ISSN 2175-3369

Scientific article

doi: 10.1590/2175-3369.016.e20220211

urbe
Revista Brasileira de Gestão Urbana
scielo.br/urbe

PUCPRESS

Land use mix and walking for transportation among older adults: an approach based on different metrics of the built environment

Uso misto do solo e a caminhada para fins de transporte em idosos: uma abordagem baseada em diferentes métricas do ambiente construído

Catharina Cavasin Salvador [a]
Londrina, PR, Brazil
[a] State University of Londrina (UEL), Department of Architecture and Urbanism

Adalberto Aparecido dos Santos Lopes [b]
Belo Horizonte, MG, Brazil
[b] Federal University of Minas Gerais (UFMG), Observatory for Urban Health

Renato Tibiriçá de Saboya [c]
Florianópolis, SC, Brazil
[c] Federal University of Santa Catarina (UFSC), Department of Architecture and Urbanism

Milena Kanashiro [a]
Londrina, PR, Brazil
[a] State University of Londrina (UEL), Department of Architecture and Urbanism

CCS is Architect and Urbanist, MSc. in Architecture and Urbanism, PhD student, e-mail: catharinacavasin@gmail.com
AASL is Research Assistant, PhD in Physical Activity & Health and Geoprocessing Specialist, e-mail: aadalberto@hotmail.com
RTS is Architect and Urbanist, Associate Professor, PhD in Civil Engineering, e-mail: renato.saboya@ufsc.br
MK is Architect and Urbanist, Associate Professor, PhD in Environmental and Development, e-mail: milena@uel.br
ED'O, Titular professor, Medicine, PhD in Epidemiology and Quantitative Methods in Health, e-mail: eleonora.dorsi@ufsc.br

Eleonora d'Orsi [d]
Florianópolis, SC, Brazil
[d] Federal University of Santa Catarina (UFSC), Department of Public Health

How to cite: Salvador, C. C., Lopes, A. A. S., Saboya, R. T., Kanashiro, M., & D'Orsi, E. (2024). Land use mix and walking for transportation in older adults: an approach based on different metrics of the built environment. *urbe. Revista Brasileira de Gestão Urbana*, v. 16, e20220211. https://doi.org/10.1590/2175-3369.016.e20220211

Abstract

The presence of land use mix (LUM) in a neighborhood has been shown as an important aspect to promote walking as a daily means of transport. However, few studies in the area have applied different measurement strategies to test their effect on alternative modes of travel behavior, such as older adults walking. We applied six LUM measures of land use mix in two neighborhood definitions (500 and 1000m network buffers) and assessed their associations with walking for transport outcomes in adults over age 60 years from the EpiFloripa Aging study, living in the municipality of Florianópolis, Brazil, in 2013/14. Accounting for sociodemographic and environmental variables, adjusted associations found a positive relationship between four LUM and walking. The entropy index and three alternative measures defined by the intensity of commercial and nonresidential uses were positively associated with the walking for transportation, regardless of neighborhood definition. Stronger positive associations were seen when using smaller buffers and measures of the proportion of commercial uses, proportion of nonresidential uses and destination density. The results show that alternative measurements can overcome the entropy index, pointing out the need to adapt LUM measures and neighborhood scale to the geographic context and age group under analysis.

Keywords: Walkability. Active transport. Physical Activity. Buffer. Entropy index.

Resumo

A presença de diferentes usos do solo em um bairro tem se mostrado um aspecto importante para promover a caminhada como meio de transporte diário. No entanto, poucos estudos na área aplicaram diferentes estratégias de mensuração para testar seu efeito em modos alternativos de comportamento de viagem, como a caminhada de idosos. Aplicamos seis medidas de uso do solo em duas definições de bairro (buffers de rede de 500 e 1000m) e avaliamos suas associações com a caminhada para fins de transporte em participantes (≥ 60 anos) do estudo EpiFloripa Idoso (2013/14) de Florianópolis, Brasil. Considerando variáveis sociodemográficas e ambientais, as associações ajustadas encontraram uma relação positiva entre quatro medidas e a caminhada. O índice de entropia e três medidas alternativas de intensidade de usos não residenciais associaram-se positivamente com a caminhada para transporte, independentemente da definição de bairro. Associações positivas mais fortes foram observadas ao usar buffers menores e medidas de proporção de usos comerciais, proporção de usos não residenciais e densidade de destinos. Os resultados mostram que medidas alternativas podem superar o índice de entropia, apontando a necessidade de adaptação das métricas e da escala de vizinhança ao contexto geográfico e à faixa etária em análise.

***Palavras-chave**: Caminhabilidade. Transporte Ativo. Atividade física. Buffer. Índice de entropia.*

Introduction

Aging is a worldwide demographic trend, posing the challenging issue of fostering wellbeing and health for a growing proportion of older adults. Active commuting in daily life is a key factor in promoting and encouraging healthy aging (Weiss *et al*., 2010; Giehl, 2014). Walking is indicated as a preventive and therapeutic measure for chronic diseases, recovery from disabilities and functional limitations, reduction of depression and anxiety, maintenance of independence and increased community involvement, and overall improvement in quality of life (Strawbridge *et al*., 2002; Lee & Park, 2006). Among older adults, walking for transportation purposes is the most popular type of walking and is strongly associated with attributes of the built environment (Michael *et al*., 2006; Barnett *et al*., 2017; Gharaveis, 2020; Y L; Yun, 2019).

As we age, our spatial area is reduced to the immediate vicinity, making the study of attributes at the community scale progressively more relevant (Lawton *et al*., 1978; Handy *et al*., 2002; Weiss *et al*., 2010). The access to diverse local destinations, such as stores, offices, services, and social interaction places within walking distance from the residence is one of the major factors affecting walking for transport (Handy & Clifton, 2001; Michael *et al*., 2006; Van Cauwenberg *et al*., 2012; Bordoloi *et al*., 2013; Barnett *et al*., 2017; Cerin, Nathan, *et al*., 2017; Yun, 2019). Systematic reviews highlight that the proximity to nonresidential destinations can promote active transport among older adults (≥65 years old) (Barnett *et al*., 2017; Cerin, Nathan, *et al*., 2017; Yun, 2019). Therefore, older people living in mixed use neighborhoods can increase their physical mobility, psychological well-being, independence and interaction with the community through walking for transport (Frank, Kerr, *et al*., 2010).

Land use mix (LUM) has been defined in a variety of ways and, as a result, its measures are not standardized (Handy *et al*., 2002). The most widely accepted and commonly used measure of LUM is the Entropy index (Bordoloi *et al*., 2013) whose formula captures the evenness of distributions of different uses in a given territorial unit, disregarding the impacts of the presence of qualitatively different uses for walkability. Thus, for instance, a neighborhood with an uneven proportion of parks, schools, residences and commerce will have a lower score when compared to a neighborhood with balanced commercial, unifamiliar and multifamiliar uses, but no recreational or educational uses. Some important distortions may arise from such way of measuring land use diversity, since areas in which residential and commercial land use is 60%/40%, respectively, will have an equal numerical result as an area in which the proportions of theses use are reversed (40%/60%) (Brown *et al*., 2009). Some authors also argue that broad quantitative measures of land use, such as entropy, can hide important qualitative differences within land use categories, leading to the debate of the suitability of the index as an indicator of the micro scale (parcels and blocks) LUM (Cervero & Kockelman, 1997; Brown *et al*., 2009). For instance, corner stores and automobile sales lots are usually classified under the same general category of commercial uses, despite very different potentials in generating and attracting walking trips. These limitations point out the need to explore alternative or complementary LUM measures (Christian *et al*., 2011; Gehrke & Clifton, 2016; Wei *et al*., 2016).

The lack of geographic comprehensiveness in available studies makes it difficult to generalize the findings (Gehrke & Clifton, 2016; Song *et al*., 2013). Brazilian research on the topic is scarce and few studies address this type of physical activity among older adults (Parra *et al*., 2011; Giehl, 2014; Hino *et al*., 2014; Rech *et al*., 2014). In addition, much of the evidence uses self-reported data about the environment, which have a low degree of agreement when comparing with neighborhood objective measures (based on GIS) (Kirtland *et al*., 2003; Michael *et al*., 2006). Objective measures of the built environment are mostly developed and applied in high-income countries, indicating limited evidence and the need to verify the application of these methods in other urban contexts with different spatial, cultural and demographic aspects (Christian *et al*., 2011; Koohsari *et al*., 2016; Yun, 2019).

Therefore, the main purpose of this study is to evaluate the performance of different land use mix (LUM) metrics, in search for those best able to reveal associations with walking in older adults. Additionally, we analyzed several environmental and sociodemographic factors, as well as the effects of different network buffers to explore the scale that most effectively represents the neighborhood area of this age group.

Methods

We used a representative sample of 919 older adults in Florianópolis, Brazil, obtained through the EpiFloripa Aging cohort study. Through face-to-face surveys, the study investigated the health and living conditions of older people (≥60 years) of Santa Catarina state's capital, located in the South of Brazil. The city has 574.200 inhabitants (IBGE, 2022) with 11.4% of the population over the age of 60 (IBGE, 2010).

Data from the second wave of the survey (2013/2014) were selected due to the temporal approximation with the built environment database (2010-12). Among the 1197 respondents, we excluded participants who, at the time of the interview, reported not having physical ability to walk; lived for less than a year in the reported neighborhood; had incomplete data; or had moved to other cities prior to the second wave. The research design was approved by the Ethics Committee and all participants consented to participate in it. Study design, sample, and data collection methods are documented in more detail elsewhere (Confortin *et al*., 2017; Schneider *et al*., 2017).

Study Variables

Spatial unit

To measure the individual's neighborhood environment, two scales of street network buffers were used around each participant's address: 500 and 1000 meters, corresponding to 10- and 15-minutes walking. The spatial unit was based on literature reviews (Cerin, Nathan, *et al*., 2017; Yun, 2019) and on the average walking speed of older people (0.86 meters/second) (Weber, 2016), maintaining comparability with existing literature. Therefore, the calculation of land use measures considered all the parcels comprised by the buffers, aggregating their respective data.

Walking for transportation

Data were obtained from the long version of the International Physical Activity Questionnaire (IPAQ) embedded in the Epifloripa survey, which has high comparability in different countries and good reproducibility in samples of older Brazilians (Benedetti *et al*., 2004; Benedetti *et al*., 2007). Respondents were instructed to report the activities performed in a normal/usual week, with a minimum duration of ten minutes.[1] Participants were then classified through a binary variable representing those that spent at least 10 minutes walking per week to access places such as stores,

[1] Questionnaire is available at: http://www.epifloripa.ufsc.br/category/inqueritos/epi_idoso/epifloripa-idoso-2013/questionario_id13

services, community centers, churches, and friends' and families' houses, and those that did not (Table 1).

Land-use Mix

Six LUM measures were used: (1) Entropy index (Jost, 2006); (2) Richness, defined as the total number of different uses in the buffer (Ritsema van Eck & Koomen, 2008); (3) Retail building coverage ratio (BCR); (4) Proportion of commercial and residential units; (5) Proportion of nonresidential and residential units (Hoek, 2008); and (6) Destination density (Hirsch *et al*., 2016) (Table 1).

Since, as argued before, measures that view Land Use Mix as equal balance of land uses have important limitations (Saboya, 2021), we also employed other types of measures to examine their performance and potential complementarity in characterizing this aspect. Richness quantifies the number of distinct land use types in the buffer and was included to account for a dimension of diversity that is poorly considered in the entropy measure. The Retail BCR measure, defined by the retail building floor area footprint divided by the plot size, indicates the presence of developments with substantial parking or greater setbacks, two factors believed to hinder pedestrian access (Frank *et al*., 2010). The measure, despite not strictly a diversity measure, was added to explore the intensity of commercial use and verify its suitability to the Brazilian context. Two other proportion measures were also used, considering broader categories of land use than the ones usually included in entropy measures, the rationale being that a more balanced proportion (50/50) between commercial (or non-residential) and residential uses is associated with higher degrees of street life (Hoek, 2008). Finally, the destination density takes into account the total number of non-residential destinations within reach in the buffer divided by its area, an aspect that is largely neglected in the other measures.

Individual variables

Individual variables included were gender (female/male), age group (60-74 years; 75-84 years; 85 or older), marital status (single/have a partner), education (no formal education; 1-4 years; 5-8 years; 9-11; 12 or more years of schooling); per capita household income (quartile); main type of transport (individual motorized; public transport; and active transport - on foot or bicycle); years living in the current address (1-10 years, 11 years or more); and perceived presence of nonresidential neighborhood destinations (Table 1).

Table 1 – Study variables: description, calculation and sources

Variables	Description	Measurement unity	Level	Source
Dependent variable				
Walking for transport	Participants were classified through a binary variable in two groups: those that spent at least 10 minutes walking per week to access places such as stores, services, community centers, churches, and friends' and families' houses, and those that did not.	Binary: 1 or 0	Individual	International Physical Activity Questionnaire (IPAQ) – EpiFloripa Aging study (2013/14)
Neighbourhood perception (Control)				
Commerce	Presence of supermarkets, convenience stores / mini markets / grocery stores, farmers' markets.	Perception of destinations availability within 15 minutes walking	Individual	Adapted version of the Neighborhood Environment Walkability Scale (NEWS)(Florindo *et al*., 2012) – EpiFloripa Aging study (2013/14)
Commerce and services	Presence of stores, bookstores, banks, pharmacies, beauty parlors, barbershops.			
Food services	Presence of restaurants, bakeries, snack bars, coffee shops.			
Social and health facilites	Presence of health centers or community centers			
Neighborhood Variables (Control)				
Average Slope	Average of slope values for each neighborhood (buffer).	Percentage (%)	Buffer	Florianópolis digital elevation model (DEM, 2012)
Buffer area	Area of the polygon formed by the buffer, which varies according to its radius and the connectivity of the road network around the residence.	Square kilometers (Km^2)	Buffer	Street network (PMF, 2012); EpiFloripa Home Addresses (2013/14)
Average per capita household income	Monthly nominal income of people aged 10 or over considering the average value of the census tracts included in the buffer.	Reais BRL (R$) Income quartiles	Buffer	IBGE Census (2010) Tabular data and census tracts
Independent Variables				
Land use balance	Entropy= $-\sum_{i=1}^{N}(pi \times \ln(pi))/\ln(N)$, where pi is the proportion of land use category i to total land use, and N is the number of land use categories: residential, commercial, services (including buildings with mixed use), institutions (religious and educational) and public services. The reduction to five categories followed previous studies (Frank & Engelke, 2005; Brown *et al*., 2009; Christian *et al*., 2011), excluding categories of non-walkable uses (industrial uses and vacant land).	Continuous variable normalized to values from 0 to 1	Buffer	Land Use data at parcel level (PMF, 2012).

Variables	Description	Measurement unity	Level	Source
Richness	Number of different land use categories in the buffer, considering nine categories: residential, commercial, industrial, mixed use, parks, services, religious institutions, public service and educational institutions.	1 to 9 land use categories	Buffer	
Retail Building Coverage Ratio – BCR	Ratio between the sum of the land area occupied by commercial buildings and the sum of the size of the parcels on which the buildings are located, considering all lots with commercial uses that touched the buffer polygon and its total area, regardless of whether they were completely inside the polygon boundary.	∑ commercial buildings area footprint (m²)/∑ commercial lots area (m²)	Buffer	Building footprint and Land Use at parcel level data (PMF, 2012).
Proportion of commercial and residential parcels	The relation between commercial and residential parcels within the buffer.	# commercial parcels/# residential parcels		
Proportion of nonresidential and residential parcels	The relation between nonresidential parcels (commercial, industrial, mixed use, parks, services, religious institutions, public service and educational institutions) and residential parcels within the buffer (Hoek, 2008).	# nonresidential parcels/# residential parcels	Buffer	Land Use data at parcel level (PMF, 2012).
Destination density	Number of parcels with non-residential uses divided by the buffer area.	# nonresidential parcels/Buffer area (km²)		

Abbreviations: PMF, Municipal Government of Florianópolis; IBGE, Brazilian Institute of Geography and Statistics; #: number.

Statistical Analysis

Descriptive statistics were calculated for individual and environmental variables. Prior to statistical modelling, Spearman's correlation coefficients were used to compare LUM scores. Multilevel logistic regressions (odds ratios and 95% confidence intervals) were used to analyze the association between walking for transportation (any walking, ≥10 min/week) and environment attributes, adjusting for individual covariates and perceptions of neighborhood destinations, considered here as a potential mediator. The rationale is that, in order for land use mix to exert any influence on respondents' behaviors, it should first be perceived by them as mixed. In addition, models were adjusted to take into account confounders at the neighborhood level: (1) average slope (%); (2) buffer area (km^2); (3) average mean income of the census tract sectors contained within the buffer area. All environmental measures, except richness, were normalized by a z-score. The analyses were performed using IBM SPSS Version 22.0 (Armonk, NY, USA) and Stata IC v.13.0 (StataCorp LP, Texas, USA), considering the design effect (cluster adjustment) and level of significance set at 0.05.

Results

The sample (*n*=919) consisted mostly of male and young older adults (60 to 74 years old) (see Table 2). A large proportion has lived in the neighborhood for at least 11 years, has a partner and more than half of the participants used private transport (car or motorcycle) as their main mode of transport. A large part of the sample reported walking for transport (70%) and reported the presence of commercial destinations, services, food services and public facilities in the neighborhood. The monthly per capita household income reflected socioeconomic inequalities, with half of the sample reporting an income of less than 2 times the minimum wage in 2013.

Most of the participants (70%, n=643) reported an active behavior, defined here as walking to access places for at least 10 continuous minutes in a typical week. However, the proportion of older adults who engaged in any walking for transportation was higher among women, with 60 to 74 years old, higher education (≥ 9 years of schooling) and those reporting the use of public transport. Perceived access to commerce, services and food services increased the chances of walking for transport.

Table 2 – Descriptive and multilevel logistic regression statistics showing association between the profile of the sample, perception of the environment and walking for transportation in Florianopolis, Brazil. EpiFloripa Ageing Cohort Study, 2013-2014 (n=919)

Variables	Categories	Total sample (n=919)		Walking for transport ≥ 10 min/week		
		n	%	OR	CI95%	p
Walking for transport	0 min/week	276	30,0	-	-	-
	≥10 min/week	643	70,0			
Individual Variables						
Sex	Female	248	38,6	1		
	Male	395	61,4	1,47	1,06-2,04	0,020*
Age (years)	60-74	409	63,6	1		
	75-84	207	32,2	0,68	0,48-0,94	0,022*
	≥85	27	4,2	0,49	0,24-0,98	0,045*
Marital Status	Single	279	43,4	1		
	Have a partner	364	56,6	1,07	0,77-1,47	0,668
Education (years of study)	No formal education	35	5,4	1		
	1-4	210	32,7	1,22	0,66-2,25	0,515
	5-8	111	17,3	1,48	0,75-2,93	0,251
	9-11	106	16,5	2,32	1,13-4,76	0,021*
	≥12	181	28,1	2,15	1,10-4,20	0,025*
Household per capita income (quartile)	R$ 80-723	145	22,6	1		
	R$ 724-1,392	157	24,4	1,00	0,65-1,54	0,972
	R$ 1,400-2,900	162	25,2	1,13	0,72-1,76	0,572
	R$ 3,000-23,000	179	27,8	1,43	0,89-2,28	0,134
Type of transport	Own car/motorcycle	322	50,1	1		
	Bus	307	47,7	2,85	2,01-4,04	<0,001*
	Walking/Cycling	14	2,2	1,17	0,43-3,20	0,747
Years living at current address	1 - 10	100	15,6	1		
	≥11	543	84,4	1,02	0,66-1,58	0,907
Neighbourhood perception†						
Commerce	Absent	44	6,8	1		
	Present	599	93,2	2,77	1,63-4,70	<0,001*
Commerce and services	Absent	78	12,1	1		
	Present	565	87,9	2,05	1,32-3,17	0,001*
Food services	Absent	55	8,6	1,00		
	Present	588	91,4	2,73	1,69-4,42	<0,001*
Social and health facilites	Absent	165	25,7	1		
	Present	478	74,3	1,35	0,93-1,96	0,107

OR: Odds ratios; CI95%: Confidence interval; p: p value; *: Statistical significance set to p<0.05; † : Data obtained from an adaptation of the Neighborhood Environment Walkability Scale (NEWS) (Saelens *et al.*, 2003) validated in Brazil (MALAVASI, 2006). Perceptions of the neighborhood destinations within 15min walking from participants' home.

Associations with household income, years living in the neighborhood and the presence of social and health facilities were non-significant (Table 2). Environmental values had great variability in the sample, indicating the presence of variations in the connectivity of the street network, land use mix, and natural aspects of the territory (see Table 3). The average slope of the neighborhoods shows that few of those included in the sample are in sharp inclined terrains, despite the presence of steep areas in the city.

Table 3 – Descriptive statistics of objectively measures of built environment in Florianopolis, Brazil. EpiFloripa Ageing Cohort Study, 2013-2014 (n = 919)

Built environment measures	Unit	500m Network Buffer			1000m Network Buffer		
		Mean	**SD**	**Min-Max**	**Mean**	**SD**	**Min-Max**
Built environment and sociodemographic							
Buffer area	Km2	0,249	0,107	0,026 - 0,512	1,153	0,391	0,355 - 2,167
Average slope (%)	%	10,968	7,034	1,317 - 41,310	12,300	6,622	2,161 - 40,025
Neighborhood income †	Brazilian Real (R$)	1.859,42	813,47	525,87 - 4.561,88	1.887,13	807,71	805,36 - 3.906,94
Land use mix ‡							
Land use balance - Entropy	0 - 1	0,214	0,120	0 - 0,512	0,368	0,155	0,087- 0,791
Richnessb	1 - 9	5,15	1,325	1-8	6,20	0,972	3-8
Retail Building Coverage Ratio – BCR (n=909)	commercial buildings area (m²)/commercial lots area (m²)	0,292	0,197	0,005 - 1,165	0,303	0,159	0,010 - 0,927
Proportion of commercial parcels	# commercial parcels/ # residential parcels	0,213	0,366	0 - 3,658	0,180	0,237	0,018- 1,247
Proportion of non-residential parcels	# non-resid. parcels/ # residential parcels	0,391	0,717	0 - 6,28	0,323	0,472	0,03 - ,54
Destination density	# non-resid. parcels/ buffer area (km²)	229,968	218,16	0 - 1.217,82	178,993	166,010	15,695 - 766,060

SD standard deviation, **Min** minimum, **Max** maximum; †: Neighborhood income was available at the census tract level using data from the national census (IBGE, 2010); ‡: Data obtained from the City Hall (Prefeitura Municipal de Florianópolis, 2012); #: number. All environmental measures, except richness, were normalized by a z-score.

Relationships among various measures of land use mix highlight four measures highly interrelated: commercial proportion, non-residential proportion, destination density and entropy (Table 4). Therefore, the increase in the proportion of commercial and non-residential uses may indicate a greater balance (entropy), on average, in the distribution of these uses in the neighborhood. Moreover, the moderate positive relationship between richness, entropy and density of non-residential destinations indicates that an increase in the presence of more land use categories (richness) is associated with the increase in the balance in the distribution of these uses (entropy) and a greater density of destinations in the neighborhood.

Table 4 – Correlations among land use measures in Florianopolis, Brazil (n = 919)

Spearman Correlation Coefficient	500-m Network Buffer					1000-m Network Buffer				
	1	2	3	4	5	1	2	3	4	5
1.Entropy	1,00					1,00				
2. Retail BCR	0,12*	1,00				0,24*	1,00			
3.Richness	0,53*	0,21*	1,00			0,26*	-0,02	1,00		
4.Commercial Proportion	0,82*	-0,002	0,24*	1,00		0,91*	0,16*	0,04	1,00	
5.Non-residential Prop.	0,94*	0,06	0,39*	0,95*	1,00	0,99*	0,22*	0,22*	0,94*	1,00
6.Destination Density	0,81*	0,26*	0,65*	0,68*	0,77*	0,77*	0,39*	0,44*	0,60*	0,75*

*: p < 0,05; 4. Commercial Proportion is represented by the Proportion of commercial and residences.

The affinities in the representation of LUM between the measures can also explain the strength of the relationships with walking behavior. After considering confounding variables, the interrelated LUM measures had strong and significant relationships with older adults walking for transportation: proportion of commercial uses; proportion of non-residential uses; destination density; and land use balance (Figure 1). The superior results of the measures of commercial proportion (OR = 2.13; $CI_{95\%}$: 1.31–3.47; 500m buffer) and proportion of non-residential uses (OR = 2.04; $CI_{95\%}$: 1.29 –3.22; 500m buffer) indicate that higher occurrences of commercial and non-residential uses increase by 113% and 104% the odds of walking for transport, respectively. Weaker associations were found for measurements computed in 1000m buffers, except for the entropy measure, which had a higher relationship with walking (OR=1.80; 95%CI; 1.35-2.39) in this radius. The odds ratios for built environment and sociodemographic measures, such as slope and neighborhood income, had no significant effect on walking. The relationship with the buffer area indicates that larger polygons, with a well-connected street network, increase the odds of walking for transport (OR=1.38; 95%CI; 1.10-1.73; buffer 1000m).

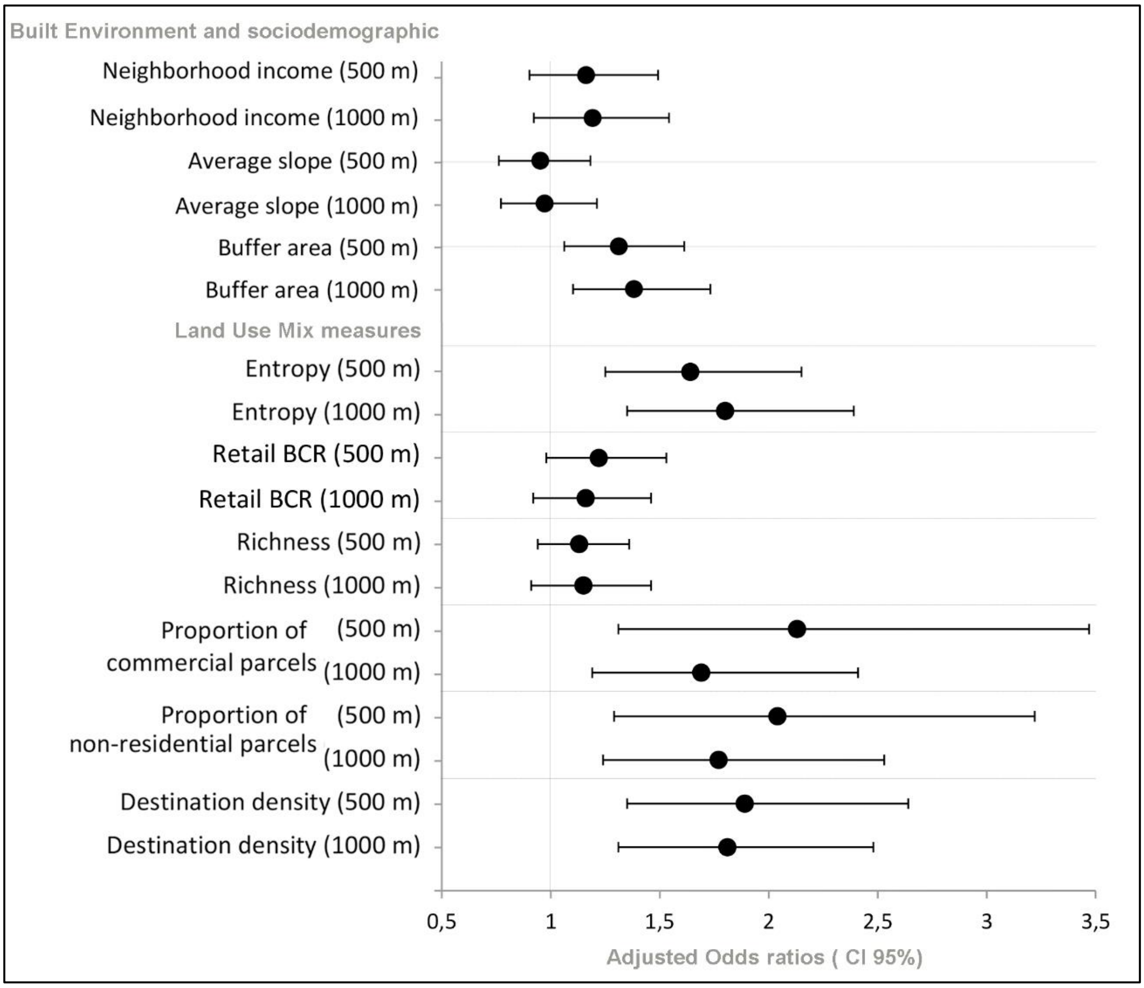

Figure 1 – Plot of adjusted odds ratios and 95% confidence intervals for objectively measured features of the built environment and walking for transportation (≥ 10 min/week). EpiFloripa Ageing Cohort Study, 2013-2014 (n=919). Statistical significance set to $p<0.05$; CI95%: Confidence interval.

Discussion

The results suggest that aspects of the built environment can influence older adults walking for transportation (WT) even when controlling for individual characteristics and neighborhood-level aspects such as slope and income. Positive associations were found between walking and physical characteristics of the neighborhood. Walking for transport for at least 10min/week was positively associated with being male; having higher education; using public transport; perceived presence of non-residential destinations in a 15-minute walking radius; and living in a neighborhood with street connectivity (network buffer area) and with land use mix (as measured by entropy, proportion of commercial parcels, proportion of nonresidential parcels, and nonresidential density, but not by retail BCR nor richness). On the other hand, age was negatively associated with walking.

The high rate of active participants can be explained by two factors: the high concentration of older people in the downtown area, a region that can be more walkable than other neighborhoods; and the investigated walking domain, which is more prevalent among older adults compared to the leisure domain (Neto, 2019). This reveals the value of WT as an accessible, easily integrated into the daily routine and low-intensity activity, which can play a key role for the health promotion (Van Holle *et al.*, 2014) and maintenance of an active life for older adults in general, and Brazilians in particular (Neto, 2019).

Among the six measures of land use mix (LUM), four showed strong and significant associations with walking, emphasizing that older people living in neighborhoods with a higher commercial proportion in relation to residences; greater non-residential proportion in relation to residences; more non-residential destinations per unit of area; and a higher land use balance (entropy), are more likely to walk for transport. The findings are consistent with previous studies with adults (Michael *et al.*, 2006; Hoehner *et al.*, 2005; Krizek & Johnson, 2006; Frank *et al.*, 2007; Hino *et al.*, 2014; Hirsch *et al.*, 2016) and older adults (Michael *et al.*, 2006; Van Cauwenberg *et al.*, 2012; Cerin *et al.*, 2013; Cerin, Mitáš *et al.*, 2017; Yun, 2019). In this sense, access to non-residential destinations in the neighborhood can be a key environmental correlate.

Relationships among LUM measures indicate that these measures associated with walking are also highly interrelated. Thus, although the calculation of the entropy index does not show the contribution of separate land use categories to diversity (Brown *et al.*, 2009), this study indicates that higher entropy scores can be an effective approximation to the presence of more mixed uses in the studied neighborhoods. However, the superior performance of alternative measures suggests that it is the presence of different land uses that can more strongly increase the chances of an older adult walking as a means of locomotion, not the balance of land use distribution based on entropy scores.

Our results also indicate that environmental variables associated with walking vary according to the neighborhood definition, emphasizing that 500m (10 min.) buffers can more effectively represent the neighborhood area of this age group. On the other hand, the entropy index had weaker associations with WT in the small neighborhood scale. Although the 1000m buffer associations were generally weaker in relation to the other measures, with the entropy index the strength of the relationships was greater in buffers of 1000 meters. The results are consistent with previous publications that found a greater entropy effect on travel mode choice on scores calculated at a relatively higher aggregated level (Zhang & Kukadia, 2005). Other previous research highlighted different results (Forsyth *et al.*, 2008; Brownson *et al.*, 2009; Lu *et al.*, 2018; Wei *et al.*, 2016). Divergences may be due to methodological discrepancies (such as land use categories included in the index) or geographic variations in the study area and participating populations (McConville *et al.*, 2011).

It is noteworthy that the simplification of land use categories to a count of richness reduced the possibility of contribution of different uses to walking and weakened the results. However, the moderately positive relationship of richness values with entropy and destination density values indicates that the increased richness can explain: a) the increase in balance in the distribution of uses (entropy); and b) a greater density of destinations in the studied neighborhoods. Likewise, the measure of retail BCR was not associated with walking, differing from results observed in North American cities (Wood *et al.*, 2010; Wei *et al.*, 2016). Although it is argued that a higher retail BCR can mean more choice of destinations within walking distance, no large retail activities (e.g. shopping malls), less parking space and more pedestrian comfort (Leslie *et al.*, 2007; Wei *et al.*, 2016), the results that found association with walking for transportation were not corroborated in the Brazilian context. Discrepancies indicate limitations and reinforce the need to apply alternative measures, appropriate to the urban context under investigation.

Having nearby destinations and mixed land use refers to only one of the three components of walkability: land use mix. Another attribute explored by walkability is design, here represented by the connectivity. The strong association between walking and the buffer area indicates that walking can be facilitated by optimizing the connectivity of the street network, that result in larger area neighborhoods. In other words, urban grids that maximize the reach through the network for a given radius tend to facilitate the access to more potential destinations and thus promote walking. A previous study with the first wave of EpiFloripa Aging cohort study reinforces this understanding (Giehl *et al.*, 2016).

This study has some limitations. First, the EpiFloripa Aging cohort study was not developed to investigate specific effects of the built environment on physical activity (PA), even though the database was an essential source of information for this work. Self-reported measure of WT may be subject to recall bias and IPAQ only capture activities of at least 10 min, which can be more than the usual commuting of some older adults. Pre-existing environmental data may have risks of inaccuracy in the degree to which they reflect reality. Further studies can explore monitored WT data and its variation over time by longitudinal designs. In addition, further research exploring the influence of qualified and safe amenities for the utilitarian walk is needed (e.g. the presence or absence of sidewalks and lighting, traffic volume and maintenance of places) (Hirsch *et al.*, 2016; Barnett *et al.*, 2017; Yun, 2019). Despite the limitations, our results show the significance of the associations and the impact of mixed land use in the social and health context.

Conclusion

Our findings indicate that urban planning and design policies that promote neighborhoods with access to non-residential destinations - such as markets, grocery stores, restaurants, retail stores and bakeries - may lead to more engagement in walking for transport, reducing motorized trips and promoting healthy behaviors among older adults. This study also identified that the less active groups are the oldest (above 85 years), women and people with lower education levels, indicating the need for urban and public health policies more adapted to these groups.

Studying physical activity environmental correlates means understanding ways to create healthier and sustainable communities, preparing cities for the future demographic trend. Directions for future research include analyses that evaluates the relationship of specific destinations to objectively measured walking or involve GPS-based spatial units of analysis. Longitudinal designs and verifications on the influence of socioeconomic aspects on the relationship between built environment and walking can be included.

Data availability statement

The dataset that supports the results of this paper is available at SciELO Data and can be accessed via https://doi.org/10.48331/scielodata.C8LYSR

Acknowledgements

Catharina Cavasin Salvador had a fellowship from CAPES - Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil - Code 001. The EpiFloripa Elderly cohort study (2013/14) was funded by Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) (nº 526.126/2013) and developed by the Federal University of Santa Catarina.

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Responsible editor: Geisa Bugs

Received: 10 out. 2022

Approved: 02 maio 2023