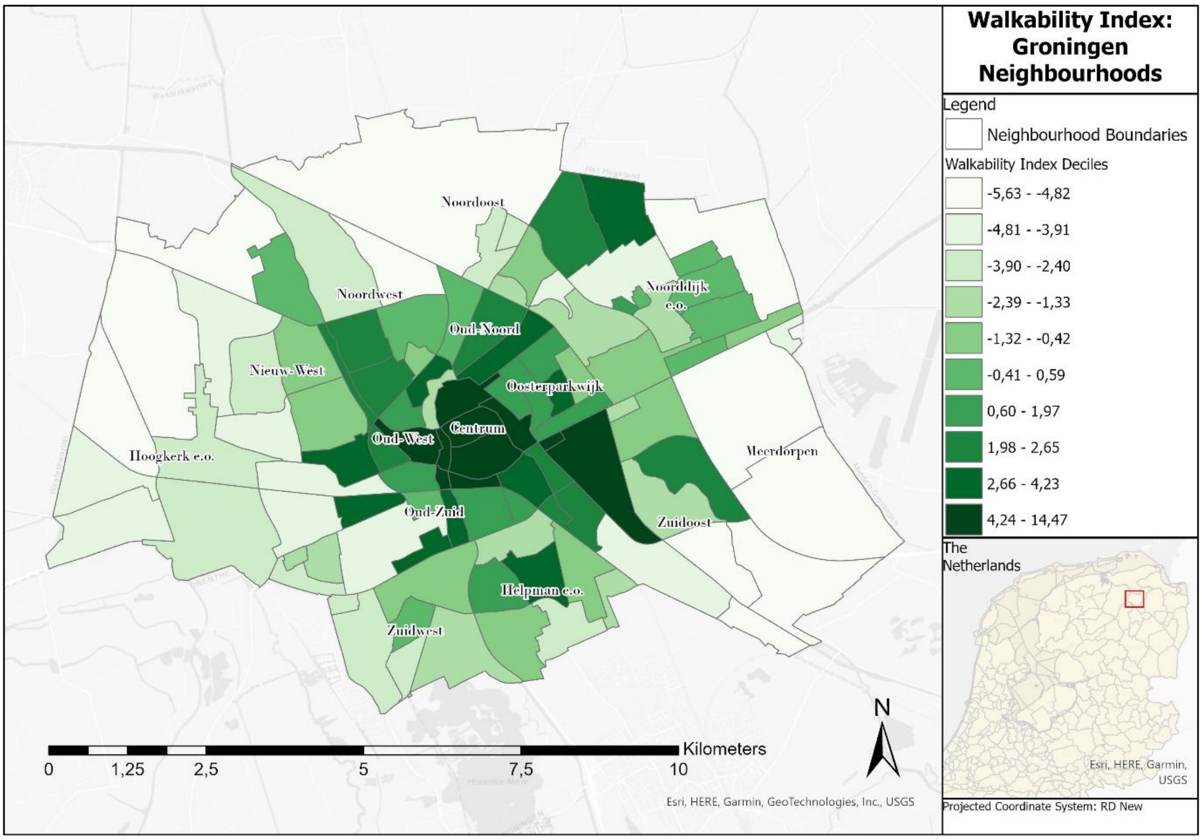

Figure 2: Map showing the WAI outcome per neighbourhood

4.1.1 Highest Scoring Neighbourhoods

As it is visible in figure 2, the neighbourhoods located within the city centre of Groningen exhibit the highest scores in terms of objective walkability according to the WAI. Specifically, the central neighbourhoods Binnenstad-Noord, Binnenstad-West and Kop van Oost show exceptionally high scores, ranging from roughly 13 to 14 standard deviations above the mean, as it is visible in table 2. It is also visible here that the high scores of Binnenstad-Noord and Binnenstad-West are mainly attributed to their high retail floor area ratio (FAR), whereas the connectivity stands out for the Kop van Oost neighbourhood. When examining the specific categories within the highest scoring decile of neighbourhoods according to the WAI, it is observed that the category of FAR receives the highest scores. This suggests that the availability of retail facilities plays an important role in the high objective walkability of these neighbourhoods.

	Neighbourhood	***Z-scores:*** **Residential Density**	**Connectivity**	**FAR**	**Entropy**	**WAI**
Highest	Binnenstad-Noord	2,03	2,59	4,66	2,60	14,47
	Kop van Oost	1,10	4,45	1,03	1,66	12,69
	Binnenstad-West	3,16	0,90	5,49	2,24	12,69
	Binnenstad-Zuid	2,01	1,17	3,80	2,01	10,15
	Badstratenbuurt	2,32	2,93	0,43	0,57	9,18
	Binnenstad-Oost	2,71	1,47	0,91	1,81	8,36
	Hortusbuurt-Ebbingekwartier	2,08	0,79	1,21	1,34	6,20
	Stationsgebied	-0,11	2,52	0,19	0,59	5,72
	Schildersbuurt	2,41	0,88	0,21	0,55	4,93
	Eemskanaal	-0,84	1,16	2,31	0,67	4,46
Lowest	Leegkerk	-0,85	-1,31	-0,45	-1,71	-5,63
	Waterhuizen	-0,85	-1,25	-0,45	-1,80	-5,61
	Dorkwerd	-0,84	-1,28	-0,45	-1,56	-5,42
	Koningslaagte	-0,85	-1,26	-0,40	-1,64	-5,41
	Middelbert	-0,85	-1,22	-0,45	-1,67	-5,41
	Noorddijk	-0,84	-1,19	-0,45	-1,64	-5,31
	Roodehaan	-0,85	-1,20	-0,45	-1,56	-5,26
	Engelbert	-0,82	-1,18	-0,45	-1,39	-5,02
	Zuidwending	-0,85	-1,28	-0,45	-1,14	-5,01
	Selwerderhof	-0,85	-0,99	-0,45	-1,61	-4,89

Table 2: Highest and lowest decile of WAI outcomes

4.1.2 Lowest Scoring Neighbourhoods

In contrast, the lowest scoring neighbourhoods in terms of objective walkability, as indicated by the WAI, are predominantly located on the outskirts of Groningen. Specifically the Leegkerk and Waterhuizen neighbourhoods show considerably lower WAI scores compared to the central neighbourhoods. Table 2 shows that their WAI scores are approximately 6 standard deviations below the mean. These two neighbourhoods show especially low scores in terms of Entropy. Analysing the specific categories within all of the ten lowest scoring neighbourhoods, it is noteworthy that the category of Entropy, or in other words Mixed Land Use, consistently receives the lowest scores. This indicates a lack of diversity of functions in this neighbourhood in terms of objective walkability.

4.1.3 Overall Pattern

The analysis of the WAI reveals a distinct radial pattern of objective walkability in Groningen. The neighbourhoods in the city centre demonstrate higher levels of objective walkability, while the outlying areas show lower levels. This pattern is visually depicted in Figure 2, which illustrates the spatial distribution of the lowest scoring neighbourhoods concentrated in the northwestern and southeastern outskirts of Groningen.

4.2 Neighbourhood Environment Walkability Scale

In this section, key findings of the NEWS regarding the perceived walkability of the studied neighbourhoods. These findings shed light on various aspects such as aesthetics, accessibility, traffic and crime safety, and neighbourhood satisfaction, providing valuable insights into the perceived walkability of the areas surveyed. As it was described in the methods section, the final score is an aggregation of the ordinal scores of each category, following the specific formula. The total survey count for NEWS-CFA within the preselected neighbourhoods is 219.
The results here, are divided into quartiles for comparison purposes, with each quartile consisting of ten neighbourhoods.

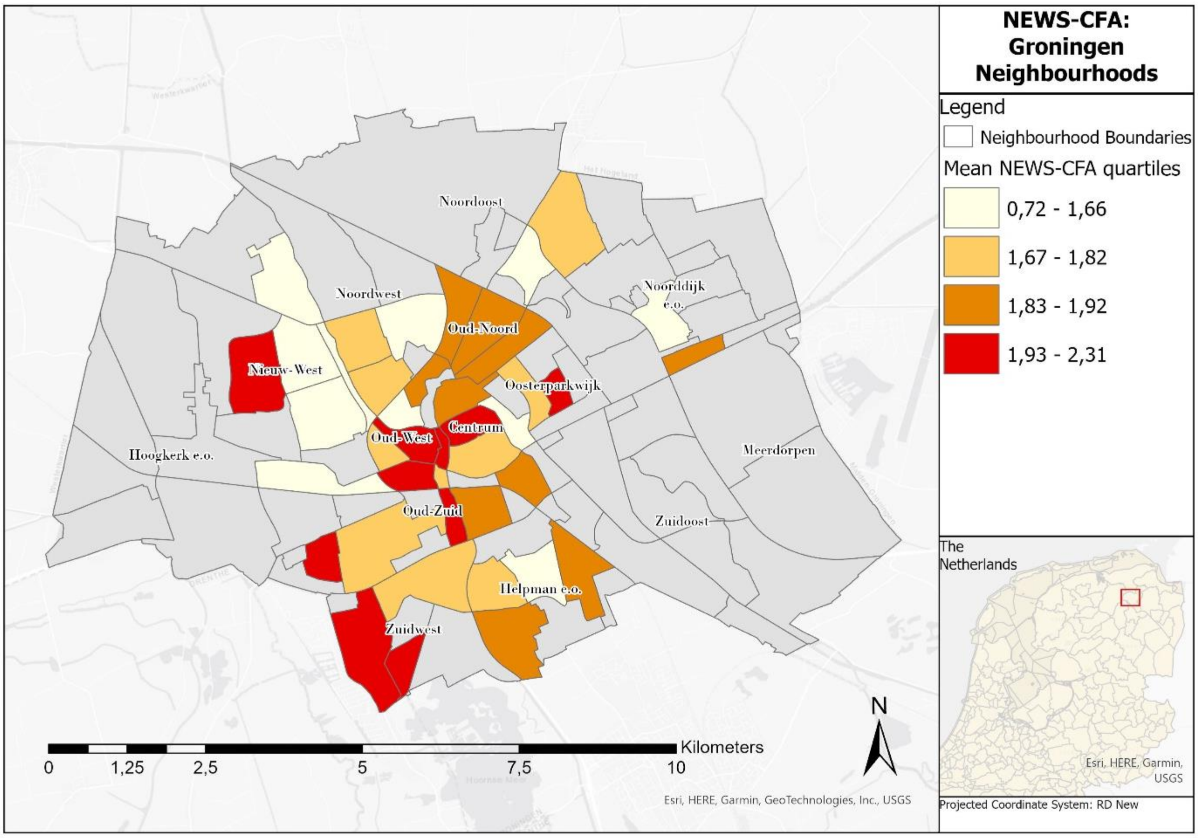

Figure 3: Map showing the mean NEWS-CFA outcome per neighbourhood

4.2.1 Highest Scoring Neighbourhoods

As it is visible in figure 3, the analysis of the NEWS-CFA reveals that the highest scoring neighbourhoods in Groningen are primarily located in the central areas. It is important to note that Hoornse Park and Piccardthof stand out with the highest NEWS-CFA scores, averaging approximately 2.3 according to Table 3. These two neighbourhoods stand out in terms of their perceived land use mix diversity, aesthetics and lack of cul-de-sacs. However, these findings may be considered outliers due to the low survey counts of 2 and 1, respectively. In contrast, the central neighbourhoods within the highest scoring quartile, such as Binnenstad-Noord, Binnenstad-West, Schildersbuurt, and Zeeheldenbuurt, demonstrate higher survey counts. These four neighbourhoods specifically show a high degree of perceived land-use mix in terms of diversity. The overall highest scoring categories within the highest quartile of results, are Land-use mix in terms of access and aesthetics.

4.2.2 Lowest Scoring Neighbourhoods

Among the 10 lowest scoring neighbourhoods as determined by the NEWS-CFA, Suikerfabriekterrein, Lewenborg-West and De Hunze stand out. As it is visible in table 3, these neighbourhoods exhibit lower perceived walkability scores compared to others. They scored especially low in terms of the perception of infrastructure and safety for walking. However, due to their low survey counts these findings could be considered outliers. On the contrary, the 13 participants living in the neighbourhood of Selwerd perceived their neighbourhood as a lowly walkable one and this was mainly attributed to a perceived lack of social interaction, according to the NEWS-CFA. The overall worst scoring categories in the lowest quartile of the NEWS-CFA results are the perceptions of crime, but to a lesser extent also the lack of parking and limited social interactions. It is important to note that the low score in crime is a good thing, as this score is deducted from the overall score. However, according to the results it is too easy to park cars in these ten neighbourhoods and social interactions while walking are low, reducing their perceived walkability.

4.2.3 Overall Pattern

The overall pattern revealed by the NEWS-CFA outcomes in figure 3, indicates a less clear concentration of the highest scoring neighbourhoods. While four out of the ten highest scoring neighbourhoods are clustered in central areas, the remaining six are scattered throughout the city. However, these scattered neighbourhoods show low survey counts and could, therefore, be outliers, whereas the central ones show higher survey counts. In contrast, the lowest scoring neighbourhoods are predominantly located on the outskirts of the city.

Neighbourhoods	Mean NEWS	Land-use mix – diversity	Land-use mix – access	Street connectivity	Infra-structure & safety	Aesthetics	Traffic hazards	Crime	Lack of parking	Lack of cul-de-sacs	Social inter-action	Survey Count
Hoornse Park	2,31	3,53	3,50	2,50	3,80	3,75	1,67	1,33	2,00	4,00	3,00	2
Piccardthof	2,29	3,83	2,67	3,50	3,40	3,50	1,00	1,00	1,00	4,00	3,00	1
De Buitenhof	2,09	3,91	2,44	2,67	3,73	3,58	1,78	1,33	1,67	2,67	3,33	3
Binnen-stad-West	2,08	1,51	4,00	3,58	3,37	3,21	2,33	1,72	2,67	3,17	3,33	6
Bloe-men-buurt	2,06	2,17	3,67	2,50	4,00	3,63	1,33	1,00	1,50	3,00	2,50	2
De Held	2,06	3,22	2,33	3,50	3,40	3,50	1,33	1,00	1,00	3,00	3,00	1
Binnen-stad-Noord	2,01	1,38	3,76	3,29	3,31	2,96	2,19	1,60	3,07	3,29	2,86	14
Gruno-buurt	2,01	2,28	3,33	3,50	3,20	3,75	3,00	2,00	3,00	4,00	2,00	1
Schil-ders-buurt	1,97	1,85	3,67	3,23	3,09	3,00	2,31	1,76	3,07	3,07	2,80	15
Zeehel-den-buurt	1,93	2,26	3,47	3,30	3,28	2,90	2,20	1,27	3,20	3,00	1,40	5
Suiker-fabriek-terrein	0,72	2,00	0,67	0,50	0,90	0,75	3,33	1,33	2,00	2,00	3,00	2
Lewen-borg-West	0,97	3,39	3,00	2,50	1,60	2,25	3,67	3,33	1,00	1,00	2,00	1
De Hunze	1,17	2,72	2,00	2,00	2,00	2,00	2,33	2,67	2,00	2,00	2,00	1
Friese-straat-weg	1,53	3,22	3,17	2,00	2,90	2,88	2,00	1,83	2,50	1,50	1,00	2
Binnenstad-Oost	1,55	1,93	2,56	2,67	2,87	2,67	2,89	2,33	2,33	2,33	3,33	3
Selwerd	1,56	2,67	3,31	2,58	3,00	2,13	2,53	2,03	2,00	2,67	1,83	12
Help-man	1,58	1,97	3,07	2,80	2,88	2,30	2,40	1,80	2,40	2,20	2,40	5
Reit-diep	1,63	2,65	3,10	2,43	2,89	2,68	2,10	1,81	1,86	2,43	2,14	7
Oranje-buurt	1,65	2,56	3,67	3,00	3,40	3,25	2,67	1,67	2,00	2,00	1,00	1
Vinkhuizen-Zuid	1,66	2,38	3,40	3,10	3,04	2,55	2,33	2,13	1,40	3,20	2,00	5
Mean	1,78	2,44	3,26	2,94	3,11	2,76	2,29	1,81	2,17	2,87	2,31	

Table 3: Mean NEWS-CFA scores per neighbourhood. Green displays high scores in the highest quartile, whereas red shows low scores in the lowest quartile of the data.

4.3 Agreement between WAI and NEWS per neighbourhood

In this section, the level of agreement between the WAI and the NEWS-CFA is covered through usage of a bivariate choropleth analysis and map. A total of 41 neighbourhoods were compared, as this corresponds to the amount of data coverage by the NEWS-CFA. The data are divided across through three data quantiles, labelled as high, middle and low, each containing roughly 33% of the data.

4.3.1 High agreement

In neighbourhoods characterized by high agreement as illustrated in figure 3, both WAI and NEWS-CFA scores demonstrate agreement in high as well as low walkability levels. The range of values covered by each category is shown in table 4. Exceptionally, for 8 out of 41 neighbourhoods WAI and NEWS-CFA show this high agreement regarding high scores, as compared to only one neighbourhood regarding lower scores, called the Suikerfabriekterrein. It is also evident that the highest agreement is visible in the centrally located neighbourhoods, aligning with previously found patterns. These neighbourhoods often showed high objective FAR, Residential Density and Entropy according to the WAI. Besides, almost all of these neighbourhoods also showed a high perceived land use mix according to the NEWS-CFA, as shown in table 5.

4.3.2 Low agreement

Regarding the low agreement between WAI and NEWS-CFA, neighbourhoods in which either WAI or NEWS-CFA showed contrary outcomes are highlighted in pink and light blue colours, as shown in figure 4. In total the WAI and NEWS-CFA showed these contradictory outcomes for 10 neighbourhoods. This disagreement is dispersed, as 6 neighbourhoods are centrally located and 4 are located on the outskirts.

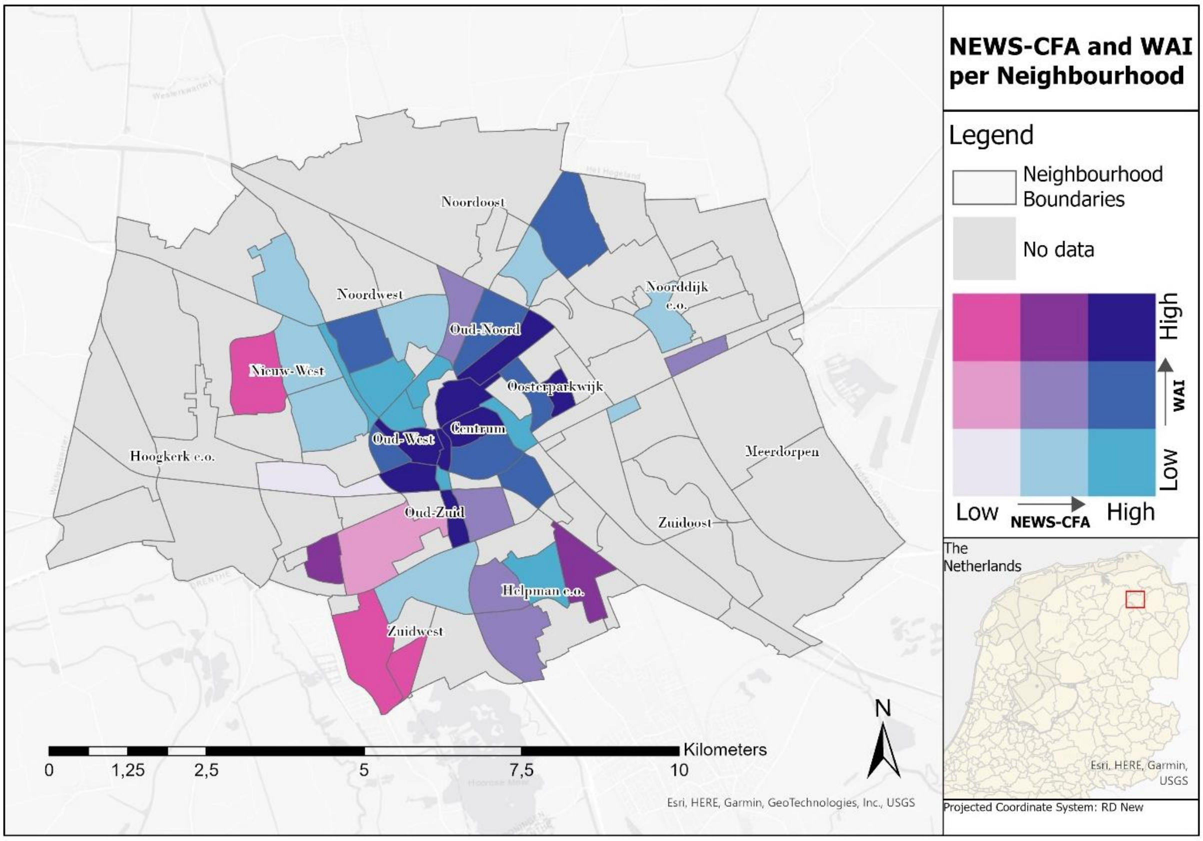

Figure 4: Bivariate Choropleth map showing the agreement between WAI and NEWS-CFA per neighbourhood

Quantile Classification	WAI	NEWS-CFA
Low	-5.63 - -1.93	0.72 - 1.72
Middle	-1.92 - 1.61	1.73 -1.89
High	1.62 - 14.47	1.90 - 2.31

Table 4: Chloropleth Quantile Classifications and their associated values

	Neighbourhood	WAI categories	NEWS-CFA categories
High scoring	Professorenbuurt	Residential Density	land use mix -access
	Bloemenbuurt	Residential Density	Infrastructure and safety for walking
	Hortusbuurt-Ebbingekwartier	Residential Density	land use mix -access
	Binnenstad-Noord	FAR	land-use mix-diversity
	Binnenstad-West	FAR	land-use mix-diversity
	Schildersbuurt	Residential Density	land-use mix-diversity
	Zeeheldenbuurt	Residential Density	land-use mix-diversity
	Grunobuurt	Entropy / mixed land use	Lack of cul-de-sacs
Low	Suikerfabriekterrein	Entropy / mixed land use	Traffic hazards

Table 5: Neighbourhoods showing high agreement between WAI and NEWS-CFA including their highest scoring categories

4.3 Reported Favourite Walking Routes

This section focuses on the RFWR, which acts as a comparison to the WAI and NEWS-CFA. The neighbourhoods withing the highest scoring decile of the FWR data are identified, highlighting the areas that residents favour for walking. Additionally, the overall pattern of RFWR is compared to the WAI and the NEWS-CFA to understand the similarities and differences between objective and perceived walkability measurements in Groningen.

4.3.1 Highest Scoring Neighbourhoods

Among the highest scoring decile of the Reported Favorite Walking Routes (RFWR) density, the neighbourhoods that stood out are Noorderplantsoen, Binnenstad-West, Binnenstad-Noord, and Binnenstad-Zuid. The high density of RFWR in these neighbourhoods, reflect residents' preferences for walking and highlight their attractiveness as desirable walking environments. Especially, the Noorderplantsoen contains the highest density of favourite walking routes, with a density of 1676 kilometres per square kilometre, as shown in table 6. However, this neighbourhood does not have many functions other than it being a park.

4.3.2 Overall Pattern

The pattern of RFWR, as shown in figure 5, shows many similarities to the WAI but with some variations. The eight neighbourhoods in the highest quartile of RFWR data are predominantly concentrated in the city centre, including Binnenstad-West, Binnenstad-Noord, and Binnenstad-Zuid.

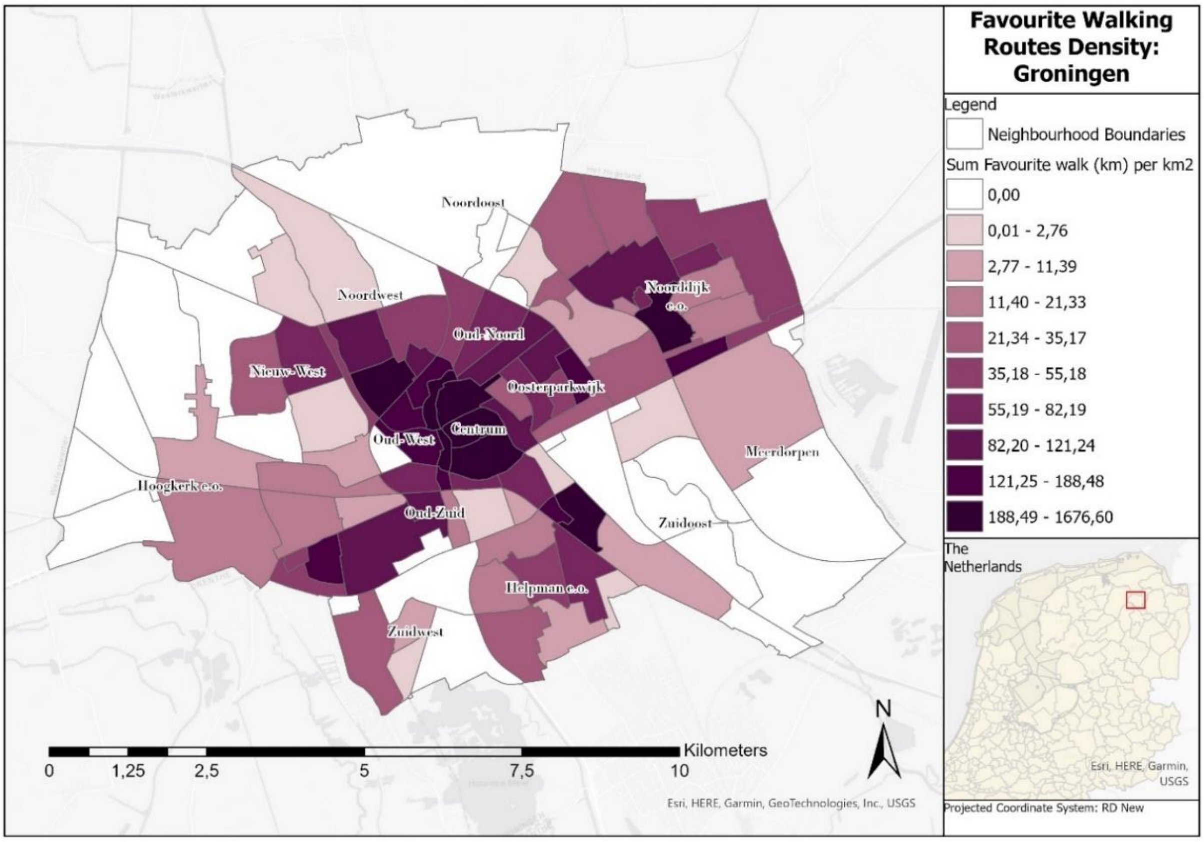

Figure 5: Map showing the sum of the outcome of the RFWR dataset per neighbourhood.

Neighbourhood	Favourite Walking Routes density in km/km2
Noorderplantsoen	1677
Binnenstad-West	346
Binnenstad-Noord	306
Binnenstad-Zuid	252
Europapark	251
Hortusbuurt-Ebbingekwartier	244
Paddepoel-Zuid	225
Lewenborg-West	190
Badstratenbuurt	188
De Linie	170

Table 6: Sum of RFWR density per neighbourhood

4.3.3 Comparison to NEWS and WAI

When comparing the highest scoring neighbourhoods in RFWR to the objective and perceived walkability instruments (WAI and NEWS), clear patterns and overlaps emerge. First, the WAI and the RFWR show a very high level of agreement in assessing walkability levels. The WAI shows a highly similar pattern to RFWR, in which the central neighbourhoods of Groningen score the highest in terms of walkability, gradually decreasing as we move further outward. This pattern is visible in figures 2 and 5. Notably, four out of ten neighbourhoods in the highest scoring decile overlap exactly in both the WAI and RFWR. To be more specific, these neighbourhoods are Hortusbuurt-Ebbingekwartier, Binnenstad Noord, Binnenstad-Zuid and Binnenstad-West. In contrast, the highest decile of NEWS-CFA reveals a more scattered pattern compared to RFWR, although there are still some areas of overlap. Specifically, Binnenstad-West and Binnenstad-Noord are among the highest scoring neighbourhoods in terms of objective walkability in both the NEWS-CFA and RFWR density. Consequently, these findings highlight Binnenstad-West and Binnenstad-Noord as highly walkable areas according to both objective and perceived walkability measures, as well as residents' RFWR.

5. Discussion and Conclusion

This research primarily focused on answering the question: To what extent do the NEWS-CFA questionnaire and the WAI relate to residents' RFWR in Groningen, the Netherlands? Besides, the level of agreement between objective walkability measures (WAI) and perceived walkability measures (NEWS-CFA) was investigated. Subsequently, this research examined the spatial distribution of high-scoring neighbourhoods based on objective walkability measures (WAI), perceived walkability measures (NEWS-CFA), and residents' RFWR. Lastly, the key factors of objective and perceived measures that contribute to high and low walkability scores in neighbourhoods were analysed.

Important objective built environment factors, like connectivity, entropy, FAR and density which have been reported to have a high influence on the walkability and physical activity, have been included in the WAI analysis (Clark et al., 2014; Cruise et al., 2017; Dovey & Pafka, 2020; Ellis et al., 2015; Fonseca et al., 2022; Frank et al., 2005, 2010). Based on the findings obtained from the WAI, it can be concluded that the objectively measured walkability relates strongly to the RFWR of residents in Groningen as many similarities between spatial patterns were observed. This suggests that the WAI is a reliable indicator for assessing walkability in relation to people's favourite walking routes in the context of Groningen. Unexpectedly, the findings revealed that the NEWS-CFA does not show similar results to the RFWR and therefore, does not appear to be strongly associated RFWR in the context of Groningen. This observation is noteworthy considering the literature suggesting a relationship between the built environment factors encompassed by the NEWS-CFA and walking preferences (Buck et al., 2015; Cerin et al., 2007; Cruise et al., 2017; Esteban-Cornejo et al., 2016; Fonseca et al., 2022; Huang et al., 2019; Learnihan et al., 2011; Lovasi et al., 2011; Nichani et al., 2019; Pelclová et al., 2013; Van Dyck et al., 2012). An explanation could be that residents in Groningen prioritize factors other than those covered by the NEWS-CFA when selecting their favourite walking routes. However, this needs to be investigated in future research.

Regarding the level of agreement between the objective walkability through the WAI and perceived walkability as measured with the NEWS-CFA, the results are in line with previous research, which showed that one third of the people misperceived objectively walkable neighbourhoods as lowly walkable (Arvidsson et al., 2012; Ding & Gebel, 2012). This research has also indicated a partial agreement between WAI and NEWS-CFA results, as shown by the choropleth analysis. It showed that the agreement between WAI and NEWS is stronger regarding neighbourhoods with higher walkability scores, as compared to lower scoring neighbourhoods. While overall, the WAI and NEWS-CFA demonstrate greater disparities in Groningen's context, the instances of agreement between these measures are concentrated in central locales, whereas their disagreement is more geographically dispersed.

Additionally, this study identified key factors that contribute to high and low levels of both objective and perceived walkability. The WAI revealed that the FAR and residential density played an important role in determining high objective walkability, while entropy was associated with low objective walkability. These findings differ from the results of the NEWS-CFA in that, high perceived walkability was primarily influenced by land-use mix and aesthetics. Conversely, low perceived walkability was associated with limited parking availability and a lack of social interactions during walking. It is important to note that these observations indicate a pattern rather than a direct relationship. To further explore the relationships and identify the most significant explanatory factors for both perceived and objective walkability, additional statistical analyses are required. Furthermore, due to the subjective nature of the NEWS-CFA, walkability outcomes between participants may differ significantly. Moreover, participants were recruited in cultural hot spots of various neighbourhoods within Groningen and only 41 out of 105 pre-selected neighbourhoods were covered. Therefore, future research should survey participants in the entire selection of neighbourhoods to ensure equal distribution of the dataset for increased representativity. Not only for the NEWS-CFA dataset, but also for the RFWR, more participants are required to obtain a representative sample. Furthermore, to make generic statements regarding the similarities between WAI and RFWR, more participants are required. However, it is important to acknowledge the limitations in the ability to generalize the findings to the entire population of pedestrians. This is mainly due to the fact that it concerns a single case study. However, the research design allows for ease of replication of this research in other cities, which would make generalisation possible for similar contexts. Hence, future studies should compare multiple cities in order to support these findings.

Overall, this case study made valuable contributions to walkability research by investigating the relationship between objective and subjective measures of walkability and their alignment with residents' RFWR in neighbourhoods of Groningen. A multitude of studies have researched the effects of objective and perceived Walkability on physical activity, but none have compared it to RFWR (Buck et al., 2015; Ellis et al., 2015; Frank et al., 2005; Jacobs et al., 2021; Larranaga et al., 2019; Liao et al., 2020; Moura et al., 2017; Van Dyck et al., 2012). Notably, the WAI results align closely with the RFWR, suggesting that the WAI can be a useful tool for predicting the RFWR in Groningen's neighbourhoods. Finally, neighbourhoods showing high levels of walkability can provide valuable insights for spatial planning by providing inspiration for improving areas with lower walkability to create more pedestrian-friendly environments throughout cities.

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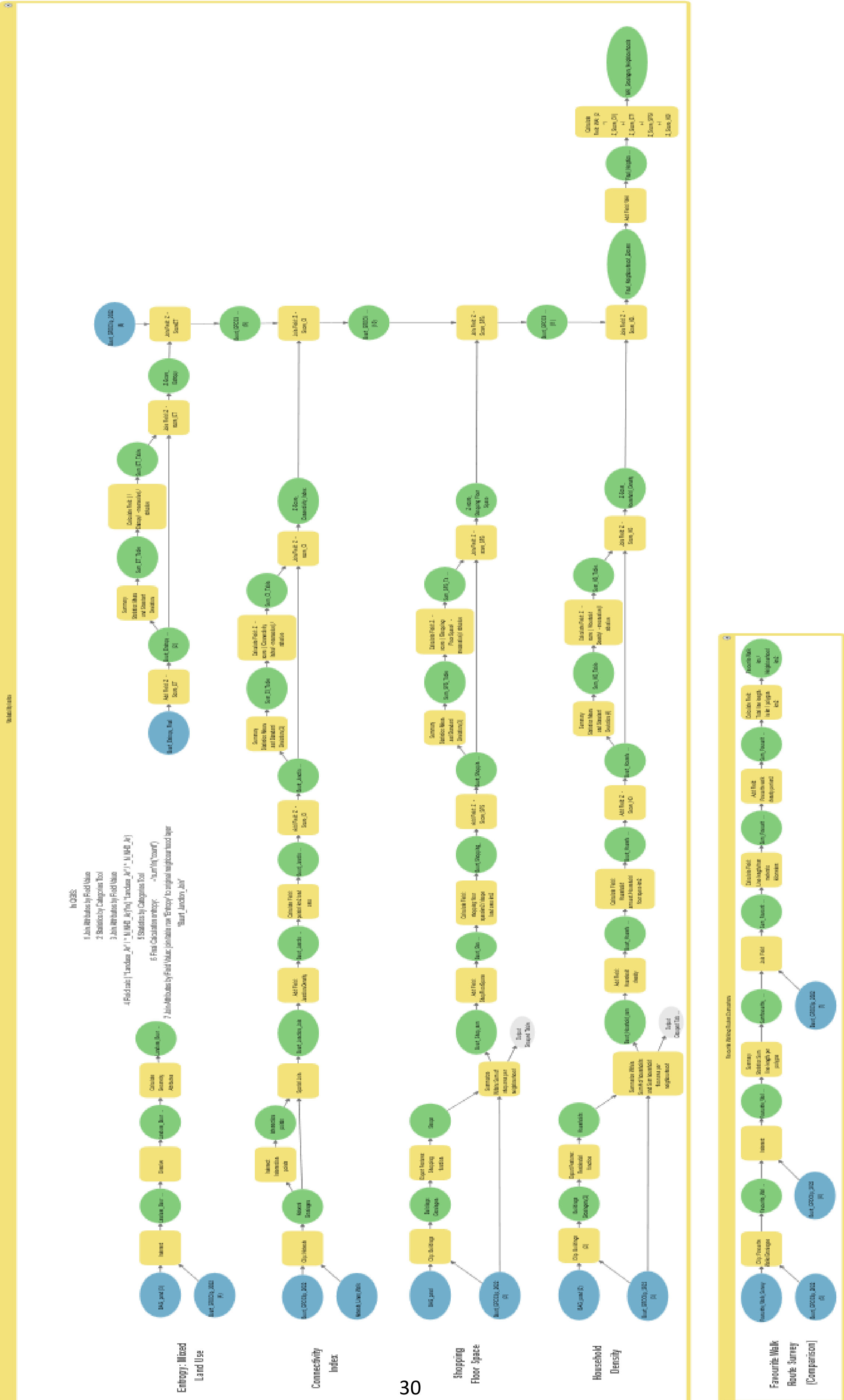
Appendices

Appendix 1: Data requirements Walkability Index

Requirement	Spatial data	Attribute data	Name dataset	Last updated date	location dataset
Within neighbourhoods of Groningen (applies to all of the indices)	Polygon data of neighbourhoods	Neighbourhood name / code Geometry (shape area)	Wijk- en buurtkaart 2022	2022	https://www.cbs.nl/
Favourite walking routes	Line features	Geometry (line length), location	Maptionnaire secondary dataset	2021	Personal drive
Walkability Index:					
Connectivity index	Sidewalk line features	Geometry (line length), location	OpenStreetMap	2023	https://www.openstreetmap.org/#map=13/42.9429/-8.3803&layers=T
(Shannon's) entropy index	Polygon features (buildings)	Geometry (shape area), entire variety of functions	Basisregistratie Adressen en Gebouwen (BAG)	16-02-2022	https://data.overheid.nl/dataset/basisregistratie-adressen-en-gebouwen--bag-#panel-resources
shopping floor space	Polygon features (buildings)	Geometry (shape area), shopping function	Basisregistratie Adressen en Gebouwen (BAG)	16-02-2022	https://data.overheid.nl/dataset/basisregistratie-adressen-en-gebouwen--bag-#panel-resources
household density	Polygon features (buildings)	Geometry (shape area), residential function, amount of households	Basisregistratie Adressen en Gebouwen (BAG)	16-02-2022	https://data.overheid.nl/dataset/basisregistratie-adressen-en-gebouwen--bag-#panel-resources

Table 7: Data requirements WAI

Appendix 2: WAI - Flowchart of analysis steps



Appendix 3: English NEWS-CFA

Start of Block: Algemeen

Intro Dear respondent, Thank you for your interest in this research on the walkability of neighborhoods in the city of Groningen. Walkability refers to the extent to which the built environment is pedestrian-friendly for people who live, shop, spend time, or visit an area. We would like to learn more about your experiences and perceptions of your neighborhood and the surrounding area in terms of walkability. This research focuses on various aspects, including the presence of sidewalks, lighting, safety, proximity to amenities, and so on. We kindly request that you answer the questions as accurately as possible, based on your own experiences and perceptions. This research is being conducted by the University of Groningen. The questionnaire will take approximately 10 minutes to complete. Your cooperation is greatly appreciated.

Page Break

AL1 What is your..

	Please fill in (1)
full postal code? (1)	
age? (2)	

AL2 What is your gender?

- ◯ Male (1)
- ◯ Female (2)
- ◯ Non-binary (3)

End of Block: Algemeen

Start of Block: A

A2. How common are the following types of housing in your immediate neighborhood?

	None (1)	A few (2)	Some (3)	Most (4)	All (5)
Detached single-family houses (1)	○	○	○	○	○
Townhouses or row houses of 1-3 stories (2)	○	○	○	○	○
Apartments or condos 1-3 stories (3)	○	○	○	○	○
Apartments or condos 4-6 stories (4)	○	○	○	○	○
Apartments or condos 7-12 stories (5)	○	○	○	○	○
Apartments or condos more than 13 stories (6)	○	○	○	○	○

End of Block: A

Start of Block: B

B1 About how long would it take to get from your home to the nearest businesses or facilities listed below if you walked to them? Please select one option for each facility.	1-5 min (1)	6-10 min (2)	11-20 min (3)	21-30 min (4)	31+ min / No idea (5)
supermarket (1)	○	○	○	○	○
nightshop (2)	○	○	○	○	○
bakery (3)	○	○	○	○	○
clothing store (4)	○	○	○	○	○
post office (5)	○	○	○	○	○
library (6)	○	○	○	○	○
elementary school or other schools (7)	○	○	○	○	○
cinema (8)	○	○	○	○	○
butcher (9)	○	○	○	○	○
restaurant (10)	○	○	○	○	○
coffee place (11)	○	○	○	○	○
pharmacy/drug store (12)	○	○	○	○	○
salon/barber shop (13)	○	○	○	○	○

your job or school (14)	○	○	○	○	○
bus stop (15)	○	○	○	○	○
park (16)	○	○	○	○	○
sports facility (17)	○	○	○	○	○
book store (18)	○	○	○	○	○

End of Block: B

Start of Block: C

C1. Stores are within easy walking distance.

○ Strongly disagree (1)

○ Somewhat disagree (2)

○ Somewhat agree (3)

○ Strongly agree (4)

Page Break

C2. There are many places to go within walking distance at my home.

- Strongly disagree (1)
- Somewhat disagree (2)
- Somewhat agree (3)
- Strongly agree (4)

C3. It is easy to walk to a transit stop (bus, train) from my home.

- Strongly disagree (1)
- Somewhat disagree (2)
- Somewhat agree (3)
- Strongly agree (4)

End of Block: C

Start of Block: D

D1 The distance between intersections in my neighborhood is usually short.

- Strongly disagree (1)
- Somewhat disagree (2)
- Somewhat agree (3)
- Strongly agree (4)

D2. There are many alternative routes for getting from place to place in my neighborhood.

- Strongly disagree (1)
- Somewhat disagree (2)
- Somewhat agree (3)
- Strongly agree (4)

End of Block: D

Start of Block: E

E1. There are sidewalks on most of the streets in my neighborhood.

- Strongly disagree (1)
- Somewhat disagree (2)
- Somewhat agree (3)
- Strongly agree (4)

E2. Sidewalks are separated from the road/traffic in my neighborhood.

- Strongly disagree (1)
- Somewhat disagree (2)
- Somewhat agree (3)
- Strongly agree (4)

E3. My neighborhood is well lit at night.

- ◯ Strongly disagree (1)
- ◯ Somewhat disagree (2)
- ◯ Somewhat agree (3)
- ◯ Strongly agree (4)

E4. Walkers and bikers on the streets in my neighborhood can be easily seen by people in their homes.

- ◯ Strongly disagree (1)
- ◯ Somewhat disagree (2)
- ◯ Somewhat agree (3)
- ◯ Strongly agree (4)

E5. There are crosswalks and pedestrian signals to help walkers cross busy streets in my neighborhood.

- ◯ Strongly disagree (1)
- ◯ Somewhat disagree (2)
- ◯ Somewhat agree (3)
- ◯ Strongly agree (4)

End of Block: E

Start of Block: F

F1. There are trees along the streets in my neighborhood.

- ○ Strongly disagree (1)
- ○ Somewhat disagree (2)
- ○ Somewhat agree (3)
- ○ Strongly agree (4)

F2. There are many interesting things to look at while walking in my neighborhood.

- ○ Strongly disagree (1)
- ○ Somewhat disagree (2)
- ○ Somewhat agree (3)
- ○ Strongly agree (4)

F3. There are many attractive natural sights in my neighborhood.

- ○ Strongly disagree (1)
- ○ Somewhat disagree (2)
- ○ Somewhat agree (3)
- ○ Strongly agree (4)

F4. There are attractive buildings/homes in my neighborhood.

- Strongly disagree (1)
- Somewhat disagree (2)
- Somewhat agree (3)
- Strongly agree (4)

End of Block: F

Start of Block: G

G1. There is so much traffic along the street I live on that it makes it difficult or unpleasant to walk in my neighborhood.

- Strongly disagree (1)
- Somewhat disagree (2)
- Somewhat agree (3)
- Strongly agree (4)

G2. The speed of traffic on most nearby streets is usually slow.

- Strongly disagree (1)
- Somewhat disagree (2)
- Somewhat agree (3)
- Strongly agree (4)

G3. Most drivers exceed the posted limits while driving in my neighborhood.

- ◯ Strongly disagree (1)
- ◯ Somewhat disagree (2)
- ◯ Somewhat agree (3)
- ◯ Strongly agree (4)

End of Block: G

Start of Block: H

H1 There is a high crime rate in my neighborhood.

- ◯ Strongly disagree (1)
- ◯ Somewhat disagree (2)
- ◯ Somewhat agree (3)
- ◯ Strongly agree (4)

H2 The crime rate in my neighborhood makes it unsafe to...

	Strongly disagree (1)	Somewhat disagree (2)	Somewhat agree (3)	Strongly agree (4)
go on walks during the day (1)	◯	◯	◯	◯
go on walks at night (2)	◯	◯	◯	◯

End of Block: H

Start of Block: I

I1 Parking is difficult in local shopping areas.

- ◯ Strongly disagree (1)
- ◯ Somewhat disagree (2)
- ◯ Somewhat agree (3)
- ◯ Strongly agree (4)

End of Block: I

Start of Block: J

J1 The streets in my neighborhood do not have many cul-de-sacs.

- ◯ Strongly disagree (1)
- ◯ Somewhat disagree (2)
- ◯ Somewhat agree (3)
- ◯ Strongly agree (4)

End of Block: J

Start of Block: Block 12

N1 I see and speak to other people when I am walking in my neighborhood.

- ◯ Strongly disagree (1)
- ◯ Somewhat disagree (2)
- ◯ Somewhat agree (3)
- ◯ Strongly agree (4)

End of Block: Block 12

Start of Block: Toekomstige deelname

einde Thank you for your cooperation. Are you open to future research from the University of Groningen? If so, please provide your email address.

____

End of Block: Toekomstige deelname

Appendix 4: Dutch NEWS-CFA

Start of Block: Algemeen

Intro Beste respondent, Bedankt voor uw interesse in dit onderzoek naar de loopbaarheid van buurten in de stad Groningen. Loopbaarheid betreft de mate waarin de gebouwde omgeving vriendelijk is voor de mensen die in een gebied wonen, winkelen, tijd doorbrengen of op bezoek zijn. We willen graag meer te weten komen over uw ervaringen en percepties van uw buurt en de omgeving rondom uw woning, met betrekking tot de loopbaarheid. Dit onderzoek richt zich op verschillende aspecten, waaronder de aanwezigheid van trottoirs, verlichting, veiligheid, nabijheid van voorzieningen, enzovoort. We vragen u om de vragen zo nauwkeurig mogelijk te beantwoorden, gebaseerd op uw eigen ervaringen en percepties. Dit onderzoek wordt uitgevoerd vanuit de Rijksuniversiteit Groningen. De vragenlijst duurt ongeveer 10 min. We stellen uw medewerking bijzonder op prijs.

Page Break

AL1 Wat is uw...

	Graag invullen (1)
volledige postcode? (1)	
leeftijd? (2)	

AL2 Wat is uw geslacht?

- ○ Man (1)
- ○ Vrouw (2)
- ○ Onzijdig (3)

End of Block: Algemeen

Start of Block: A

A2. Hoe gebruikelijk zijn de volgende woongelegenheden in uw directe buurt?

	Geen (1)	Een paar (2)	Sommige (3)	De meeste (4)	Alle (5)
Vrijstaande eengezinswoningen (1)	○	○	○	○	○
Rijtjeshuizen of huizen van 1-3 verdiepingen (2)	○	○	○	○	○
Appartementen of flatgebouwen van 1-3 verdiepingen (3)	○	○	○	○	○
Appartementen of flatgebouwen van 4-6 verdiepingen (4)	○	○	○	○	○
Appartementen of flatgebouwen van 7-12 verdiepingen (5)	○	○	○	○	○
Appartementen of flatgebouwen van 13 of meer verdiepingen (6)	○	○	○	○	○

End of Block: A

Start of Block: B

B1 Hoe lang zou het ongeveer duren om <u>lopend</u> van uw huis naar de dichtstbijzijnde voorzieningen te gaan? Kies alstublieft één optie per voorziening.	1-5 min (1)	6-10 min (2)	11-20 min (3)	21-30 min (4)	31+ min / Geen idee (5)
Supermarkt (1)					
Nightshop (2)					
Bakker (3)					
Kledingwinkel (4)					
Postkantoor (5)					
Bibliotheek (6)					
Basisschool of andere school (7)					
Bioscoop (8)					
Slager (9)					
Restaurant (10)					
Koffiezaak (11)					
Drogisterij (12)					
Kapsalon (13)					
Uw werk of school (14)					

Bushalte (15)	○	○	○	○	○
Park (16)	○	○	○	○	○
Sportinstantie (17)	○	○	○	○	○
Boekenwinkel (18)	○	○	○	○	○

End of Block: B

Start of Block: C

C1. Winkels zijn gemakkelijk te voet bereikbaar.

○ Volledig mee oneens (1)

○ Mee oneens (2)

○ Mee eens (3)

○ Volledig mee eens (4)

Page Break

C2. Er zijn veel plekken op loopafstand van mijn huis om naartoe te gaan.

- ○ Volledig mee oneens (1)
- ○ Mee oneens (2)
- ○ Mee eens (3)
- ○ Volledig mee eens (4)

C3. Het is gemakkelijk om vanuit mijn huis naar een ov-halte (bus, trein) te lopen.

- ○ Volledig mee oneens (1)
- ○ Mee oneens (2)
- ○ Mee eens (3)
- ○ Volledig mee eens (4)

End of Block: C

Start of Block: D

D1 De afstand tussen kruispunten in mijn buurt is meestal klein.

- ○ Volledig mee oneens (1)
- ○ Mee oneens (2)
- ○ Mee eens (3)
- ○ Volledig mee eens (4)

D2. Er zijn veel alternatieve routes om van de ene naar de andere plek in mijn buurt te komen.

- Volledig mee oneens (1)
- Mee oneens (2)
- Mee eens (3)
- Volledig mee eens (4)

End of Block: D

Start of Block: E

E1. Er liggen voetpaden langs de meeste straten in mijn buurt.

- Volledig mee oneens (1)
- Mee oneens (2)
- Mee eens (3)
- Volledig mee eens (4)

E2. Voetpaden zijn in mijn buurt gescheiden van de weg/verkeer.

- Volledig mee oneens (1)
- Mee oneens (2)
- Mee eens (3)
- Volledig mee eens (4)

E3. Mijn buurt is 's nachts goed verlicht.

- ○ Volledig mee oneens (1)
- ○ Mee oneens (2)
- ○ Mee eens (3)
- ○ Volledig mee eens (4)

E4. Voetgangers en fietsers op straat in mijn buurt kunnen gemakkelijk worden gezien door mensen in hun huizen.

- ○ Volledig mee oneens (1)
- ○ Mee oneens (2)
- ○ Mee eens (3)
- ○ Volledig mee eens (4)

E5. Er zijn zebrapaden en/ of stoplichten om voetgangers te helpen om drukke straten over te steken in mijn buurt.

- ○ Volledig mee oneens (1)
- ○ Mee oneens (2)
- ○ Mee eens (3)
- ○ Volledig mee eens (4)

End of Block: E

Start of Block: F

F1. Er staan bomen langs de straten in mijn buurt.

- ◯ Volledig mee oneens (1)
- ◯ Mee oneens (2)
- ◯ Mee eens (3)
- ◯ Volledig mee eens (4)

F2. Er zijn veel interessante dingen om naar te kijken tijdens het wandelen in mijn buurt.

- ◯ Volledig mee oneens (1)
- ◯ Mee oneens (2)
- ◯ Mee eens (3)
- ◯ Volledig mee eens (4)

F3. Er zijn veel aantrekkelijke groenvoorzieningen in mijn buurt.

- ◯ Volledig mee oneens (1)
- ◯ Mee oneens (2)
- ◯ Mee eens (3)
- ◯ Volledig mee eens (4)

F4. Er zijn aantrekkelijke gebouwen of huizen in mijn buurt.

- ○ Volledig mee oneens (1)
- ○ Mee oneens (2)
- ○ Mee eens (3)
- ○ Volledig mee eens (4)

End of Block: F

Start of Block: G

G1. Er is zoveel verkeer in nabijgelegen straten dat het moeilijk of onplezierig is om in mijn buurt te wandelen.

- ○ Volledig mee oneens (1)
- ○ Mee oneens (2)
- ○ Mee eens (3)
- ○ Volledig mee eens (4)

G2. De snelheid van het verkeer in de meeste nabijgelegen straten is meestal langzaam.

- ○ Volledig mee oneens (1)
- ○ Mee oneens (2)
- ○ Mee eens (3)
- ○ Volledig mee eens (4)

G3. De meeste bestuurders overschrijden de aangegeven snelheidslimieten tijdens het rijden in mijn buurt.

◯ Volledig mee oneens (1)

◯ Mee oneens (2)

◯ Mee eens (3)

◯ Volledig mee eens (4)

End of Block: G

Start of Block: H

H1 Er is veel criminaliteit in mijn buurt.

◯ Volledig mee oneens (1)

◯ Mee oneens (2)

◯ Mee eens (3)

◯ Volledig mee eens (4)

H2 Criminaliteit in mijn buurt maakt het onveilig om...

	Volledig mee oneens (1)	Mee oneens (2)	Mee eens (3)	Volledig mee eens (4)
overdag te wandelen (1)	◯	◯	◯	◯
's nachts te wandelen (2)	◯	◯	◯	◯

End of Block: H

Start of Block: I

I1 Parkeren is moeilijk in dijchtbijzijnde winkelgebieden.

- ◯ Volledig mee oneens (1)
- ◯ Mee oneens (2)
- ◯ Mee eens (3)
- ◯ Volledig mee eens (4)

End of Block: I

Start of Block: J

J1 De straten in mijn buurt zijn bijna nooit doodlopend.

- ◯ Volledig mee oneens (1)
- ◯ Mee oneens (2)
- ◯ Mee eens (3)
- ◯ Volledig mee eens (4)

End of Block: J

Start of Block: Block 12

N1 Ik zie en spreek andere mensen als ik in mijn buurt loop

- ◯ Volledig mee oneens (1)
- ◯ Mee oneens (2)
- ◯ Mee eens (3)
- ◯ Volledig mee eens (4)

End of Block: Block 12

Start of Block: Toekomstige deelname

einde Bedankt voor uw medewerking. Staat u open voor toekomstig onderzoek van de Rijksuniversiteit Groningen? Indien dit het geval is, vul dan graag uw emailadres in.

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End of Block: Toekomstige deelname