DISPERSION INDEX OF URBAN AREAS APPLIED TO LARGE BRAZILIAN CITIES

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ABSTRACT

The overall objective of this study is to assess the Dispersion Index (DI) of the city of Porto Alegre, located in the state of Rio Grande do Sul (RS), Brazil. In order to design its methodology, an analysis of the urban spatial configuration to verify population distribution through the use of DI was chosen. The results obtained revealed high values of dispersion for Porto Alegre, with a strong tendency to increase the DI. Thus, it is possible to demonstrate Urban Dispersion as a way to strengthen analyses of urban spatial configuration, which addresses distance and population density issues, and follows criteria to define course of actions of public policies capable of making urban mobility more sustainable.

KEYWORDS: *Public Policies, Urbanization, Urban Sustainability*

I. INTRODUCTION

Cities which aim at future actions and focus on sustainability perspectives [1, 2] need to revise their urban planning by carrying out applied research which involves their functional roadway. They specially [2, 3] need to list alternatives that generate analyses of urban design for the understanding of the structure of the road system, and to favor the creation of improvements in urban mobility.

Investigating urban mobility in relation to the Dispersion Index (DI) of Brazilian cities becomes of fundamental importance as Brazil is an underdeveloped country and has constant economic and population growth [4]. Thus, large Brazilian cities, such as Porto Alegre, located in the state of RS, Brazil, increasingly need changes in their urban structure due to disparities between regular and irregular routes, which influence the way users travel [4, 5].

Some studies carried out in Porto Alegre (RS), Brazil [5] considered the impact of urban structure on the periodicity of pedestrian journeys. Besides analyzing urban and socioeconomic characteristics, it was through data collection that it was found out how individuals perceive urban structure characteristics. These data provided by the population were necessary in order for the public power to understand which are the priorities and, therefore, create strategies that aim at improving these urbanized physical structures [5, 6].

The demands to improve urban mobility [7,8] point to the need for Brazil to develop course of actions in its cities, which consider aspects of physical infrastructure of mobility. It is believed that [9] accelerated growth entails demands planning in land-use and road infrastructure whose dynamics are fundamental for sustainable urban mobility.

When considering sustainability in relation to urban mobility standards [10], one must take into account the need for alternatives that guarantee better mobility conditions for the population.

Regarding population dispersion in the city [11], factors that somehow contribute to urban dispersion are: economic growth, owning a car, highway design based on motorways, as well as other social and

cultural factors. As can be seen [12, 13], there are many indicators to measure urban dispersion, however, density is considered the most important, as it takes into account population densities (inhabitants per km² or hectare).
The verification of spatial distribution of population [14] is carried out through the use of the Dispersion Index (ID) whose calculations examine urban form in a systematic way. An array of measures was designed with widely consistent data indicating the extension of the urban area that can be dispersed. These measures are based on distances between urban sectors including the population of this sector and the Commerce Service Center (CSC). Thus, it is clear that the CSC concentrates a cluster of services, jobs and goods movement of an urban center [13, 14].
This model of population dispersion index for cities finds persistent patterns of decentralization as people's earnings increase and cities experience increasing population growth [14]. Thus, the concentration and migration of the population to different points of the urban area generate a greater number of jobs in these central areas. In dispersed cities, the population is far from the CSC [14] due to the high cost of housing in urban centers [14, 15].
For instance [16], the expansion of urban population causes changes in the form of consumption of urban space, that is, the poorer population usually moves to more peripheral regions, further away from main centers. As a result, it causes economic development to be in a more scattered, dispersed manner as well as it generates new demands for infrastructure inherent to urbanization processes which negatively impact forms of urban mobility [17].
In this context, this study considered urban design, by taking Porto Alegre, located in the state of Rio Grande do Sul, Brazil, as object of study, and evaluated its potentialities in relation to the DI. Thus, this is the research question, "Can the urban dispersion index serve as an evaluation tool for the implementation of public policies related to the improvement of urban mobility in large urban centers?"
In the same vein [18], it is important to identify the spatial organization, which includes the arrangement of identification of mobility systems in cities, based on a conjuncture of centers and sub-centers, in order to plan the territory in its transport systematization. This study is relevant as the public policies of urban mobility in Brazilian cities need to contemplate a structure that presents alternatives to implement actions for improvement in social, economic and environmental dimensions, so that development can be sustainable.
The general objective of this study is to verify dispersion indices of Porto Alegre, in the state of RS, Brazil. Thus, the following specific objectives are: (a) to allocate theoretical contributions according to the proposed theme; (b) to apply the DI in the urban area of Porto Alegre (RS), the capital city of Brazil's southernmost region; and (c) to verify the index potential in relation to urban mobility.
This study is of utmost importance as it highlights the need to recover the relevance of studies related to urban spatial configuration, their articulations and socioeconomic influences [11,14]. The optimal results of this study enable the theoretical and practical foundation of the DI for the public power to evaluate potentialities of spatial configuration. It also provides recommendations of possible public mobility policies that will use the DI as a criterion for defining more sustainable actions in relation to urban mobility.

II. MATERIALS AND METHODS

The objects of study consist of 2,433 census tracts of Porto Alegre (RS), which is a city located in the South of Brazil and had an estimated population of 1472,482 inhabitants in 2017. The territorial area of Porto Alegre (RS) consists of 496,682 km², and has a population density of 2,837.53 inhabitants per km² (Figure 1) [19].
In a systematic manner, the research stages in order to assist in the understanding and analysis of the data collected were outlined. Then [20], the method of the comparative exploratory approach was chosen as it is recognized as an important applied research technique in social groups. This method assisted with the comparison of the similarities between the 2,433 census tracts surveyed.

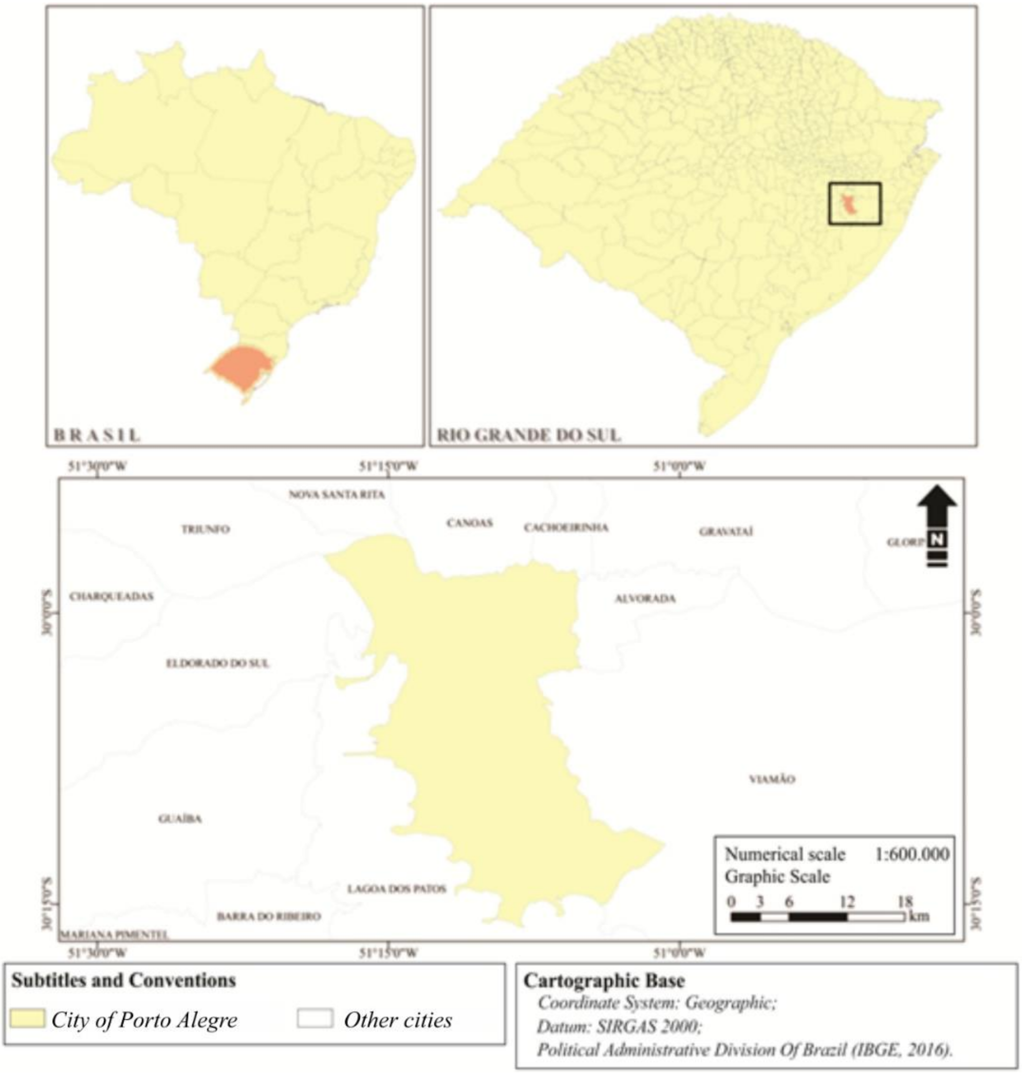

Figure 1. Location map of Porto Alegre (RS) in the Brazilian territory
Source: Adapted from the IBGE database [19]

The DI survey was applied through the analysis of urban spatial configuration, called DI, by means of the comparison between an actual and a hypothetical city in a cylindrical form, taking into account the area that the urban population is inserted [21]. From this metrics, population distribution and distances traveled to shopping malls and services were analyzed.

The influence of urban form [22] was analyzed through dispersion models in order to identify and apply metrics in the design of forms and properties that emerge from the cities. The data used to obtain the DIs were collected through the Geographic Information System (GIS), which considered polygons with equivalent area and city limits for the generation of statistical data bases [19].

From the compilation of vector data, the Commerce Service Center (CSC) is established as a functional center and is represented by a point in digital maps of census tracts that coincides with the historical center of each city as well as the satellite imagery aid. Thus, the configuration of this urban nucleus called "center" takes into account characteristics of agglomerations of people, commerce and services, and is a result of urban growth processes. To exemplify the situation, the CSC was represented by a (centroid) point in digital maps, located through the assistance of ArcGis 10.1 [21].

The location of the Functional Center [23, 24] was from a point of origin in the cities, based on the main square and its Mother Church, which later became the historical center. In Porto Alegre, the Commerce Service Center (CSC) was identified from the Metropolitan Cathedral of Porto Alegre (RS), Brazil.

For the scope of the sample, the following calculation of the ID was performed, respectively: location of the CSC in Porto Alegre; delimitation of centroids of polygons within territorial limits, by using ArcGis 10.1, including the equivalent population; calculation of centroid distances of each urban sector

to the CSC, by using ArcGis 10.1, and spreadsheet for data export; calculation of the resulting area in km² of the analyzed sectors; and delimitation of the cylindrical form of the equivalent area.
Thus, the calculation of the ID was performed through the application of the following Equation (1) [21, 25].

Equation (1):

$$\frac{\rho = \sum i \ \ di \; pi}{PC}$$

Where ρ is Dispersion Index (symbol corresponding to the Greek letter ρ /roʊ/); d is the distance from the centroid of each urban sector to the "center" (CSC); p is the population of each urban sector; P is the total urban population; C is the average distance from the points of a circle with an area equivalent to that of the city (in this case the urban sector) analyzed to its center (value = 2/3 of its radius, through integral calculus). Such a conversion allows the results to be viewed on a scale of (-1 to +1) through the formula, as follows: (2 * (Observed value - Minimum value) / (Maximum value - Minimum value)) - 1.

III. RESULTS AND DISCUSSION

Through the territorial area of Porto Alegre, the quantitative population of 1,472.482 inhabitants in all the census sectors analyzed is estimated. Population density is measured by (inhabitants per km²). According to the 2010 census data [19], Brazil consists of 44.64 inhabitants per km², whereas in Porto Alegre (RS), the average is 37.96 inhabitants per km².
Figure 2 represents Porto Alegre with the Commerce Service Center (CSC) and the division of 2,433 census tracts [19]. The polygons of the census tracts contain the population count of each census sector. These measures reveal population distances to the CSC. Through this concentration, it is possible to assess spatial distribution of the urban population.

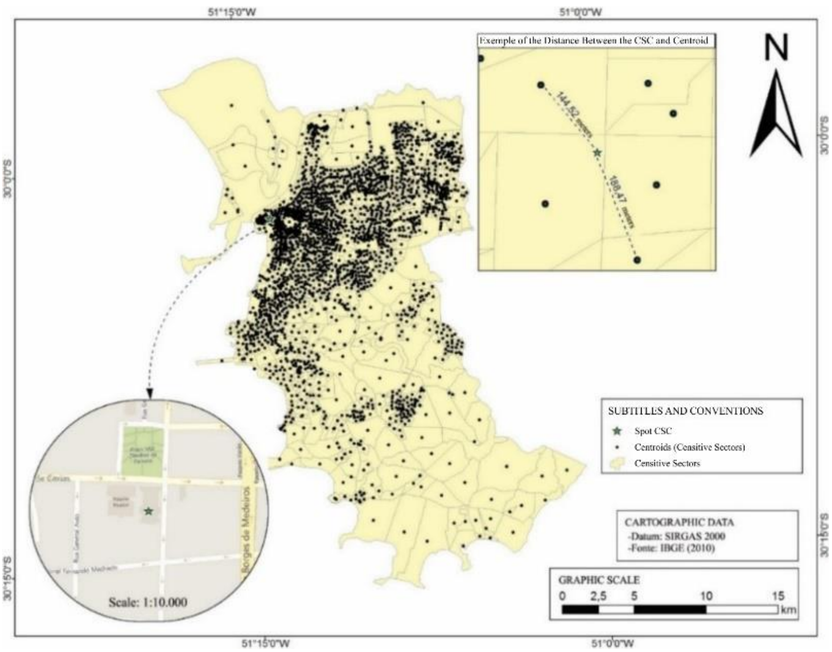

Figure 2. Census sectors and location of the CSC in Porto Alegre (RS)
Source: Map created with data from IBGE database [19]

In relation to the hypothetical city [21], the resulting DI to the equivalent area of Porto Alegre was 496,682 km². That is, geometrically, the area is represented by its Radius (12,580 km). According to the Equation (1), this datum should be reduced to 2/3 in a compensatory manner, considering that population distribution is not homogeneous and distances are irregular. Consequently, the radius of 8.38 km was used in the calculations. Thus, the index considered the mean distance to the center of gravity of the cylindrical city whose circular base would be equal to the area and whose height would be the average density of the population (Figure 3).

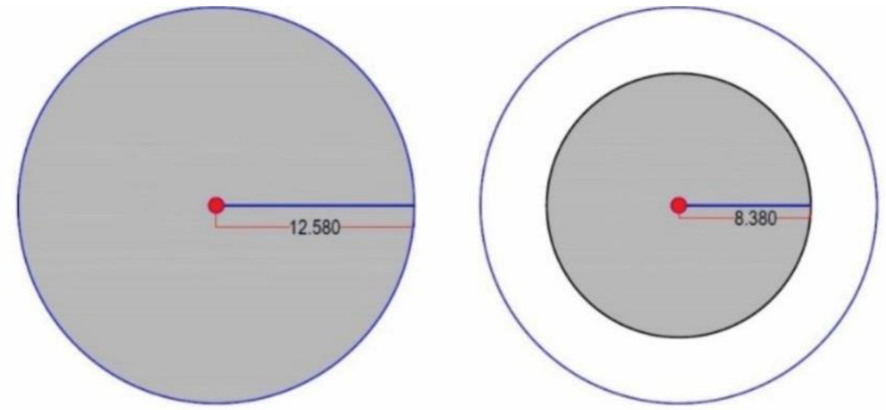

Figure 3. Geometric representation of Porto Alegre (RS)

Table 1 compiles the data per population census area (area in km²) by the metric distance of centroids of each polygon to the city's CSC. This model partially exemplifies the formulation of data referring to 2,433 census tracts in Porto Alegre (RS), and these data were obtained from the analyzed sectors [19]. Subsequently, they were processed in ArcGis 10.1 and compiled in a spreadsheet, with normalization of -0.72 to perform the calculation of DI (Equation 1).

Table 1. Data obtained from the census and CSC sectors of Porto Alegre (RS)

DI	CD Geocodi	CD Geocodi B	Residents	Area in km²	Dispersion Index	*Normalized Dispersion Index (-0.72)*
33679	431490205000133	431490205003	448	0.02241267	**0.024**	***-0.985970614***
33680	431490205000134	431490205003	305	0.006616199	**0.019**	***-0.992116711***
33681	431490205000135	431490205003	178	0.02071296	**0.011**	***-0.988483689***
33682	431490205000136	431490205003	231	0.010762797	**0.016**	***-0.986284395***
33683	431490205000137	431490205003	264	0.007913665	**0.019**	***-0.976877776***
33684	431490205000138	431490205003	442	0.011405578	**0.032**	***-0.950119079***
36703	431490205002379	431490205063	0	0.036788894	**0.000**	***-1.000258139***
36704	431490205002380	431490205063	0	0.034989146	**0.000**	***-1.000258139***
36705	431490205002381	431490205063	0	0.024248758	**0.000**	***-1.000258139***
36706	431490205002382	431490205063	0	0.056048686	**0.000**	***-1.000258139***
36710	431490205002386	431490205061	0	0.132366316	**0.000**	***-1.000258139***

Source: Adapted from the data obtained from IBGE database [19]

For the normalization of the DI, based on the results obtained from the application of Equation 1, the results are converted to the scale of representation between (-1 to +1) [26]. In the sample, the following results were obtained (Figure 4) for the knowledge of the standardized DI, related to the quantitative data of urban population of Porto Alegre.

In this sense, two neighborhoods with positive results (Santa Tereza and Lomba do Pinheiro) and two other neighborhoods with negative results (Hípica and Crystal) were mentioned in the sectoral compositions. However, Figure 4 represents dispersion, with greater expressiveness in the general result of the DI of (-0.72) demonstrated by the concentration of points that represent the population in the analyzed urban sectors.

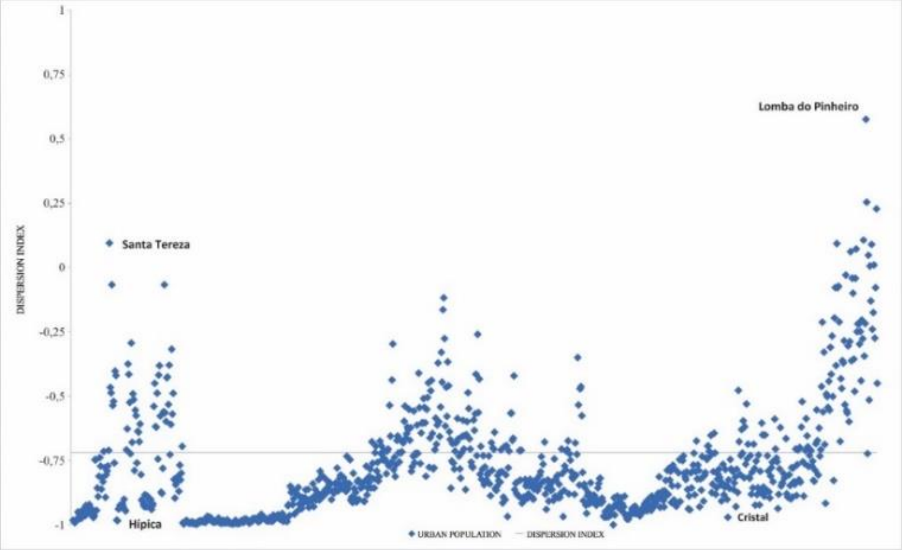

Figure 4. Dispersion Index of Porto Alegre (RS)

The updated data of Porto Alegre in relation to the 2010 census tracts and the population estimates for 2017, translated by the normalized DI (-0.72), demonstrate that Porto Alegre is a dispersed city. As a result, in a wide range of values, it contradicts other surveys carried out in 2000 in Porto Alegre, where the DI was 0.31 [26]. This result demonstrates a strong tendency to increase urban population dispersion over the 10-year period (between 2000 and 2010 censuses).

Figure 5 represents the distance (km) the population travels to get to the CSC of Porto Alegre, with a significant population growth in relation to the increase in distance to the CSC. Therefore, the DI (-0.72) can be confirmed. Consequently, sectors with zero population are 5.3 km far from the CSC, different from the Rubem Berta neighborhood, which is one of the sectors with 2,207 inhabitants and is 12.4 km far from the CSC. This growth entails demands on the planning of land use and road infrastructure, which causes possible urban sprawl [27].

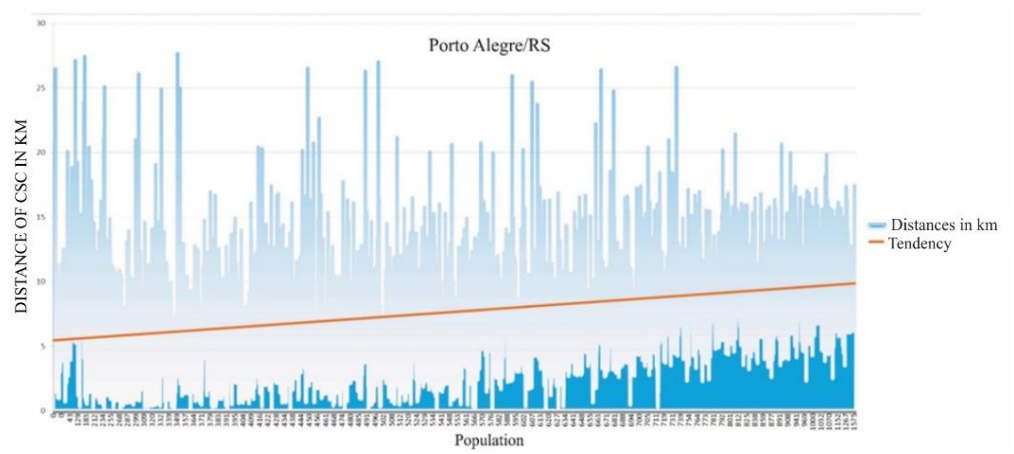

Figure 5: Population distance in km to the CSC of Porto Alegre (RS)

In this case, the distance traveled by the resident population in the urban center (Figure 6) confirms the convergence between 5 and 10 km to the CSC. However, there is also certain expressiveness between 10 and 15 km. This population distribution does not occur on an orderly manner. Yet, it is perceived that efforts for urban densification that may result in a compact city model, where social functions may occur in smaller pathways. For instance, polycentric forms that comprise several nuclei of commerce and services that address such densification, with leaner and more sustainable structures.

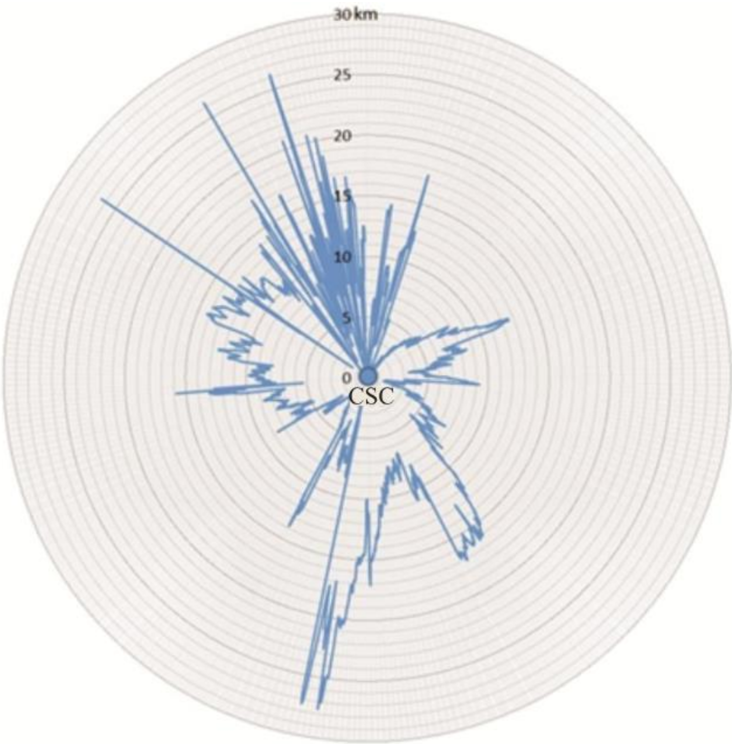

Figure 6. Population distance in km to the CSC of Porto Alegre (RS)

IV. CONCLUSIONS

From the classification of census tracts of the demarcation of the Commerce Service Center (CSC) and the characterization of the centrality of Porto Alegre, the capital city of the state of Rio Grande do Sul, one can perceive the maintenance of strong centralities, which originated from the beginning of the constitution of each analyzed sector.

The demarcation of the CSC has mentioned historical reference that remains even before the spread and densification of large centers, such as Porto Alegre. Population distribution is within the limits of these census tracts. These dispersion data can serve as support for urban planners to better visualize the city and employ public policies capable of monitoring urban growth.

Considering the above, according to the results obtained from the implementation of this methodology, the normalized DI for Porto Alegre is (-0.72), which is a representative datum that reveals the increasing dispersion of Porto Alegre. Likewise, this index demonstrates its potential through analyses of urban spatial configuration, as the result of the index related to the question of distances compared to densification highlighted the confirmation of urban sprawl shown by the sectors with the largest population and far from the CSC.

ACKNOWLEDGEMENTS

The authors wish to thank the *Stricto Sensu* Graduate Program in Architecture and Urbanism of IMED (PPGARQ-IMED); NEPMOUR (Nucleus of Studies and Research in Urban Mobility) for the support; and IMED Foundation for the Productivity Scholarship (Bolsa Produtividade).

REFERENCES

[1]. Kirby, A. (2019) "Transdisciplinarity and sustainability science: A response to Sakao and Brambila-Macias in the context of sustainable cities research", *Journal of Cleaner Production*, Vol. 210, No. 1, pp 238-245.

[2]. Fenton, P. & Gustafsson, S. (2015) "Contesting sustainability in urban transport - perspectives from a Swedish town". *Natural Resources Forum*, Vol. 39, No. 1, pp 15-26.

[3]. Saravanan, V. S. (2018) "Contestation and negotiation of urban health in India: A situated political approach". *World Development*, Vol. 104, No. 2, pp 375-387.

[4]. Awasthi, A.; Omrani, H.; & Gerber, P. (2018) "Investigating ideal-solution based multicriteria decision making techniques for sustainability evaluation of urban mobility projects". *Transportation Research Part A: Policy and Practice*, Vol. 116, No. 6, pp 247-259.

[5]. Larranaga, A. M.; Cybis, H. B. B.; & Torres, T. B. (2015) "Influence of the urban structure on the decision to make foot trips in Porto Alegre", *Transportes*, Vol. 2, No. 4, pp 89-97.

[6]. Awasthi, A.; & Omrani, H. (2018) "A scenario simulation approach for sustainable mobility project evaluation based on fuzzy cognitive maps". *International Journal of Modelling and Simulation*, Vol. 1, No. 1, pp 1-11.

[7]. Villaça, F. (2012) Reflections on Brazilian cities, São Paulo, Studio Nobel.

[8]. Medeiros, V. A. S. (2016) "The street and the road network: reflections on urban mobility in Brazilian cities", *R. TCEMG*, Vol. 34, No. 3, pp 19-33.

[9]. Libardi, R. (2014) "Mobilidade urbana frente à complexidade urbana", *EURE, Revista Latino americana de estúdios Urbanos e Regionales*, Vol. 40, No. 1, pp 273-276.

[10]. Lerner, J. (2009) "Comparative evaluation of urban public transport modalities", **NTU**, pp 1-92.

[11]. Bezerra, M. C. de. L; & Gentil, C. D. A. (2014) "Elements of urban form related to sustainable mobility", *Cadernos de Arquitetura e Urbanismo*, Vol. 20, No. 26, pp 129-148.

[12]. Li, X.; & Xue, F. (2018) "Bayesian inversion of inflow direction and speed in urban dispersion simulations", *Building and Environment*, Vol. 144, No. 4, pp 555-564.

[13]. Kristóf, G.; & Papp, B. (2018) "Application of GPU-Based Large Eddy Simulation in Urban Dispersion Studies", *Atmosphere*, Vol. 9, No. 11, pp 442-456.

[14]. Bertaud, A. (2003) "The Spatial Distribution of Population in 48 World Cities", *Implications for Economies in Transition*. http://alainbertaud.com.

[15]. Li, Y.; & Liu, X. (2018) "How did urban polycentricity and dispersion affect economic productivity? A case study of 306 Chinese cities", *Landscape and Urban Planning*, Vol. 173, No. 3, pp 51-59.

[16]. Liu, F.; Zhang, Z.; Zhao, X.; Wang, X.; Zuo, L.; Wen, Q.; Yi, L.; Xu, J.; Hu, S.; & Liu, B. (2019) "Chinese cropland losses due to urban expansion in the past four decades", *Science of The Total Environment*, Vol. 650, No. 1, pp 847-857.

[17]. Zambon, I.; Colantoni, A.; & Salvati, L. (2019) "Horizontal vs vertical growth: Understanding latent patterns of urban expansion in large metropolitan regions", *Science of The Total Environment*, Vol. 654, No. 2, pp 778-785.

[18]. Karimi, K. (2017) "Space syntax: consolidation and transformation of an urban research field", *Journal of Urban Design*, Vol. 23, No. 1, pp 1-4.

[19]. IBGE. (2017) "Population and territory data", Brazilian Institute of Geography and Statistics.

[20]. Marconi, M. de A.; & Lakatos, E. M. (2007) "Research Techniques", São Paulo: Atlas.

[21]. Bertaud, A. (2003) "The Spatial Distribution of Population in 48 World Cities: Implications for Economies in Transition". http://alainbertaud.com

[22]. Salvati, L. (2016) The "Sprawl Divide: Comparing models of urban dispersion in mono-centric and polycentric Mediterranean cities", *European urban and regional studies*, Vol. 23, No. 3, pp 338-354.

[23]. Nogueira, A. D. (2005) Spatial-syntactic analysis of Aracaju - 1855 to 2013, *Aracaju*, Vol. 4, No. 1, pp 59-76.

[24]. Decraene, J.; Monterola, C.; Lee, G. K. K.; Hung, T. G. G.; & Batty, M. (2013) "The Emergence of Urban Land Use Patterns Driven by Dispersion and Aggregation Mechanisms", *Plos One,* Vol. 8, No. 12, pp 80309-80316.

[25]. Holanda, F. De.; Medeiros, V.; Ribeiro, R.; & Moura, A. (2015) "The configuration of the metropolitan area of Brasilia", *Brasilia: transformations in the urban order*, Rio de Janeiro: Letra Capital, pp. 64-97.

[26]. Ribeiro, R. J. da. C. (2008) "*Composite index of urban quality of life: aspects of spatial, socioeconomic and urban environmental configuration*". Thesis (Doctorate in Architecture and Urbanism), University of Brasília, Brasília, 238pp.

[27]. Libardi, R. (2014) "Urban mobility versus urban complexity", *EURE*, Vol. 40, No. 2, pp 273-276.

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