Factors Influencing Subjective Walkability: Results from Built Environment Audit Data

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ABSTRACT

Walkability refers to a combination of the ease of walking and accessing destinations in an area as well as the general walking experience. It can be determined by a mix of built environment and land use characteristics. 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 fails to reflect the experience of walking. This study aims to better understand subjective walkability for both utilitarian and leisure walking by investigating its relationship with the built environment and land use characteristics. Data was collected from 848 street segments in Montreal, Canada using the MAPS-mini audit tool and synthetic subjective walkability scores. Mixed effect multilevel models were generated by using utilitarian and leisure subjective walkability scores as dependent variables and measures collected through the audit as independent variables. Key significant positive predictors found for both utilitarian and leisure walking were streetlights, sidewalk characteristics, tree cover, and speed limits, while parking lots negatively impacted both scores. Differential results were also observed with physically separated bicycle lanes positively predicting utilitarian walking while the number of parks did so for leisure walking. Results also showed that commercial and mixed land-use had no effect on utilitarian scores while having a significant negative impact on leisure scores. 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.

Keywords: Walkability, Subjective Walkability, Audit, Built Environment

HIGHLIGHTS

- Subjective walkability differs greatly from objective walkability
- Multilevel mixed effects models were used to account for inter-rater variability
- Distinct built environment elements affect perceived walkability differently
- Differences exists between subjective walkability for travel and for leisure
- Walkability scores that consider objective and subjective measures is needed

1. INTRODUCTION

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. A large body of literature has used primarily objective metrics (walkability) to measure the pedestrian friendliness of streets or areas (Arellana et al., 2020). These metrics use a variety of approaches and tend to include many characteristics of the built and social environment. There is wide variability between researchers in term of which elements of the built environment are targeted and which metrics are to be used to quantify walkability (Fonseca et al., 2021; Shashank & Schuurman, 2019). Despite this variability, there are still some predominant metrics used as the basis for urban planning policies. This is the case for Walkscore©, a popular tool that quantifies access to opportunities in an area (Carr et al., 2010). While such measures have proven efficient in highlighting some components of the built environment that have an impact on walkability, they are still not necessarily accurate in predicting actual walking behaviours (Consoli et al., 2020; Herrmann et al., 2017; Tuckel & Milczarski, 2015), or capturing the subjective experience of walking in diverse settings (Battista & Manaugh, 2017; Gebel et al., 2009; Koohsari et al., 2021; Tuckel & Milczarski, 2015). It is by considering these shortcomings of objective measurement of walkability that this study aims to analyze the elements of the of the built environment, including the micro scale elements that predict the experience of walking on a street. Highlighting the best predictors of subjective walkability could allow for better leverage points in improving the experience of walking, which many practitioners are aiming for.

2. LITTERATURE REVIEW

Walkability can be separated into two main components – the ease of reaching destinations and the walking experience – with both being assessed by analyzing a plurality of factors. Fonseca et al. (2021) separate these factors into six categories: land-use, accessibility, street-connectivity, pedestrian facility and comfort, safety and security, as well as streetscape design. The first three categories are usually considered when assessing the ease of reaching destinations in an area while the latter three are more common when assessing walking experience. While these categories are universally applicable, their relative importance will vary through time and space (Berry et al., 2017). Different measurements have been used to assess any given factor. This includes simply correlating walking outcomes with a density measure, as a proxy to walkability

(Hajna et al., 2013), or by using other composite measures of walkability, for example walkability indices calculated from the 3 Ds (diversity of land use, residential density, and design of the streets connectivity) (Cervero & Kockelman, 1997), or the Walkscore©; which is a measure of local accessibility (Carr et al., 2010). Such objective walkability indices – most precisely those that assess the accessibility or ease of travel in a particular area – are used in the majority of studies that measures the relationship between walking behaviour and physical activity outcomes (Fonseca et al., 2021; Hajna et al., 2015). A recurrent problem in walkability research arises from discrepancies between actual walking rates and predicted walking levels estimated through these objective walkability indices (Consoli et al., 2020; Hajna et al., 2013; Herbolsheimer et al., 2020; Herrmann et al., 2017; Nyunt et al., 2015; Shashank & Schuurman, 2019; Tuckel & Milczarski, 2015). This is particularly true when looking separately at utilitarian and leisure walkability (Wasfi et al., 2017). Such measures have also presented at-most low to medium correlation with perceived walkability (Koohsari et al., 2021).

To address such shortcomings, a wave of research was conducted on the development of audits to better quantify the built environment in new walkability indices. This includes tools such as 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 (Boarnet et al., 2011), particularly for leisure (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 (Blecic et al., 2016; Brown & Jensen, 2020).

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; Herbolsheimer 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). Amongst the limited scholarship on perceived or subjective walkability, the most common approach remains centered around perceived accessibility and ease of walking at a neighborhood level (Alidoust et al., 2018; Bodeker, 2018; Hanák et al., 2015; Hanibuchi et al., 2015). This includes measures such as the Neighborhood Environment Walkability Scale (NEWS) (Brown & Jensen, 2020; Jensen et al., 2017; Notthoff & Carstensen, 2017). Other areal methods used to estimate subjective walkability includes walking interviews (Alidoust et al., 2018) and mental mapping (Bodeker, 2018). Literature on micro-scale (i.e. street level) evaluations of perceived walkability from built environment characteristics is very limited with the main method used being synthetic subjective walkability scores and machine learning evaluation (Blecic et al., 2018; Blecic et al., 2019; Yameqani & Alesheikh, 2019). Past research has also been conducted on building 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). 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 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 predict synthetic subjective walkability scores axed on walking experience at the street level using physical and functional elements of the built environment as well as characteristics pertaining to the usage of the street space collected through an audit. To our knowledge, only one previous paper has attempted this (Blecic et al., 2016). Our paper expands on this research by differentiating between utilitarian and leisure walking, integrating a larger sample, and accounting for raters' effect on subjective score through a mixed effect multilevel modelling, which has not been done previously.

3. METHODOLOGY

3.1 Built Environment Audit

Data was collected as part of the first wave of a built environment audit around the future stations of the upcoming Light Rail Transit (LRT) system in Montreal, Canada (Figure 1). The aim of the audit is to determine the state of the street-level built environment in a 500-meter service area around each station prior to the arrival of the new transit system as well as documenting measures taken by municipal governments to adapt the built environment around the stations to promote active transportation.

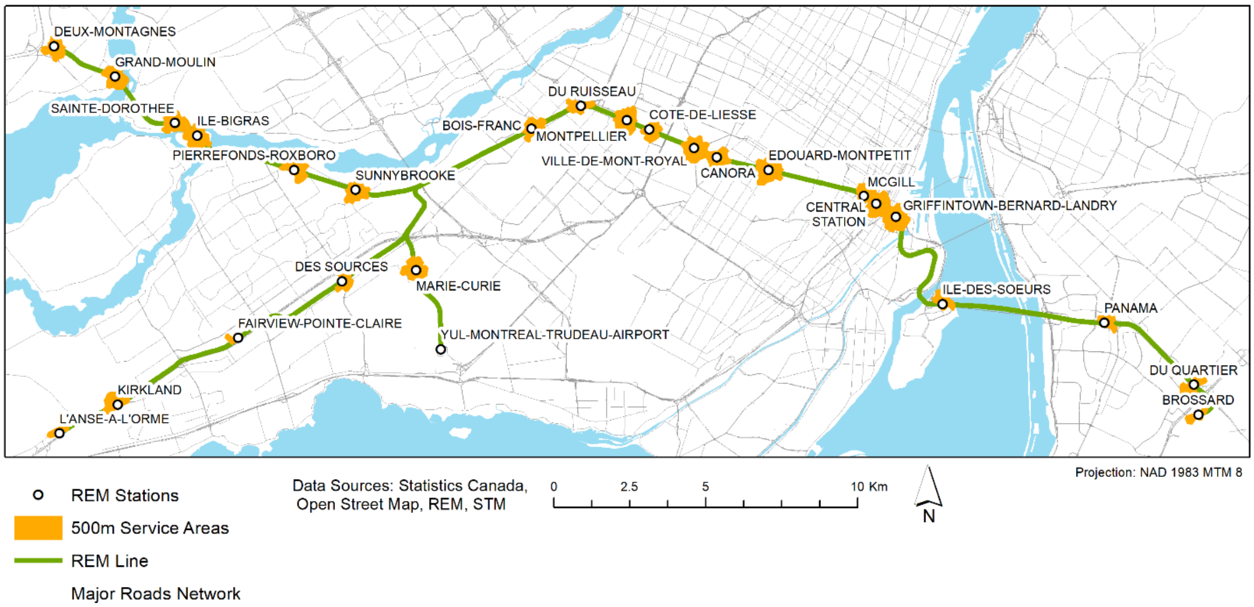


Figure 1 Map of the REM network with 500 meters service areas

The MAPS-mini audit tool, which has been validated in previous research (Sallis et al., 2015), was used as the basis for the survey component of the audit. For resource purposes, the tool was adapted to audit both sides of a street as one segment rather than individually. To maintain the integrity of the validated tool, questions were adapted to reflect the increased choice while keeping the same scores that were attributed to each question. In addition to the fifteen questions from the MAPS-mini audit tool, two additional questions were added from the MAPS-abbreviated audit tool (Cain et al., 2015), one from the SPACES Instrument (The University of Western Australia, 2000) as well as three original ones (Table 1). In addition to the survey, components of the built environment were also mapped. These consisted of benches, trash cans, stop signs, speed bumps, water fountains, and public toilets. Finally, external data was also collected and linked to each segment through ArcGIS. Data included: transit stop location acquired from local transit agencies; speed limits derived from municipal guidelines; cul-de-sac categorization added using google map; and Walkscore© retrieved through an API using the centroid of each segment.

Table 1 Content of the survey component of the REM built environment audit

Questions	Responses	Score	Audit Tool Source
Segment Code	Written	-	-
Street Name	Written	-	-
Cross Streets	Written	-	-
Is the segment auditable?	Yes / No	-	-
Intersection			
1. Is a pedestrian walk signal present?	No Yes at one intersection Yes at both intersections	0 1 2	MAPS Mini
1.1 What is the crossing time given to pedestrians?	# of seconds	-	Authors
2. Is there a ramp at the curb(s)?	No Yes, at least at one curb at one intersection Yes, at all curbs at one intersection Yes, at both intersections but not at all curbs Yes, at all curbs at both intersections	0 1 1 1 2	MAPS Mini
3. Is there a visible marked crosswalk?	No Yes, at one intersection Yes, at both intersections	0 1 2	MAPS Mini
3.1 What is the composition of the marked crosswalk?	Different Material / Painted / Raised	-	Authors
Land Use			
4. Residential land-use [4 categories]	Count [Buildings with separate entrances]	-	MAPS Abb.
5. Other land-uses [22 categories]	Count [Buildings with separate entrances; lots]	-	MAPS Abb.
5.16 Parks	0 1 2+	0 1 2	MAPS Mini
6. Main type of land use	Greenspace / Vacant / Industrial / Residential Commercial / Mixed	0 1	MAPS Mini
Street Amenities			
7. How many public transit stops are present?	0 1 2+	0 1 2	MAPS Mini
8. Are streetlights installed?	None Some Ample	0 1 2	MAPS Mini
9. Are there any benches or places to sit (include bus stop benches)?	No Yes	0 1	MAPS Mini
10. Presence of bicycle racks?	Count [0 – 20+]	-	Authors

Questions	Responses	Score	Audit Tool Source
11. Is there a designated bike path?	No	0	MAPS Mini
	Sharrow	0	
	Painted line	1	
	Physical barrier - Multi-use path	2	
	Physical barrier – Bollard	2	
	Physical barrier – Concrete / grass buffer	2	
Aesthetic			
12. Are the buildings well maintained?	0-99%	0	MAPS Mini
	100%	1	
13. Is graffiti/tagging present (do not include murals)?	Yes	0	MAPS Mini
	No	1	
14. Cleanliness – is there any litter, rubbish, broken glass, discarded items in the segment?	None or almost none.	-	SPACES
	Yes, some.		
	Yes, lots.		
Sidewalks			
15. Is a sidewalk present?	No	0	MAPS Mini
	Yes, on one side	1	
	Yes, on both sides.	2	
	Pedestrian Street	2	
15.1 Are there poorly maintained sections of the sidewalk that constitute major trip hazards?	Any	0	MAPS Mini
	None	1	
15.2 Is a sidewalk buffer present?	No	0	MAPS Mini
	Yes, on one side	1	
	Yes, on both sides	2	
16. What percentage of the length of the sidewalk/walkway is covered by trees, awnings or other overhead coverage?	0-25 % / no sidewalk	0	MAPS Mini
	26-75%	1	
	76-100%	2	

The 500-meters service area around each station was calculated using ArcGIS's network analyst using the street network. Street segments were then defined as street sections between two intersections that intersect with the service area. Exemptions were made for suburban segments forming complex cul-de-sacs. Of the 951 segments identified, a total of 848 were audited. The remaining 103 segments were omitted as they were either deemed unsafe due to a lack of sidewalks, high volume and/or speed of traffic or were under construction and could not be audited. Data was collected using the ArcGIS Survey 123 and the ArcGIS Field Map apps between May 25th and July 1st, 2021. A total of 14 auditors participated in the data collection. All auditors were trained prior to the audit on the objective data collected both online as well as on the ground for a trial run on the same 10 segments near McGill Station. Data from the training audit session was used to assess inter-rater reliability and bring corrections to questions with significant discrepancies. Verifications were also conducted after the data collection process through google-street view – which has been validated for the MAPS mini audit tool (Fox et al., 2021) – and by comparing entries collected for the same segment.

3.2 Subjective Walkability Scores Collection

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 2). 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.

Table 2 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)

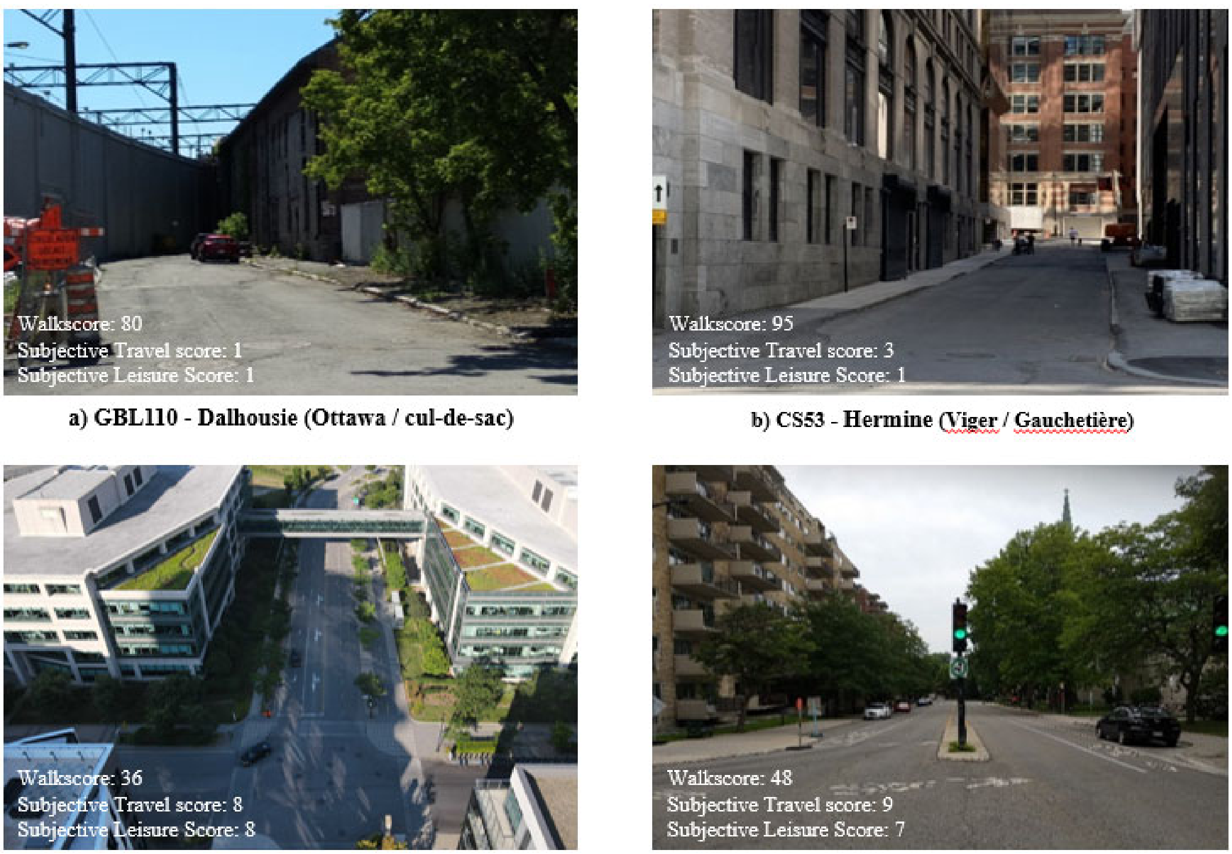
A first wave of data was collected in Summer 2021 at the same time as the built environment audit for all 848 segments by 12 of the 14 auditors. To control for any potential influence of the audit process on the subjective scoring, a second wave of data was collected in Fall 2021 by 5 independent raters that had not been involved at any point in the audit process and received no training for the evaluation of the streets. 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 that were audited.

Raters were all less than 40 years old; their average age was 25.4 years. 65% identified as men and 35% as women. Around 44% grew up in a suburban setting, 44% grew up in urban settings, and 12% grew up in rural settings. There was also homogeneity amongst raters in education levels as all had completed or were in completion of 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.

4. ANALYSIS

4.1 Spatial mismatches

Figure 2 highlights examples of a mismatch between objectively measured walkability, and subjectively rated scores. (i.e., segments that were given low subjective scores but had a high Walkscore© (e.g., segment #GBL110, CS53), or vise versa (e.g segment # IDS4, EM15)). The discrepancies here are important as Walkscore© is an areal metric that takes into account access to opportunities through walking. As a result, it does not represent the exact ability to walk, or feeling of walking, on a street segment in areas with dense road networks. Other elements pertaining to the micro-scale environment of the streets also play a role in dictating the experience of walking.



a) GBL110 - Dalhousie (Ottawa / cul-de-sac)

b) CS53 - Hermine (Viger / Gauchetière)

c) IDS4 - de la Pointe-Nord (Jacques-le-Ber / Round about)

d) EM15 - Vincent-d'Indy (Willowdale / Côte-Sainte-Catherine)

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

4.2 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. Audited segments are nested within auditors (17 auditors) to isolate the bias that could arise from the personal characteristics between auditors and from the simultaneous collection of the built environment data (i.e., isolate the inter-rater variability in the subjective scores).

All the components from the original MAPS-mini audit tool were used as independent variables in the model. Building on preliminary results, variables coming from other questions of the audit as well as mapping data such as speed bumps and speed limits were also added in the model. Variation inflation factors (VIF) were calculated for all independent variables. Variables with a factor above five were excluded from the model to avoid collinearity. This was the case for questions 3 (ramps at the curbs) and 15.1 (presence of sidewalks). Additionally, all independent variables were tested for correlation with non-significant, moderately correlated variables being removed as well. This included data from questions 1 (walk signals), 2 (crosswalks) as well as transit stops. Parks were also removed because of their correlation with the “greenspace” category in the primary land-use question. Because the parks information is more detailed than the main land-use information, the models were also run without the main land-use and with the number of parks per segment instead solely to extract the effect of individual parks.

Table 3 displays descriptive statistics for fixed effects variables that were tested in the models. Both dependent variables were normally distributed and have similar mean and standard deviation. Independent variables that remained in the model for utilitarian walking but are not present in the model for leisure walking or vice-versa were removed because of a lack of statistical significance only.

Table 3 Descriptive statistics of variables included in the statistic model

Variables	Mean	St. Dev	Min	Max
Dependent variables				
Subjective walkability score for travel	6.05	2.22	1	10
Subjective walkability score for leisure	5.73	2.30	1	10
Independent Variables				
Cul-de-sac	0.05	0.21	0	1
Parks	0.13	0.37	0	2
Parking lots	0.30	0.94	0	10
Main Land use				
Residential	0.52	0.5	0	1
Vacant	0.03	0.17	0	1
Greenspace	0.02	0.16	0	1
Industrial	0.03	0.17	0	1
Commercial	0.22	0.41	0	1
Mixed	0.18	0.38	0	1
Streetlights				
None	0.07	0.25	0	1
Some	0.77	0.42	0	1
Ample	0.16	0.36	0	1
Benches				
Yes	0.25	0.43	0	1
No	0.75	0.43	0	1
Bicycle path				
No	0.85	0.36	0	1
Sharrow	0.04	0.18	0	1
Painted lines	0.06	0.24	0	1
Physical barrier	0.06	0.23	0	1
Building maintenance				
0 - 99%	0.33	0.47	0	1
100%	0.67	0.47	0	1
Sidewalks				
No	0.18	0.39	0	1
One side	0.16	0.36	0	1
Two sides	0.65	0.48	0	1
Pedestrian street	0.01	0.1	0	1
Sidewalk buffer				
No	0.73	0.44	0	1
One side	0.09	0.29	0	1
Two side	0.17	0.38	0	1
Sidewalk tree cover				

Variables	Mean	St. Dev	Min	Max
0 - 25 % - no sidewalk	0.73	0.44	0	1
26 - 75%	0.22	0.41	0	1
76 - 100%	0.05	0.21	0	1
Sidewalk maintenance				
No poorly maintained sections	0.64	0.48	0	1
Any poorly maintained sections	0.36	0.48	0	1
Graffiti				
No	0.91	0.28	0	1
Yes	0.09	0.28	0	1
Speed Limit [km/h]	40.04	7.18	0	50
Speed Bumps	0.10	0.41	0	5

5. RESULTS

The statistical model predicting subjective utilitarian walkability yielded a conditional R^2 of 0.690 while the model predicting subjective leisure walkability obtained a conditional R^2 value of 0.566 (Table 4) suggesting a high and moderate explanatory power respectively compared to previous studies in the literature (Blecic et al., 2016). Results revealed that 17 out of 22 predictors included in the model were statistically significant in predicting subjective utilitarian walking scores with the same number also shown to be statistically significant in predicting leisure walking scores. Overall, 15 out of 23 predictors were statistically significant in predicting both utilitarian and leisure walking scores.

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 (τ_{00})) from the total variance of the error term (i.e., the residual σ^2). The ICC suggests that 62% of the unexplained variance in the error term is related to between raters' variability. Similarly, for leisure walking subjective scores, 43% 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.

Table 4 Statistical Models Predicting Subjective Scores from micro-scale street characteristics

	Subjective Score for Travel			**Subjective Score for Leisure**		
Predictors	*Estimates*	*CI*	*p*	*Estimates*	*CI*	*p*
(Intercept)	5.64	4.47 – 6.82	**<0.001**	7.38	6.24 – 8.53	**<0.001**
Cul-de-sac	-0.89	-1.37 – -0.41	**<0.001**			
Parking lots	-0.15	-0.26 – -0.03	**0.011**	-0.20	-0.33 – -0.07	**0.003**
Main Land Use (Reference: Residential)						
Green Space	0.76	0.09 – 1.43	**0.026**	0.78	0.00 – 1.55	**0.049**
Vacant	-0.78	-1.39 – -0.16	**0.014**	-1.80	-2.51 – -1.08	**<0.001**
Industrial	-0.97	-1.70 – -0.23	**0.01**	-1.39	-2.24 – -0.55	**0.001**
Commercial	0.15	-0.18 – 0.49	0.376	-0.99	-1.38 – -0.61	**<0.001**
Mixed	0.10	-0.23 – 0.42	0.567	-0.61	-0.99 – -0.24	**0.001**
Streetlights (Reference: None)						
Some	0.40	0.00 – 0.79	**0.049**	0.47	0.02 – 0.93	**0.043**
Ample	0.75	0.26 – 1.24	**0.003**	1.15	0.58 – 1.72	**<0.001**
Benches	0.47	0.21 – 0.73	**<0.001**	0.42	0.12 – 0.72	**0.006**
Bicycle Path (Reference: No)						
Sharrow	0.46	-0.09 – 1.02	0.103			
Painted lines	0.39	-0.06 – 0.84	0.091			
Physical barrier	0.66	0.20 – 1.12	**0.005**			
Sidewalk State	0.77	0.53 – 1.01	**<0.001**	0.53	0.25 – 0.81	**<0.001**
Sidewalk Buffer (Reference: No)						
One Side	0.65	0.27 – 1.03	**0.001**	0.66	0.22 – 1.10	**0.003**
Two Sides	1.1	0.76 – 1.44	**<0.001**	0.92	0.53 – 1.32	**<0.001**
Walkway cover from trees and awning (Reference: 0-25% / no sidewalk)						
26-75%	0.58	0.32 – 0.85	**<0.001**	0.78	0.47 – 1.08	**<0.001**
76-100%	0.70	0.20 – 1.19	**0.006**	1.03	0.46 – 1.61	**<0.001**
Building Maintenance	0.31	0.07 – 0.55	**0.013**	0.62	0.35 – 0.90	**<0.001**
Graffiti	-0.23	-0.62 – 0.15	0.231	-0.40	-0.85 – 0.04	0.074
Speed Limit	-0.03	-0.04 – -0.01	**<0.001**	-0.07	-0.09 – -0.05	**<0.001**
Speed Bumps	0.38	0.13 – 0.63	**0.003**	0.43	0.14 – 0.72	**0.003**
Random Parameters:						
σ^2 (within variance)	2.01			2.7		
τ_{00} (Between raters variance)	3.23 $_{\text{Rater}}$			2.04 $_{\text{Rater}}$		
Intraclass correlation	0.62			0.43		
N	17 $_{\text{Rater}}$			17 $_{\text{Rater}}$		
Observations	848			848		
Marginal R^2 / Conditional R^2	0.192 / 0.690			0.239 / 0.566		

5.3.1 Street connectivity and land-use

As the only street connectivity predictor, the presence of a cul-de-sac had a statistically significant negative impact of 0.89 points for utilitarian walking scores while keeping all other variables constant at their means. Moving to specific land-use, the presence of ground level uncovered parking lots had a negative and statistically significant effect on both utilitarian and leisure walking scores with each added parking lots leading to a decrease of 0.15 and 0.20 points respectively. For main land use, compared to residential, segments considered to be dominated by greenspaces had a statistically significant impact on both utilitarian and leisure walking scores with an increase of 0.76 and 0.78 points respectively. It is to be noted as well that when running the models without the main land-use data and with the number of parks by segments, the number of parks had a significant positive impact only on leisure scores with 0.80 points added per added parks while keeping all other variables constant at their means. On the contrary, vacant segments had a negative and statistically significant effect on both utilitarian walking and leisure walking scores with a decrease of 0.78 and 1.80 points respectively. A similar effect was also observed for industrial segments with a decrease of 0.97 points in utilitarian walking scores and 1.39 for leisure walking scores. Lastly, both commercial and mixed land use had a negative impact on leisure scores with a decrease of 0.99 and 0.61 points respectively compared to residential.

5.3.2 Sidewalk characteristics

The state of the sidewalk had a statistically significant effect on both travel and leisure scores with an increase of 0.77 and 0.53 respectively for segments that had no deteriorated parts of the sidewalk compared to those that did. One-sided sidewalk buffer led to a significant increase of 0.65 points in utilitarian scores and 0.66 in leisure scores compared to no buffer at all while buffers on both sides of the street led to an increase of 1.1 and 0.92 points for utilitarian and leisure walking scores respectively. Finally, walkway cover was also a statistically significant predictor of both scores with 26 – 75% cover leading to an increase of 0.58 and 0.78 points and 76 – 100 % cover leading to an increase of 0.70 and 1.03 points compared to no tree cover for utilitarian and leisure subjective scores respectively.

5.3.3 Street amenities

The presence of streetlight had a positive and statistically significant impact on both utilitarian and leisure walking scores with some streetlights compared to none leading to an increase of 0.40 and 0.47 points respectively and ample streetlight generating scores 0.75 and 1.15 points higher. The presence of benches on a street segment also had a significant effect in both models as it led to an increase of 0.47 points in utilitarian scores and 0.42 points in leisure scores compared to segments without any benches. Lastly, the presence of physically separated bicycle paths had an impact on utilitarian walking scores only, generating scores 0.66 points higher than streets with no bicycle paths. Sharrows and painted lanes were not significantly associated with higher scores in our models.

5.3.4 Aesthetics and traffic safety

For aesthetic components of the models, street segments with well maintained buildings were associated with a statistically significant increase of 0.31 points in utilitarian scores and 0.62 points in leisure scores while graffiti did not have an impact on either score in our models. For traffic safety related elements, speed limit was statistically significant and decreased the subjective walkability by 0.03 and 0.07 points per added km/h for utilitarian and leisure walking scores respectively while keeping all variables constant at their mean. Lastly, speed bumps also had a statistically significant effect on both scores with an increase of 0.38 and 0.43 points per added speed bumps on a segment for utilitarian and leisure scores respectively.

6. DISCUSSION

The variance observed between effects of some predictors on utilitarian and leisure walking is coherent with previous research (Tuckel & Milczarski, 2015). Functionality and pleasantness of elements of the built environment do not necessarily align across socio-demographic groups and even more at the micro-level across individuals. Such variability is highlighted by the high ICC obtained for the added levels of auditors. The lower conditional R^2 obtained for leisure walking subjective walkability scores suggests that while our model predicts subjective scores for leisure walking rather well, there remain potential predictors that were not measured in the data collected from the audit. This is true for utilitarian subjective walkability scores as well, but to a lesser extent. The usage of mixed methods could allow for a more holistic analysis of the factors influencing subjective walkability at the street level.

6.1 Street connectivity and land-use

The statistically significant negative effect registered for cul-de-sac on perceived walkability for travel contradict previous research analyzing walking behaviours and physical activity for travel (Boarnet et al., 2011). Street connectivity and the possibility to employ a street segment to go to the desired destination is a credible pathway to explain the effect found. 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.

Moving to land use elements, the positive effect of greenspaces on both subjective walking scores 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. Additionally, parks provide opportunities for leisure activities making them appealing for leisure walking.

The statistically significant negative effect of parking on both scores is also consistent with the literature. Previous research has found a similar correlation between the presence of parking and walking in the context of utilitarian walking, however, it has yet to be evaluated in the context of subjective scores for leisure walking (Boarnet et al., 2011). These effects can be explained by both the functional disruptions that parking lots entries create for walking and their aesthetics as well as the lack of destinations of segments with numerous empty lots.

The statistically significant negative effect of industrial and vacant segments was also expected. Segments with such land-use are generally characterised by poor access to destinations. Other variables that were not collected during the audit but may be correlated with these two categories of land-use are heavy truck traffic as well as noise and air pollution.

The lack of a significant difference between commercial or mixed land-use and residential land-use on subjective utilitarian walking as well as the negative effects on leisure walking contradict the literature on the subject as it has been assumed – especially through indices such as Walkscore© – that land use providing destinations is a primary predictor of walkability and thus of walking patterns (Blecic et al., 2016; Boarnet et al., 2011; Manaugh & El-Geneidy, 2011).

This finding is particularly significant when considering the raters all have previous knowledge of the urban planning and walkability literature – one would expect the raters to value commercial and mixed streets higher than residential ones because they provide more destinations. As such, the fact that we are observing the opposite effect in the case of leisure scores and no effect for utilitarian scores suggests that the factors commonly considered to evaluate walkability at the areal level are not necessarily applicable to predict walking experience. 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 utilitarian purposes, but that do not perceive the environment in which they walk as highly walkable (Suarez-Balcazar et al., 2020). Such findings coincide with previous research suggesting that subjective and objective walkability measures are complementary and should therefore be used together rather than separately (Arvidsson et al., 2012; Nyunt et al., 2015).

6.2 Street amenities

The statistically significant effect of streetlights on both subjective scores is coherent with the findings of previous research (Blecic et al., 2016). This effect might be explained by the increased feeling of safety that proper street lighting creates (Davoudian et al., 2016). Moving on to benches, the significant effect observed on both utilitarian and leisure scores is in agreeance with prior research and was expected as benches provide opportunities to rest during a walking trip (Blecic et al., 2016).

The statistically significant effect from physically separated bicycle paths on travel scores contradict a previous study that used a built environment audit and suggested that bicycle paths were not associated with walking for travel (Boarnet et al., 2011) but aligns with another study that found that subjective walking scores were associated with perceived cyclability (Blecic et al., 2016). The principal explaining factor for this finding is that physically separated bicycle paths act as buffers between the sidewalks and car lanes. This would be coherent with the positive and statistically significant association we found between sidewalk buffers on both sides of the street and subjective walking scores for travel. Additionally, the difference between utilitarian and leisure scores could be explained by bicycle paths displaying opportunities for active transport on a street. Lastly, results also suggest that sharrows – and to a lesser extent painted lanes – are not efficient in promoting active transport.

6.3 Sidewalk characteristics

The statistically significant results obtained between sidewalk maintenance (i.e. the presence of cracks and holes in the sidewalk) and subjective scores contradict 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). 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.

The statistically significant positive effect from sidewalk buffers on both subjective scores, mainly when present on both sides, is coherent with previous research (Blecic et al., 2016; Boarnet et al., 2011). 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. 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. Taking into account both the sidewalk buffer and the sidewalk maintenance's effects on subjective walkability scores, it can be extrapolated that the presence of sidewalks does impact subjective walkability. Presence of sidewalk was excluded from the model due to its strong correlation with sidewalk attributes, which is a result of the structure of the MAPS-mini audit tool.

The statistically significant effect of sidewalk tree cover on both subjective scores is coherent with past research predicting subjective walkability (Blecic et al., 2016), but it contradicts 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 again 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).

6.4 Aesthetics and traffic safety

Aesthetics elements represented in the model displayed different outcomes with building maintenance having a statistically significant effect on both subjective scores while graffiti did not have an impact on either dependent variable. These findings contradict recent literature suggesting building aesthetics are not important predictors of utilitarian walking (Boarnet et al., 2011). The differential outcome between building maintenance and graffiti can be explained by a difference in scale which results in buildings having a larger impact on the streetscape than graffiti. Small graffiti were also more omnipresent throughout the audited urban sectors than poorly maintained buildings thus decreasing their impact.

Lastly, in term of safety components included in the model, the statistically significant negative effect of speed limit on both subjective scores as well as the positive effect of speed bumps align with previous research predicting walking behaviour using audit measures (Boarnet et al., 2011) but they contradict a previous study predicting subjective scores using characteristics of the streetscape (Blecic et al., 2016). The underlying mechanism behind the correlation rely on the decrease of safety that comes with increased traffic speed (Suarez-Balcazar et al., 2020). Additionally, routes with increased speed will also tend to have denser traffic which lead to increase air and noise pollution levels. Traffic calming measures such as speed bumps therefore act as an extended reduction of speed limits by reducing further the travelling speed of motorized vehicle on a segment.

7. CONCLUSION

Overall, this study emphasises the shortcomings of areal, objective walkability indices such as Walkscore© in predicting perceived walkability and walking experience. We underscore the impact of street characteristics and amenities on perceived walkability. Specifically, the presence of parking lots negatively impacts subjective walkability while streetlighting, sidewalk buffers, tree cover as well as speed regulations all having a significant positive impact on the collected synthetic scores. Differential results were also observed with physically separated bicycle lanes promoting perceived utilitarian walkability while parks and greenspaces were more significant for perceived walkability for leisure suggesting that it is necessary to separate trip purpose when studying walkability. Our analysis also put back in perspective the disproportionate place that commercial or mixed land use have been given in the walkability literature. The focus on destinations density as a main driver of walkability should also be reconsidered as a positive predictive factor of walking accessibility but not walking experience. Given these results, we support previous calls from other researchers that the predictors of perceived walkability and walking experience needs 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). We also argue for a multi-scalar approach to walkability by integrating perceived walkability at the street level in addition to the more common considerations of perceived walking accessibility at the neighborhood level.

This study presents a few limitations. The first is related to the potential bias integrated in the collection of subjective scores by the completion of the built environment audit at the same time for some of the raters. This was controlled for by the integration of independent raters in wave 2 of the data collection and through using a multilevel statistical approach to isolate the effects of the raters who collected some of the audit variables. The second pertains to the homogeneity of raters, especially in terms of knowledge of the walkability and planning literature. While this implies that the results found in relation to the effect of specific predictors might not be representative of the population as a whole, the homogeneous population also allows us to highlight a flawed assumption in the field of walkability. As previously discussed, having raters that are all familiar with planning theory strengthens the results observed between commercial and mixed land-use and subjective walkability scores and gives more weight to the finding that predictors of walking accessibility are not necessarily applicable to walking experience. 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 or along socio-demographic characteristics in a given urban context. Further, a similar analysis could be conducted between subjective walkability and measured walking patterns to predict the main push or pull factors that lead to captive walking.

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9. AUTHORS CONTRIBUTION

The authors confirm contribution to the paper as follows: study conception and design: Rodrigue, Daley, Ravensbergen, Manaugh, Wasfi, Butler & El-Geneidy; data collection: Rodrigue, Daley, Ravensbergen, El-Geneidy; analysis and interpretation of results: Rodrigue, Daley, Ravensbergen, Manaugh, Wasfi, El-Geneidy; draft manuscript preparation, Rodrigue, Daley, Ravensbergen, Manaugh, Wasfi, Butler & El-Geneidy. All authors reviewed the results and approved the final version of the manuscript.

WORKS CITED

Adkins, A., Barillas-Longoria, G., Martinez, D. N., & Ingram, M. (2019, Sep). Differences in social and physical dimensions of perceived walkability in Mexican American and non-hispanic white walking environments in Tucson, Arizona. *Journal of Transport & Health, 14*, Article 100585. https://doi.org/10.1016/j.jth.2019.100585

Alidoust, S., Bosman, C., & Holden, G. (2018, Mar). Talking while walking: an investigation of perceived neighbourhood walkability and its implications for the social life of older people. *Journal of Housing and the Built Environment, 33*(1), 133-150. https://doi.org/10.1007/s10901-017-9558-1

Arellana, J., Saltarín, M., Larrañaga, A., Alvarez, V., & Henao, C. (2020, 2020/03/03). Urban walkability considering pedestrians' perceptions of the built environment: A 10-year review and a case study in a medium-sized city in Latin America. *Transport Reviews, 40*(2), 183-203. https://doi.org/10.1080/01441647.2019.1703842

Arvidsson, D., Kawakami, N., Ohlsson, H., & Sundquist, K. (2012, Feb). Physical Activity and Concordance between Objective and Perceived Walkability. *Medicine and Science in Sports and Exercise, 44*(2), 280-287. https://doi.org/10.1249/MSS.0b013e31822a9289

Battista, G., & Manaugh, K. (2017). Using embodied videos of walking interviews in walkability assessment. *Transportation Research Record, 2661*(1), 12-18.

Battista, G., & Manaugh, K. (2018). Stores and mores: Toward socializing walkability. *Journal of Transport Geography, 67*, 53-60.

Berry, N., Coffee, N., Nolan, R., Dollman, J., & Sugiyama, T. (2017, Sep). Neighbourhood Environmental Attributes Associated with Walking in South Australian Adults: Differences between Urban and Rural Areas. *International Journal of Environmental Research and Public Health, 14*(9), Article 965. https://doi.org/10.3390/ijerph14090965

Blecic, I., Canu, D., Cecchini, A., Congiu, T., & Fancello, G. (2016). Factors of perceived walkability: A pilot empirical study. In O. Gervasi, B. Murgante, S. Misra, A. Rocha, C. Torre, D. Tanier, B. Apduhan, E. Stankova, & S. Wang (Eds.), *Computational Science and Its Applications - Iccsa 2016, Pt Iv* (Vol. 9789, pp. 125-137). https://doi.org/10.1007/978-3-319-42089-9_9

Blecic, I., Cecchini, A., & Trunfio, G. (2018, Jul 02-05). Towards automatic assessment of perceived walkability.*Lecture Notes in Computer Science* [Computational science and its applications - iccsa 2018, pt iii]. 18th International Conference on Computational Science and Its Applications (ICCSA), Monash Univ, Caulfield Campus, Melbourne, AUSTRALIA.

Blecic, I., Santos, A., Moura, A., & Trunfio, G. (2019, Jul 01-04). Multi-criteria evaluation vs perceived urban quality: An exploratory comparison.*Lecture Notes in Computer Science* [Computational science and its applications - iccsa 2019, pt iii: 19th international conference, saint petersburg, russia, july 1-4, 2019, proceedings, part iii]. 19th International Conference on Computational Science and Its Applications (ICCSA), Saint Petersburg, RUSSIA.

Boarnet, M., Forsyth, A., Day, K., & Oakes, J. (2011). The street level built environment and physical activity and walking: results of a predictive validity study for the Irvine Minnesota Inventory. *Environment and Behavior, 43*(6), 735-775. https://doi.org/10.1177/0013916510379760

Bodeker, M. (2018, Jul). Walking and Walkability in Pre-Set and Self-Defined Neighborhoods: A Mental Mapping Study in Older Adults. *International Journal of Environmental Research and Public Health, 15*(7), Article 1363. https://doi.org/10.3390/ijerph15071363

Bohte, W., Maat, K., & Van Wee, B. (2009). Measuring attitudes in research on residential self-selection and travel behaviour: a review of theories and empirical research. *Transport Reviews, 29*(3), 325-357.

Brown, B. B., & Jensen, W. A. (2020, Feb). Dog Ownership and Walking: Perceived and Audited Walkability and Activity Correlates. *International Journal of Environmental Research and Public Health, 17*(4), Article 1385. https://doi.org/10.3390/ijerph17041385

Cain, K., Millstein, R., Sallis, J., Conway, T., Gavand, K., Frank, L., Saelens, B., Geremia, C., Chapman, J., Adams, M., Glanz, K., & King, A. (2015). *Microscale audit of pedestrian streetscapes (MAPS)*. https://activelivingresearch.org/microscale-audit-pedestrian-streetscapes

Carr, L., Dunsiger, S., & Marcus, B. (2010). Walk score™ as a global estimate of neighborhood walkability. *39*(5), 460-463.

Cervero, R., & Kockelman, K. (1997). Travel demand and the 3Ds: Density, diversity, and design. *Transportation research part D: Transport environment*

2(3), 199-219.

Consoli, A., Nettel-Aguirre, A., Spence, J. C., McHugh, T. L., Mummery, K., & McCormack, G. R. (2020, Dec). Associations between objectively-measured and self-reported neighbourhood walkability on adherence and steps during an internet-delivered pedometer intervention. *Plos One, 15*(12), Article e0242999. https://doi.org/10.1371/journal.pone.0242999

Davoudian, N., Mansouri, A., & Cie. (2016). Does street lighting affect pedestrian behaviour at night? In *Proceedings of Cie 2016 Lighting Quality and Energy Efficiency* (pp. 588-595). <Go to ISI>://WOS:000386326700076

Day, K., Boarnet, M., Alfonzo, M., & Forsyth, A. (2006, 2006/02/01/). The Irvine–Minnesota Inventory to measure built environments: development. *American Journal of Preventive Medicine, 30*(2), 144-152. https://doi.org/https://doi.org/10.1016/j.amepre.2005.09.017

Fancello, G., Congiu, T., & Tsoukias, A. (2020, Dec). Mapping walkability. A subjective value theory approach. *Socio-Economic Planning Sciences, 72*, Article 100923. https://doi.org/10.1016/j.seps.2020.100923

Fonseca, F., Ribeiro, P., Conticelli, E., Jabbari, M., Papageorgiou, G., Tondelli, S., & Ramos, R. (2021). Built environment attributes and their influence on walkability [Review; Early Access]. *International Journal of Sustainable Transportation*, 20. https://doi.org/10.1080/15568318.2021.1914793

Fox, E., Chapman, J., Moland, A., Alfonsin, N., Frank, L., Sallis, J., Conway, T., Cain, K., Geremia, C., Cerin, E., Vanwolleghem, G., Van Dyck, D., Queralt, A., Molina-Garcia, J., Hino, A., Lopes, A., Salmon, J., Timperio, A., & Kershaw, S. (2021, Jun). International evaluation of the Microscale Audit of Pedestrian Streetscapes (MAPS) global instrument: comparative assessment between local and remote online observers. *International journal of behavioral nutrition and physical activity, 18*(1), Article 84. https://doi.org/10.1186/s12966-021-01146-3

Gebel, K., Bauman, A., & Owen, N. (2009, Apr). Correlates of Non-Concordance between Perceived and Objective Measures of Walkability. *Annals of Behavioral Medicine, 37*(2), 228-238. https://doi.org/10.1007/s12160-009-9098-3

Hajna, S., Dasgupta, K., Halparin, M., & Ross, N. (2013, Jun). Neighborhood walkability field validation of Geographic Information System measures. *American Journal of Preventive Medicine, 44*(6), E55-E59. https://doi.org/10.1016/j.amepre.2013.01.033

Hajna, S., Ross, N., Brazeau, A., Belisle, P., Joseph, L., & Dasgupta, K. (2015, Aug). Associations between neighbourhood walkability and daily steps in adults: a systematic review and meta-analysis. *Bmc Public Health, 15*, Article 768. https://doi.org/10.1186/s12889-015-2082-x

Hanák, T., Marović, I., & Aigel, P. (2015, 2015/01/01/). Perception of residential environment in cities: a comparative study. *Procedia Engineering, 117*, 495-501. https://doi.org/https://doi.org/10.1016/j.proeng.2015.08.202

Hanibuchi, T., Nakaya, T., Yonejima, M., & Honjo, K. (2015, Oct). Perceived and objective measures of neighborhood walkability and physical activity among adults in Japan: A multilevel analysis of a nationally representative sample. *International Journal of Environmental Research and Public Health, 12*(10), 13350-13364. https://doi.org/10.3390/ijerph121013350

Herbolsheimer, F., Mahmood, A., Ungar, N., Michael, Y., Oswald, F., & Chaudhury, H. (2020). Perceptions of the neighborhood built environment for walking behavior in older adults living in close proximity. *Journal of applied gerontology*, 0733464820979258.

Herrmann, T., Boisjoly, G., Ross, N., & El-Geneidy, A. (2017). The missing middle filling the gap between walkability and observed walking behavior [Article]. *Transportation Research Record*(2661), 103-110. https://doi.org/10.3141/2661-12

Jensen, W., Brown, B., Smith, K., Brewer, S., Amburgey, J., & McIff, B. (2017, Sep). Active transportation on a complete street: perceived and audited walkability correlates. *International Journal of Environmental Research and Public Health, 14*(9), Article 1014. https://doi.org/10.3390/ijerph14091014

Jun, H., & Hur, M. (2015, 2015/08/01/). The relationship between walkability and neighborhood social environment: The importance of physical and perceived walkability. *Applied Geography, 62*, 115-124. https://doi.org/https://doi.org/10.1016/j.apgeog.2015.04.014

Koohsari, M., McCormack, G., Shibata, A., Ishii, K., Yasunaga, A., Nakaya, T., & Oka, K. (2021, Sep). The relationship between walk score (R) and perceived walkability in ultrahigh density areas. *Preventive Medicine Reports, 23*, Article 101393. https://doi.org/10.1016/j.pmedr.2021.101393

Manaugh, K., & El-Geneidy, A. (2011, 2011/06/01/). Validating walkability indices: How do different households respond to the walkability of their neighborhood? *Transportation Research Part D: Transport and Environment, 16*(4), 309-315. https://doi.org/https://doi.org/10.1016/j.trd.2011.01.009

Manaugh, K., & El-Geneidy, A. (2013, 2013/04/01/). Does distance matter? Exploring the links among values, motivations, home location, and satisfaction in walking trips. *Transportation Research Part A: Policy and Practice, 50*, 198-208. https://doi.org/https://doi.org/10.1016/j.tra.2013.01.044

Moura, F., Cambra, P., & Gonçalves, A. (2017, 2017/01/01/). Measuring walkability for distinct pedestrian groups with a participatory assessment method: A case study in Lisbon. *Landscape and Urban Planning, 157*, 282-296. https://doi.org/https://doi.org/10.1016/j.landurbplan.2016.07.002

Notthoff, N., & Carstensen, L. (2017, Jun). Promoting walking in older adults: Perceived neighborhood walkability influences the effectiveness of motivational messages. *Journal of Health Psychology, 22*(7), 834-843. https://doi.org/10.1177/1359105315616470

Nyunt, M., Shuvo, F., Eng, J., Yap, K., Scherer, S., Hee, L., Chan, S., & Ng, T. (2015). Objective and subjective measures of neighborhood environment (NE): relationships with transportation physical activity among older persons. *International journal of behavioral nutrition and physical activity*

12(1), 1-10.

Sallis, J., Cain, K., Conway, T., Gavand, K., Millstein, R., Geremia, C., Frank, L., Saelens, B., Glanz, K., & King, A. (2015). Is your neighborhood designed to support physical activity? A brief streetscape audit tool. *Preventing chronic disease, 12*. https://doi.org/10.5888/pcd12.150098

Shashank, A., & Schuurman, N. (2019, 2019/01/01/). Unpacking walkability indices and their inherent assumptions. *Health & Place, 55*, 145-154. https://doi.org/https://doi.org/10.1016/j.healthplace.2018.12.005

Shuvo, F., Mazumdar, S., & Labib, S. (2021, May). Walkability and greenness do not walk together: Investigating associations between greenness and walkability in a large metropolitan city context. *International Journal of Environmental Research and Public Health, 18*(9), Article 4429. https://doi.org/10.3390/ijerph18094429

Suarez-Balcazar, Y., Early, A., Garcia, C., Balcazar, D., Arias, D., & Morales, M. (2020). Walkability safety and walkability participation: a health concern. *Health Education & Behavior, 47*(3), 430-438. https://doi.org/10.1177/1090198120903256

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Tuckel, P., & Milczarski, W. (2015, Mar). Walk score (TM), perceived neighborhood walkability, and walking in the US. *American Journal of Health Behavior, 39*(2), 241-255. https://doi.org/10.5993/ajhb.39.2.11

Wasfi, R., Steinmetz-Wood, M., & Kestens, Y. (2017). Place matters: A longitudinal analysis measuring the association between neighbourhood walkability and walking by age group and population center size in Canada. *PLoS ONE* *12*(12), e0189472.

Yameqani, A., & Alesheikh, A. (2019, Jul). Predicting subjective measures of walkability index from objective measures using artificial neural networks. *Sustainable Cities and Society, 48*, Article 101560. https://doi.org/10.1016/j.scs.2019.101560