To walk, or not to walk? – That is the question:

Assessing the influence of objective measures of walkability on sustainable travel behavior of Dutch residents

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Abstract: This study investigates how objective components of walkability influence sustainable travel behavior among Dutch residents. The central research question asks how specific walkability components affect (1) the share of sustainable trips at the neighborhood level and (2) the distance individuals are willing to travel sustainably. Using data from the 2020 Dutch National Travel Survey (ODiN), this study combines travel behavior with objective walkability measures derived from national spatial datasets. Linear regression analyses were conducted at two levels: the four-digit postal code (PC4) level and the individual level.

At the neighborhood level, results show that population density and retail/service destination density are positively associated with the share of sustainable trips, while greenspace density has a significant negative relationship. At the individual level, sustainable travel distance is most influenced by sociodemographic factors; however, walkability components still play a role. Higher retail/service density is associated with shorter sustainable travel distances, while greenspace density positively influences the distance residents are willing to walk or bike. Additionally, higher NO_2 concentrations negatively affect sustainable travel distance. These findings highlight the importance of compact, amenity-rich urban environments in promoting sustainable travel.

Keywords: Walkability, Sustainability, Spatial planning, Density, 15-minute City

1. Introduction

Urban settings provide the unique opportunity to accommodate a variety of needs within a compact area. Following from this, as populations rise, the needs of cities rise. With an estimated ⅔ of the world's population growth occurring in cities by 2050 (United Nations, 2025), cities are becoming more and more pertinent for the organization of people and services. This requires that the spatial planning of cities adequately considers these increasing needs in a sustainable way.

The 15-minute city (15mC) is an emerging idea within spatial planning; Moreno et al. (2021) introduced this idea as a city wherein all of an individual's needs can be met in 15 minutes of sustainable travel. While different studies consider sustainable travel differently, this study chooses to define sustainable travel as walking or biking. This 15mC concept seeks to unify the distribution of amenities within cities by reducing urban sprawl and thus the negative externalities to both humans and the environment this causes. However, in order to achieve this, we must ask how can sustainable travel be further encouraged?

Walking has long been acknowledged as an advantageous form of moderate exercise, leading to reductions in chronic ailments such as cardiovascular disease and diabetes (Feuillet et al., 2015). Typically, research on walking focuses on this human health perspective, seeking to increase walking primarily for the associated health benefits. Connected to these ideas on the benefits of walking, is the evolving field of walkability. Walkability concerns how environments can be made more accessible for the pedestrian (Lo, 2009). While initially from the human health perspective, the field has expanded to consider transport and sustainability. Section 1.1 contains an overview of evolutions and relevant definitions within this field, highlighting the aspects of walkability most pertinent to this research. Most common in research on walkability is the creation of a walkability index. Many such indices have been created over the last 60 years, in both the academic, and commercial sectors. These composite indices contain standardized scores for a variety of different components of walkability, creating a singular walkability score (often between 0 - 100). This is beneficial for observing general trends of walking, although provides less detailed information for determining which improvements should be made to the built environment in order to encourage walking, as there is no differentiation between the scores for the individual components entered in the index; it is also not possible to identify how much each component matters in the overall decisions to walk. In addition, a walkable neighborhood has yet to be clearly defined in terms of the maximum distance one will walk.

The primary goal of this study is to ascertain the connection between components of objective walkability and the influence they have on trips taken using sustainable travel, to be able to recommend where emerging urban settings should invest to encourage sustainable travel (defined as travel exclusively by walking or biking). This is done on two levels; the first level (neighborhood), asks the question: which components of walkability impact the share of sustainable travel? The second level (individual), asks the question: which components of walkability influence the distance residents are willing to travel sustainably? A final level of analysis is applied to different distance intervals per each walkability component, in order to comment on the appropriate size of a walkable neighborhood. By looking at these different levels this study seeks to attain a comprehensive answer to the question: how do walkability components influence sustainable travel patterns? To answer these questions, this paper will first give a relevant overview of walkability, followed by an explanation of the methods used (and components considered), concluding with a discussion of the results and their implications.

1.1“Walkability”

Walkability is a newly evolving field – with emerging connections to transport, human health, urban planning, and sustainability (Shields et. al., 2021). Conceptually, walkability can be defined as the spatial qualities of an environment that favor the pedestrian. It is thus necessary for assessments of walkability to be based on the pedestrian. In the simplest terms, a pedestrian can be defined as “a person traveling on foot; a walker” (Harper Collins Publisher, 2022). Following this, a walkable city has to be one where a resident can move around easily. Within transportation, the “3D’s” of the built environment have been highlighted as most relevant for travel by foot (i.e. walking). These are: density (the amount of goods/services present), design (the quality of distribution of said goods/services), and diversity (the different services available). However, as the field evolves, these no longer encompass all attributes impacting travel decisions – leading to the inclusion of two more attributes: destination accessibility and distance to transit (Venerandi et al., 2024). In walkability, these attributes are often operationalized in metrics such as population density, landmix, street connectivity, public transit stop density, etc – section 2.2 contains the walkability attributes (and their derivation) deemed most relevant to this research.

Cervero and Kockelman (1997) were the first to introduce the idea of the 3D’s. This was done from the transport perspective, as a means to explain trip generation, trip length, and modal choice. They were able to find that density and diversity reduce the length of trips, and increase the amount of daily trips (with most of the new trips being walked). Their final finding was that diversity also significantly increases the decision to walk over drive (modal choice). These findings serve as the core for the evolutions of walkability research.

While not directly related, Moreno et al. (2021) propose a similar idea in their introduction to the 15mC. The four pillars, as they describe, of the 15mC are density, diversity, proximity, and digitalization. Density, diversity, and proximity can be understood as the D's explained above (with proximity representing distance to amenities), but digitalization is a new aspect to add to this conversation. Digitalization exists under the smart city concept and thus does not correlate with spatial planning as the other pillars do. It's important to keep these overlapping concepts in mind when researching towards the implementation of such cities.

1.1.1 Perceived vs. objective

One of the most important areas of discourse to highlight within walkability is the difference between objective walkability and perceived walkability. Objective walkability refers exclusively to measurable attributes of the built environment (such as amount of greenspace or population density), whereas studies on perceived walkability look at the interpretation by individuals of their lived environment (typically done through the usage of surveys). While it would be most beneficial for planning purposes for these two metrics to have the same results, this is unfortunately not the case. Koohsari et al. (2014) found that when individuals perceive their environment as less walkable they walk less (and vice versa) – regardless of the built environment. They owe this to familiarity (or lack thereof) of surroundings, i.e. those that are outside more often perceive their environment as more walkable because they spend more time in it, whereas those that do not spend time in their environment are unfamiliar to it – making their perception skewed. Additionally, individual attitudes also impact the perceived walkability. van der Vlugt et al. (2025) found that individual attitudes of walking, in combination with the objective measures, impacts walking frequency, duration, and length; this contributes further evidence to the role of perception in these transport behaviors. However, without the means to distribute a survey, perception cannot be measured and thus cannot be considered.

1.1.2 Existing indices

Many indices have been created to measure walkability. Following from the previous section, indices can choose to center on perceived or objective measures of walkability – with the majority focusing on objective measures – and within different sectors. One of the most well known of these indices is WalkScore™; this index considers distance to 13 different amenity types, but no other aspects of the built environment. WalkScore™ has been found to be positively correlated to people's perceptions of walkability (Carr et al., 2010), making it a good metric to combine both perspective and objective walkability. However, WalkScore™ is still mainly a US based index and does not calculate a score beyond a 30 minute walk, nor does it allow you to look at individual influence of the different proximity to amenities – making it unfit to consider for most international settings and limited in scope. Other ways to account for differences in walkability are to assess walkability with weighted components, or from the perspective of different populations (such as the elderly); it is outside the scope of this research to surmise these different indices. Venerandi et al. (2024) provides a comprehensive review of 32 of the most relevant to the current conversations on walkability.

Considering the Dutch setting, Lam et al. (2022) has recently created an objective walkability index for all of the Netherlands. This index considers population density, retail/service destination, public transport stop density, greenspace density, street connectivity, sidewalk density, and landmix – all in line with the 5D’s mentioned earlier. This index is the most relevant index to this study as it focuses exclusively on the Dutch context. This index combines all components equally.

2. Methods

To identify the influence of the different components of walkability on the walking behavior of Dutch residents, two levels of analysis were employed: neighborhood and individual. Both levels we used to assess daily sustainable trips – with sustainable trips being defined as only trips taken by walking or biking. At the neighborhood level (defined as the four digit postal code, henceforth referred to as PC4), the share of sustainable trips was investigated against the walkability components of the built environment. In this way, non-walkers/neighborhoods with low walking were captured by the analysis. To be able to conclude how walkability components influence the choice to travel sustainably. Following from the neighborhood level, individual walking behavior was investigated to consider sociodemographic variables with the walkability components. This level of analysis serves to investigate how those that chose to walk are influenced by their built environment. In the following section, data sources will be assessed, walkability operationalized, and the model used to ascertain these influences explained – all in line with the research objectives of encouraging sustainable travel.

2.1 Data sources

2.1.1 Dutch National Travel Survey (ODiN)

Onderweg in Nederlands (ODiN) is the Dutch national travel survey. This survey is conducted annually, asking randomly selected participants to log one entire day of movements. While it has evolved in name and structure, the Netherlands has been administering a travel survey since the late 70s; the most recent ODiN data is available from 2023, however, for the purposes of this study only ODiN data from 2020 was used. This was in order to align ODiN data with available walkability data (from 2020). ODiN asks participants a variety of questions about each trip they take in the day, with almost 250 response variables. ODiN is administered by the Centraal Bureau voor de Statistiek (henceforth CBS) – an independent Dutch organization that collects and calculates a variety of statistics for the Netherlands For this study, the most relevant variables from ODiN were identified; appendix 1 contains the relevant variables with their descriptions and coding. It's important to acknowledge that ODiN measures two different levels of movement: displacement (verplaatsing) and ride (rit). Verplaatsing/displacement variables concern the whole journey (from start to end point) the individual takes; rit/ride variables concern each leg of the trip. As this study is most interested in each individual leg of the respondents journey's (and the modal choice of said legs), all variables included in this analysis for trip length and mode were on the rit level. This is evident by the R in each variable's coding.

Before processing, ODiN 2020 contained 176730 rides across the whole of the Netherlands, however as some postal codes are rather small/unpopulated not all postalcodes are ubiquitously represented within the ODiN data, leading to 713 postal codes being missing in the data. This research concerns built environment attributes of home origin trips, as this is the most often origin point for all trip types (Millward et al., 2013). After filtering ODiN for only home addresses origins, 70370 trips remained for all trip purposes using all modes of transport. Additional trips abroad (267) and trips to unknown PC4s (1256) were removed to account for daily travel exclusively in the Netherlands. As well all entries were removed with no income coding from the income variable (HHWelvg). To complete the preprocessing only walking/biking trips were selected, and average distance traveled per trip per person was calculated; this resulted in a final dataset of only daily home origin trips done walking/biking for 29045 individuals.

In order to create a model that is representative of individual choice, it was necessary to control for sociodemographic variables. The variables of household prosperity, number of people per household, age, and gender are well established as impacting travel patterns/modal choices (Riggs & Sethi, 2019; Lindelöw, et al., 2017; Distefano, et al, 2023). To include these within the model, these variables were extracted from the ODiN survey.

2.1.1 Walkability components

Walkability is a complex topic with multiple definitions and a multitude of different indices to measure it. For the purposes of this study, walkability is to be assessed for only the most relevant components identified in the literature. These objective components mainly center around the 3/5D's discussed in section [1.1]. The individual components used in this study were provided by the GEoscience and health Cohort COnsortium (GECCO); this Dutch group created in 2018 that seeks to provide high quality spatial data relating to health and exposure. The GECCO components are available with euclidean buffers from 150-2000 meters (intervals of 150-500). A buffer size of 750m was used to align with Wei et al., (2016)'s definitions of a walkable neighborhood as not more than 800m. Additionally, walkability has been found as a proxy for bikeability (Riggs & Sethi, 2019) – allowing this analysis to expand to all forms of sustainable travel, not simply walking.

GECCO calculates these components at the highly detailed address level (six digit postal code + house number), however PC6's are not publicly available information and ODiN contains only the PC4 per ride. This made it necessary to aggregate all of the components to the PC4 level. This was done using SPSS “aggregate data” command to the PC6 level, then mapping this into QGIS and joining to the PC4 level using “Join attributes by location (summary)” with the mean parameter to describe each buffer range of the components. The result is the mean measure per each component at the PC4 level. Below each component of walkability entered into the model is justified, followed by table [] which summarizes the relevant information for the interpretation of each component. The majority of the selected components were chosen because of their relation to the findings by Cervero and Kockelman (1997) on the 3D’s of the built environment.

2.1.2 Population Density

Population density is one of the most acknowledged metrics that influences walking behavior. Starting with Cervero and Kockelman (1997) acknowledging it in their 3D’s framework, it is ubiquitous in transport/spatial planning research. It’s been found as a predictor of transport walking (Wei, et al (2016); Lam et al, (2022)), and is necessary to sustain the 15mC principle as there must be people for there to be proximate services.

In this analysis, population density was attained via the CBS Wijk- en burrtkaarten. This download provides a variety of statistics at the municipal, neighborhood, and district level. Within these attributes population density is also provided. This data is computed as the number of inhabitants per km^2 for the year of 2021.

2.1.3 Retail & Service Destination Density

Retail density is similarly important to sustainable walking behavior, and again contained in Cervero and Kockelman (1997)'s framework. Retail trips are the most common sort distance utilitarian trip (Milward et al, 2013). By incorporating this metric into both levels of analysis, this relation can also be tested. Additionally, from a societal standpoint, Riggs & Sethi (2019) found that for lower income families retail density had the strongest effect on sustainable travel decisions.

This density calculation is done via the selection of 'Detailhandel en horeca" and 'Sociaal-culturele voorzieningen' landuses from the Bestand BodemGebruik (BBG) land use map, produced by CBS. The former class covers all locations for retail and restaurants, while the latter accounts for social/cultural/service institutions such as schools, theaters or hospitals. Both of these classes have been shown as valuable to walking behavior (Fonseca et al., 2021). This calculation is done as the ratio of said classes per PC4 landparcel – the resulting unit is the number of retail/service destinations per km^2 per PC4 for 2020. While BBG is useful to acknowledge general land patterns, it's important to acknowledge that using this measure is relying on this generalized land use instead of, per se, individual building or PC6 level data. Due to the PC4 level of the available ODiN data, it was deemed unfit to use any smaller unit for walkability components.

2.1.4 Green (& blue) space Density

Urban greenspaces provide numerous benefits through both the inclusion of green and the activities they facilitate. When these spaces are large, attractive, and well designed they have been found to positively contribute to physical activity in the form of walking (Kaczynski & Henderson, 2007). Using the measure of greenspace density (as opposed to quality), directly relates to the current discussion on density as a metric to motivate travel. Moreno et al. (2021) also advocate for the inclusion of green within the 15mC.

Similar to the previous component, green space density was derived from the BBG landuse classification – using the classes of 'parken en plantsoen', 'bos', and 'begraafplaats'. These classes contain all areas that are used for primarily parks, and forests; all relevant areas when considering the level of urban green. However, this analysis chose to include the expanded selection of urban green space that includes areas deemed 'blue' areas. This greater selection of classes includes agricultural areas and wet/dry natural terrain. This is motivated by the benefits of water features for motivating walking behaviors (Giles-Corti et al., 2005).

2.1.5 Street Connectivity & Sidewalk Density

An important aspect of both perceived and objective walkability is the quality of the walking environment. Distefano et al. (2023) found infrastructure/sidewalk quality as an important component in the decision to walk. As well, street connectivity is directly related to the metric of Design. For these reasons, both metrics were included in this study – however, after preliminary analysis, both variables were found to be highly correlated with each other; this led to the removal of both.

2.1.6 Land use mix

This component relates to the diversity of land. Frank et al. (2005) found that areas with more land use mix lead to greater walking, this follows from the metric of Diversity. Additionally, Koohsari et al (2014) found that the perceived landuse mix plays a role in the decision of an individual to walk.

To measure this diversity an entropic index was applied using the BBG landuse map.

2.1.7 Extended components

Noise, and pollution have been proven to impact residents' willingness to walk (Brookfield, 2016). Following from this, these components were deemed valuable to add to this test. The assessment of noise used is the mixed cumulative annual noise for the year 2020-2021; this includes noise from roads, planes, trains, and industrial sources (such as wind turbines). The median decibel per PC4 was added as an explanatory variable for both models. For pollution, PM10, PM2.5 and NO2 levels were considered as these are associated with the negative externalities from cities (such as burning of fossil fuels) and have negative impacts on human health (Mebrahtu et al., 2023). These pollution levels used were averaged for the year 2020, and are reported in micrograms per m^3. The final component entered into the model was bikepath density. This variable was included to add a component directly related to bikeability.

Table 1: Summary of walkability components

Walkability Component	**Unit (all on PC4 level)**	**Data source(s)**
Population Density	Inhabitants per km^2	2021 – CBS Wijk- en buurtkaarten
Retail & Service Destination Density	R/S amenities per km^2	2020 – BBG
Sidewalk Density	Sidewalks per km^2	2019 –Basisregistratie Grootschalige Topografie (BGT)
Green (& blue) space Density	GSa per km^2	2020 – BBG Parks, public gardens, forest, graveyards. Daytime recreation, agricultural GS, dry/wet natural terrain, surface water
Street Connectivity	Intersections per km^2	2020 – TOP10 intersections
Noise	Average median decibel level per PC4	2020-2021– cumulative mixed (for all types of roads/ industry)from RIVM
Pollution PM10	Mircograms per m^3	2020 – RIVM, average outdoor pollutant
Pollution PM2.5	Mircograms per m^3	2020 – RIVM, average outdoor pollutant
Pollution NO2	Mircograms per m^3	2020 – RIVM, average outdoor pollutant

2.2 Statistical analysis

2.2.1 Neighborhood level (model 1)

With the goal of ascertaining the influence of the individual components of walkability to the walking behavior of Dutch residents, this study deemed regression analysis the most relevant statistical model to use. Linear regression involves the process of fitting data to a straight line. This allows for the creation of a slope that can be interpreted to give the influence of each variable. The magnitude of the slope pertains to the strength of the independent variables impact on the dependent variable. For the neighborhood level, the share of sustainable trips per neighborhood (PC4) was investigated against the walkability components. No sociodemographic variables were included at this level.

2.2.2 Individual level (model 2)

At the individual level, sociodemographic variables were included into the model, using the average distance of actively traveled trips per individual per day was used as the dependent variable; this decision is also supported by previous studies looking at sustainability and walking (Millward et al., 2013; Lam et al., 2022). The independent variables for this analysis were outlined in section [] , however not all variables were found to be significant. Table [] contains all the variables that were entered into the final model, with all being significant in explaining the average trip distance using active travel.

3. Results

3.1 Neighborhood level (model 1)

Before running the model, regression assumptions were checked. Appendix 2 contains the relevant figures from this analysis – no assumptions were violated and thus the regression was run. Table 2 contains the relevant descriptives for model 1, and table 3 contains the significant variables for said model.

Table 2: Descriptives for model 1

Name	Min	Max	Mean	Standard deviation
Share of sustainable trips (PC4)	0	1	.51	.24
Greenspace Density	.65	98.78	49.63	26.94
Retail/Service Density	0	47.28	5.95	5.70
Population Density	0.10	205.05	88.06	27.76

n=3287

Table 3: Significant coefficients for model 1

Variable	Beta	Standardized
Greenspace	-.001**	-.160
Retail/service density	.001*	.138
Population density	.002**	.049

* - <.05 sig , ** - <.001 sig

With an R2 of .100, this model explains 10% of the variance in the data. After entering all walkability components, only three showed significance: greenspace density, retail/service density, and population density. This is unsurprising considering the existing literature on these three metrics as being valuable to walking activity. Greenspace had the most significant impact on the share of sustainable trips with an unstandardized coefficient of -.001, this corresponds to a .1% decrease in the sustainable travel per km^2 increase in greenspace density at the PC4 level. Greenspace was the only significant variable with a negative relation, and had the biggest magnitude for the standardized coefficient of -.160. Similarly impactful, with a standardized beta of .138, was retail/service density. This variable had a positive relation of .001 (unstandardized), relating to an increase in the share of sustainable travel. Population density also had a positive impact on sustainable travel – yielding a beta of .002 (unstandardized) and .049 (standardized). This variable had a ⅓ of the impact on the share of sustainable travel when compared to greenspace density.

Additionally, in line with the regression assumptions, correlations between the significant variables were investigated. With a person's correlation coefficient of -.664 retail density and greenspace density are correlated but have not met the .8 threshold. For this reason, this result remains valid.

3.2 Individual level (model 2)

Again regression assumptions had to be checked before the model could run. Differently from the previous level, normality and heteroscedasticity were not apparent in the data; to account for this, the dependent variable (average distance in hectometers of sustainable trip from home) was log transformed. Appendix 3 contains the graphs for before and after this transformation. Following from this the model was run. Initially, 15 variables were entered into the model, however only seven were found to be significant. Table 4 contains the descriptives for each variable and table 5 contains the significant variables with the corresponding magnitude of their beta coefficients, in order of the power of their influence.

Table 4: Model 2 descriptives

Variable name	min	max	mean	Standard deviation
Log of average distance (hm) of sustainable trips	0	3.19	1.32	.50
Age	6	97	43.31	21.67
Gender	1	2	1.52	.5
Household	1	10	2.79	1.38
Household Prosperity	1	10	6.39	2.77
Greenspace	.65	97.79	31.87	18.89
Retail/service	0	47.28	5.95	5.70
NO2	5.20	27.99	15.60	4.34

n= 28295

Table 5: Model 2 significant coefficients [DV = log(avg. sustainable trip distance)]

Variable	beta	standardized
Age	.003	.110
Gender	-.074	-.074

hhwelvg	.012	.068
Retail/service	-.004	-.044
NO2	-.013	-.036
Greenspace	.001	.032
Household composition	-.006	-.018

R^2= .036

For this analysis the R2 was significantly lower, yielding an only 3.6% fit to the data. However, with this model, more variables reached the significance threshold. The influence of greenspace density had a positive effect in this model, but a similar magnitude. Control variables (household prosperity, age, gender) were the most influential in this model, however household composition was the least influential of all variables. Among the walkability components, retail/service density and NO2 were also found to be significant. Differently from the previous model, greenspace was the least influential of all walkability components. In terms of direction of influence, age, household prosperity, and greenspace had a positive effect. Household composition was significant but at the lowest threshold when compared to the other variables entered (p=.009), yet still far below the p=.05 threshold.

In this model, greenspace and retail density were the closest to correlation with a Person's coefficient of -.559. Yet still remained under the .8 threshold.

4. Discussion

4.1 Neighborhood level

On the level of PC4, this study was able to prove greenspace, retail/service, and population density all have a significant impact on the share of sustainable trips taken. With greenspace eliciting a negative influence on the share of sustainable trips, while population and retail/service density have a positive influence on the share of sustainable trips. The result concerning green space is surprising as supporting studies have found greenspace as positively influencing willingness to walk/travel sustainably. These findings, however, suggest that neighborhood green alone is not enough to motivate sustainable travel. However, important to consider with these results is the calculation of greenspace. Within this analysis greenspace density also included water features and arable land. Large areas of arable land create areas of land that are not easily walkable (because of the distance) and are not attractive for leisure strolls, forcing residents to rely on other unsustainable forms of travel for daily trips. This finding could suggest that the highly agricultural nature of the Netherlands current land use is a barrier to sustainable travel and should thus be deprioritize in future planning practices.

On the other hand, the significance and magnitude of population and retail/service density is unsurprising. As has been previously referenced, population density encourages walking. This study found that this influence was equivalent to a .2% increase in sustainable travel per inhabitant increase per km^2, this suggests that as cities rise in population and densities increase there could be greater sustainable travel. This is an optimistic result considering the relevance of rising populations within the city setting. In relation to policy implications, this findings suggests that the spatial planning of cities should value highrise/high density buildings over sprawling peripheral suburbs, to maintain high population density.

The finding in relation to retail/service density also corroborates the findings of previous studies. This study found that increasing retail density increases the share of sustainable travel, with a beta coefficient of .004 – correlating to a .4% increase of sustainable travel with added retail/service destination density. This finding provides evidence for the necessity of areas with high retail density in motivating sustainable travel.

In relation to the 15mC ideal, all of these findings provide quantitative evidence for it’s implementation. Following this model, a city with high population and retail density – but with limited expanses of greenspace – is a city that will be the most sustainable for travel. While Moreno et al. (2021) also advocates for green in cities, this study provides evidence that too much green could be potentially disadvantageous for sustainable travel and suggests that the benefits of greenspace could be scale dependent.

4.2 Individual level

The individual level of this analysis sought to enrich the PC4 findings by investigating the components that impact the distance in which an individual is willing to walk. This level only considers trips made using sustainable travel, and considers the logarithmic average distance traveled per trip (henceforth referred to as DV2). These results sought to further enrich the PC4 level model by determining which of the components (and at what magnitude) contribute to how far residents are willing to walk.

Unlike on the PC4 level, greenspace was found to have a positive influence. This suggests that increasing greenspace density will increase the distance residents are willing to travel – thus further supporting the necessity of green in cities. However, this component was the least influential of the walkability components. The most influential of walkability components was retail/service destination density; this corroborates the findings from the previous model. In this model, however, retail density has a negative impact on DV2 meaning that with increasing retail density the distance residents travel decreases. This follows from the lack of necessity to travel further because amenities (retail/service locations) are closer to you. Considering DV2 is measured as log distance, the beta coefficient of -.004 can be expressed as $e^{-.004}$ which is equivalent to ~1km decrease in average distance traveled when retail density is increased. This 1km follows inline with average walking distances.

The final, most surprising, significant walkability component was NO2 levels. NO2 is directly associated with the burning of fuel and is often in high concentrations in urban areas. This study found NO2 to have a negative impact on DV2, providing evidence for the reduction of car emissions positively contributing to resident's willingness to travel further. Considering the log transformation of DV2, this beta correlates with $e^{-.013}$ decrease in the distance resident walkers are willing to travel – this is similar in magnitude to retail density. However, it's important to note the different reasons for these two results. NO2 levels are the result of negative externalities from cars (and other fossil fuel burning sources), making this result direct evidence for these externalities negatively contributing towards increasing the distance of sustainable travel in cities. Whereas the results from retail density can be attributed to the lack of necessity to travel farther when you have greater amenities, providing greater evidence for the 15mC compact city concept.

The most impactful of the variables entered into model 2 were those associated with sociodemographic variables. This corroborates the substantial research surrounding how such variables impact an individual's ability to travel. Of these variables, age and gender were the most relevant predictors – with age having a positive influence and gender having a negative one. Considering the gender variable is coded as 1 for men and 2 for women this translates to men being more willing to walk than women. These findings have been well supported by previous studies that have a deeper focus on the societal context in which travel decisions occur, this study sought to focus on walkability components and thus included such variables to improve the model/control for these effects.

4.3 Sensitivity Analysis

Considering the debated definitions of a walkable neighborhood, this study also explored the impact of two different buffer sizes (350m and 1650m) on both models. Appendix 4 contains the results from this regression. There were no significant differences from the presented models in terms of variables or magnitude/direction of magnitude. However, interesting to note, is that with smaller buffer sizes the R^2 improved in both cases. Another consideration deemed important was the timing of the given datasets. During 2020, the COVID-19 pandemic occurred; such an event had an impact on travel patterns and individuals ability to travel. To explore the impact of this on the results, both models were also run using 2022 ODiN data. Appendix 5 contains the resulting tables. Again, these models did not differ significantly from those presented in this study.

4.4 Limitations + future directions

Due to time constraints, not all factors of walkability could be properly explored in the preceding analysis. For the future, the inclusion of sociodemographic variables in the PC4 level model would paint a more complete picture of motivations behind sustainable travel and could potentially increase the R^2. Additionally, car/driver license ownership were not considered. A major limitation within the data availability is the PC4 level detail of ODiN. While walkability components were available at the PC6 level, this could not be combined with ODiN data and thus these could not be used to deepen the analysis. Instead the corses PC4 level of the ODiN data prevailed. Following from this, to account for variation amongst different areas a geographically weighted regression model could be considered for the future. This model would allow for differing betas per different regions of the Netherlands. The final recommendation for future studies is to consider longitudinal data, although walkability components are far less subject to change as they are typically immovable infrastructure.

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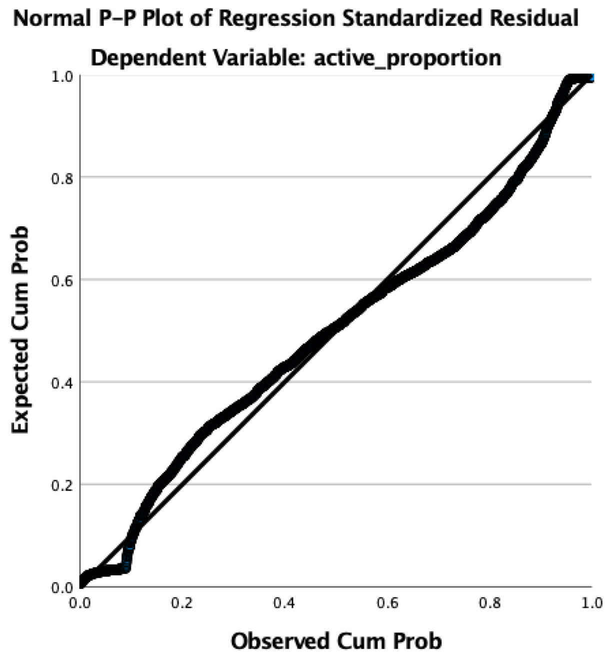
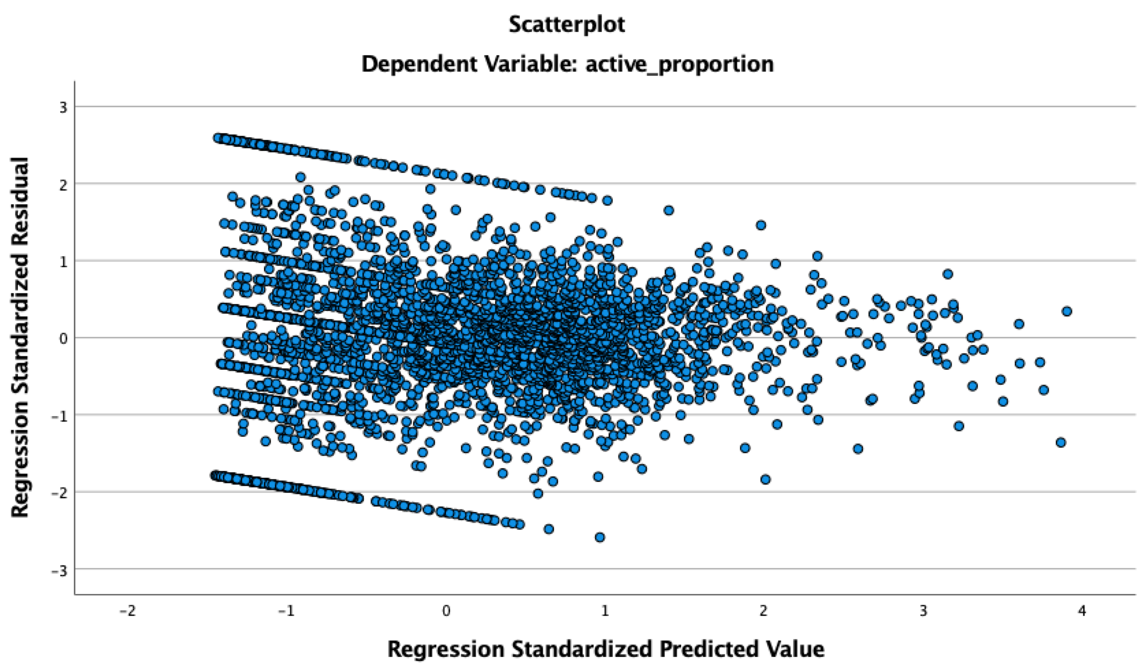
Appendix 1: Relevant ODiN variables

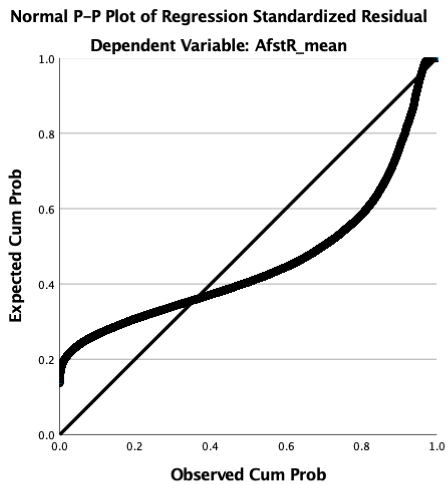
Variable name	**Code in documentation**	**Explanation**
Vertloc	1	Leaving location
KRvm	5/6	Mode of transport class
AfstR	Hectometres traveled	Necessary for DV calculation
WoPC	PC4	Home PC4
HHWelvg	1-10 in 10% groups	Household prosperity variable
HHpers	Number	Number of people in household
Leeftijd	Number	Age
Geslacht	1- male; 2 - female	Gender
AankPC	PC4	Arrival PC4

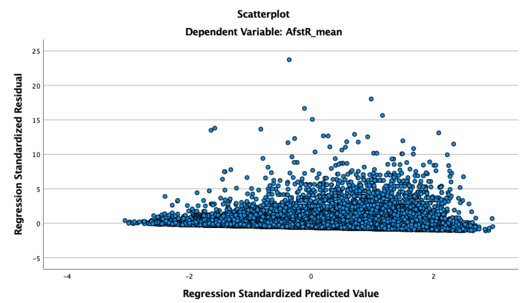
Appendix 2: Model 1 regression assumptions

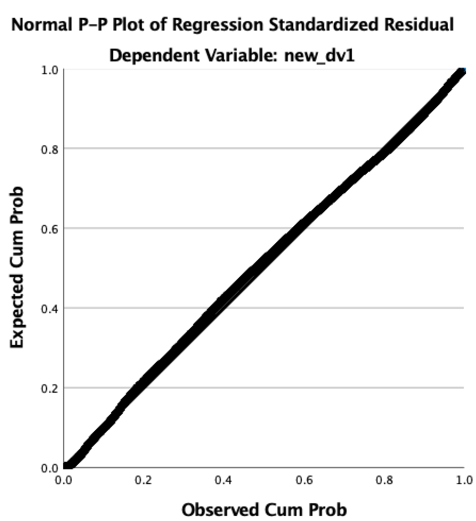


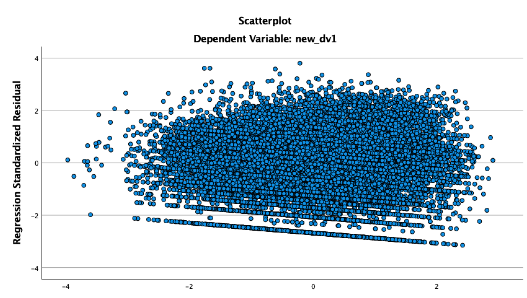


Appendix 3: Model 2 regression assumptions before and after transformation









Appendix 4: influence of buffers on Models 1 + 2

PC4 level	350m // R^2 = .100		1650m // R^2 = .099	
Variable	beta	standardized	beta	standardized
Greenspace	-.002**	-.162	-.001	-.118
Retail density	.002**	.046	.006	.088
Population density	.001**		.001	.123

Individual level	350m // R^2 = .037		1650m // R^2 = .036	
Variable	beta	standardized	beta	standardized
Greenspace density	.001**	.036	.001	.023
Retail density	-.003**	-.044	-.005	-.042

** - p<.001
(control variables and NO2 have no buffers)

Appendix 5: Influence of time on models 1 + 2

PC4 level 2022 -

Variable name	Beta	Standardized Beta
Greenspace density	-.001**	-.164
Population density	.001**	.135
Retail Density	.002*	.045

* - $p < .05$, ** - $p<.001$
$R^2 = .099$

Individual level 2022 -

variable	beta	Standardized beta
Greenspace	.001**	.034
NO2	-.014**	-.033
Retail density	-.004**	-.046
Gender	-.074**	-.073
Age	.003**	.110
Household comp	-.006**	-.018
Household prosperity	.013**	.069

** - $p <.001$, $R^2 = .036$