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Urban Mobility Resilience Index for Small and Medium-Sized Cities: Structure, Indicators, and Perspectives

Urban Mobility Resilience Index for Small and Medium-Sized Cities: Structure, Indicators, and Perspectives

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SUMMARY

Resilience in urban mobility is essential for sustainable development and quality of life in cities. This study presents an assessment index for resilience in urban mobility (ARMU), focused on small and medium-sized cities. The ARMU index includes 15 indicators grouped into three domains: Urban Infrastructure, Active Transport Modes, and Essential Services. These indicators were structured and weighted based on the literature and consultation with 19 experts, supported by the *Structured Pairwise Comparison* (SPC) method.
Indicators related to pedestrian infrastructure stand out, from the perspective that resilience in urban mobility is essentially based on this mode of transport.
In this sense, the ARMU index aims to be an instrument for urban planning analyses and discussions to contribute to public practices and policies that seek to qualify urban mobility, seeking more resilient and sustainable urban development.
Keywords: Urban Mobility, Urban Resilience, Sustainable Planning.

ABSTRACT

Resilience in urban mobility is essential for sustainable development and quality of life in cities. This study presents an urban mobility resilience assessment index (ARMU), focused on small and medium-sized cities. The ARMU index includes 15 indicators grouped into three domains: Urban Infrastructure, Active Transport Modes, and Essential Services. They were structured and weighted based on the literature and consultation with 19 experts, supported by the Structured Pairwise Comparison (SPC) method. Indicators related to pedestrian infrastructure stand out, given that resilience in urban mobility is essentially based on this mode of transport. Therefore, the ARMU index aims to be a tool for urban planning analysis and discussions, contributing to public practices and policies that seek to improve urban mobility, striving for more resilient and sustainable urban development.
Keywords: Urban Mobility, Urban Resilience, Sustainable Planning.

1 INTRODUCTION

Considering cities as dynamic systems, urban mobility is defined as the ability of inhabitants to move through urban spaces to carry out their work, social, and leisure activities (Costa, 2008). According to Litman (2003), this movement involves variables such as land use and occupation, social conditions, health conditions, and urban transportation. For a city's inhabitants to maintain good performance in their activities, it is essential to consider and value good and efficient urban planning, ensuring public policies that promote access to the city for all.

In this context, the concept of resilience has recently been incorporated into studies on urban and transportation planning. Resilience in urban mobility is essential to ensure that the system can withstand impacts, adapt, and transform.

providing consistent performance over time (Azolin *et* al., 2019).
According to Santos (2014), Leobons *et al.* (2020) and Varejão and Serra (2020), the lack and/or inefficiency of urban planning, public policies and human dependence on motorized modes of transport contribute to low resilience in urban mobility.

This lack of resilience negatively impacts economic and social activities and exacerbates social inequalities, especially for the lower classes, who rely predominantly on public transportation and face longer commutes due to their housing locations, typically in peripheral areas (Maricato, 2000; Inostroza *et* al., 2010; Litman, 2003; Yañez-Pagans *et al.,* 2019). Therefore, it is necessary to develop analytical tools that allow us to understand the reality of cities in relation to resilience in urban mobility.

Urban mobility resilience indices, composed of multiple weighted indicators, provide a systematic approach to this analysis. Martins and Silva (2018), Fernandes *et al.* (2019), and Leiva *et al.* (2020) assessed urban mobility resilience in the cities of São Carlos, Rio de Janeiro, and New York, respectively. However, the topic still lacks research in this area, especially regarding developing countries, such as Brazil, and small and medium-sized cities. It should be noted that most studies in this area focus on large cities, but the number of small and medium-sized cities in the country is quite significant and often lacks specific studies. Furthermore, given the particular spatial and housing characteristics of Brazilian cities, which vary considerably, constructing an index for such an assessment is challenging.

The scope of this work, therefore, proposes the development of an Urban Mobility Resilience Assessment Index (ARMU) applicable to small and medium-sized cities.
Its structure allows, based on the spatial scale of the data used, an analysis of the city as a whole or desirable sub-regions. This index will contribute to the analysis of urban mobility resilience, providing a tool to support discussions, planning, and public policies aimed at improving urban mobility. This is expected to drive positive changes related to mobility, promoting more resilient and sustainable urban development.

2 METHOD

This section describes the steps for structuring the ARMU index, including its design based on literature and expert consultation, as well as the definition of weights.
of domains, themes and indicators, aided by the *Structured Pairwise Comparison* method (SPC).

2.1 Structuring the ARMU index: definitions of domains, themes and indicators

To develop the ARMU index, the following references were chosen as a starting point: the Sustainable Urban Mobility Index (IMUS), developed by Costa (2008), and the City Resilience Index (IRC), developed by Santos (2021). Furthermore, as established by Law No. 13,979/20, provisional measure No. 926/20 (Brazil, 2020), essential services such as health, education, food supply, banking, and public services were included as requirements for ideal urban mobility.

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Two main steps were considered in developing the index, as described below. In the first step, an initial structure for the index was organized, including indicators and their respective analysis parameters. These indicators were organized into a hierarchical structure of domains and themes.

Also at this stage, a survey of 19 urban mobility experts was conducted via an electronic form sent by email, seeking to qualify the indicators. The experts were asked to rate the indicators as: a) very relevant, when the indicator's use is essential to the index; b) relevant, when the indicator's use is important to the index; and c) irrelevant, when the indicator's use does not result in a significant change in the index's composition. At the end of the form, a space was provided for comments or suggestions for new indicators.

2.2 Weighting of domains, themes and indicators

The second stage aimed to define the ordering and importance of the domains, themes, and indicators. To this end, a new survey of urban mobility experts was conducted via an electronic form sent by email to gather opinions on the weighting of the domains, themes, and indicators.

The *Structured Pairwise Comparison* (SPC, Sharifi *et* al., 2006; Taleai *et* al., 2007) method was chosen , in which the expert initially analyzes the items (in this case, in general terms: domains, themes, or indicators) and ranks them in order of importance. The expert then assesses whether the first item on the list has strong or weak importance in relation to the second item, and so on.

Each weak importance judgment between two items results in a position on the importance list. For example, item A is more important than item B, indicating weak importance. Then, item A occupies position 1 on the list, followed by item B at position 2.
On the other hand, each judgment of strong importance results in two positions in the respective list. Therefore, if item A is more important than item B, presenting strong importance, item A occupies position 1 in the list, followed by item B, in position 3. An example of the application of this method can also be seen in Fonseca (2020).

Table 1 presents an example of tabulating the judgment of the degree of importance among the domains, with the same method followed for the themes and indicators. For example, respondent 1 indicated that the order of importance for the domains would be: Active Modes, then Urban Infrastructure, and finally Essential Services. He then judged that the Active Modes domain has weak importance relative to Urban Infrastructure, and that this domain has strong importance relative to Essential Services.

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Table 1 Tabulation of the results of the degree of importance of the domains of the ARMU index

Domain positions	Responding expert identification number 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
1st	MA IU IU IU SE MA SE IU IU IU IU IU SE SE MA IU SE IU MA
2nd	UI BAD IU IF IF IU SE SE MA IU
3rd	SE SE SE IU MA MA MA MA SE IU MA IU MA IF
4th	SE MA MA MA SE BAD UI IF
5th	MA SE IF BAD BAD

CAPTION
UI Urban infrastructure
MA Active modes of transport
IF Essential services

In the next step of the SPC method, the responses were reorganized into a table containing the position value of each item, based on the responses obtained. Table 2 presents this operation for the domains, using the same method used to reorganize the positions of the themes and indicators.

Table 2 Reorganization and normalization of the weights of the domains of the ARMU index

Domain	Tab	Sum 1/Sum	Normalization
UI	2 1 1 1 3 3 2 1 1 1 1 1 3 2 3 1 4 1 2 34	0.029	0.439
BAD	1 4 4 2 5 1 3 3 3 4 3 5 4 3 1 3 2 5 1 57	0.018	0.262
IF	4 3 3 3 1 5 1 2 5 2 4 3 1 1 2 2 1 3 4 50	0.020	0.299
		0.067	1,000

Taking into account the judgments of all experts, the values assigned to each item were added together, and the smallest sum indicates the most important item, as it indicates that there was a greater prevalence of that item in the first positions of the list. Then, to determine the weights, the inverse of the sum of each item is calculated, and these values are then normalized to total 1.0 (or 100%). This procedure is also illustrated in Table 2.

3 RESULTS

As a result of the first stage, related to the definition of Domains, Themes, and Indicators, the structure of the ARMU index is presented in Table 3. It can be seen that the index has 15 indicators, which are distributed across three main domains and their respective themes. Table 3 also contains brief descriptions of each indicator.

The first, called "Urban Infrastructure," is comprised of the theme "Urban Transportation," which includes the following indicators: urban road network connectivity, paved roads, and availability of public transportation stops. Also within this domain is the theme "City Topology," which includes the following indicators: circuit factor, physical barriers, urban form, urban topography, and low-speed roads.

The second domain, called “Active Transport Modes”, has the theme “Infrastructure for Active Modes” and includes the indicators: extension of infrastructure for bicycles, bicycle parking, roads with sidewalks for pedestrians.

Finally, the third domain, called "Essential Services", has the theme "Access to Essential Services" and brings together the indicators: access to health services, access to education services, access to food distributors and access to banks and public services.

Next, the results of the second stage, which aimed to obtain the weights of the domains, themes and indicators using the SPC method, are presented in Table 4.
This table shows the weights of each dimension (domain, theme or indicator) and the weighted value of each indicator, considering the weights of the corresponding theme and domain.

Table 3 Structure of the Urban Mobility Resilience Assessment Index (URIA)

Domain	Theme	Indicator
Urban infrastructure	Urban transport	**Urban road network connectivity** Assessment of urban road network connectivity in the study area
		Paved roads Proportion of paved roads in relation to the analysis area in km²
		Availability of public transport points Count or proportion of points per area in km²
	Topology of cities	**Circuit factor** Relationship between the distance traveled on the road network and the distance in a straight line between two points of interest.
		Physical barriers Proportion of physical barriers in relation to the analysis area in km²
		Urban form Comparison between compact and sprawling cities
		Urban topography Classification according to slope maps
		Low-speed roads (up to 30 km) Length of the road network in km in relation to the area in km²
assets of Transport modes	Infrastructure for active modes	**Extension of bicycle infrastructure** Proportion of bicycle infrastructure in relation to the road network for motorized transport
		Bicycle parking Existence of bicycle racks or bicycle parking in the region
		Streets with sidewalks for pedestrians Proportion of walking infrastructure to motorized transport road network
Essential services	Access to essential services	**Access to health services** Greatest distance obtained in relation to the

	health services
	Access to education services Greatest distance obtained in relation to education services
	Access to food distributors Greatest distance obtained in relation to food distributors
	Access to banks and public services Greater distance from banks and public services

Table 4 Weighting of Domains, Themes and Indicators

	Domain weight	Theme weight	Indicator weight	Weighted value
URBAN INFRASTRUCTURE	0.454			
Urban Transportation		0.532		
Urban road network connectivity			0.522	0.126
Availability of public transport points			0.252	0.061
Paved roads			0.226	0.055
Topology of cities		0.468		
Urban form			0.250	0.053
Physical barriers			0.231	0.049
Urban topography			0.204	0.043
Circuit factor			0.158	0.034
Low-speed roads (up to 30 km)			0.157	0.033
ESSENTIAL SERVICES	0.280			
Access to education services			0.324	0.091
Access to food distributors			0.286	0.080
Access to health services			0.251	0.070
Access to banks and public services			0.139	0.039
ACTIVE MODES OF TRANSPORT	0.266			
Streets with sidewalks for pedestrians			0.490	0.130
Extension of bicycle infrastructure			0.327	0.087
Bicycle parking			0.183	0.049

Regarding the weighting defined for the domains, it can be observed that the "Urban Infrastructure" domain obtained the greatest importance, being responsible for 45.4% of the index in this dimension. Next, the "Essential Services" domain, corresponding to 28.0% and, finally, the "Active Transport Modes" domain, contributing 26.6%.

The "Urban Infrastructure" domain is subdivided into two themes to better qualify its indicators. In this case, the "Urban Transportation" theme is observed, with a weight of 0.532. and the theme "Topology of Cities", with a weight equal to 0.468.

Delving deeper into the analysis of the indicators' dimension, considering the weights already weighted by the corresponding theme and domain, it is noted that the indicators "Roads with sidewalks for pedestrians" and "Connectivity of the urban road network" have, in this dimension, the greatest contributions to the index, whose weights are, respectively, equal to 0.130 and 0.126.

Next, the importance of the other indicators can be observed, in this order: “Access to education services” (0.091); “Extension of bicycle infrastructure” (0.087); “Access to food distributors” (0.080); “Access to health services” (0.070); “Availability of public transport points” (0.061); “Paved roads” (0.055); “Urban form” (0.053); “Physical barriers” (0.049); “Bicycle parking” (0.049); “Urban topography” (0.043); “Access to banks and public services” (0.039); “Circuit factor” (0.034) and “Low-speed roads (up to 30 km)” (0.033).
Figure 1 presents the distribution of the weighted values of the indicators that comprise the ARMU, also detailing the domain in which they are inserted. It is noteworthy that the indicators with the highest values, i.e., "Roads with pedestrian sidewalks" and "Urban road network connectivity," are inserted into different domains, i.e., "Active Transportation Modes" and "Urban Infrastructure," respectively. It is also noteworthy that the distribution of the indicators, ordered by their weighted value, illustrates that the relative importance of the domains is reasonably well distributed within the ARMU.

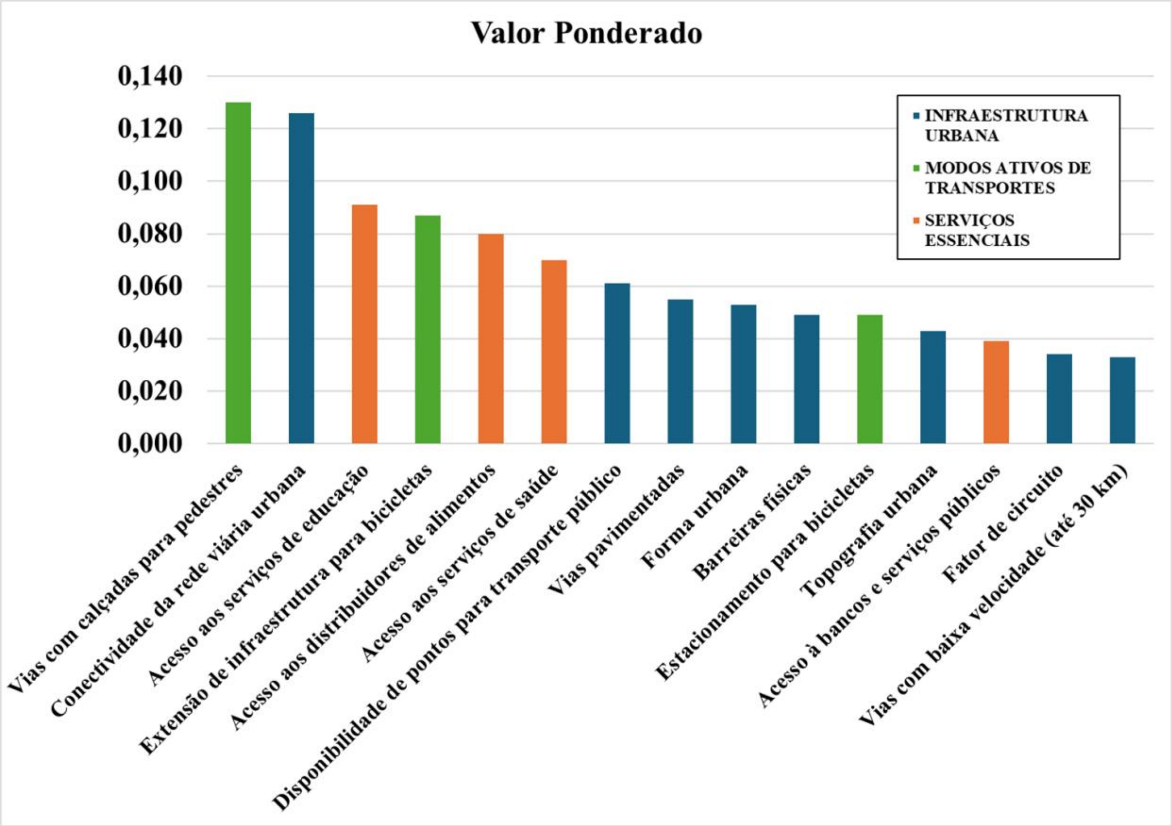

Fig. 1 Distribution of the weighted values of the indicators that make up the ARMU, categorized by the domains to which they belong

4 CONCLUSION

Resilience in urban mobility is recognized as fundamental to sustainable development and quality of life in cities. In this context, this study aimed to present an index for assessing resilience in urban mobility, specifically targeting small and medium-sized cities. To this end, urban mobility and urban resilience indices were analyzed, and expert consultations were conducted to define the components and weightings of the proposed index.

Regarding the general structure of the ARMU index, its composition consists of 15 indicators organized into four themes and three domains. Two indicators stood out, possessing the highest weighted values: "Roads with pedestrian sidewalks" and "Urban road network connectivity." The first is included in the "Active transport modes" domain, which includes indicators relevant to the choice of mobility through active modes. The second belongs to the "Urban infrastructure" domain, which contains indicators focused on the infrastructure of the transit system available in cities. This result highlights the perspective that resilience in urban mobility is essentially based on the infrastructure provided to pedestrians.

In fact, the planning and organization of urban infrastructure for pedestrians are fundamental. In terms of urban resilience, pedestrians have more flexibility in adapting to extreme events, such as traffic congestion, public transportation or power outages, natural disasters, and man-made disruptions (such as strikes). Furthermore, investing in infrastructure and policies that prioritize pedestrian safety and convenience also improves the quality of life in cities, as it reduces dependence on motorized vehicles, reduces air pollution, and contributes to public health.

In this sense, the ARMU index aims to be an instrument for urban planning analyses and discussions to contribute to public practices and policies that seek to qualify urban mobility in small and medium-sized cities, driving positive changes towards more resilient and sustainable urban development.

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