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Equity issues and the *PeCUS* index: an indirect analysis of community severance

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ABSTRACT

Urban barriers are often a consequence of the unplanned expansion of transport infrastructures, housing growth nearby existing transport infrastructures, and the vehicular traffic itself. This process, also known as "community severance", is a problem that affects the travel patterns of the population and causes negative impacts to adjacent communities, but it is not easy to assess. As an alternative to the costly technologies and restricted-access data sometimes used to analyze urban barriers, we propose an analytical approach that assesses community severance levels by classifying the quality of Pedestrian Crossings on Urban Streets (the *PeCUS* index). Additionally, the approach is used to identify possible inequities nearby the different classification groups regarding demographic data. We used the chi-square (χ2) test of independence and the standardized Pearson residuals to indicate deficits and excesses of residents regarding the demographic characteristics studied surrounding the urban streets. We found the following evidences of associations: residents with low-income or those aged up to 19 tend to live close to the worst crossings, whereas residents with permanent mobility constraints or the elderly tend to live near the crossings with the best classifications. Therefore, the study shows that the assessment of community severance by the analysis of the *PeCUS* index is feasible. Moreover, it reveals that the distribution of residents surrounding the distinct classes of quality of crossings is equitable for vulnerable social groups, except for low-income or young residents.

1. Introduction

Urban barriers are often a consequence of the unplanned expansion of transport infrastructures (railways, freeways, roadways, urban streets, etc.), housing growth nearby existing transport infrastructures and the vehicular traffic itself (Lara 2019). This process, also known as "community severance", is a problem that affects the travel patterns of the population and causes negative impacts to adjacent communities.

Community severance is characterized by physical barriers to walking trips (Soguel 1995; Guo, Black, and Dunne 2001; Mouette and Waisman 2004; Anciaes et al. 2016) and to the access to goods, services, and people (Scholes et al. 2016; Mindell et al. 2017) as a consequence of transport infrastructures, usually those with high traffic volumes and speeds (Guo, Black, and Dunne 2001; Anciaes 2015; Anciaes et al. 2016; Scholes et al. 2016). In addition, psychological barriers are related to community severance as well, separating local communities (Taylor and Crawford 2009; Scholes et al. 2016), affecting perceptions, behavior, stress (Appleyard and Lintell 1972; Hine and Russell 1993; Hart and Parkhurst 2011), well-being, health (Timperio et al. 2006; Foley et al. 2017; Nimegeer et al. 2018), social interactions (Appleyard

and Lintell 1972; Davis and Jones 1997; Hart and Parkhurst 2011; Scholes et al. 2016; Nimegeer et al. 2018) and intensifying social exclusion (Rajé 2004; Mackett and Thoreau 2015) of people who live or use the surrounding areas or need to make trips throughout or across the infrastructure or traffic stream (Anciaes 2015).

There are some social groups that are more susceptible to te effects of the community severance. In the literature, we identified that the elderly, children (Hine 1996; Mouette and Waisman 2004), residents who have a long-standing illness (Scholes et al. 2016; Foley et al. 2017), adults who need to accompany another individual with restricted mobility (Mouette and Waisman 2004), and people aged up to 19 years old and a particular lower income group (Lara and Rodrigues da Silva 2019) correspond to the social groups mainly affected.

Regarding crossing facilities, they are sometimes not favorable to pedestrian movements. Due to the type of crossing facility, its conservation status, location, on-site public lighting, among other factors, there may be pedestrian delays, risks of trampling, robbery, or violence (Lara 2019). Additionally, according to the study conducted by Mindell et al. (2017), in

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general, the presence of a median strip aids pedestrians crossing the road, by splitting the crossing into two stages. However, in many cases, median strips can become an additional barrier, if they have steps or uneven surfaces, making them inaccessible to people with mobility restrictions. The study results indicated that participants prefer to avoid crossing roads with no crossing facilities, that the level of the barrier effect of roads on pedestrians was positively related with the road characteristics (number of lanes, traffic density, and traffic speed), and that the presence of a median strip decreased the barrier effect. Another study considering road characteristics (number of lanes, presence of a median strip, traffic density, and traffic speed) was developed by Anciaes, Jones, and Metcalfe (2018), which indicated that pedestrians prefer to avoid crossing roads with more than one lane, no median strip, medium or high density, and speed equal or above 30 miles per hour. In addition, convenience, and distance of the crosswalk (Sisiopiku and Akin 2003), direct crossings (Cantillo, Arellana, and Rolong 2015), level crossings (DNIT 2010) were pointed out as pedestrians' crossing preferences. On the other hand, pedestrian bridges, high traffic flow (Cantillo, Arellana, and Rolong 2015), underground passageways, and footbridges (DNIT 2010) were identified as less preferable. Moreover, elderly people, particularly those with health-related mobility constraints, and children were identified as more likely to cross streets using crossing facilities (Hine 1996).

Other aspects related to community severance that urban planners are concerned about are the inequalities in the distribution of different social groups nearby transport infrastructures, the quality of the facilities used for crossing these transport infrastructures, and the exposure to transport-related externalities. Concerning equity, Litman (2002) presented two categories: horizontal and vertical. Horizontal equity involves the distribution of resources equally to each individual or group, whereas vertical equity implies in the distribution of resources according to each individual's or group's special needs in order to ensure they are not worse off, and that their needs are accommodated. In this study, we used the vertical equity concept.

Therefore, community severance affects day-to-day events and the behavior of people who have diverse demographic characteristics, and at different levels. The analysis of this interdisciplinary effect often involves many variables and tools, which can demand qualified and well-trained professionals (e.g. for specific data collection procedures), commitment from the target population, costly technologies, and restricted-access data (Lara 2019). For this reason, the combination of census data (although highly aggregated), open access data, and free Geographic Information System software into a single approach,

whenever possible, may save time, effort, and financial resources. It can also help to answer the following questions: Is it possible to assess community severance by analyzing the quality of pedestrian crossings? Is there any evidence of associations between the distribution of residents with distinct demographic characteristics nearby urban barriers and the quality of pedestrian crossings? Is this distribution vertically equitable?

In this paper, we propose a simple and low-cost analytical approach to assess community severance based on a classification of the quality of pedestrian crossings carried out with the Pedestrian Crossings on Urban Streets index, hereafter named *PeCUS*. Furthermore, the approach identifies possible inequities regarding demographic data in the surroundings of the distinct classes of streets identified with the index. After this brief introduction, in Section 2 we describe the study area, the databases, and the analytical procedures adopted. In Section 3, we present and discuss the results and in Section 4, the conclusions are outlined. Finally, in Section 5, recommendations for future work are indicated.

2. Materials and method

This study presents an analytical approach to assess and classify the quality of pedestrian crossings on urban streets, given that the streets themselves sometimes become barriers to cross walking. The method is also used to identify possible inequities in the surroundings of the distinct classification groups, as shown in the case study conducted in a Brazilian city.

2.1. Study area

The study area comprises a significant part of the urban area of São Carlos, which is a medium-sized city located in the state of São Paulo, Brazil (Figure 1), and it is part of a more comprehensive research initiative. For this reason, it is nearly the same area selected by Lara and Rodrigues da Silva (2019) to approach community severance caused by another transport infrastructure, a railway.

The population considered for this study comprised 213,010 inhabitants (IBGE 2010) spread over 83.5 km², 295 census tracts, and 13 weighting areas. Weighting areas correspond to geographical partitions formed by a mutually exclusive group of areas that follow technical restrictions concerning contiguity and size defined by the Brazilian Institute of Geography and Statistics (or IBGE, which in Portuguese stands for *Instituto Brasileiro de Geografia e Estatística*).

Relevant demographic characteristics of the study area are as follows: average monthly nominal income of R$ 1,601.71, 36,000 inhabitants with some level of self-declared disability (13,213 of which with
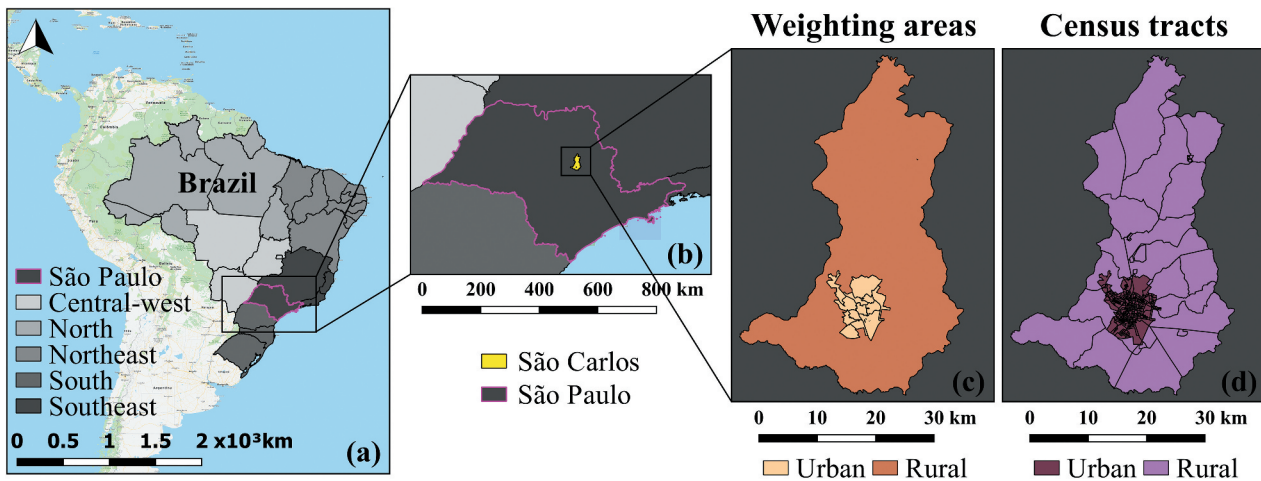
Figure 1. Location of the state of São Paulo in Brazil (a) and of the city of São Carlos in the state of São Paulo (b). São Carlos subdivisions into weighting areas (c) and census tracts (d).

permanent mobility constraints), 108,795 female residents (with an average age of 38.0 years old), and 104,215 male residents (with an average age of 35.8 years old) (IBGE 2010).

The urban street network of São Carlos is typically laid out in a grid pattern comprising local streets, collector streets, and arterial streets (primary and secondary). This functional classification of urban roads follows guidelines defined by the National Department of Transport Infrastructure (or DNIT, which in Portuguese stands for *Departamento Nacional de Infraestrutura de Transportes*) from 2010.

2.2. Databases

The assessment of vertical equity among residents within a determined area of influence was based on the following data from the 2010 Demographic Census: classes of monthly nominal income, groups of permanent mobility constraints, gender, and age. The databases have different levels of aggregation. Income and mobility constraint data are available only for weighting areas, whereas data on gender and age are available at census tract level. In addition, the spatial distribution of the population was based on the statistical grid from the 2010 Demographic Census, which is available online in shapefile format. The statistical grid comprises a system of regular cells, in which cells in urban regions are 200 m × 200 m.

In summary, four 2010 census databases with the spatial distribution of the population were used: conditions of individual mobility, income, gender, and age. In addition to the demographic data, we used the geographic database from the Open Street Map (OSM) to create the urban street network.

2.3. Data analysis procedures

The assessment of community severance was made by measuring and classifying the quality of pedestrian

crossings. Afterwards, possible inequities were identified by estimating the number of inhabitants that have specific demographic characteristics in areas nearby streets with different classes of quality. The procedures of the proposed method are summarized in Figure 2.

An urban street network map was generated using the Open Street Map (OSM) database and the free software package *Quantum GIS v.3.4.4*. Unpaved streets, private streets, parking lots, railways, and streams were not included in the map. Then, with the urban street network map containing only public urban streets, a sample of urban streets was selected by simple random sampling, in which the sample size was determined at a 95% confidence level and a 10% margin of error.
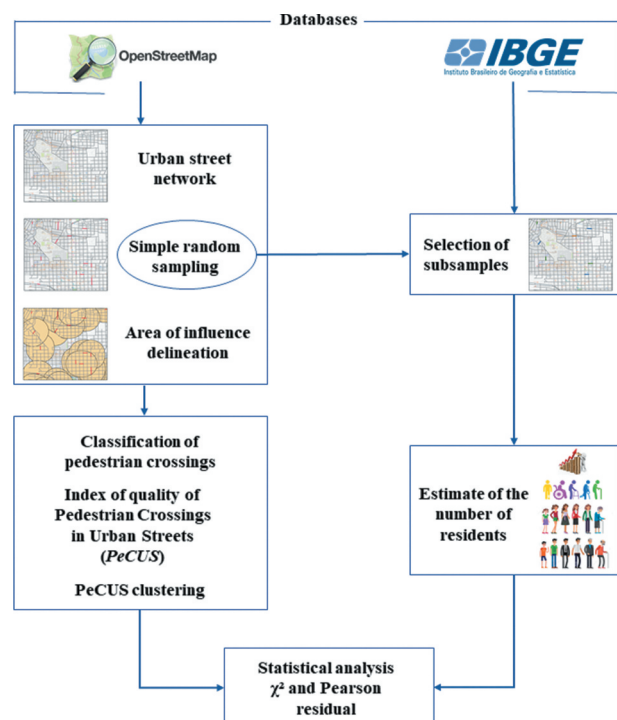
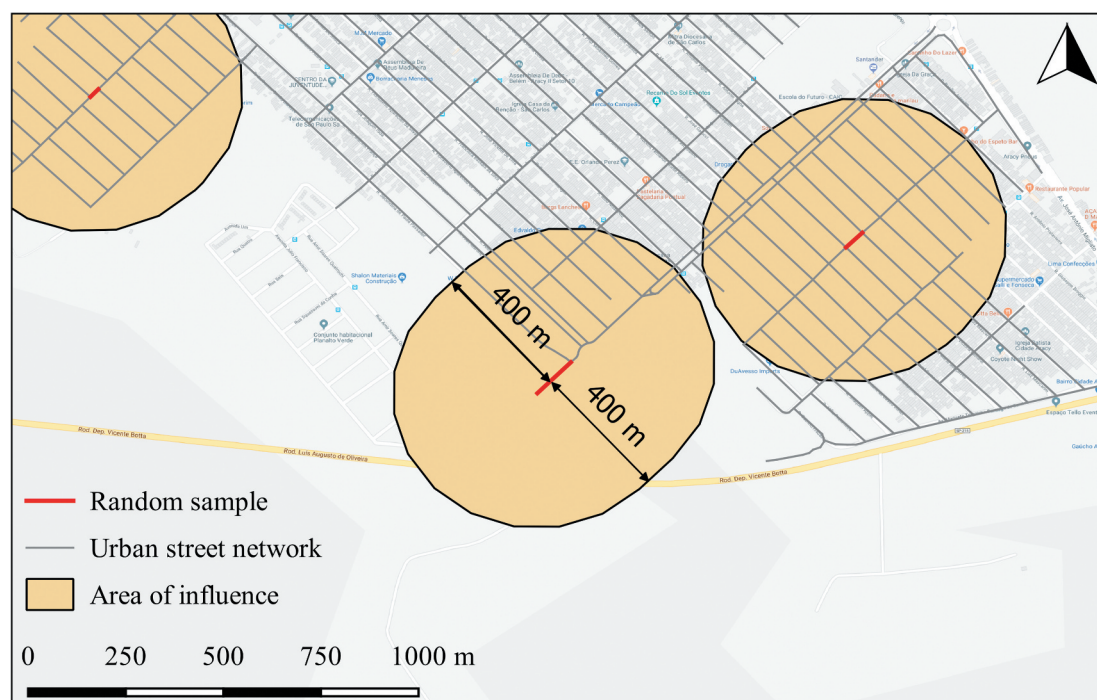**Figure 2.** Overview of the method. Source: Lara (2019)

Figure 3. Overview of the method. Source: Lara (2019)

A band of 400 meters was defined as the area of influence of the selected streets (Figure 3), as suggested by Anciaes et al. (2019). The band area was used for classifying pedestrian crossings on urban streets (e.g. number of crimes, number of inhabitants) and for estimating the demographic characteristics of residents in the streets' surroundings.

The classification of pedestrian crossings was based on 14 criteria (Table 1) related to: the geometric design of the streets, available pedestrian infrastructures, population within the selected 400-m band, safety, and maintenance conditions, as well as land use. For each criterion, score values ranging from 0 to 1 were assigned. Score 0 corresponds to the worst mobility conditions for pedestrians and score 1, to the best conditions, as indicated in Table 1. The criteria were evaluated by two specialists in the area of urban and transportation planning. Concerning the classification of pedestrian crossings on urban streets, each street was considered as an independent case. Therefore, the overlapping areas of influence did not affect the results obtained.

This combination of criteria was defined as the *PeCUS* (Pedestrian Crossings on Urban Streets) index. As the total sum of scores varies according to the quality of crossings for pedestrians, the *PeCUS* index also reflects, but inversely, the variation of trip impedances and the access of pedestrians to goods and services (and by extension, the level of community severance).

As indicated in Figure 2, we performed a cluster analysis to classify objects into groups that are highly internal (within-cluster) homogeneous and highly external (between-cluster) heterogeneous (Hair et al. 2010). We used a k-means algorithm to form the clusters. This algorithm divides the data into a user-specified number of clusters and then iteratively reassigns observations to clusters until the distance of observations from one another in a cluster is minimized and the distance between clusters is maximized (Hair et al. 2010). Thus, we conducted a cluster analysis to group the *PeCUS* index results into six classes ranging from A to F. Class A corresponds to the best quality of pedestrian crossings and F corresponds to the worst evaluation. The number of classes was based on the six pedestrian levels of service (LOS) from the Highway Capacity Manual (HCM, 2010).

The sampled streets were then classified (from A to F) regarding the quality of pedestrian crossings. Next, we examined the demographic characteristics of the residents in the streets' surroundings. However, in order to look for evidence of associations between the variables through a chi-square ($\chi2$) test of independence, each unit of the sample must be counted only once, that is, each observed element must be allocated in only one cell of the contingency table. For this reason, overlapping areas of influence must be avoided and a selection of subsamples without overlapping areas of influence became necessary.

Three subsamples were randomly selected from the original sample in such a way that only the segments that have bands that do not overlap with the bands of the segments already chosen were kept in the subsample. The new subsamples were used to estimate the number of residents within non-overlapping 400-m bands regarding the variables of range of monthly

Table 1. Summary of the criteria assessed for classifying pedestrian crossings on urban streets, as suggested by Lara (2019).

Criterion		Description	Category (score)
Geometric design	Functional classification	Urban street functional classification (DNIT 2010)	Local (1.00); collector (0.67); secondary arterial (0.33); primary arterial (0.00)
	Traffic direction	One-way or two-way direction	One-way (1.00); two-way (0.00)
	Number of lanes	Number of lanes per direction	1 (1.00); 2 (0.67); 3 (0.33); 4 or more (0.00)
Pedestrian infrastructure	Zebra crossing	Presence and type of zebra crossing	Raised (1.00); at level (0.50); absence (0.00)
	Zebra crossing location	Attractiveness of the zebra crossing location	Very attractive (1.00); attractive (0.67); not attractive (0.33); absence of zebra crossing (0.00)
	Pedestrian visibility	Driver's pedestrian visibility at intersections	Total (1.00); moderate (0.75); regular (0.50); poor (0.25); none (0.00)
	Mandatory stop	Presence of vertical and/or horizontal "STOP" signs at intersections or presence of traffic lights	Two-phase traffic light (1.00); three-phase traffic light (0.80); vertical and horizontal "STOP" signs (0.60); vertical "STOP" signs (0.40); horizontal "STOP" signs (0.20); absence (0.00)
	Median	Presence of median strip and pedestrian accommodation possibility in the median strip	Allow pedestrian accommodation (1.00); do not allow pedestrian accommodation (0.50); absence (0.00)
	Accessibility	Presence and maintenance conditions of curb ramps on both sides of the pedestrian crossing	Excellent (1.00); good (0.80); regular (0.60); poor (0.40); very poor (0.20); absence (0.00)
Safety	Number of crimes (including homicides)	Annual[a] crime rate per 1000 inhabitants combined with the annual[a] death rate per 1000 inhabitants (SSP/SP[b])	Very low (1.00); low (0.75); regular (0.50); high (0.25); very high (0.00)
Population	Number of inhabitants	Number of inhabitants within the 400-meter band	Regular (1.00); high (0.75); very high (0.5); low (0.25); very low (0.00)
Maintenance	Public lighting	Quality of public lampposts (location of lampposts was provided by the city hall)	Excellent (1.00); good (0.80); regular (0.60); poor (0.40); very poor (0.20); absence (0.00)
	Salubrity	Intensity of the presence of garbage and vegetation	Excellent (1.00); good (0.75); regular (0.50); poor (0.25); very poor (0.00)
Land use	Land use	Land use around the selected urban street	Commercial (1.00); mixed land use – commercial and residential (0.75); residential (0.50); institutional (0.25); industrial (0.00)

[a]Between 2010 and 2017.
[b]Extracted from the open data website of the Public Security Secretariat of São Paulo (in Portuguese: *Secretaria de Segurança Pública de São Paulo – SSP/SP*)

nominal income, permanent mobility constraints, gender, and age (using weighting areas and census tracts accordingly).

Finally, in order to accept or reject the null hypothesis of independence between the variables (H_0), we used the chi-square ($\chi 2$) test of independence in contingency tables built from the variables of the different databases studied. In addition to calculating the chi-square ($\chi 2$) value and its corresponding p-value, we computed the standardized Pearson residuals (Equation 1), which allows a direct comparison between each cell of the contingency table. Thus, the chi-square ($\chi 2$) test of independence was used to assess the evidence of association between the variables, whereas the standardized Pearson residuals were used to better understand the nature and the degree of dependence between the variables.

$$SPR = \frac{Observed - Expected}{\sqrt{Expected \cdot \left(1 - \frac{row_{total}}{Total}\right) \cdot \left(1 - \frac{column_{total}}{Total}\right)}} \quad (1)$$

where SPR corresponds to the standardized Pearson residual, *Observed* corresponded to the observed counts and *Expected* corresponded to the expected counts, row_{total} indicates the sum of the observed counts in the row, $column_{total}$ indicates the sum of the observed counts in the column, and *Total* indicates the sum of all observed counts.

A standardized Pearson residual that exceeds about 2 or 3 in the absolute value indicates that the cell greatly contributes to the chi-square ($\chi 2$) value and does not fit the H_0 (Agresti 2018). Larger values are more relevant when the degrees of freedom are larger, and it becomes more likely that at least one is larger simply by chance.

3. Results

The street network generated using the Open Street Map database comprised 13,329 segments of public urban streets, which are represented in gray in Figure 4. Based on the resulting map, we selected a sample of segments of urban streets by simple random sampling. The sample size corresponded to $n_0 = 100$ segments of urban streets (at a 95% confidence level and with a 10% margin of error), as highlighted in red in Figure 4.

Thereby, considering the sample of segments of urban streets selected and the area of influence defined as a band of 400 m, the segments were classified. The classification was carried out according to a qualitative assessment of the 14 criteria described in Table 1. Next, the sum of all criteria resulted in the *PeCUS* index value for each segment.

Additionally, we conducted a cluster analysis to group the *PeCUS* index results into six classes,
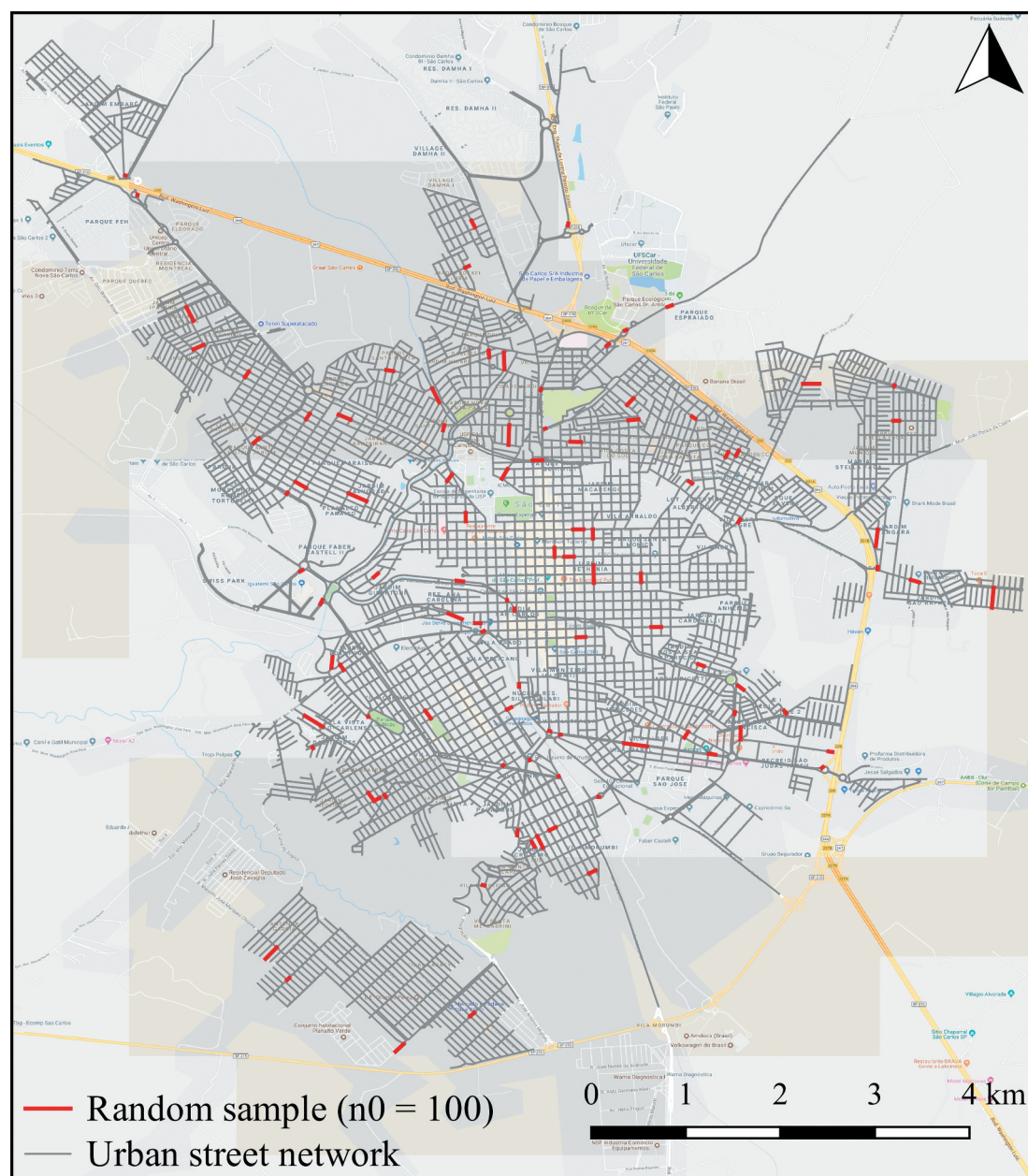
Figure 4. Urban street network, in gray, and random sample (n_0 = 100 segments), highlighted in red.

ranging from A to F, using the k-means clustering algorithm. Class A corresponds to the best quality of pedestrian crossings and F corresponds to the worst evaluation. The F-test correspond to 514.765 with a *p*-value inferior to 0.050, which indicates a good clustering quality. The number of segments grouped in each class of the *PeCUS* index is presented in Table 2. In addition, Table 3 contains the results for the highest and lowest *PeCUS* index per class, as well as their respective scores for each criterion assessed.

Table 2. Number of segments of urban streets assigned per class.

Class	A	B	C	D	E	F
Number of cases	4	9	21	31	26	9

In order to estimate the number of residents within the area of influence of 400 m, three subsamples were randomly selected from the original sample (n_0 = 100). The subsamples resulted in n_1 = 38, n_2 = 35, and n_3 = 37 segments. This was done to avoid overlapping areas of influence in the sample units. The number of residents within the area of influence was estimated for each subsample, regarding the variables of range of monthly nominal income, permanent mobility constraints, gender, and age.

Using the free software package *Quantum Gis v.3.4.4*, we calculated the distribution of inhabitants according to the class of the *PeCUS* index regarding residents' demographic characteristics, per subsample, as shown in Figures 5–9.

Figure 5 indicates an overview of the distribution of the residents for each variable per class of the *PeCUS*

Table 3. Results of the highest and lowest values for the *PeCUS* index and their corresponding scores for each criterion assessed (indicated by the segment's ID).

	ID[a]											
Criterion	13062	332	335	12917	8235	1087	2969	9867	2422	5321	145	4546
Class	A	A	B	B	C	C	D	D	E	E	F	F
PeCUS	11.86	10.71	10.14	8.89	8.27	7.14	7.07	6.17	5.92	5.02	4.92	3.62
Functional classification	0.67	0.67	0.67	0.67	0.33	0.67	1.00	1.00	1.00	1.00	0.00	1.00
Stream direction	1.00	1.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00
Number of lanes	0.67	0.67	1.00	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67
Zebra crossing	0.50	0.50	0.50	0.50	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Zebra crossing location	0.67	0.67	0.67	0.00	0.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pedestrian visibility	1.00	0.50	0.50	0.50	1.00	1.00	0.50	0.00	0.00	0.00	1.00	0.00
Mandatory stop	1.00	0.60	0.00	0.60	0.20	0.00	0.20	0.60	0.20	0.40	0.00	0.00
Median	1.00	1.00	1.00	1.00	0.50	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Accessibility	0.80	0.80	1.00	0.40	0.60	0.00	0.00	0.40	0.00	0.00	0.00	0.00
Number of crimes	0.75	0.75	0.50	0.50	0.75	0.50	1.00	0.50	0.75	0.25	0.25	0.50
Number of inhabitants	1.00	1.00	1.00	1.00	0.25	1.00	1.00	1.00	0.25	0.25	0.00	0.00
Public lighting	0.80	0.80	0.80	0.80	0.80	0.80	0.20	0.00	0.80	0.20	0.00	0.20
Salubrity	1.00	1.00	0.75	0.50	1.00	1.00	1.00	0.50	0.75	0.75	1.00	0.25
Land use	1.00	0.75	0.75	0.75	1.00	0.50	0.50	0.50	0.50	0.50	0.00	0.00

[a]Identification number of the segments of urban streets in the GIS database.
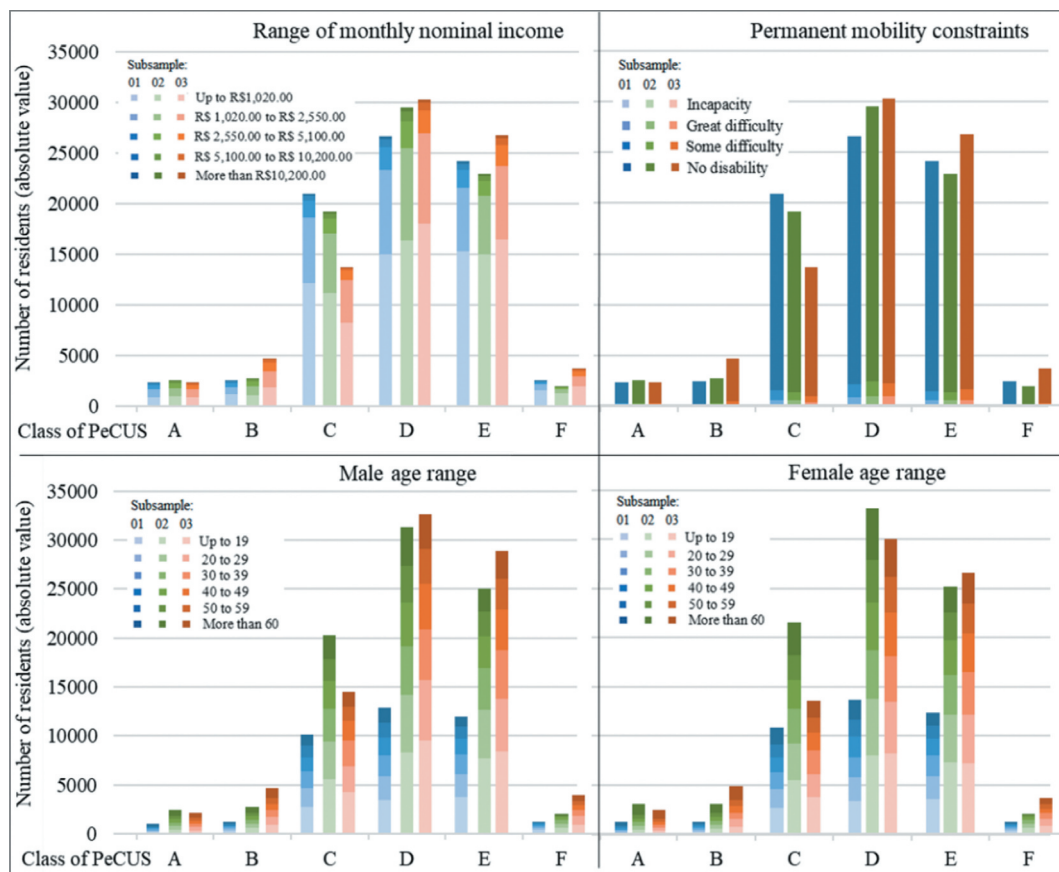
Figure 5. Number of residents distributed by class of the *PeCUS* index, for each subsample and for each variable.

index and by subsample, in absolute values. Figures 6–9 provide an overview of the main categories in the classes of the *PeCUS* index, per variable and per subsample, in percentage values.

Figure 6 indicates that more than half of the residents in classes C, D, E, and F have a monthly income below R$ 1,020.00, whereas the portion of the population with an income greater than R$ 5,100.00 that lives near classes A and B is about twice as large as the portion that lives in classes C, D, E, and F. In Figure 7, it can be observed that around 11.0% of the population has some level of self-declared permanent mobility constraints. Furthermore, the proportion of residents with some difficulty in walking or climbing stairs without the help of another person is higher among the residents that live near class A. Moreover, most of the population that lives near class A streets are over 60 years old, and this proportion is higher among
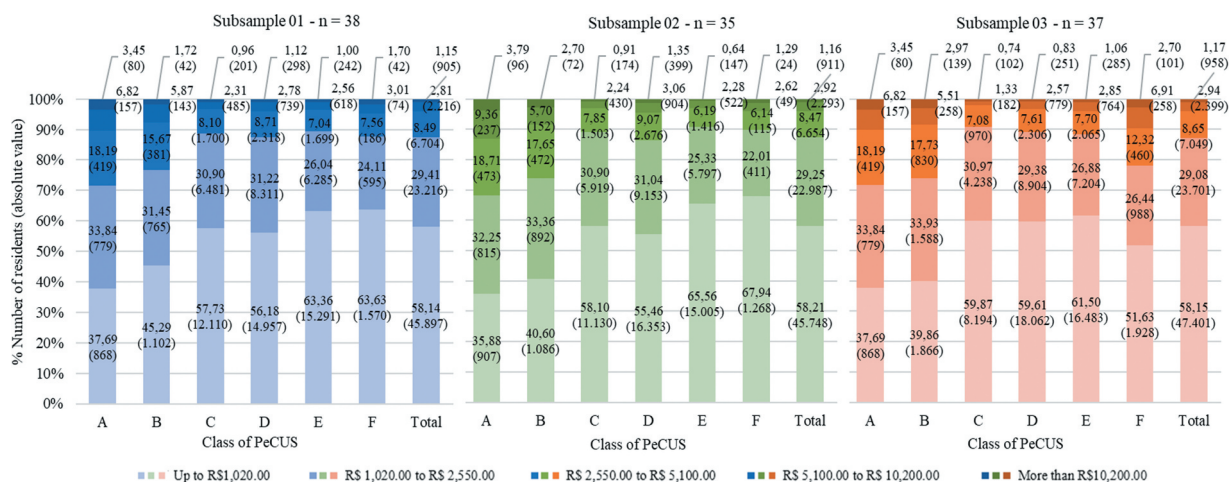
Figure 6. Number of residents by range of monthly nominal income distributed by class of the *PeCUS* index, for the three subsamples.
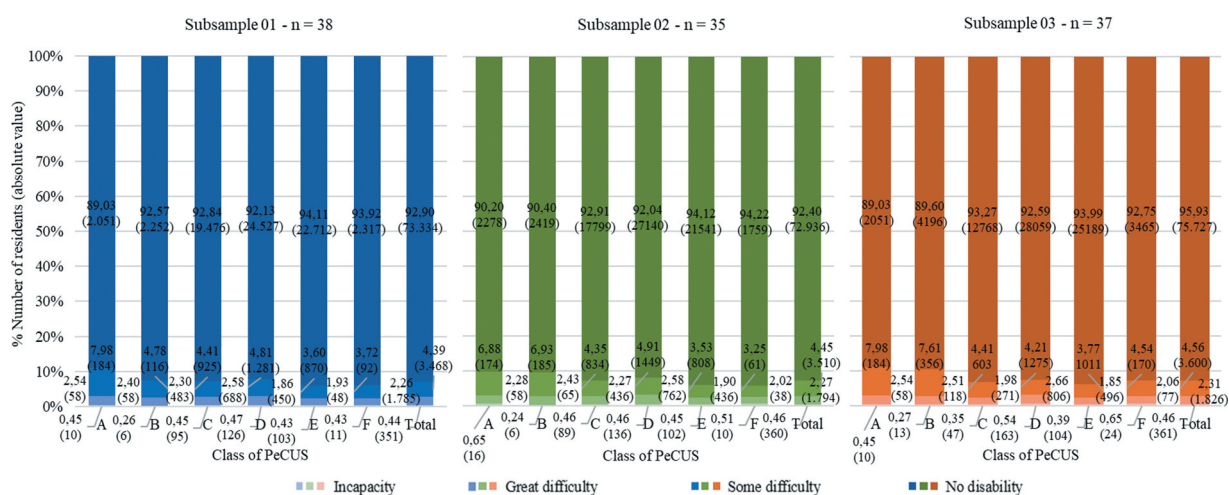

Figure 7. Number of residents by permanent mobility constraints distributed by class of the *PeCUS* index, for the three subsamples.
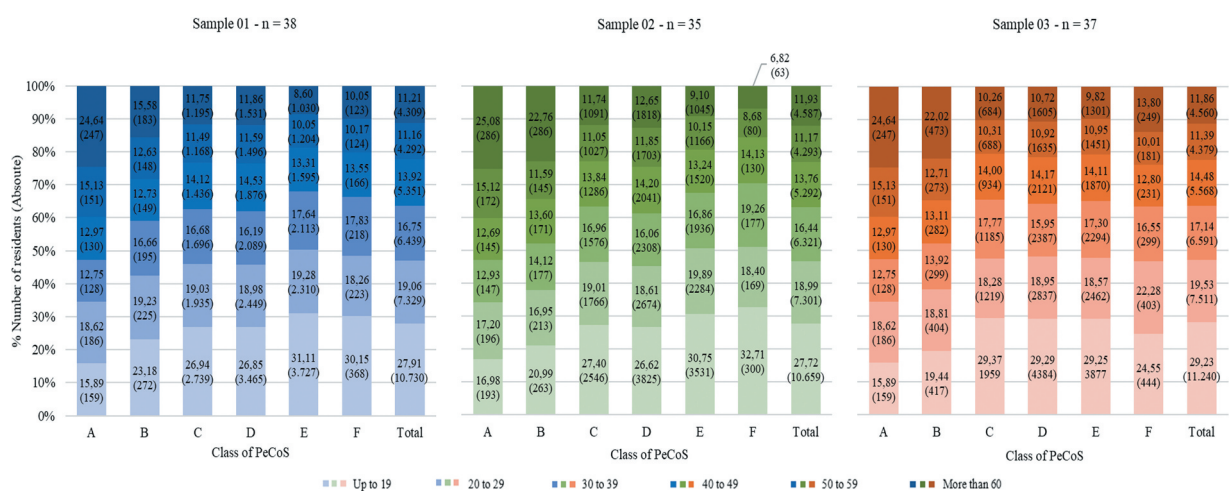

Figure 8. Number of male residents by age distributed by class of the *PeCUS* index, for the three subsamples.

women (about 1/3) than among men (about 1/4) (as shown in Figures 9 and 8, respectively). In addition, we can see in Figures 8 and 9 that most residents in class E are aged up to 19.

Regarding the vertical equity in the distribution of residents, it is expected that vulnerable social groups (elderly, young children, physically disabled, and low-income people) would be preferred throughout the
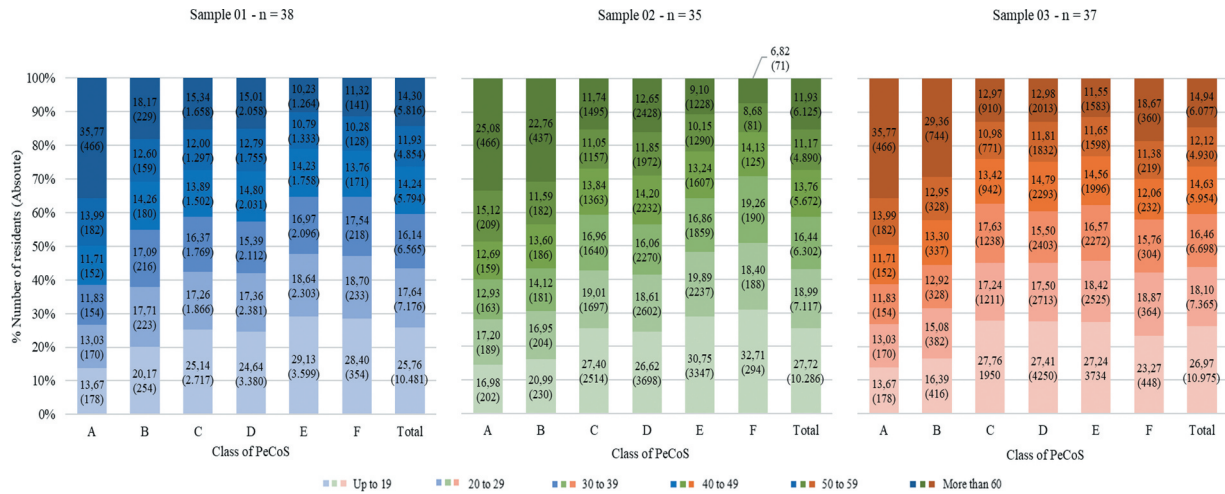
Figure 9. Number of female residents by age distributed by class of the *PeCUS* index, for the three subsamples.

best quality classes. However, the results from the exploratory data analysis indicated that low-income residents tend to live nearby the intermediate or poor-quality class and residents aged up to 19 tend to live close to the worst quality class.

The exploratory data analysis of the variables enabled us to describe aspects between the variables and make assumptions about the vertical equity in the distribution of the number of residents according to the distinct classes of the *PeCUS* index. However, it is not enough to validate the hypothesis of association between the variables or to identify the nature and the degree of dependence between the variables.

Thus, chi-square (χ2) values were calculated for the subsamples by looking at the number of residents observed and expected in each of the classes of the *PeCUS* index when combined with the classes of monthly nominal income, permanent mobility constraints, gender, and age. All values calculated for the chi-square (χ2) resulted in higher than the critical values of the chi-square (χ2) distribution, considering their respective degrees of freedom, with a p-value less than 0.025. Hence, the null hypothesis (H0) was rejected at a level of significance of less than 0.025. Therefore, a possible association between the variables cannot be ruled out.

Additionally, we calculated the standardized Pearson residuals and found cells of the cross-classification tables with population values higher than expected, indicating excesses of residents with certain demographic characteristics living in the surroundings of specific classes of the *PeCUS* index. Analogously, we also found cells with less residents than expected, indicating deficits of residents.

Table 4 presents a summary of the excesses and deficits found for each class of the *PeCUS* index regarding the variables of income, permanent mobility constraints, gender, and age. It also provides information about the positive (+), negative (−), or unclear (+/−) effect of the excess/deficit to the vertical equity, since the effect varies depending on which social group it is related to.

According to Table 4, there is a deficit of residents with an income less than R$ 1,020.00 and an excess of residents with an income greater than R$ 5,100.00 living near the best quality classes of the *PeCUS* index (classes A and B). In addition, there is an excess of people with an income less than R$ 1,020.00 living near the worst quality classes of the *PeCUS* index (classes E and F). As, in terms of vertical equity, it is expected that low-income residents will be preferably distributed throughout the best quality classes, the distributions mentioned above represent negative effects to the vertical equity. In contrast, the excess of residents with an income range between R$ 1,020.00 and R$ 5,100.00 that live nearby the best classes (A and B) and the deficit of inhabitants from the same income range that live close to one of the worst classes (class E) indicate positive effects to the vertical equity.

Regarding permanent mobility constraints, Table 4 shows an excess of people with some difficulty and a deficit of people with no disability living near one of the best classes of the *PeCUS* index (class A), which indicate positive effects to the vertical equity of residents' distribution. In addition, the deficit of people with great difficulty and some difficulty, and the excess of people with no disability living near one of the worst classes (class E) also indicate positive effects.

Concerning men's age, Table 4 points out deficits of men aged up to 19 and between 30 and 39 who live near the best classes of the *PeCUS* index, and excess of men up to 19 years old who live near one of the worst classes (class E), which represent negative effects to the vertical equity of residents' distribution. On the other hand, the excess of men aged more than 50 living near

Table 4. Summary of excesses and deficits for each class of the *PeCUS* index per variable for the three subsamples.

Variables	Categories	Class of PeCUS					
		A	B	C	D	E	F
Range of monthly nominal income	Up to R$1,020.00	Deficit (-)	Deficit (-)	NR	Deficit (±)	Excess (-)	Excess (-)
	R$ 1,020.00 to R$ 2,550.00	Excess (+)	Excess (+)	NR	Excess (±)	Deficit (+)	NR
	R$ 2,550.00 to R$ 5,100.00	Excess (+)	Excess (+)	Deficit (±)	NR	Deficit (+)	NR
	R$ 5,100.00 to R$ 10,200.00	Excess (-)	Excess (-)	Deficit (±)	NR	NR	NR
	More than R$10,200.00	Excess (-)	Excess (-)	Deficit (±)	NR	NR	NR
Permanent mobility constraints	Incapacity	NR	NR	NR	NR	NR	NR
	Great difficulty	NR	NR	NR	Excess (±)	Deficit (+)	NR
	Some difficulty	Excess (+)	NR	NR	NR	Deficit (+)	NR
	No disability	Deficit (+)	NR	NR	Deficit (±)	Excess (+)	NR
Male age range	Up to 19	Deficit (-)	Deficit (-)	NR	NR	Excess (-)	NR
	20 to 29	NR	NR	NR	NR	NR	NR
	30 to 39	Deficit (-)	NR	NR	NR	NR	NR
	40 to 49	NR	NR	NR	NR	NR	NR
	50 to 59	Excess (+)	NR	NR	NR	NR	NR
	More than 60	Excess (+)	Excess (+)	NR	NR	Deficit (+)	NR
Female age range	Up to 19	Deficit (-)	Deficit (-)	NR	NR	Excess (-)	NR
	20 to 29	Deficit (-)	NR	NR	NR	Excess (-)	NR
	30 to 39	Deficit (-)	NR	NR	NR	NR	NR
	40 to 49	Deficit (-)	NR	NR	Excess (±)	NR	NR
	50 to 59	Excess (+)	NR	NR	NR	NR	NR
	More than 60	Excess (+)	Excess (+)	NR	NR	Deficit (+)	NR

NR, Not relevant. The standardized Pearson residual has a small contribution to the chi-square (χ2) value
(+) Positive effect related to vertical equity in the distribution of the number of residents
(+/–) Unclear effect related to vertical equity in the distribution of the number of residents
(–) Negative effect related to vertical equity in the distribution of the number of residents.

the best classes and the deficit of men aged more than 60 living near one of the worst classes (class E) indicate positive effects.

Regarding women's age, Table 4 presents deficits of women up to 49 years old who live near one of the best classes (class A) of the *PeCUS* index and excesses of women up to 29 years old that live around one of the worst classes (class E), which indicates negative effects to the vertical equity. In contrast, excesses of women aged more than 50 who live near the best classes and the deficit of women aged more than 60 living near one of the worst classes (class E) indicates positive effects.

4. Conclusions

This study presented a simple and low-cost analytical approach to assess and classify the quality of Pedestrian Crossings on Urban Streets through an index. The *PeCUS* index was used to identify variations in the quality of crossings in a random sample ($n_0 = 100$) of urban streets of a medium-sized Brazilian city. Additionally, the approach was used to identify possible inequities in the surroundings of the distinct classification groups. This can be seen as an indirect assessment of community severance.

The analysis of the chi-square (χ2) tests of independence and the standardized Pearson residuals carried out with three subsamples ($n_1 = 38$, $n_2 = 35$, and $n_3 = 37$) suggested an association between the classes of the *PeCUS* index and the variables of monthly nominal income, permanent mobility constraints, gender, and age. Furthermore, the standardized Pearson residuals were also used to indicate deficits and excesses of residents regarding the demographic characteristics studied surrounding the urban streets. Additionally, it pointed out that the conditions for urban mobility of some population strata may be impaired.

Although the databases used in the study are highly aggregated, which can introduce limitations in the investigation of the population characteristics variability, the research responds to the questions formulated in Section 1. In addition, it indicates that the assessment of community severance by the analysis of the index of quality of Pedestrian Crossings on Urban Streets (the *PeCUS* index) is feasible. Furthermore, the study shows evidence of an association between the variables. Moreover, it also highlights that the distribution of the number of residents surrounding the distinct classes of the *PeCUS* index is vertically equitable for vulnerable social groups (e.g. residents with permanent mobility constraints and elderly), except for low-income residents and for male/female residents aged up to 19.

5. Recommendations

Particularly in Brazil, the analysis of the community severance caused by transport infrastructures still requires more detailed studies, which may eventually benefit from the index of quality (the *PeCUS* index) created and tested here. Moreover, the study can assist

the decision-making of transport and urban planners concerning the implementation of new or improved transport infrastructures and crossing facilities on community severance.

We recommend using this study in other medium-sized cities and comparing the results in order to identify patterns regarding the different classes of the index and the demographic characteristics of its surrounding population. In addition, the perception of residents living in the urban street surroundings could be complemented by a questionnaire. It would be interesting to analyze residents' perceptions to identify suppression of trips by active modes, impacts on social interactions, and impacts on the well-being of the inhabitants, which are also important factors to characterize community severance.

Data availability statement

The data that support the findings of this study are available on request from the corresponding author.

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