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Addressing pedestrian perceived externalities influenced by motor vehicles: A perspective from curb space typologies

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A R T I C L E I N F O

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A B S T R A C T

Pedestrian externalities are usually generated by motor vehicles on urban infrastructure. There is a part of such infrastructure, called curb space, that separates pedestrians from motor vehicles. The literature proposes four main curb space typologies regarding the right-of-way (i.e., no lateral separation, lateral separation with no vertical barriers, lateral separation with vertical barriers, and on-street parking). However, there is little research reporting on how pedestrians perceive the externalities, or on the effects of externalities considering the previously mentioned curb space typologies. The purpose of this study is to identify the influences of externalities on pedestrians from the latter's perspective and considers their interaction with the built environment. To do so, we collected 1014 pedestrian responses related to their relationship with motor vehicles on 30 different sidewalks and some objective information (e.g., sidewalk width) on those sidewalks. Using a structural equation model approach, we identified a latent variable related with the pedestrian perceived externalities, which was defined based on a multiple indicators and multiple causes model for each of the curb space typologies. It was found that socio-demographic characteristics have a greater influence on the perceived externalities on curb spaces with no vertical barriers. In contrast, for curb spaces with vertical barriers, it is the built environment and operational characteristics that have a greater influence. We also identified the built environment and operational attributes influencing the perceived externalities on each of the curb space typologies. This research provides the tools to propose public policies related to transportation infrastructure interventions to reduce pedestrian perceived externalities.

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(a) (b) (c) (d)

Fig. 1. (a) no lateral separation, (b) lateral separation with no vertical barriers, (c) lateral separation with vertical barriers, and (d) on-street parking.

1. Introduction

The planning and implementation of transportation systems have been key in addressing various urban challenges associated primarily with accessibility and connectivity. However, while doing so, transportation (mainly individual motorized transportation) has increasingly produced adverse effects in cities and on their inhabitants (Banister, 2008; Morar and Bertolini, 2013; Zegras, 2011), also referred to as negative externalities since they constitute a byproduct of the operation. Most authors agree on three kinds of externalities associated with transportation: (1) traffic congestion; (2) traffic crashes and incidents; and (3) negative environmental impacts such as pollution and greenhouse gas emissions (Croci, 2016; A. M. Das et al., 2013; Green et al., 2016; Morar and Bertolini, 2013; Pereira et al., 2016; Zegras, 2011). Other authors, in turn, propose that individual motorized transport is also associated with house value decreases, negative impacts on quality of life, social development (Croci, 2016), urban livability (Gössling, 2020), and public well-being (Zegras, 2011). Several strategies have been put to use around the world to diminish these externalities and their effects. Road pricing schemes, congestion and parking fees, or fuel tax (Croci, 2016; Pereira et al., 2016) are presented as strategies to internalize the societal costs of such externalities while discouraging individual motorized transportation.

Pedestrian activity is highly dependent on the effects of externalities (Gössling, 2020; Jones and Lucas, 2012; Lai and Kontokosta, 2018; Marois et al., 2018; Southworth, 2003; Yin, 2017), given pedestrians' direct contact with the built environment and vehicles while traveling (G. A. Barrero and Rodriguez-Valencia, 2021; Ma and Cao, 2019), and their valuation of the built environment attributes affecting their walking experience (Kim et al., 2014). Low levels of contamination (i.e., noise and pollution) and traffic and road safety had commonly been found as walking correlates (Bornioli et al., 2019; Ewing and Handy, 2009; Nieuwenhuijsen, 2020; Saelens et al., 2003; Samarasekara et al., 2011), which manifests the relationship between sustainable transportation (i.e., walking) and the assessment of externalities. Socio-economic characteristics have also served as mediators within this relationship (Pereira et al., 2016). It has been established that the impact of the externalities on pedestrians is higher in more impoverished communities (Currie et al., 2010; Lucas et al., 2016). For instance, Anbarci, Escaleras, and Register (2009) propose that lower-income communities are more susceptible to dying in traffic incidents. It has also been reported that people in such communities have limited access to vehicles and mostly travel using non-motorized modes and public transportation, increasing their exposure and vulnerability when incidents occur (Pereira et al., 2016).

Very few studies report externalities from the pedestrian perspective or explain their relationship with curb space. To contribute to filling this gap, this study aims to identify how pedestrians' perceived externalities are related to the pedestrians' characteristics (e.g., age), the built environment's characteristics (e.g., sidewalk width), and the operational characteristics (e.g., vehicular speed) from a curb space perspective. A latent variable approach was necessary given the subjective nature of the perceptions of externalities. The proposed latent variable was identified using the literature and defined using a Multiple Indicator Multiple Cause (MIMIC) model considering objectively measured characteristics and pedestrian subjectivity. To assess the heterogeneity of the infrastructure (i.e., curb space perspective), we based this study on four pedestrian infrastructure typologies, considering the separation between pedestrian and motor vehicle, proposed by Landis, Vattikuti, Ottenberg, McLeod, and Guttenplan (2001): (a) no lateral separation, (b) lateral separation with no vertical barriers, (c) lateral separation with vertical barriers (e.g., trees), and (d) on-street parking (Fig. 1).

This study provides the following contributions: (i) a quantification of the role of curb space to reduce pedestrian perceived externalities influenced by motorized vehicles by considering the main curb space typologies reported in the literature; (ii) an exploration of the influence of the externalities on pedestrians from their perceptions when walking with a definition of those externalities using objectively measured attributes from pedestrians, built environment, and operational attributes.

The rest of the paper is organized as follows. Initially, a review is presented to hypothesize a theoretical latent variable related to externalities from a pedestrian perspective. The methodology section then explains the data collection techniques and the modeling framework. This section is followed by a section presenting the results showing the identification of the externalities latent variable and the pedestrian, built environment, and operational characteristics influencing that latent variable on different curb space typologies. This result section is followed by a discussion and analysis section where the externalities from the pedestrian perspective are

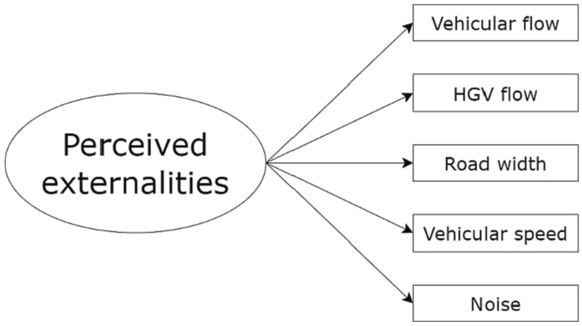


Fig. 2. Hypothesized latent variable perceived externalities.

discussed and analyzed in light of the existing literature. Finally, the last section presents the study's conclusions and provides some recommendations for further research.

2. Externalities and curb space from the pedestrian perspective review

Given pedestrians' direct contact with the built environment and surrounding elements while walking (G. A. Barrero and Rodriguez-Valencia, 2021; Ma and Cao, 2019), the walking activity is highly affected by externalities. The literature has identified characteristics within the built environment that mitigate externalities that affect pedestrians, highlighting those structures that allow social interaction and the observation of people's behavior (Evans, 2003; Leccese et al., 2000). Transparency, understood as pedestrians' capacity to see or perceive what lies beyond the limits of the public space, has been highlighted in the literature as a relevant aspect when assessing pedestrians' experience (Ewing, 2013). This aspect allows commuters to visually expand the public space and perceive a wider sidewalk while their attention shifts from the interferences with the motorized traffic to the human activity inside the buildings. Evans (2003) demonstrated that built environment features that encourage social interactions and the observation of people's behavior, such as transparency, mitigate the externalities that affect pedestrians negatively. The strengthening of these social relations enhances the pedestrian experience and positively impacts people's physical and mental health (Leccese et al., 2000).

On the other hand, a series of attributes or characteristics of the built environment have been found to strengthen pedestrians' perceived externalities negatively. The most relevant of these is the lateral separation between pedestrians and motorized traffic. A reduced lateral separation width worsens pedestrian experience as traffic noise and pollution become more intense (Dowling et al., 2009; Jensen, 2007; Landis et al., 2001; Vallejo-Borda et al., 2020). Also, non-continuous or uneven sidewalks and the density of pedestrian crossings lead to increased perceptions of danger between pedestrians and motorized vehicles (Rapegno and Ravaud, 2017; Schneider et al., 2004). Uneven sidewalks even create pedestrian distrust in the commute and could eventually lead to them getting off the sidewalk to optimize their mobility, thereby increasing vulnerability and incident risk (Pollack et al., 2014). Another element that can negatively affect the impact of externalities is the presence of a bicycle path on the sidewalk. Rodriguez-Valencia et al. (2020b) found that the pedestrian level of service (P-LOS) improved once cyclists were moved from the sidewalk to the road median. As the pedestrians do not continually have to look out for possible conflicts with bicycles, they reported a better overall experience when walking and a perception of there being less pollution and disturbances generated by motorized traffic.

Mozer (1994) initially presented an influence on the pedestrian sense of safety and aesthetic perspective. One of the proposed ways to increase pedestrians' perception of safety was by including barriers that separate them from motorized vehicle traffic. Landis et al. (2001) showed that besides lateral separation, other elements contribute to increasing the pedestrians' sense of safety when used to separate the pedestrians from motorized vehicle traffic. These elements include vertical barriers and on-street parking, and both, independently, can explain the P-LOS in the model presented by the authors. Likewise, for Jensen et al. (2007), these two elements independently appear as explanators of pedestrian satisfaction. However, in contrast to Landis et al. (2001), Jensen et al. (2007) found that the presence of on-street parking negatively influences pedestrian perceived satisfaction. Despite being different dependent variables (i.e., P-LOS (Landis et al., 2001) and perceived satisfaction (Jensen et al., 2007)) both evaluate the infrastructure's performance or service and present contradicting effects on pedestrians' infrastructure evaluation. This difference is explained by Jensen et al. (2007) as an effect of the difference between the kind of measuring strategy used to evaluate the dependent variable. Other authors have reported that pedestrians' perceived safety is related to the comfort they sense is provided by the infrastructure (Dandan et al., 2007; Jaskiewicz, 2000). In this respect, Landis et al. (2001) report that comfort can be improved by increasing lateral separations, which can also be related to on-street vehicle parking.

Pedestrian infrastructure evaluation has recently included pedestrian perception of the built environment rather than merely measuring objective attributes (e.g., sidewalk width or vehicle flow). Incorporating perceptions has provided richer source of information based on which to understand the built environment's impact on pedestrians' infrastructure assessment. In other words, a strong case has been made of supporting the exercise of mixing both objectively measured and subjective variables in service and performance evaluations of non-motorized users' infrastructure (Rodriguez-Valencia et al., 2021; Rodriguez-Valencia et al., 2020a). Having access to more comprehensive information on the factors that explain higher non-motorized LOS can also influence more active transportation, as proposed by Rahul and Manoj (2020) and Jahan et al. (2020), considering that travel behavior is influenced by user satisfaction (De Vos et al., 2021; Rodriguez-Valencia et al., 2021). Different studies using latent variables have been developed to evaluate the service or performance of non-motorized infrastructure (e.g., Geetha Rajendran Bivina and Parida (2019); Jahan et al. (2020); Vallejo-Borda et al., 2020b). Latent variable modeling favors accounting for heterogeneities (e.g., between people or groups) and has shown that structural relationships between the different variables can explain how users evaluate the infrastructure they are using.

Besides service, performance, safety, and comfort, few studies report externalities from the pedestrian perspective and/or explain their relationship with curb space. Externalities from the pedestrian perspective have been proposed in the past using a latent variable approach (Vallejo-Borda et al., 2020a, 2020b). Vallejo-Borda et al. (2020b) asked pedestrians about their perception of three different characteristics related to their interaction with motor vehicles (i.e., vehicular flow and speed, and heavy goods vehicles (HGV)) to identify the externalities latent variable. Similarly, Vallejo-Borda et al. (2020a) asked pedestrians about five different characteristics of their interaction with motor vehicles (i.e., road width, number of vehicular lanes, HGV flow, vehicular speed, and noise) to identify a similar latent variable. Other authors have also reported the relationship between pedestrians and motor vehicles from a road safety perspective. Bivina and Parida (2019) identified a latent variable called safety from the pedestrian perception of vehicular flow and speed. Mohanty, Chani, and Mohanta (2020) identified the same latent variable (i.e., safety) based on the pedestrian perception of six characteristics related to their interaction with motor vehicles (i.e., vehicular flow and speed, street crossing safety, traffic management and infrastructure, and safety from traffic).

In general, ten different indicators have been used in the literature to identify a latent variable related to the interaction between pedestrians and motor vehicles. Three of these are used by various researchers (i.e., vehicular flow and speed, and heavy goods vehicle (HGV) flow). Perceived crossing opportunity has also been included using other terms, including road width, number of vehicular lanes, and street crossing safety, which can all be represented by the perception of road width. Noise has appeared in the literature as a relevant attribute to explain externalities, and it was previously proposed by Vallejo-Borda et al. (2020a) as a pedestrian perceived externality indicator. Given that the literature had shown a similar latent variable, we proposed a perceived externalities latent variable using vehicular and HGV flow, road width, vehicular speed, and noise (see Fig. 2) as indicators. This latent variable was evaluated to confirm whether the attributes found in the literature could indicate a higher construct, which it did, allowing us to identify the objective attributes explaining this latent variable.

Particular considerations should be taken into account in terms of including subjective variables in these models. First, latent variables must include perceptions in the models since these variables can account for intangible and subjective evaluations that cannot be measured otherwise (Ortúzar and Willumsen, 2011). Secondly, latent variables are constructs evinced by more than one indicator (i.e., a set of responses to one particular perception question). Third, they can be explained by objectively measured attributes and/or other latent variables (Bollen, 2014; Kline, 2016).

3. Methodology

For this study, we considered the city of Bogota as it has been consolidated from a (mostly) informal urban development generating social inequalities when it comes to pedestrian infrastructure and transportation accessibility (Gómez et al., 2010). Green areas are not common in the localities where the lower-income population presents higher rates of walk commuting (Alcaldía Mayor de Bogotá, 2019). This, along with the low quality of sidewalks and road infrastructure in such areas, has resulted in an overall negative experience for pedestrians. The data collection process and the model development are explained in the subsections below.

3.1. Data collection

During the fieldwork, we collected information simultaneously from in-situ infrastructure audits and an interception survey at 30 different sidewalks around Bogotá, Colombia. The sidewalks were selected to attain a variety of street typologies and environments. The objective attributes that we measured on each sidewalk to define the latent variable of this study are presented in Table 1.

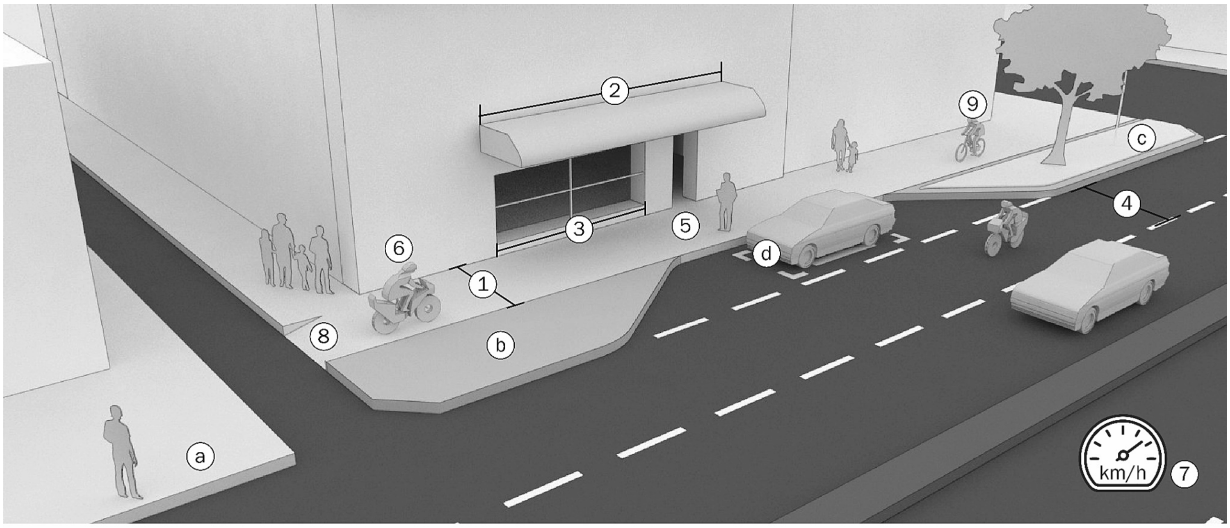
Sidewalk width, roof length, length of transparencies (i.e., elements that allow people to see inside the buildings), and outside lane width were measured in meters as absolute floor plan length. Ramps were calculated as the number of ramps counted during the in-situ audits on each sidewalk. Unpermitted flow on sidewalks was measured as the number of motorized vehicles (e.g., motorcycles, e-scooters) circulating on the sidewalk during each survey interview and expressed in five-minute periods. Bicyclist presence was determined as those cases where a bicycle flow is observed during each survey interview. Vehicular speed was calculated as the average of different speed measures using a Bushnell radar speed gun taken each minute during each survey interview. Finally, pedestrian space was measured as the sidewalk area (calculated as the multiplication between the sidewalk width and length) divided into the pedestrian occupation[1] of the sidewalk during each survey interview (Vallejo-Borda, 2019). Although vehicular flow was measured, it was not found to be significant explaining the hypothesized latent variable and was not included in the model to avoid an irrelevant variable bias. Fig. 3 shows a schematic representation of the different objectively measured attributes used for this study.

The questionnaire was based on the work of Rodriguez-Valencia et al. (2017) and has been used in other pedestrian studies (Bellizzi et al., 2019; Rodriguez-Valencia et al., 2020a; Rossetti and Hurtubia, 2020; Vallejo-Borda et al., 2020a, 2020b). The instrument was

[1] $Pedestrianoccupation = \frac{pedestrianflow * sidewalklength * 5minutes}{pedestrianspeed}$, where the pedestrian flow is expressed as the number of pedestrian in 5 min intervals, sidewalk length is expressed in meters, and pedestrian speed is assumed as 50 m/min (i.e., 3 km/h) (Vallejo-Borda, 2019).

Table 1
Sidewalk on-site objectively measured attributes.

Attribute	Units	Range
Sidewalk width	[m]	0.98 – 5.88
Roof length	[m]	0.00 – 89.65
Length of transparencies	[m]	0.00 – 345.00
Outside lane width	[m]	2.60 – 4.50
Pedestrian space	[m^2/ped]	1.98 – 1007.40
Vehicular speed	[km/h]	0.00 – 79.00
Unpermitted flow on sidewalk	[5 min]	0 – 15
Ramps	[Number]	0 – 3
Bicyclist presence	[yes/no]	0, 1



a. No lateral separation; b. Lateral separation with no vertical barriers; c. Lateral separation with vertical barriers; d. On-street parking 1. Sidewalk width; 2. Roof length; 3. Transparencies length; 4. Outside lane width; 5. Pedestrian space; 6. Unpermitted flow on sidewalk; 7. Vehicular speed; 8.Ramps; 9. Bicyclist presence.

Fig. 3. Schematic representation of curb space typologies and built environment attributes.

Table 2
List of measured indicators and socio-demographic characteristics.

Type	Question	Attribute
Indicators	Where 0 = it does not bother me at all and 10 = it bothers me a lot, rate, from 0 to 10, how much the following characteristics at this point of the sidewalk bother you.	Vehicular flow HGV flow Road width Vehicular speed Noise
Socio-demographic attributes	Sex (male = 0; female = 1) Age ($\leq 25; 26 - 40; 41 - 60; > 60$) Occupation (employee; student; self-employed; other) Marital status (single; married; domestic partnership; other)	

designed by researchers from the Sostenibilidad Urbana y Regional (SUR) research group at Universidad de los Andes. The instrument's content was validated using expert opinions through an individual aggregation and focus groups. To select the experts, their expertise and academic qualifications had to be corroborated to guarantee informed feedback (Escobar-Pérez and Cuervo-Martínez, 2008). Four experts were selected, all of them with PhDs from Universidad de los Andes and Universidad del Norte in Colombia; Pontificia Universidad Católica de Chile in Chile; and the University of California, Berkeley in the United States. The experts evaluated the instrument's items by considering their pertinence and representativeness in light of the desired measures (Pedrosa et al., 2014; Urrutia Egaña et al., 2014). This validation involved three stages: (i) individual aggregation using four national and international experts (Corral, 2009); (ii) generation of a collective consensus through two focus groups (Urrutia Egaña et al., 2014); and (iii) a pilot with 35 pedestrians selected on a sidewalk that was discarded from the collection process given of an over-representation of their

Table 3
Segregated descriptive statistics of the pedestrian survey.

Attributes				No lateral separation		Lateral separation with no vertical barriers		Lateral separation with vertical barriers		On street parking		All sidewalks	
On-site perceptions	**Vehicular flow**	Mean		5.25		3.21		4.26		4.20		4.23	
		Standard deviation		3.75		3.10		3.80		3.47		3.64	
		Frequency		Q1 = 2	62	Q1 = 0	68	Q1 = 0	125	Q1 = 0	54	Q1 = 0	286
				Q2 = 5	82	Q2 = 2	67	Q2 = 4	166	Q2 = 4	95	Q2 = 4	456
				Q3 = 9	54	Q3 = 5	70	Q3 = 8	116	Q3 = 7	55	Q3 = 8	263
	HGV flow	Mean		5.65		4.01		4.96		5.00		4.91	
		Standard deviation		3.81		3.60		3.78		3.67		3.76	
		Frequency		Q1 = 2	57	Q1 = 0	65	Q1 = 1	107	Q1 = 1	51	Q1 = 1	273
				Q2 = 6	87	Q2 = 4	76	Q2 = 5	198	Q2 = 5	84	Q2 = 5	399
				Q3 = 10	54	Q3 = 7	64	Q3 = 9	102	Q3 = 8	69	Q3 = 8	342
	Road width	Mean		5.39		3.02		3.03		3.43		3.57	
		Standard deviation		3.72		3.23		3.43		3.39		3.56	
		Frequency		Q1 = 2	56	Q1 = 0	81	Q1 = 0	178	Q1 = 0	75	Q1 = 0	376
				Q2 = 6	88	Q2 = 2	60	Q2 = 2	125	Q2 = 3	72	Q2 = 3	329
				Q3 = 9	54	Q3 = 5	64	Q3 = 6	104	Q3 = 6	57	Q3 = 6	309
	Vehicular speed	Mean		5.88		4.63		4.95		4.90		5.06	
		Standard deviation		3.38		3.58		3.70		3.45		3.59	
		Frequency		Q1 = 3	53	Q1 = 0	52	Q1 = 1	107	Q1 = 2	63	Q1 = 2	306
				Q2 = 6	87	Q2 = 5	99	Q2 = 5	165	Q2 = 5	82	Q2 = 5	381
				Q3 = 9	58	Q3 = 8	54	Q3 = 8	135	Q3 = 8	59	Q3 = 8	327
	Noise	Mean		8.01		6.99		7.73		7.28		7.55	
		Standard deviation		2.40		3.12		2.93		3.06		2.99	
		Frequency		Q1 = 6	50	Q1 = 5	64	Q1 = 6	189	Q1 = 5	56	Q1 = 6	311
				Q2 = 10	42	Q2 = 8	67	Q2 = 9	23	Q2 = 8	52	Q2 = 9	245
				Q3 = 10	106	Q3 = 10	74	Q3 = 10	195	Q3 = 10	106	Q3 = 10	458
Socio-demographic attributes	**Sex**	Male	Frequency	106		106		206		100		518	
			%	53.54 %		51.71 %		50.61 %		49.02 %		51.08 %	
		Female	Frequency	92		99		201		104		496	
			%	46.46 %		48.29 %		49.39 %		50.98 %		48.92 %	
	Age	Young (≤25 years)		76	38.38 %	81	39.51 %	149	36.70 %	57	27.94 %	363	35.83 %
		Young adult (26–40 years)		66	33.33 %	49	23.90 %	134	33.00 %	77	37.75 %	326	32.18 %
		Middle adult (41–59 years)		38	19.19 %	50	24.39 %	79	19.46 %	54	26.47 %	221	21.82 %
		Elderly (≥60 years)		18	9.09 %	25	12.20 %	45	10.84 %	16	7.84 %	104	10.17 %
	Marital status	Single	Frequency	114		112		231		120		577	
			%	57.58 %		54.63 %		56.76 %		58.82 %		56.90 %	
		Married	Frequency	28		44		76		42		190	
			%	14.14 %		21.46 %		18.67 %		20.59 %		18.74 %	
		Civil union	Frequency	46		38		80		32		196	
			%	23.23 %		18.54 %		19.66 %		15.69 %		19.33 %	
		Widowed	Frequency	2		4		3		4		13	
			%	1.01 %		1.95 %		0.74 %		1.96 %		1.28 %	
		Divorced	Frequency	4		3		4		1		12	
			%	2.02 %		1.46 %		0.98 %		0.49 %		1.18 %	
		Separated	Frequency	4		4		13		5		26	

(continued on next page)

Table 3 (*continued*)

Attributes				No lateral separation		Lateral separation with no vertical barriers		Lateral separation with vertical barriers		On street parking		All sidewalks	
			%	2.02 %		1.95 %		3.19 %		2.45 %		2.56 %	
	Occupation	Student	Frequency	49		59		106		36		250	
			%	24.75 %		28.78 %		26.04 %		17.65 %		24.65 %	
		Employed	Frequency	80		61		143		96		380	
			%	40.40 %		29.76 %		35.14 %		47.06 %		37.48 %	
		Unemployed	Frequency	13		14		31		10		68	
			%	6.57 %		6.83 %		7.62 %		4.90 %		6.71 %	
		Self-employed	Frequency	42		48		77		46		213	
			%	21.21 %		23.41 %		18.92 %		22.55 %		21.01 %	
		Retired	Frequency	7		16		20		10		53	
			%	3.54 %		7.80 %		4.91 %		4.90 %		5.23 %	
		Other	Frequency	7		7		30		6		50	
			%	3.54 %		3.41 %		7.37 %		2.94 %		4.93 %	
Built environment attributes	**Sidewalk width**	Mean		2.36		2.09		3.14		3.13		2.77	
		Standard deviation		1.02		0.68		0.94		1.54		1.15	
		Median		2.92		1.97		3.21		3.52		2.70	
		IQR		1.10 – 3.06		1.33 – 2.70		2.48 – 3.88		1.45 – 3.78		1.97 – 3.52	
	Roof length	Mean		48.09		35.51		24.86		29.55		32.49	
		Standard deviation		28.26		29.76		32.33		28.36		31.43	
		Median		49.60		40.10		0.00		24.25		33.68	
		IQR		35.30 – 75.00		0.00 – 68.60		0.00 – 47.90		0.00 – 52.22		0.00 – 52.20	
	Transparencies length	Mean		59.24		23.45		53.74		51.33		48.21	
		Standard deviation		130.44		23.22		42.28		43.04		68.31	
		Median		0.00		14.00		62.80		45.55		20.75	
		IQR		0.00 – 0.00		6.20 – 40.10		4.70 – 93.60		6.00 – 87.35		0.00 – 71.40	
	Outside lane width	Mean		3.46		3.17		3.25		3.76		3.38	
		Standard deviation		0.52		0.34		0.36		0.43		0.46	
		Median		3.50		3.00		3.25		3.80		3.40	
		IQR		3.20 – 3.70		2.90—3.40		3.00 – 3.45		3.40 – 4.10		3.10 – 3.60	
	Pedestrian space	Mean		71.53		38.23		29.32		52.71		44.07	
		Standard deviation		178.01		37.24		48.37		79.38		94.33	
		Median		26.50		27.00		14.38		29.33		19.41	
		IQR		10.94 – 51.00		11.60 – 49.25		7.93 – 27.33		11.81 – 71.12		10.00 – 48.66	
	Vehicular speed	Mean		28.86		25.48		35.00		26.78		30.22	
		Standard deviation		11.94		11.02		13.29		12.79		13.12	
		Median		27.00		23.00		33.00		24.00		28.00	
		IQR		20.75 – 34.00		19.00 – 28.00		27.00 – 43.00		19.00 – 33.75		21.00 – 37.00	
	Unpermitted flow in sidewalk	Frequency		0	187	0	195	0	342	0	174	0	898
				5	11	5	10	5	54	5	22	5	97
				10	0	10	0	10	8	10	2	10	10
				15	0	15	0	15	3	15	6	15	9
		%		0	94.44 %	0	95.12 %	0	84.03 %	0	85.29 %	0	88.56 %
				5	5.56 %	5	4.88 %	5	13.27 %	5	10.78 %	5	9.57 %
				10	0 %	10	0 %	10	1.97 %	10	0.98 %	10	0.99 %
				15	0 %	15	0 %	15	0.74 %	15	2.94 %	15	0.89 %
	Ramps	Frequency %		0	65	0	138	0	170	0	100	0	473
				1	133	1	0	1	135	1	35	1	303

(*continued on next page*)

Table 3 (*continued*)

Attributes			**No lateral separation**		**Lateral separation with no vertical barriers**		**Lateral separation with vertical barriers**		**On street parking**		**All sidewalks**	
			2	0	2	67	2	67	2	69	2	203
			3	0	3	0	3	35	3	0	3	35
		%	0	32.83 %	0	67.32 %	0	41.77 %	0	49.02 %	0	46.65 %
			1	67.17 %	1	0 %	1	33.17 %	1	17.16 %	1	29.88 %
			2	0 %	2	32.68 %	2	16.46 %	2	33.82 %	2	20.02 %
			3	0 %	3	0 %	3	8.60 %	3	0 %	3	3.45 %
	Bicyclist presence	Frequency	0	185	0	165	0	196	0	156	0	702
			1	13	1	40	1	211	1	48	1	312
		%	0	93.43 %	0	80.49 %	0	48.16 %	0	76.47 %	0	69.23 %
			1	6.57 %	1	19.51 %	1	51.84 %	1	23.53 %	1	30.77 %

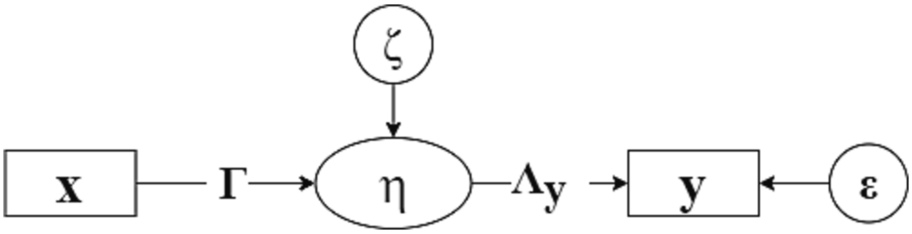


Fig. 4. MIMIC generic model.

characteristics.

The questionnaire included general perception questions and sidewalk-related perception statements or questions. It also contained questions relating to the pedestrians' specific trips and their socio-demographic characteristics. After depuration, we obtained 1014 responses from a sample distributed by age, sex, and income level into groups that reflect Bogotás population. The survey was applied from June 2 to June 19, 2018, during working days from 08:00 to 18:00. Each survey lasted approximately eight minutes, and the overall response rate was 33 %. Surveyors picked one in every three passing pedestrians to respond. For this paper, we only used the sidewalk-related perception questions according to the identified indicators presented in Fig. 2 and the socio-demographic characteristics (see Table 2).

We calculated the Cronbach's alpha to measure the internal consistency of the indicators, obtaining a reliability value of 0.78. As this is greater than 0.75, it can be considered acceptable in terms of reliability (Hernández Sampieri et al., 2014).

In this study, we intended to detect associations between four different curb space typologies presented in the literature review (i.e., no lateral separation, lateral separation with no vertical barriers, lateral separation with vertical barriers, and on-street parking). To do so, we calculated the required sample size using a power calculation. As recommended in the literature, to calculate the sample size, we assumed a significance level of 0.05, a power of 0.80, and an effect size of 0.3 (Hair Jr. et al., 2014). A minimum sample size of 176 responses per category was required. In the end, we collected 198 responses for sidewalks with no lateral separation, 205 responses for sidewalks with lateral separation and no vertical barriers, 407 responses for sidewalks with lateral separation and vertical barriers, and 204 responses for sidewalks with on-street parking. We used the R function "pwr.t.test" from the "pwr" package to calculate the sample size (Champely, 2018; R Core Team, 2019).

The last Bogotá origin–destination (OD) survey showed that 53 % of the travelers are women, while 47 % are men. The OD also shows that 37 % of the travelers are aged under 25, 23 % are aged between 26 and 40, 24 % are aged between 41 and 60, and 16 % are aged above 60. Concerning socio-economic strata (In Colombia, the socio-economic strata serve to differentiate people based on their income level, with 1 being the poorest and 6, the richest), 11 % of the travelers are classified as stratum 1, 39 % as stratum 2, 35 % as stratum 3, 10 % as stratum 4, 3 % as stratum 5, and 2 % as stratum 6 (Alcaldía Mayor de Bogotá, 2019). Table 3 presents the descriptive statistics of the collected data segregated by curb space typologies.

3.2. Definition of the perceived externalities latent variable

Latent variables are commonly identified from subjective information captured by asking users about their perception of different elements, and can not be directly measured (Ortúzar and Willumsen, 2011). Since the nature of the available information on externalities for this study is subjective (i.e., responses to how bothersome different traffic-related aspects are on a particular site), the appropriate approach is latent variable modeling.

Once the perceived externalities latent variable was confirmed (i.e., satisfactory adjustment levels according to Hair et al. (2014) and Schreiber et al. (2006)) we wanted to know which were the objective attributes that explained this unique latent variable. In this study, we used a forward, backward, and stepwise approach comparing the different results between them, where the non-significant relationships (i.e., t statistic values lower than 1.64) were rejected. This was perfomed for all the pedestrian infrastructure typologies considered in this study.

Latent variables are commonly used in advanced statistical methods such as structural equation models (SEM). To define a latent variable, a particular type of SEM model called multiple indicators and multiple causes (MIMIC) model (Bollen, 2014; Ortúzar and Willumsen, 2011; Schumacker and Lomax, 2016) should be used. The latent variable can be explained based on the objectively measured characteristics of both the infrastructure and its users using MIMIC models. In this case, there is only one latent variable (i.e., perceived externalities) and, hence, no structural relationship could be analyzed between latent variables, and no mediator variable or indirect effect analysis could be developed given the study objective. Our goal was to identify the direct effect of objective attributes on the latent variable, thus, we did not test any relationship between objective variables which implies that only two kinds of relationships will be estimated and reported (i.e., LV loadings on the indicators given by Equation (1) and the direct effects of the objectively measured variables on the latent variable given by Equation (2). Fig. 4 presents a generic MIMIC model.

MIMIC models are made up of a latent variable (η), indicators ($\mathbf{y}$), and objectively measured attributes ($\mathbf{x}$). The right side of Fig. 4 is called the measurement model and can be calculated using Equation (1). This part of the model reflects the existence of a latent variable that is indicated by pedestrian perceptions of something being bothersome, in the case of this study. The left side of Fig. 4 is the structural model and can be calculated using Equation (2). This part corresponds to the set of significant explanatory relationships

Table 4
MIMIC model goodness of fit indices.

Indicator	Explanation	Threshold accepted
Normed χ^2	This indicator measures the discrepancy between the sample and model covariances matrices corrected for degrees of freedom.	< 3.00
SRMR	This indicator calculates the square root of the difference between the sample and the hypothesized model covariances matrix residuals.	< 0.05
CFI	This indicator compares the proposed model χ^2 with a non-correlated model between latent variables.	> 0.95
RMSEA	This indicator determines the model fit to the covariance matrix of the sample with unknown coefficients.	< 0.05

between the built environment, operational, and pedestrians' characteristics (i.e., objectively measured variables) and the latent variables, as presented in Ortúzar and Willumsen (2011).

$$\boldsymbol{y} = \boldsymbol{\Lambda}_y \eta + \boldsymbol{\varepsilon} \tag{1}$$

$$\eta = \Gamma \mathbf{x} + \zeta \tag{2}$$

In Fig. 4 and equations (1) and (2), $\mathbf{y}$ represents the indicators vector that identifies the latent variable (i.e., vehicular flow, HGV flow, road width, vehicular speed, and noise); Λ_y is the coefficient vector that indicates the change in the value of the indicators if there is a change of one unit in the latent variable; η is the latent variable (i.e., perceived externalities); ε is the error vector associated with the indicators; Γ is the structural parameter row vector that indicates the change in the value of the latent variable if there is a change of one unit in the respective objectively measured attribute; $\mathbf{x}$ represents the objectively measured attributes column vector; and ζ is the latent variable random error term. For this study, we assumed the error terms (i.e., ε and ζ) to be normally distributed with an expected value of 0.

All the assumed relationships presented in Fig. 4 must be considered simultaneously, and the complete model fit has to be tested. To test the goodness of fit of the entire MIMIC model, we used absolute (i.e., normed χ^2 and SRMR), incremental (i.e., CFI), and parsimonious (i.e., RMSEA) fit indices (see Table 4). The literature also includes RMSEA as an absolute indicator (Gana and Broc, 2019).

We developed a MIMIC model for each of the typologies presented in the literature review (i.e., no lateral separation, lateral separation with no vertical barriers, lateral separation with vertical barriers, and on-street parking), following the process presented above. The coefficients obtained using the MIMIC model reflect the attributes' metrics and cannot be directly compared to each other. We used the standardized coefficients that indicate the expected increase of the dependent variable in standard deviation units to make them comparable (Gana and Broc, 2019). Using the standardized results of the different relationships, we quantified the influence of each objectively measured attribute (i.e., $\mathbf{x}$) on the perceived externalities latent variable. In the end, we grouped the objectively measured attributes to quantify the influence of each group (i.e., socio-demographic and built environment and operational attributes) considering the curb space typologies. The process presented above was developed using the R function "sem" of the "lavaan" package (R Core Team, 2019; Rosseel, 2012).

4. Results

Based on the MIMIC model, we defined the latent variable perceived externalities identified according to the pedestrian perceived interaction with motor vehicles (i.e., vehicular and HGV flow, road width, vehicular speed, and noise). We identified this latent variable for the different curb space typologies presented in the methodology section (i.e., no lateral separation, lateral separation with no vertical barriers, lateral separation with vertical barriers, and on-street parking). The statistically significant measurement model was obtained using standardized values to compare the typologies and is presented in Table 5.

We then identified the different socio-demographic, built environment, and operational attributes that statistically define the latent variable perceived externalities for each curb space typology. The MIMIC model of the perceived externalities latent variable was considered for each curb space typology based on fifteen attributes (socio-demographic, built environment, and operational) and five latent variable indicators. Fig. 5 shows the graphic representation of the perceived externalities MIMIC model tested for each sidewalk typology.

The standardized effects from the objectively measured attributes over the perceived externalities we identified in each sidewalk typology are presented in Table 6.

Based on the grouping of attributes proposed in the methodology section, we were able to quantify the effect of socio-demographic and built environment attributes on the perceived externalities. Using only the significant attributes for each group previously identified, in Table 7, we present the degree of influence that each group has on the pedestrian perceived externalities when walking.

The MIMIC model related to all sidewalks appears to fit the data well. The normed χ^2 is 1.88; SRMR is 0.04; CFI is 0.99; and RMSEA is 0.03. We did not conduct post-hoc modifications given the MIMIC model's good fit.

Table 5
Standardized parameters of the perceived externalities measurement model.

Indicator	No lateral separation	Lateral separation with no vertical barriers	Lateral separation with vertical barriers	On-street parking	All sidewalks
Vehicular flow (z)	0.85 (27.20)	0.92 (34.54)	0.91 (57.69)	0.92 (40.52)	0.90 (82.02)
HGV flow (z)	0.84 (30.32)	0.79 (22.89)	0.87 (50.02)	0.83 (28.46)	0.83 (63.46)
Road width (z)	0.71 (16.42)	0.66 (14.82)	0.63 (19.29)	0.72 (19.82)	0.67 (34.24)
Vehicular speed (z)	0.69 (16.03)	0.64 (13.21)	0.82 (38.96)	0.75 (22.91)	0.73 (42.43)
Noise (z)	0.41 (5.76)	0.16 (2.29)	0.47 (10.46)	0.54 (9.76)	0.43 (14.76)

Note: Standardized parameter coefficients are presented with their respective t-statistic in parentheses.

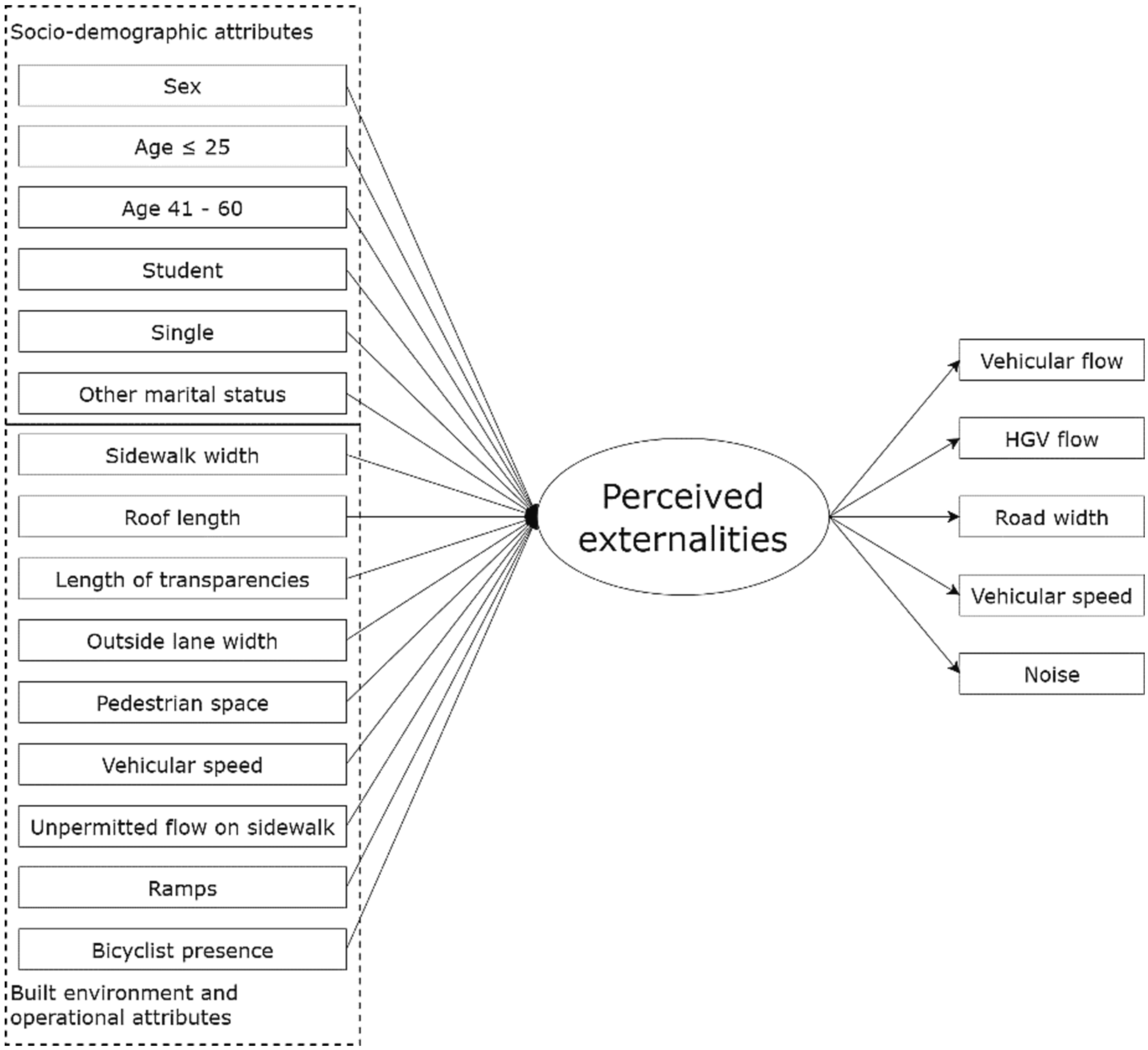


Fig. 5. Graphic representation of the perceived externalities MIMIC model.

5. Discussion and analysis

Despite the difficulty of modifying pedestrian socio-demographic characteristics, this study allowed us to identify the role of pedestrian subjectivity in the evaluation of the effect of externalities on different curb space typologies. Recognizing the individual and social characteristics of road users has been reported as relevant in terms of the design of functional road environments considering age, gender, and ability to move (Jiménez Martín et al., 2015; Moura et al., 2017; Pulvirenti et al., 2020). In this study, we also

Table 6
Standardized parameters of the perceived externalities structural model.

Attribute	No lateral separation	Lateral separation with no vertical barriers	Lateral separation with vertical barriers	On-street parking	All sidewalks
Sex (t)	−0.01 (−0.14)	**−0.13 (−1.71)**	−0.07 (−1.26)	−0.05 (−0.67)	−0.05 (−1.54)
Age ≤ 25 (t)	**−0.17 (−1.64)**	−0.03 (−0.23)	**−0.14 (−1.71)**	−0.11 (−1.08)	**−0.14 (−2.96)**
Age 41–60 (t)	0.10 (1.22)	0.13 (1.47)	0.07 (1.20)	**0.15 (1.96)**	**0.09 (2.50)**
Student (t)	0.05 (0.52)	**0.27 (2.68)**	0.08 (1.06)	−0.00 (−0.10)	**0.08 (1.80)**
Single (t)	**0.16 (1.70)**	**−0.24 (−2.54)**	0.07 (1.05)	−0.05 (−0.56)	0.03 (0.66)
Other marital status (t)	**−0.12 (−1.93)**	**0.18 (2.01)**	0.02 (0.47)	0.01 (0.16)	0.03 (0.79)
Sidewalk width (t)	−0.19 (−0.41)	0.08 (0.54)	−0.23 (−1.56)	0.14 (0.55)	**−0.14 (−3.44)**
Roof length (t)	0.22 (−0.29)	**0.23 (1.64)**	0.10 (0.74)	−0.14 (−0.73)	**0.15 (3.47)**
Length of transparencies (t)	0.16 (0.35)	−0.20 (−1.58)	**0.13 (1.69)**	**−0.42 (−2.06)**	**0.09 (2.11)**
Outside lane width (t)	0.06 (0.17)	−0.01 (−0.04)	**0.17 (2.01)**	**0.21 (2.05)**	0.05 (1.48)
Pedestrian space (t)	0.14 (1.30)	0.07 (0.81)	**−0.13 (−2.01)**	−0.03 (−0.37)	0.01 (0.36)
Vehicular speed (t)	−0.06 (−0.52)	0.04 (0.31)	−0.01 (−0.23)	**0.22 (1.99)**	0.01 (0.29)
Unpermitted flow on sidewalk (t)	−0.13 (−1.51)	0.02 (0.22)	0.01 (0.13)	**0.15 (1.89)**	0.01 (0.24)
Ramps (t)	−0.23 (−0.93)	**−0.32 (−1.78)**	−0.22 (−1.24)	−0.01 (−0.03)	**−0.11 (−2.68)**
Bicyclist presence (t)	**0.22 (3.33)**	0.17 (1.07)	−0.03 (−0.57)	0.13 (0.92)	0.03 (0.82)

Note 1: Standardized parameter coefficients are presented with their respective t-statistic in parentheses.
Note 2: The statistically significant coefficients (i.e., t statistic values equal or higher than 1.64) are shown in bold font.

Table 7
Influences of socio-demographic and built environment attributes on perceived externalities.

Curb space typology	Socio-demographic [%]	Built environment and operational [%]
No lateral separation	67.16	32.84
Lateral separation with no vertical barriers	59.85	40.15
Lateral separation with vertical barriers	24.56	75.44
On-street parking	13.04	86.96
All sidewalks	38.75	61.25

identified the influence of the built environment and operational characteristics on the perceived externalities, which can be easily modified to reduce perceived externalities from the decision-makers' perspective.

According to our results, it is easier to reduce pedestrian perceived externalities from built-environment interventions when the curb space typologies separate and protect pedestrians from motor vehicles. On those sidewalks with no lateral separation, the built environment and operational characteristics explain the smaller proportion of the perceived externalities (i.e., 33 %). On sidewalks with lateral separation but no vertical barriers, the influence of the built environment and operational characteristics increases, but remains as a smaller proportion (i.e., 40 %). These influences evince that pedestrian characteristics have a greater influence on curb spaces without vertical barriers making it challenging to reduce the perceived externalities from built environment interventions. In other words, the absence of physical elements separating pedestrians from motor vehicles increases pedestrians' awareness of their relationship with motor vehicles, increasing the perceived risk regarding road safety (L. H. Barrero et al., 2013). On the other hand, on sidewalks with vertical barriers, the built environment and operational characteristics explain the higher proportion of the perceived externalities (i.e., 75 %) reaching the maximum proportion on those sidewalks with on-street parking (i.e., 87 %). However, it is also relevant to consider that on-street parking may negatively affect pedestrian comfort (Jensen et al., 2007).

5.1. Socio-demographic influences on the perceived externalities

In terms of socio-demographic characteristics, it is interesting to see that of the people in the sample, women and people aged under 25 minimized their perception of externalities. On the other hand, people aged between 41 and 60 perceived an increased externality, mainly on curb space with on-street parking. These results may be supported by previous literature reporting that pedestrian interaction with curb spaces depends on age (Pulvirenti et al., 2020), gender, and capacity to move (Jiménez Martín et al., 2015; Pulvirenti et al., 2020). Thus, it may be that older people rationalize their relationship with road elements. The information presented above can be supported by that reported by Moyano and Mladinic (2001) regarding increased perceived road safety risk in older people because of their relationship with motor vehicles when walking. Similar behavior has been reported by (Martínez Ruiz et al., 2015) in women and extreme age groups (i.e., young people), making them a risk group for traffic incidents.

On sidewalks with a curb space that does not consider any separation, the socio-demographic characteristics have a greater influence on the perceived externalities. On curb space that includes only a lateral separation, some built environment attributes seem to be somewhat significant. According to our results, the presence of ramps appears to reduce perceived externalities, they provide access to different kinds of users, they are commonly-found on wide sidewalks, and they has been found to be a correlate of positive responses towards pedestrian infrastructure. On the other hand, roof length proved to increase perceived externalities. In curb spaces that do not include vertical separation, pedestrians are expected to more drastically perceive common adverse effects like noise and pollution because of the enclosure generated by facades and roofs.

5.2. Built environment and operational attributes influences on the perceived externalities

When the curb space includes vertical separation or on-street parking, the significance of built environment and operational attributes is enhanced (see Table 6) as are their influence (see Table 7) on perceived externalities. In infrastructures with these conditions, individual characteristics decrease their significance and influence, which implies that physical interventions would have a greater impact on perceived externalities. When the curb space includes vertical separation, increases in pedestrian space are associated with a decreasing perception of externalities. This finding, which is related to crowding, implies that the traffic externalities are intensified on denser sidewalks, sparking discussion around pedestrian volumes and pedestrian infrastructure. Commonly, pedestrian density has been used to assess P-LOS from a perspective of space use. However, based on our results, we suggest that such density is a mediator that influences the perception of motorized traffic externalities. Thus, assessing crowding from a perspective that considers the traditional influence on P-LOS and how externalities are perceived is a relevant action. In this case, pedestrian space acquires a unique relevance since vertical barriers might also constrain pedestrians' walking space (enclosure effect). Accordingly, increases in volume or pedestrian density can exert a negative effect on the pedestrians' perception of the infrastructure. As shown in the literature, pedestrian density and volumes have a negative effect on infrastructure service indicators such as perceived satisfaction and P-LOS (Jensen et al., 2007; Landis et al., 2001); thus, constrained space can decrease the service provided by the sidewalk when the volumes and densities increase. The literature has also shown that proximity and interference from other pedestrians can affect how the sidewalks are perceived and can even influence intentional avoidance behaviors (Ortiz-Ramirez et al., 2021), which highlights the importance of providing enough space for people to be able to walk freely.

In curb spaces with vertical barriers, outside lane width and the length of transparencies showed a positive association with perceived externalities. The former attribute, as expected, increases perceived externalities, since wider lane widths are correlates of higher vehicle speeds, which constitute everyday pedestrian stressors. The latter, however, shows a contradictory finding related to the effect of the length of transparencies, which allegedly increases sidewalk safety.

Likewise, externalities on infrastructure where on-street parking can be found seem to depend mostly on built environment and operational attributes, rather than on individual ones (see Table 6 and Table 7). Furthermore, in this kind of infrastructure, built environment and operational attributes show a higher impact on perceived externalities than the other three typologies. In this case, the length of transparencies reveals an expected negative association with perceived externalities. The above-mentioned association means that increased permeability of the adjacent buildings increases positive responses towards the infrastructure and the experiences and reduces perceived externalities. Furthermore, it can be expected that having a "solid" separation between lanes and sidewalk allows pedestrians to engage in activities that occur inside the buildings which are associated with interactions (Evans 2003). Outside lane width seems to be consistently associated with an increased perception of externalities, which is similar to the case of infrastructure with curb space considering vertical barriers where increases in width are positively associated with a greater impact on pedestrians' perceived externalities. From this perspective, in infrastructure where curb space includes a physical separation (i.e., vertical barriers or on-street parking), the effect of the width of the outside lane becomes relevant. Similarly, our results suggest that increases on the vehicular speed in this kind of typology, which can be related to wider lanes (FDOT, 2009; Landis et al., 2001; Transportation Research Board, 2010, 2016), also becomes pertinent as it increases pedestrian perceived externalities. The above-mentioned information coincides with the literature describing an adverse effect of traffic volumes and speed on pedestrian perceptions of stress (Mozer, 1994), QoS, and safety (Arellana et al., 2019).

5.3. Transversal considerations of the perceived externalities

When analyzing the results associated with the impact of the length of transparencies, we found that its effect varies depending on the typology. Although for curb spaces with on-street parking, it was found that the length of transparencies mitigates externalities, our results indicate that the effect is adverse when there is no discrimination by typologies. In other words, in contrast to Evan's (2003) findings, pedestrian perception of the externality becomes more acute, as the length of transparencies along the sidewalk increases. This result may be due to crowds and commercial activity in terms of noise and space occupancy. The counterproductive effect of transparencies on perceived externalities becomes more relevant in the lateral separation with vertical barriers typology (0.13 [1.69]) (see Table 6).

Our results highlight the relevance of the role of other sidewalk users (different from pedestrians and bicyclists) on pedestrians' perceptions. Besides other pedestrians and bicyclists on the sidewalks, we found that new users (e.g., e-bikes, motorcycles, e-scooters) increase the externalities perceptions on sidewalks with on-street parking. The interactions between pedestrians and these new sidewalk users, as expected, generate negative responses, mostly based on the differences in speeds and space use (Gibson et al., 2021). However, these new users and technology seem to be here to stay as gig-economy and shared- and micro-mobility have taken hold cities worldwide (Biloria, 2020; Mouratidis et al., 2021). Our results highlight the relevance of careful design for shared- and micro-mobility in areas with on-street parking. In these contexts, right-of-way space distribution can aim to separate flows to minimize the vehicles' interactions and disruptions for pedestrians (Gibson et al., 2021). Furthermore, on-street parking can be repurposed to provide space to integrate the new vehicles' stations instead of using pedestrian space.

As shown by the literature review and our results, different kinds of separation elements (i.e., vertical barriers and on-street parking) exert different effects on pedestrians' perceptions. Whereas both kinds of buffers comply with configurational invariance (i.e., the same latent variable is manifest in both groups (Kline, 2016), the objective variables explaining the perception of externalities were different as shown in the previous analyses. Furthermore, in terms of public policy, the implications of on-street parking involve more stakeholders than any of the other typologies. In other words, multi-agency efforts are relevant in this kind of typology since it compromises sidewalk and parking management agencies. Hence, the latter should consider the effect of implementing or eliminating a parking lane on pedestrian perceptions of externalities. Under this perspective, on-street parking gains a multifaceted perspective because it provides parking spots for drivers while decreasing pedestrian perceptions of externalities on adjacent sidewalks.

Even though sidewalk width did not appear to significantly influence perceived externalities for each typology, it becomes pertinent when assessing the whole set of streets in which the data was obtained as this aspect obtained the highest t-statistic value (−0.14 [−3.44]) (see Table 6). As evinced in the literature, wider sidewalks mitigate the effect of externalities as they expand the space for pedestrians helping to segregate them from the motorized traffic (Asadi-Shekari et al., 2013; Banerjee et al., 2018; G. R. Bivina et al., 2018; Nag et al., 2019; Raad and Burke, 2018). It also reduces the perceived enclosure that tends to darken the sidewalk and make it less attractive. Added to the fact that it minimizes interference with other pedestrians, anchorage is one of the variables that designers must take into account when creating infrastructures intended to mitigate externalities.

5.4. Policy implications

Public policy implications arose from these analyses. First, it is key to acknowledge that there are differences between the curbside typologies on pedestrians' perceptions which means that the curbside possibly requires different management strategies according to such differences. Our results proved that when there is no separation or the separation has no elements, the externalities' perception depends mostly on the individuals' characteristics which are not intervenable. However, when other elements appear in the curb space, built environment and operational characteristics play a more relevant role. This highlights the pertinence of implementing either vertical barriers and/or on-street parking to minimize the pedestrian perception of vehicle externalities. In terms of vertical separation, trees provide a sustainable alternative that also helps to mitigate and adapt urban environments to climate change effects (Pulighe et al., 2016), grant ecosystem services (e.g., (Torres et al., 2017)), and even increase land value (Grêt-Regamey et al., 2017). From this perspective, these spaces (i.e., lateral separation with trees as vertical barriers) can be planned and implemented as green infrastructures, which besides supplying the mentioned services, also contribute to mitigating the motorized traffic's externalities perceived by pedestrians. Hence, finding space to allocate such green infrastructure is crucial to fostering sustainable streets (Rodriguez-Valencia and Ortiz-Ramirez, 2021; Torres et al., 2020) and requires the development of sophisticated methodologies (e.g., (Torres et al., 2016, 2020)), particularly in the climate crisis that is affecting cities worldwide, and to control —at least partly— the negative effects of vehicular traffic on pedestrians.

On-street parking is another strategy that can be used to separate vehicular traffic from pedestrians. In terms of public policy, the considerations around on-street parking can be enriched by our research. Generally, parking management agencies determine the cities' streets where on-street parking is required, given the land uses, demand, and presence of off-road parking, among others (Roman et al., 2018). Our study proposes to add to this list the buffering effect of on-street parking on pedestrians. That is, parking management agencies can guide their decisions regarding on-street parking implementation, considering that pedestrians can benefit from such implementation. When considering the implementation of curbside parking, transparency on the first floors of adjacent buildings should be considered. As shown by our results, transparency can mitigate the perceived externalities in the presence of curbside parking because it provides the opportunity for interaction between pedestrians and the inside of buildings while it separates pedestrians from moving traffic. For this reason, first-floor transparency, despite not being a common factors to analyze when developing on-street parking, seems to be pertinent when it comes to choosing spaces to implement this kind of parking service. Generally, in commercial and business districts where on-street parking is very common (D. Das and Ahmed, 2018; Gragera and Albalate, 2016; Khaliq et al., 2019), pedestrians would have a minor perception of traffic externalities compared to other kinds of districts. This provides an opportunity to increase the coverage of on-street parking to different kinds of land uses or districts and, as such, increase the parking fee revenue while reducing pedestrian perception of the traffic externalities.

6. Conclusions and further research

This paper proposes a new approach based on which to consider externalities from users' subjectivity as well as actions concerning the built environment that could help reduce the perceived externalities in pedestrians and their effects. We identified that perceived externalities could be easily controlled and reduced via infrastructure and operational interventions on those sidewalks providing a clear horizontal and vertical separation between pedestrians and motor vehicles (e.g., on-street parking). We should also consider pedestrians' socio-demographic information, and built environment and operational characteristics related to externalities to enhance public policy effects to reduce pedestrians' perceived externalities.

Our results suggest that sidewalk audits should not only consider the existence of a curb space with lateral separation when assessing pedestrian infrastructure performance, as the walking experience is influenced by aspects beyond the physical attributes of the sidewalk. Additionally, classification by curb space typology highlights which type of attributes have the greatest effect on the latent variable related to the externalities perceived by pedestrians. Results indicate that externalities related to infrastructures with on-street parking and with horizontal and vertical separations are more likely to be explained by built-environment and operational variables than by socio-demographic variables. Hence, street designers have greater control over the externalities perceived by pedestrians on streets with this typology since they can control features associated with the physical space. Socio-demographic variables, on the other hand, can become more complex to control.

6.1. Limitations and further research

Further research can enrich the assessment of externalities from multiple perspectives. First, our proposed latent variable provides information on how pedestrians evaluate the externalities generated by traffic. Hence, it can be used as a proxy for the internalization of externalities. In other words, the latent variable proposed in this study can be used to price the impact of externalities on pedestrians within pricing schemes that contribute to demotivating private car use. In second place, further research could include the assessment of perceived externalities and their impact on mental health. Many studies have focused on measuring the impact of externalities on physical health but very few examine their impact on mental health. As such, we propose that future research could enrich our understanding of how perceived externalities can affect the mental health of pedestrians, and even bicyclists, who are the most exposed users on rights of way. We aso found that it would be useful to explore the relationship between the objectively measured attributes (e.g., vehicular flow) and the perception about such attributes, considering that not all the objectively measured characteristics were found significant to explain the latent variable identified through the perception of those attributes.

Further research can also focus on evaluating right of way redistribution and its impacts. As shown by our results, the curbside space and its characteristics affect pedestrian perceptions, and hence, a follow-up to this study could be an empirical research based on measuring the effects of temporary changes in space allocation. This proposed empirical research would serve two main purposes. First, to validate our findings and evaluate our results within different contexts where curbside parking is regulated (as opposed to the case of Bogota), which would be useful to propose a more generalized framework that contributes to decision-making processes. Second, to propose new right of way layouts that enhance the space use for different users, transportation technologies, and infrastructure (e.g., green infrastructure to mitigate effects of climate change).

CRediT authorship contribution statement

Jose Agustin Vallejo-Borda: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Writing – original draft, Writing – review & editing. **Laura Juliana Barchelot-Aceros:** Conceptualization, Data curation, Formal analysis, Investigation, Resources, Software, Supervision, Validation, Writing – original draft, Writing – review & editing. **German A. Barrero:** Conceptualization, Formal analysis, Investigation, Resources, Supervision, Validation, Writing – original draft, Writing – review & editing. **Hernan Alberto Ortiz-Ramirez:** Conceptualization, Formal analysis, Investigation, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. **Daysy Katherine Pabón-Poches:** Conceptualization, Data curation, Formal analysis, Investigation, Resources, Software, Supervision, Validation, Writing – original draft, Writing – review & editing. **Claudia Susana Silva-Fernández:** Conceptualization, Data curation, Formal analysis, Investigation, Resources, Software, Supervision, Validation, Writing – original draft, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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