

## Factors influencing subjective walkability: Results from built environment audit data

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**Abstract:** Subjective walkability is a measure of the perceived friendliness of walking in an area. Though subjective walkability is less commonly assessed than objective measurements, the latter often fail to reflect the experience of walking. This study aims to better understand subjective walkability and how it varies between travel and leisure walking by investigating its relationship with the built environment and land-use characteristics. Data is collected from 848 street segments in Montreal, Canada, using the MAPS-mini audit tool, external measurements including Walkscore as well as synthetic subjective walkability scores. Mixed effect multilevel models are then generated using travel and leisure subjective walkability scores as dependent variables and built environment features as independent variables. Statistically significant positive predictors of perceived walkability differ between walking for travel and walking for leisure. Walkscore is found to have a weak but significant effect on perceived walkability for travel but no effect at all for leisure. Based on this research, a multi-scalar approach both at the street and neighborhood level making use of a combination of objective and subjective walkability measures should be employed to study predictors of walking behavior. Lastly, distinctions of walking behaviors based on trip purpose should be integrated in future research.

**Keywords:** Walkability, subjective walkability, audit, built environment

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## 1 Introduction

### 1.1 Conceptual framing

The health and environmental benefits of increased levels of walking are clear and have received increased attention in many fields over the past two decades (Andrews et al., 2012; Lee & Buchner, 2008; Tobin et al., 2022). While a large body of literature has been dedicated to studying the determinants

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of walking behaviours, debates remain about how to properly define and conceptualise “walkability” (Andrews et al., 2012; Tobin et al., 2022). Indeed, walkability definitions and frameworks vary widely between researchers and this will often impact the elements of the built and social environments which are considered and the measures used to assess them (Shashank & Schuurman, 2019). On a broader scale, walkability can be conceptualized as a sub-component of Active Living Environments (ALEs) which focuses specifically on the impact of the built and social environment on walking behaviors (Tobin et al., 2022). Walking behaviors can be separated into either walking for travel, also referred to as utilitarian or purposive walking which represent walking to a fix destination (i.e., commuting, running errands or going to any pre-determined location by walking), and walking for leisure, also referred to as recreational or discursive walking, which represent walking without going to a set destination (Hsieh & Chuang, 2021). Such conceptual distinctions are important as previous research has established that determinants of both travel and leisure walking vary with land-use diversity being relevant for walking for travel while aesthetics and walking facilities being more relevant for leisure walking (Boarnet et al., 2011; Inoue et al., 2010; Inoue et al., 2011). For the sake of consistency, we will be using walking for travel and walking for leisure to refer to the two types of walking behaviors for the rest of this paper.

Like walking behaviours, the concept of walkability can also be divided into two components: meso-scale walkability which primarily – but not exclusively – centers around the ease of reaching destinations and micro-scale walkability which focuses predominantly on the built and social environment features that pedestrians directly interact with while walking. Walkability can also be aggregated at the macro-scale for a neighborhood or city level from micro or meso-scale features. One of the foundational framework used in walkability research, the 3 Ds (diversity of land use, residential density, and design of the streets connectivity) developed by Cervero and Kockelman in 1997 (Cervero & Kockelman, 1997), primarily focuses on macro-scale features of walkability. Expansions of this framework integrated destination accessibility, distance to transit (Ewing & Cervero, 2001; Ewing et al., 2009) as well as demand management and demographics (Ewing & Cervero, 2010) which allowed for a more complex understanding of walking behaviours. The integration of demographics, while not a characteristic of the walking environment, points out to an integration of notions of equity and differential interactions with the built environment based on individual characteristics (e.g., age, gender, income). This latter point is important as it allows for a distinction between objective walkability measurements – which assess the built and social environment independently of the identity and perceptions of pedestrians – and subjective walkability measurements – which integrates the intermediate factor of pedestrians’ perceptions of the built and social environment to understand walking behaviours. Subjective preferences behind walking behaviours have been shown to be important mechanisms through which the built environment impacts individuals’ walking behaviors (Arvidsson et al., 2012; Consoli et al., 2020; Herbolsheimer et al., 2020; Jun & Hur, 2015; Manaugh & El-Geneidy, 2013; Nyunt et al., 2015). Past research has highlighted that characteristics of the walking environment can influence avoidance or approach behaviors through the primary emotional and psychological reactions of pedestrians which are inherently dependant on individual preferences and characteristics (Ortiz-Ramirez et al., 2021).

Lastly, a conceptual distinction must also be made on what measurement of walking behavior should be considered to establish the priority of a geographical area to receive interventions to improve walkability. Indeed, when aiming to provide walkability improvements, one can either focus on improving walking rates or walking experience. Improving walking rates means that areas of focus will be the ones where walking is less prevalent, which are likely going to be wealthier suburban areas. On the opposite, focusing on improving walking experience will shift the focus on areas with significant existing levels of walking but poor perceived walkability by pedestrians (i.e., captive pedestrians), which are more likely to be areas with lower incomes (Manaugh & El-Geneidy, 2011).

## 1.2 Methods in walkability research

The latest systematic review of the methods used in the field of walkability separates the built environment factors considered into six categories: land use, accessibility, street connectivity, pedestrian facility and comfort, safety and security, as well as streetscape design (Fonseca et al., 2021). The first three categories – land use, accessibility and street connectivity – have been mostly used at the meso-scale while the latter three – pedestrian facility and comfort, safety and security as well as streetscape design – have been mainly used to evaluate walkability at the micro-scale. While these categories are universally applicable, their relative importance will vary through time and space (Berry et al., 2017) as well as from one researcher to another (Shashank & Schuurman, 2019). That being said, there are still predominant measurements used in the field of walkability research which are for the most part both objective as well as meso-scale (Fonseca et al., 2021; Hajna et al., 2015). These include residential, population, amenities, and intersection densities as well as Retail Floor Area (RFA), entropy measures quantifying land-use diversity at a meso-scale and distance to amenities (Fonseca et al., 2021). These measures have been used in combination with one another to form composite indices such as Walkscore, a popular proprietary tool designed for real-estate which integrate distance to amenities with intersection density to quantify access to opportunities in an area on a scale of 0 to 100 (Carr et al., 2010). Another similar composite walkability index is Frank's walkability index which integrates intersection and residential density along with entropy measures of land-use mix and RFA (Frank et al., 2010). While these built environment measures have been demonstrated to have an impact on walkability, they have also been shown to be limited in their ability to accurately predict walking rates (Consoli et al., 2020; Hajna et al., 2013; Herbolzheimer et al., 2020; Herrmann et al., 2017; Nyunt et al., 2015; Shashank & Schuurman, 2019; Tuckel & Milczarski, 2015) and even more to capture the subjective experience of walking in diverse settings (Battista & Manaugh, 2017; Gebel et al., 2009; Koohsari et al., 2021; Tuckel & Milczarski, 2015; Yang & Diez-Roux, 2017). This latter reality is particularly true when looking separately at travel and leisure walkability – a distinction that is rarely made when using such walkability measurement (Wasfi et al., 2017). These issues can be partly attributed to the lack of consideration of micro-scale characteristics such as sidewalk presence or maintenance as well as tree cover (Herrmann et al., 2017).

To address such shortcomings, a smaller portion of the walkability scholarship has simultaneously been dedicated to built environment factors mostly assessed at the micro-scale (i.e., pedestrian facility and comfort, safety and security as well as streetscape design) and which have been mainly used to evaluate walking experience (Fonseca et al., 2021). One of the most common tools used to assess these factors objectively have been audits, which are observational surveys of the built and social environment. Audits, through their focus on micro-scale features, have the advantage of providing more detailed portraits of the built environment which can be better used to predict walking experience at the street level. Amongst the most popular audit tools used are the Irvine Minnesota Inventory (Day et al., 2006) and the MAPS audit tool (Cain et al., 2015; Sallis et al., 2015). While such tools present a more accurate portrait of the built environment, they remain limited in their ability to predict actual walking rates, particularly for leisure walking (Boarnet et al., 2011; Sallis et al., 2015). Nevertheless, the added level of detail they provide as well as their focus on micro-scale environments makes them more suitable to the evaluation of the effect of the built environment on walking experiences than the previously discussed measures used to assess the ease of reaching destinations (Blecic et al., 2016; Brown & Jensen, 2020).

Lastly, in contrast to the larger body of research that has made use of objective measurements of the built environment, subjective walkability has been less often integrated in past studies assessing the relationship between built environment features and walking behaviors (Fonseca et al., 2021). Indeed, while subjective preferences behind walking behaviours have been proven to be important mechanisms

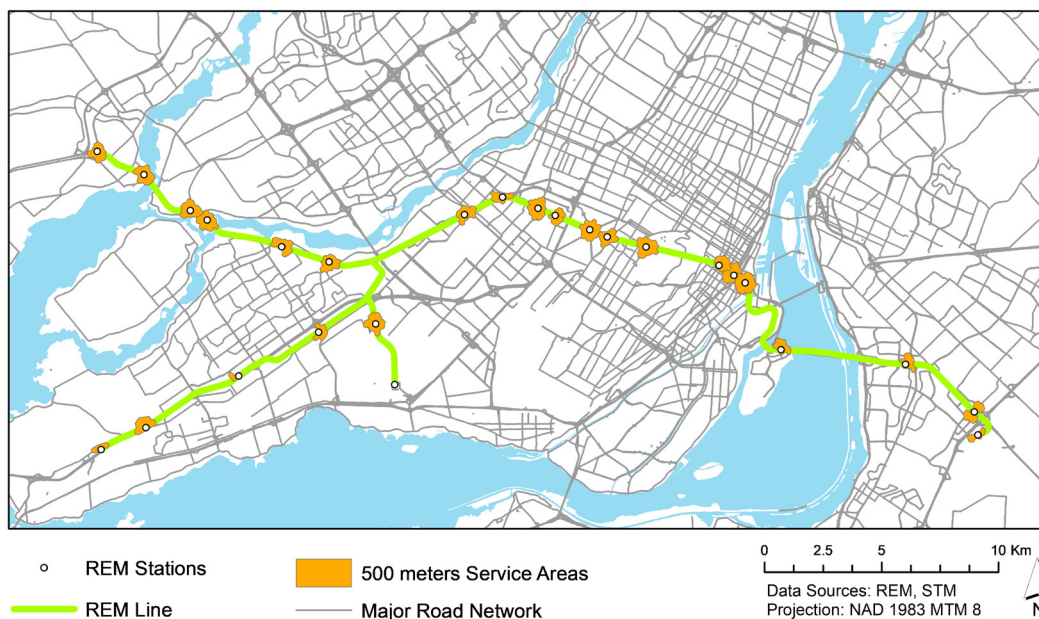
through which the built environment impacts individuals (Arvidsson et al., 2012; Consoli et al., 2020; Herbolzheimer et al., 2020; Jun & Hur, 2015; Manaugh & El-Geneidy, 2013; Nyunt et al., 2015), their consideration remains limited in research analyzing the impact of the built environment on walkability (Bohte et al., 2009; Fonseca et al., 2021). The current scholarship can be divided along two factors, whether it is qualitative or quantitative as well as the spatial scale of the unit of analysis. With the quantitative research done on subjective walkability, the most common approach has been to assess the perceived accessibility and ease of walking at a neighborhood level (Alidoust et al., 2018; Bodeker, 2018; Hanák et al., 2015; Hanibuchi et al., 2015) with tools such as the Neighborhood Environment Walkability Scale (NEWS) (Brown & Jensen, 2020; Jensen et al., 2017; Notthoff & Carstensen, 2017). A limited body of literature has made use of quantitative methods to quantify the perceived pedestrian friendliness at the micro-scale level (Arellana et al., 2020; Fonseca et al., 2021) with synthetic subjective walkability scores and machine learning evaluation built upon such synthetic scores being the primary tools used (Blecic et al., 2018; Blecic et al., 2019; Yameqani & Alesheikh, 2019). On the qualitative side, research has been more spread out with past research making use of walking interviews (Alidoust et al., 2018; Herrmann-Lunecke et al., 2021) and mental mapping (Bodeker, 2018) as well as conducting focus groups to build decision processes relying on subjective walkability measures to better inform urban policy (Fancello et al., 2020; Moura et al., 2017). Overall, potential predictors of perceived walkability can be categorized according to their level of objectivity (Battista & Manaugh, 2018; Blecic et al., 2016) with the presence of sidewalks being on the objective end, cleanliness or pollution in the middle and psychological effects of the environment on the subjective end. Significant street-level predictors found in previous research include the presence of sidewalks, sidewalk width, streetlights, and shading (Blecic et al., 2016; Jensen et al., 2017). The impact of specific predictors on subjective walkability has also been shown to vary within populations according to socio-demographic conditions (Adkins et al., 2019; Manaugh & El-Geneidy, 2011; Moura et al., 2017; Shashank & Schuurman, 2019).

Building upon previous research, this paper aims to consider a combination of built-environment factors both at the meso-scale and micro-scale to predict the experience of walking on a street as quantified through synthetic subjective walkability scores. Our paper expands on past research by differentiating between travel and leisure walking, integrating a larger sample, and accounting for raters' effect on subjective scores through mixed effects multilevel modelling in which raters are added as a second level. Highlighting the best predictors of subjective walkability and providing a realistic application of currently used methods to quantify walking experience will allow us to highlight better leverage points for improving the experience of walking, which many practitioners are aiming for.

## **2 Data and methods**

### **2.1 Built environment data**

The data for this study were collected as part of the first wave of a built environment audit conducted around the future stations of the upcoming Réseau Express Métropolitain (REM), a new light-rail train (LRT) system in Montreal, Canada (Daley et al., 2022). Areas sampled, which were within a 500-meter service area of a new station of the REM, are displayed in Figure 1. In total, 848 street segments were audited using an adapted version of the MAPS-mini audit tool (Daley et al., 2022), which has been validated in previous research (Sallis et al., 2015). Data collection took place on weekdays between 9:00PM and 5:00PM and required a total of 240 hours from 14 auditors which were all trained prior to the audit on the collection of the objective data. Auxiliary data such as Walkscore, speed limits, and population densities were also integrated in the data set used (Daley et al., 2022).



**Figure 1.** Service areas audited around the REM stations

## 2.2 Subjective walkability scores

As previously stated, the focus of this study is the walking experience component of walkability which framed the creation of the synthetic subjective walkability scores collected (described in Table 1). The distinction made between the two scores collected was explained to the raters as if they were to walk on the street segment to get to a particular destination (i.e., walking for travel) versus if they were to walk on it for a non-purposive walk (i.e., walking for leisure). Raters were given no additional directions on what to consider when scoring a segment to ensure that they would be scoring based on their own perception. All segments were scored in situ by raters.

**Table 1.** Synthetic subjective walkability scores

Question	Scale
On a scale of 1-10, how walkable would you rate this segment for travel?	1 (completely unwalkable) – 10 (perfectly walkable)
On a scale of 1-10, how walkable would you rate this segment for leisure?	1 (completely unwalkable) – 10 (perfectly walkable)

A first wave of data was collected in Summer 2021 at the same time as the built environment audit for all 848 segments by 12 of the 14 auditors. To control for the potential influence of the audit process on the subjective scoring, a second wave of subjective data was collected in Fall 2021 by 5 independent raters that had not been involved at any point in the audit process. In total, 314 segments were scored again during this second wave. The collected scores were used to replace the scores originating from the first wave for the given 314 segments thus maintaining only one subjective score entry per segment for each of the 848 segments for which built environment data had been collected.

Overall, all 17 raters were less than 40 years old; their average age was 25.4 years. Eleven identified as men and six as women. Eight raters grew up in an urban setting, seven grew up in a suburban setting and the remaining two were from rural areas. Heterogeneity was also present in nationality between

the raters. Conversely, there was homogeneity amongst raters in education levels as all had completed or were completing a university level degree. Lastly, it is important to note that all auditors were either working for McGill University's School of Urban planning or were students in the department of Geography with experience in walkability research. This decision was made based on resources available during the completion of the audit process. Implications from this decision on the results will be covered in the discussion section.

### 2.3 Multilevel regression models

Multilevel mixed effects models are used to estimate the factors associated with synthetic subjective walkability scores at the street level, the main exposure of interest (independent variables) are the physical and functional elements of the built environment identified through the audit or collected as auxiliary data. Audited segments are nested within raters (17 raters) to isolate the bias that could arise from the personal characteristics between raters and from the simultaneous collection of the built environment data (i.e., isolate the inter-rater variability in the subjective scores). Variability between raters' socio-demographic in term of gender, childhood environment and other socio-demographic are therefore captured together through the multilevel approach.

**Table 2.** Descriptive statistics of variables included in the statistic model

Variables	Mean	St. Dev	Min	Max
<b>Dependent variables</b>				
Subjective walkability score for travel	6.05	2.22	1	10
Subjective walkability score for leisure	5.73	2.3	1	10
<b>Independent Variables</b>				
<b>Land use</b>				
Main Land use				
<i>Residential</i>	0.53	0.50	0	1
<i>Vacant / Industrial</i>	0.06	0.24	0	1
<i>Commercial</i>	0.22	0.42	0	1
<i>Mixed</i>	0.19	0.39	0	1
Parks (Binary)	0.13	0.37	0	2
<i>No (0)</i>	0.88	0.33	0	1
<i>Yes (1)</i>	0.12	0.33	0	1
Parking lots (Binary)				
<i>No (0)</i>	0.84	0.37	0	1
<i>Yes (1)</i>	0.16	0.37	0	1
Transit Stops (Binary)				
<i>No (0)</i>	0.75	0.43	0	1
<i>Yes (1)</i>	0.25	0.43	0	1
<b>Accessibility</b>				
Walkscore (normalized on 10)	6.18	2.73	0.4	9.9
<b>Street Connectivity</b>				
Cul-de-sac (Binary)				

Variables	Mean	St. Dev	Min	Max
<i>No (0)</i>	0.95	0.21	0	1
<i>Yes (1)</i>	0.05	0.21	0	1
<b>Safety and security</b>				
Pedestrian light signal				
<i>None</i>	0.67	0.47	0	1
<i>One intersection</i>	0.20	0.40	0	1
<i>Two intersections</i>	0.13	0.34	0	1
Speed Limit [10km/h]	4.00	0.72	0	5
Streetlights				
<i>None</i>	0.07	0.25	0	1
<i>Some</i>	0.77	0.42	0	1
<i>Ample</i>	0.16	0.36	0	1
<b>Pedestrian facility and comfort</b>				
Benches (Binary)				
<i>No (0)</i>	0.75	0.43	0	1
<i>Yes (1)</i>	0.25	0.43	0	1
Sidewalk buffer				
<i>No</i>	0.73	0.44	0	1
<i>One side</i>	0.10	0.29	0	1
<i>Two sides</i>	0.17	0.38	0	1
Sidewalk maintenance (Binary)				
<i>Any poorly maintained sections (0)</i>	0.36	0.48	0	1
<i>No poorly maintained sections (1)</i>	0.64	0.48	0	1
Sidewalk tree cover				
<i>0 - 25 % - no sidewalk</i>	0.69	0.46	0	1
<i>26 - 75%</i>	0.26	0.44	0	1
<i>76 - 100%</i>	0.05	0.22	0	1
<b>Streetscape design</b>				
Building maintenance (Binary)				
<i>0 - 99% (0)</i>	0.33	0.47	0	1
<i>100% (1)</i>	0.67	0.47	0	1

All built-environment components collected from the audit process (Daley et al., 2022) were used as independent variables in the model in addition to Walkscore and other auxiliary data (e.g., speed limits, population density, median household income). Variation inflation factors (VIF) were calculated for both models with all independent variables with a factor above five being excluded from the model to avoid collinearity (Akinwande et al., 2015). Concurrently, independent variables were individually tested for their significance in predicting the response variables (i.e., synthetic subjective walkability scores for travel and leisure) independently for both models. Non-significant variable that did not contribute to improve the prediction power of a given model were removed while those that did were kept as these acts as suppressor variables (i.e., they capture some level of variability that could otherwise be wrongly attributed to other variables) (Akinwande et al., 2015). Both models were also tested separately for the influence of a rater having also acted as an auditor through the integration of a dummy variable for auditors. Table 2 displays descriptive statistics for fixed effects variables that were included in the final

models. It should be noted that both dependent variables were normally distributed and have similar mean and standard deviation.

To assess significance level of the models, the Bonferroni correction was applied meaning that the significance level was now the initial value ( $\alpha = 0.05$ ) divided by the number of variables included. For the travel model, this meant that the corrected significance level was 0.005 (10 variables) while it was 0.0045 (11 variables) for the model for leisure walking scores.

#### 2.4 Walkscore correlation with subjective walkability

Simple regressions were conducted to explore the relationship between Walkscore and the synthetic subjective walkability scores collected. In addition to that, specific segments were extracted to act as further examples to explain the results observed.

### 3 Results

The statistical model predicting subjective walkability for travel yielded a conditional  $R^2$  of 0.701 while the model predicting subjective leisure walkability obtained a conditional  $R^2$  value of 0.578 (Table 3) suggesting a high and moderate explanatory power respectively compared to previous studies in the literature (Blecic et al., 2016). The lower conditional  $R^2$  obtained for the leisure walking model suggests that while it predicts subjective scores for leisure walking rather well, there remain potential predictors that were not included in the data collected from the audit or from external sources. This is true for subjective walkability scores for travel as well, but to a lesser extent. A notable variance was also observed in the significance and magnitude of effect of some predictors between travel and leisure walking which is coherent with previous research (Tuckel & Milczarski, 2015).

The Intraclass correlation coefficient (ICC) measures the proportion of unexplained variance in the error term that is related to between class variation (i.e., between raters' variance ( $\tau_{00}$ )) from the total variance of the error term (i.e., the residual  $\sigma^2$ ). The ICC suggests that 63% of the unexplained variance in the error term is related to between raters' variability in the walking for travel model. Similarly, for leisure walking subjective scores, 44% of the variance in the error term is explained through between raters' variability. The high ICC values confirm the importance of using a multi-level modeling approach. It also further highlights the variability of perceived walkability between individuals. Lastly, it should be noted that the integration of the auditor variable did not have any incidence on the models as it was neither significant nor did it change the significance or magnitude of the effect of other independent variables. The fact that all raters had knowledge of urban planning or walkability related literature could have also muted the potential bias from the audit process on their subjective walkability scores.

#### 3.1 Land use

Land-use variables tested in the models included main land use, the presence of parks, the presence of parking lots, the presence of transit stops as well as population density and residential density. However, only the first four had significant effects and solely for the model predicting leisure walking scores.

**Table 3.** Statistical Models Predicting Subjective Scores from micro-scale street characteristics



<i>Predictors</i>	<b>Subjective Score for Travel</b>			<b>Subjective Score for Leisure</b>		
	<i>Estimates</i>	<i>CI</i>	<i>p</i>	<i>Estimates</i>	<i>CI</i>	<i>p</i>
(Intercept)	4.75	3.54 – 5.96	<0.001	6.48	5.33 – 7.55	<0.001
<b>Land Use</b>						
Main land use (Reference: Residential)						
<i>Vacant / Industrial</i>				-1.31	-1.88 – -0.74	<0.001
<i>Commercial</i>				-0.81	-1.20 – -0.43	<0.001
<i>Mixed</i>				-0.47	-0.84 – -0.10	0.012
Parks				0.83	0.47 – 1.19	<0.001
Parking lots				-0.65	-0.98 – -0.32	<0.001
Transit stops				-0.64	-0.95 – -0.32	<0.001
<b>Accessibility</b>						
Walkscore	0.16	0.10 – 0.21	<0.001			
<b>Street connectivity</b>						
Cul-de-sac	-0.99	-1.47 – -0.50	<0.001			
<b>Safety and security</b>						
Pedestrian light signal (Reference: None)						
<i>One Intersection</i>	-0.37	-0.66 – -0.07	0.014			
<i>Two Intersections</i>	-0.01	-0.41 – -0.39	0.971			
Speed limit	-0.33	-0.49 – -0.18	<0.001	-0.56	-0.74 – -0.38	<0.001
Street lighting (Reference: None)						
<i>Some</i>	0.47	0.07 – 0.87	0.020	0.57	0.12 – 1.02	0.014
<i>Ample</i>	0.85	0.35 – 1.35	0.001	1.23	0.67 – 1.79	<0.001
<b>Pedestrian facility and comfort</b>						
<i>Benches</i>	0.47	0.22 – 0.73	<0.001	0.61	0.29 – 0.94	<0.001
Sidewalk buffer (Reference: None)						
<i>One side</i>	0.65	0.28 – 1.03	0.001	0.57	0.14 – 1.00	0.009
<i>Two sides</i>	0.89	0.54 – 1.24	<0.001	0.81	0.42 – 1.20	<0.001
Sidewalk maintenance	0.72	0.48 – 0.96	<0.001	0.53	0.27 – 0.80	<0.001
Sidewalk tree cover (Reference: 0-25%)						
<i>26 - 75%</i>	0.58	0.34 – 0.81	<0.001	0.94	0.66 – 1.22	<0.001
<i>76 - 100%</i>	0.76	0.29 – 1.23	0.002	1.29	0.75 – 1.83	<0.001
<b>Streetscape design</b>						
Building Maintenance	0.46	0.23 – 0.70	<0.001	0.49	0.22 – 0.75	<0.001
<b>Random Effects</b>						
$\sigma^2$ (within variance)	2.03	2.61				
$\tau_{00}$ (Between raters' variance)	3.44 <sub>Rater</sub>	2.02 <sub>Rater</sub>				
Intraclass Correlation	0.63	0.44				
N	17 <sub>Rater</sub>	17 <sub>Rater</sub>				
Observations	848	848				
Marginal R <sup>2</sup> / Conditional R <sup>2</sup>	0.195 / 0.701	0.250 / 0.577				

To start, a segment being characterized as vacant or industrial led to a significant decrease in leisure scores of 1.31 points compared to residential ones. This effect was expected as segments with such land use are generally characterised by heavy truck traffic, poor aesthetics as well as noise and air pollution

all of which discourage walking behavior (Herrmann-Lunecke et al., 2021). The other categorization of main land use of a segment that had a significant negative effect on leisure scores was commercial which led to a decrease of 0.81 points compared to residential. This effect was also expected as predominantly commercial street segments can be categorized by heavy traffic across modes which has been shown in previous research to discourage leisure walking (Herrmann-Lunecke et al., 2021). Lastly for the main land-use variable, no significant effect was observed for segment categorized as mixed according to the significance levels derived from the Bonferroni correction. Such null and negative effects of land-use mixity and destination-rich areas respectively are in accordance with previous research that observed similar results on leisure walking, for women in particular (Inoue et al., 2010). Still, the result for mixed land use could also be partly attributable to opposite effects pertaining to the level of mixity. Indeed, mixed segments were categorized as such in the audit data collected when there were both residential land use and another destination type of land use (i.e., commercial, institutional, industrial) on a segment without any of the land uses being noticeably dominant. Given that, a further breakdown of the characteristics pertaining to the level of mixity would be necessary to further evaluate this relationship.

Moving on to specific land uses, having at least one park on a segment had a significant positive impact on leisure scores with 0.83 points while keeping all other variables constant at their means. This effect is coherent with recent research on the influence of greenspaces on walkability (Shuvo et al., 2021). Greenspaces provide a change in the developed urban scenery which can be associated with increased perceived well-being (Herrmann-Lunecke et al., 2021). Additionally, parks provide opportunities for leisure activities making them appealing for leisure walking. Next, the presence of ground level uncovered parking lots had a negative and statistically significant effect on leisure walking scores with segments that had at least one scoring 0.65 points less than those that did not have any. This coincides with previous research that found a similar correlation between the presence of parking and walking but in the context of walking for travel, as leisure walking was not considered (Boarnet et al., 2011). These effects can be explained by the functional disruptions that parking lots entries create for walking, their aesthetics as well as the lack of destinations of segments with numerous empty lots. Lastly, the presence of transit stops was also significantly associated with a decrease in leisure walking scores of 0.64 points. This finding was not expected as previous research has not found any such link and the direct mechanism of explanation is not evident. Still, the main plausible explanation for this finding is that the presence of a transit stop is indicative of a street with a busier traffic flow – an element that has previously been linked with lower perceptions of walkability (Herrmann-Lunecke et al., 2021).

### 3.2 Accessibility

The only accessibility variable tested in the model was Walkscore which only had a significant effect on subjective walking for travel scores with an increase in 0.16 points for every increase of 10 in Walkscore. The lack of effect on leisure walking scores was expected as per definition leisure walking is discursive meaning that pedestrians are not walking to a specific destination and as such having access to destinations – which is what Walkscore quantifies – is likely not important. Such differential results in destination diversity between walking for travel and walking for leisure were also observed in past research (Inoue et al., 2010). Further analysis was conducted to explore the relationship between Walkscore and subjective walkability. A weak correlation for walking for travel ( $R^2 = 0.1368$ ) was observed while no correlation was observed for leisure scores ( $R^2 = 0.0136$ ). To explore this, segments with mismatched Walkscore and subjective walkability scores (i.e., when the scores have opposite values) are presented in Figure 2.



**Figure 2.** Outlier segments with subjective scores mis-matched to their Walkscore

Figure 2 displays pictures of streets visited and scored by raters that exemplify the limitation of areal metrics like Walkscore in predicting walking experience at a micro-scale. Indeed, it shows that is plausible to have segments with poor perceived walkability in objectively highly walkable areas overall area objectively (e.g., segments #GBL110, CS53) or, on the opposite, segments being given high perceived walkability scores that are located in poorly accessible areas (e.g., segment # IDS4, EM15). This further emphasizes that Walkscore – which is an areal metric that assesses access to opportunities through walking – cannot on its own account for perceived walkability, especially for leisure walking for which it is not accurate at all. This coincides with previous research that attributed similar discordances between Walkscore and walking rates to the lack of consideration for micro-scale elements such as sidewalks characteristics and tree cover (Herrmann et al., 2017).

### 3.3 Street connectivity

The only street connectivity indicator tested – cul-de-sacs – had a significant impact only on the model for travel walking scores for which it led to a decrease of 0.99 points. This finding differs from previous research analyzing walking behaviours and physical activity for travel (Boarnet et al., 2011). Still, street connectivity and the possibility to employ a street segment to go to the desired destination is a credible pathway to explain the effect observed on walking for travel. It should be noted that the homogeneity of the auditors used in this study might be reflected here. Indeed, since all auditors were working for the department of urban planning or had research experience on walkability, it is plausible that they would have been more sensitive to larger scale elements such as street connectivity when scoring each segment.

### 3.4 Safety and security

Speed limit had a statistically significant effect on both subjective walkability models as it decreased travel scores by 0.33 points and leisure scores 0.56 points per added 10km/h while keeping all other variables constant at their mean. This result aligns with previous research predicting walking behaviour using audit measures (Boarnet et al., 2011). The underlying mechanisms behind the correlation rely on the decrease of safety that comes with increased traffic speed (Suarez-Balcazar et al., 2020). Additionally, routes with higher speed limits will also tend to have denser traffic which lead to increase air and noise pollution levels, both of which have been associated with (Herrmann-Lunecke et al., 2021). The next safety variable – street lighting – only had a significant impact on both models when in ample presence compared to none with an increase of 0.85 and 1.23 points for travel and leisure scores respectively. This finding aligns with previous research (Blecic et al., 2016) and it can be explained by the increased feeling of safety that proper street lighting creates (Davoudian & Mansouri, 2016). It should be noted that the relative importance of streetlighting might vary based on the time of day, an element that was not captured in the audit process as all data was collected during the day. Lastly, the presence of pedestrian light signals did not present any significant effect in either model but, as it led to an increase in the predictability of the travel model, it was kept as a suppressor variable.

### 3.5 Pedestrian facility and comfort

The presence of benches on a street segment had a significant effect in both models as it led to an increase of 0.47 points in travel scores and 0.61 points in leisure scores compared to segments without any benches. This finding is in agreement with prior research and was expected as benches provide opportunities to rest during a walking trip (Blecic et al., 2016). With this in mind, the smaller effect on travel score is also coherent as walking of travel being purposive, stopping to sit on a bench is less likely than when walking for leisure in which no set destination has been established before the start of the trip. The relative importance of this finding might once again vary between different social groups; for example, seniors and people suffering from a disability that limits their mobility are likely to stop more often during a walking trip.

Moving on to sidewalk characteristics, the presence of sidewalk buffers and the maintenance of the sidewalk both had significant effects in both models. Indeed, one-sided sidewalk buffers led to a significant increase of 0.65 points in travel scores and 0.57 in leisure scores compared to no buffers at all while having buffers on both sides of the street led to an increase of 0.89 and 0.78 points for travel and leisure walking scores respectively. This significant effect is coherent with previous research (Blecic et al., 2016; Boarnet et al., 2011) as buffers provide a separation both through added distance but also through added objects (e.g., streetlights, trees) that create an increased feeling of safety from traffic (Herrmann-Lunecke et al., 2021). The impact of a sidewalk buffer will differ between a calm residential street with a low-speed limit (i.e., 30km/h) and a busier arterial road with higher speed limit (i.e., 50km/h). While the former could still be pleasant and feel safe with a narrow sidewalk to walk on, the latter will provide an increasingly stressful experience that could likely lead to pedestrian avoidance. Next, sidewalk maintenance also had a statistically significant effect on both travel and leisure scores with an increase of 0.72 points and 0.53 points respectively for segments that had no deteriorated parts of the sidewalk compared to those that did. This finding differs from previous research that found no impact on subjective walking scores (Blecic et al., 2016) while it aligns with research that worked on predicting physical activity levels from objectively-measured qualities using built environment audits (Boarnet et al., 2011) as well as past qualitative research (Bohte et al., 2009). The main mechanism to explain this finding is that well-

maintained sidewalks provide a safer and more pleasant travelling environment than those with visible cracks and holes. Such effects are likely to be more important in demographics such as elderly adults and people with mobility impairments (Herrmann-Lunecke et al., 2021) which were not captured in the rater population used for this study meaning that the strength of the effect measured in the models might be lower than that of the population as a whole.

Lastly, walkway tree cover was also a statistically significant predictor of both scores with 26 – 75% cover leading to an increase of 0.58 and 0.94 points and 76 – 100% cover leading to an increase of 0.76 and 1.26 points compared to a tree cover of 0 – 25% for travel and leisure subjective scores respectively. This finding is coherent with past research predicting subjective walkability (Blecic et al., 2016) as well as assessing mediators of the relationship between socio-economic status and walking for travel (Cerin et al., 2009), but it differs from research that predicted walking behaviour with built environment characteristics (Boarnet et al., 2011). Discrepancies between results observed here and those of previous research using objective walkability measurements might be extrapolated as a reflection of captive pedestrians that do not have a choice to walk on routes they do not perceive as very walkable for travel. Recent research contrasting greenness and walkability in a large metropolitan context established that areas are rarely both green and objectively walkable, with suburban areas being often greener but less walkable and urban areas being less green but more walkable (Shuvo et al., 2021).

### **3.6 Streetscape design**

The only streetscape design element that had a significant outcome in the models was building maintenance with street segments having solely well-maintained buildings having scores 0.46 points and 0.49 points higher for walking for travel and leisure respectively. This finding differs recent literature suggesting building aesthetics are not important predictors of walking for travel (Boarnet et al., 2011). The potential pathway of explanation behind this finding might be linked to poorly maintained buildings being associated with a reduced feeling of security – likely through associations with criminality – or building in construction being associated with heightened levels of stress likely from the repairs being conducted (Herrmann-Lunecke et al., 2021).

## **4 Discussion**

Overall, this study highlights differential results between determinants of perceived walkability for walking for travel and walking for leisure primarily regarding the influence of land-use density and mixity which is on par with past research (Boarnet et al., 2011; Hsieh & Chuang, 2021; Inoue et al., 2010; Inoue et al., 2011). The negative effect observed between commercial land use and perceived walkability for leisure as well as the lack of effect of mixed-land use on the later suggest that a focus on destination-rich land uses as promoting walking is likely not sufficient to understand walking experience itself. The same can also be said for the minimal effect of Walkscore on perceived walkability for travel as well as its lack of effect for leisure walking. These findings are particularly relevant when considering that all raters had previous knowledge of the urban planning and walkability literature. Indeed, one would then expect if there was to be a bias introduced through the homogeneity in education background, that the raters would value commercial and mixed streets higher than residential ones because they provide more destinations – an element commonly emphasized in the urban planning and walkability literature. As such, the fact that we are observing the opposite effect in the case of leisure scores and weak effects for travel scores suggests that the factors commonly considered to evaluate walkability objectively and at the areal level are not necessarily adequate to explain walking experience at the micro-scale level which

is coherent with past research (Battista & Manaugh, 2017; Gebel et al., 2009; Koohsari et al., 2021; Tuckel & Milczarski, 2015; Yang & Diez-Roux, 2017). Observed levels of walkability might differ from subjective scores in the case of areas with a high density of destinations such as a downtown core. This could reflect what can be defined as “captive walkers,” people that are forced to walk in a certain area for travel purposes, but that do not perceive the environment in which they walk as highly walkable (Suarez-Balcazar et al., 2020).

Walkability is more than solely walking accessibility; it also incorporates elements pertaining to walking experience. This experience itself is a result of the interaction between pedestrians and their walking environment, both physical and social, and as such cannot be understood as solely objective. In fact, features of the walking environment can shape emotional responses that in turn can promote or deter walking in certain areas (Herrmann-Lunecke et al., 2021; Ortiz-Ramirez et al., 2021). Functionality and pleasantness of elements of the built environment do not necessarily align across socio-demographic groups and even less so at the individual level. This consideration is important to integrate here given the limitation of this paper in term of the demographics of the raters. The homogeneity of raters, especially in terms of age and education levels entails that the significance of specific features of the built environment on perceived walkability might not be representative of the population as a whole with elements such as sidewalk states and benches having potentially a stronger importance in an older demographic while element such as cul-de-sacs are likely not as relevant for the broader population. Still, the pathways of action discussed in this paper in relation to the specific predictors of the built environment included in the models are relevant considerations to have as they are likely to be relevant for a specific subgroup of the population given the high variability of individual preferences. We would strongly encourage replication of this study with a wider variety of raters completing only the subjective scoring to be able to infer any generalizable trends at the population level. We would also suggest disaggregating along socio-demographic characteristics (e.g., gender, age, income, (dis)ability) – which was not feasible for this paper given the small rater sample size ( $n = 17$ ) – to identify variation in perceived walkability between social groups and devise policy recommendations to address potential inequities. However, given the expected variety in the psychological and emotional responses of individuals to the built and social environment while walking that have been observed in previous research (Adkins et al., 2019; Herrmann-Lunecke et al., 2021), it is possible that even a slightly larger, more representative sample would be limited in its ability to extrapolate on population-wide trends.

Still, these considerations do not form the primary contribution that this paper aims to bring to the walkability field. Rather, we want to highlight the discrepancies discovered between walking for leisure and walking for travel for a given set of individuals as well as the discordances observed between subjective and objective walkability as the two primary components for which this study can help advancing the field. Recognizing variability in perceptions of the built environment and its suitability for walking based on trip purpose could further contribute to better understanding the specific determinants of walking for leisure and walking for travel and tailor specific interventions according to the type of walking that is aimed to be promoted. Additionally, we want to stress the need to move away from solely using objective and areal measurement to assess walkability which often has the result of conflating walking accessibility with walkability as a whole. Walkscore and other similar walkability indices should not be discounted totally on the basis that they do not align with perceived walkability as they still provide crucial information about the built environment which shape the possibility to take a walking trip in the first place. However, whether individuals will or will not take a certain walking trip is not solely a matter of whether they can but also whether they want to. This latter addition introduces an element of subjectivity that must be considered in walkability research to achieve a better understanding of walking behavior. Subjective walkability measurements can be used here to explore the factors behind discor-

dances between walking rates predicted through objective walkability measurements and observed rates.

Overall, this paper positions itself as a contributor to the necessary reframing of the field of walkability research and its assumptions that has been underway over the last decade (Andrews et al., 2012; Shashank & Schuurman, 2019; Tobin et al., 2022). What our findings suggest is that subjective and objective walkability measures are complementary and should therefore be used together rather than separately as to construct a more complete understanding of the relationship between the social and built environment and walking behavior (Arvidsson et al., 2012; Nyunt et al., 2015). The same can also be said in relation to the scale of walkability measurements with micro and meso-scale indices quantifying different relevant aspect of the built and social environment and as such needing to be used in combination with one another to quantify the propensity of a given environment to promote walking for a diverse set of individuals.

## **5 Conclusion**

Overall, this study emphasises the differential results in the built environment determinants of perceived walkability based on trip purpose. We also further support past research in highlighting the shortcomings of areal, objective walkability indices such as Walkscore in predicting perceived walkability and walking experience. The focus on destination density as a main determinant of walkability should also be reconsidered as a positive predictive factor of walking accessibility, but not as a predictor of walking experience per se. Given these results, we suggest the need to integrate more readily the differentiation between walking for travel and walking for leisure in walkability research. We support previous calls from other researchers that the predictors of perceived walkability and walking experience need to be more studied and better incorporated in policy design as complements to objective measures (Blecic et al., 2016; Fancello et al., 2020; Manaugh & El-Geneidy, 2013; Moura et al., 2017; Tuckel & Milczarski, 2015). Lastly, we argue for a multi-scalar approach to walkability by integrating micro-scale features of the street environment alongside the more common meso-scale metrics such as Walkscore or Frank's walkability index in order to provide a more complete portrait of the complex determinants of walking behavior.

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