SPATIAL MODELING METHOD FOR IDENTIFYING URBAN HOMOGENEOUS ZONES OF OPEN SPACES SUPPLY: A STUDY OF BRASÍLIA, BRAZIL

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ABSTRACT

Open spaces are important natural and cultural entities of cities, being a fundamental part of urban sustainability and resilience, as they offer multiple benefits for urban populations. For this, indicators of quantity and spatial configuration of urban open spaces can be used as important instruments for assessing environmental quality and quality of life in cities. However, reading complex urban forms into homogeneous patterns that support land use management requires the development of tools able to compute relevant spatial metrics and organize them in patterns. In this context, this study aims to develop a straightforward methodology to identify urban homogeneous zones of open space supply based on elements of urban form that represent compactness. The developed method uses three spatial metrics to analyze the urban form: lot occupancy rate, lot size and distance between buildings. Each of this metrics are individually interpolated using the Inverse Distance Weighting (IDW) and them intersected by means of a weighted average. This methodology was applied to the city of Brasilia, Brazil, and the results demonstrate its ability to organize large amount of data into homogenous patterns consistently with other urban patterns mapping results that uses different methodologies. Keywords: open spaces, compactness, homogeneous zones, urban patterns.

INTRODUCTION

There are many different definitions for urban open spaces; some authors and countries legal frameworks define than as: any undeveloped land within an urban area, public or private; green and blue space, such as yards, gardens, urban parks, forests, and sports fields; and not built artificial grounds such as squares, roads, parking lots, and recreational facilities *(Yang et al., 2019)*. Open space provides a range valuable services to urban populations, like: recreation and leisure; circulation routes; environmental preservation; ecological services, such as storm-water drainage, micro-climate stabilization and air and water purification; wildlife habitat; aesthetic enjoyment; health benefits; and agricultural functions (McConnell & Walls, 2005; Van den Berg et al., 2010; Ståhle, *2010;* Custódio et al., 2011; Tian et al., 2014).

For these reasons, in recent years, the concern over mapping and categorizing urban open spaces has been growing. Several methodologies were developed to indicate their quantity, spatial configuration and impact in cities environmental quality and quality of life (van den Bosch, 2016; Buccheri Filho & Nucci, 2006). However, in addition to these indicators, it is also important for land use management to identify similar patterns of homogeneous open space features, since accurately delineated homogeneous zones can highlight local conditions and provide better understanding of urban spatial dynamics.

The increasingly availability of remote sensing data and computer capacity offers entirely new opportunities for assessments of urban land cover, and consequently for measuring indicators of urban open spaces and multivariate delineation of homogeneous zones. However, identifying elements of the urban form and reading them into patterns can be challenging due to the spatial heterogeneity and variation of structures in cities.

In this context, this research aims to develop a simple and rapidly computed method able to delimit homogeneous zones based on a composite index of individual spatial metrics, that characterize urban areas in relation to its supply of open spaces. For this, the methodology uses three spatial metrics: (i) lot occupancy rate, (ii) lot size and (iii) distance between buildings. Each of this metrics are individually interpolated using the Inverse Distance Weighting (IDW). These three interpolations are intersected by means of a weighted average, which generate the interpolated composite index. Finally, it is applied to the result a filter that seeks to homogenize nearby areas according to the prevailing pixel patterns. This methodology was applied to the city of Brasilia, Brazil, using official spatial data provided by the government.

URBAN HOMOGENEOUS ZONES - SPACE ORGANIZATION AND STRUCTURE

Decision-makers and city planners need efficient methods for large-scale monitoring of urban areas and better understand of links between urban structures and environmental and socio-economic process. Dividing cities into regions of similar features is a crucial step to obtain space continuous data to assist in this type of analysis (de Castro et al., 2019). Urban homogeneous zones can describe the composition of an urban region, considering its artificial and natural elements, based on the assumptions that cities show a positive spatial autocorrelation. That is, adjacent elements tend to have similar structures, composing defined patterns (Getis, 2010; Voltersen et al., 2014).

The delineation methods of homogeneous zones boundaries can be either derived empirically based on the visual evaluation of aerial photographs and auxiliary data (Herold, Couclelis, & Clarke, 2005; Seraphim & Bezerra, 2019); or it can be calculated based with spatial correlation statistics methods (Rosa & Wiesmann, 2013; Walde et al., 2014). There are several interpolation methods than can use point or areal data (Lam, 1983). Furthermore, point methods can be further subdivided in exact, as for example IDW and radial basis functions; or approximate methods, as for example global polynomial and kernel interpolation with barriers, according to whether they preserve the original sample data or not; and areal methods can subdivide to whether they preserve volume (Lam, 1983). And all point methods need ancillary data to define zones boundaries, either of existing borders as, for example, a road layer; or of artificial borders, such as, chessboard generated to divide the city into preset square areas or a mesh of grids derivate from the data points (Lam, 1983).

METHOD FOR IDENTIFYING URBAN HOMOGENEOUS ZONES OF URBAN OPEN SPACES

The method presented in this article was reasoned for delimiting homogeneous zones of availability of open spaces, based on data points related to the urban spatial configuration. The developed method considers open space any piece of land, private or public, that is undeveloped (has no built structures), and uses urban form parameters to determinate the level of building density and by contrast the level of open space supply in an urban space. The method has three phases: (i) delimitation of an analysis area; (ii) calculation of the spatial metrics, and (iii) interpolation of these metrics into zones of similar characteristics.

First, it is necessary to delimit the urban area to be analyzed. This can be either formal or informal urbanized areas. The urbanized areas are identified by the presence of continuous constructions, demarcation of lots and road capillarity. It also includes open spaces, green areas, and urban parks within the limits of the urbanized region, but does not include environmental preservation areas, water bodies and areas with rural characteristics.

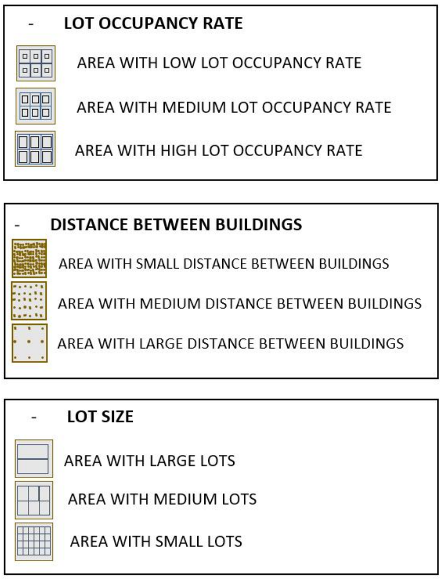


Figure 1. Individual spatial metrics of lot occupancy, lot size, and distance between buildings

After delimiting the area of analysis, we can calculate the individual spatial metrics of the elements of the urban form within the area: (i) lot occupancy rate, (ii) lot size, and (iii) distance between buildings. The lot occupancy rate is calculated by dividing the total first flor building area of all buildings structures inside a lot by the total area of the lot, the unit of measurement being a percentage. The lot size is the calculation of the area of the lot, the unit of measurement being squares meters. The distance between buildings is calculated by the geoanalysis tool 'Near', that compute the distance between an origin object and another object that is the closest to it, the unit of measurement being meters.

The choice of the individual spatial metrics was based on how well they can represent the building density of the urban form consistently for different scenarios and areas of interest. The two elements of the urban form necessary to calculate the chosen spatial metrics are lots and buildings. These elements are normally present in every urbanized area, regardless of socioeconomic, cultural or climate differences. Furthermore, these elements require modest data input, being normally present in official government geodatabases.

Following the calculation of the individual spatial metrics related with lots (lot occupancy rate and lot size) and buildings (distance between buildings), the results were interpolated using the Inverse distance weighted (IDW) in order to create surface values based on the average values of each isolated point. The choice of this method was made by visual analysis comparison of results between IDW, Kriging and Natural Neighbor interpolation methods in a small area of study.

To combine the interpolated results of the spatial metrics into one composite index, that will be the final result, each generated raster was categorized into five groups identified by the numbers 1 to 5. Being that, for this classification, the closer to 1 were areas with more concentration of open spaces, that is: lower occupancy rates, larger lots, and more distant buildings. And the closer to five, areas with less open space and a bigger concentration of buildings structures. The categorized groups are needed to intersect the raster results by means of a weight average of the groups. Finally, to obtain more homogeneous areas, it is applied to the average result the Majority Filter tool that aims to homogenize nearby areas according to the prevailing pixel patterns.

It is important to note that the calibration process, of the IDW tool, of the results classification into categories, and of the weighted average intersection need to be manipulated and checked to see if the results are sensible for each different analysis area, as demonstrated in the study area, the Federal District in Brazil.

STUDY AREA – FEDERAL DISTRICT, BRAZIL.

The Federal District in Brazil is the birthplace of Brazil capital city, Brasília. It has a total area of 5,802 km^2 and is divided into 31 administrative regions that function as something between a municipality and a neighborhood. Its territory has a wide variety of urban configurations, from the modernist layout of Brasilia, to slums with low infrastructure and high density, and large residential areas with suburban characteristics. What makes this a good area of study for applying the developed methodology.

To perform the analysis, geospatial data available in the System of Territorial and Urban Information of the Federal District (Siturb) were used: (i) polygon of the urban occupation area in 2015, (ii) polygon of the Urban Zone defined by the local master plan, (iii) polygon of buildings, (iv) polygon of lots, (v) polygon of lakes and rivers, and (vi) polygon of environmentally protected areas.

Firstly, the urbanized area where the analysis will be made was delimited, using the existing 2015 data about urban occupation area and intersecting it with the Urban Zone defined by the legal framework, and disregarding environmentally protected areas and water bodies. Then the individual spatial metrics were calculated for the lots and buildings elements within the analysis area: (i) lot occupancy rate, (ii) lot size, and (iii) distance between buildings.

To each of these results was applied the IDW tool. The calibration of the IDW tool to the area of study was made based in tests in a small area. Due to the large scale of the analysis area and the high density of information within this area, the output cell size was defined as 100; the power, which is the exponent of distance, was set as the default, 2; and the search radius was set as variable.

Following the interpolation, the 3 raster results were classified manually into the 5 classes, from the least compact to the most. To separate the classes, 2 decision criteria were used: (i) an investigation on how the data present itself when classified by equal interval, equal quantile, Jenks natural breaks and standard deviation methods, which indicate for example a predominance of lot around 600m^2 and a distance between buildings of 10m; (ii) and the data relation with the reality of the Federal District. For example, according to the local legal framework, the minimum area of the urban plot must be of 125m^2, which can indicate an informal development; and lots occupancy rates below 20% are considered underused.

The lot occupancy rate was divided in these 5 classes: (1) less than 10%; (2) between 10% and 25%; (3) between 25% and 50%; (4) between 50% and 75%; and (5) more than 75%. The lot size was divided in these 5 classes: (1) more than 20,000m^2; (2) between 2,500m^2 and 20,000m^2; (3) between 600m^2 and 2,500m^2; (4) between 125m^2 and 600m^2; and (5) less than 125m^2. The distance between buildings was divided in these 5 classes: (1) more than 100m; (2) between 50m and 100m; (3) between 25m and 50m; (4) between 10m and 25m; and (5) less than 10m. The results of the 3 classified interpolations is show in the figures 2, 3 and 4.

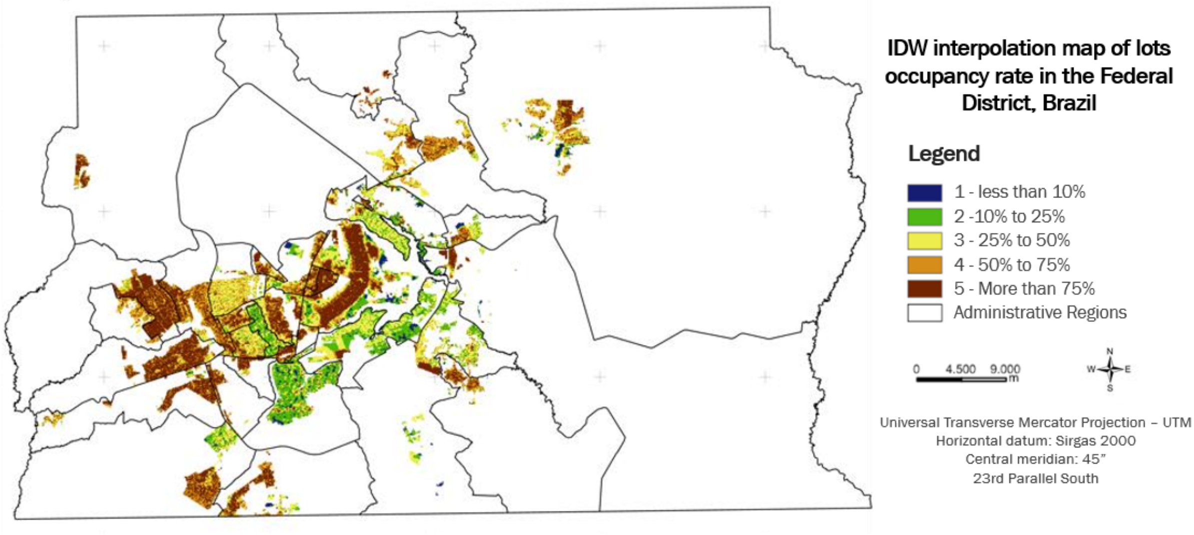


Figure 2. IDW Interpolation map of lots occupancy rate in the Federal District, Brazil

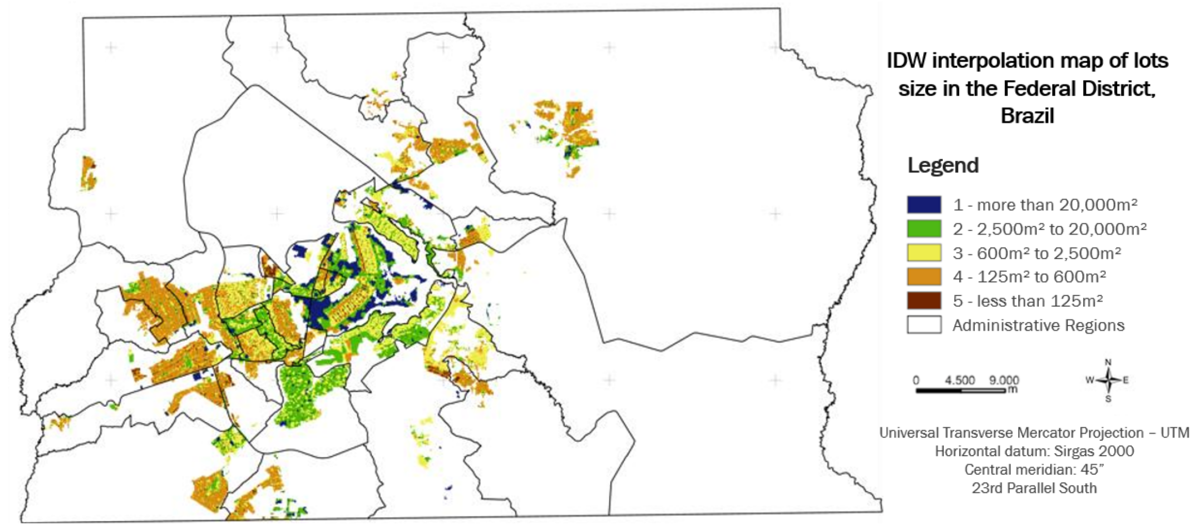
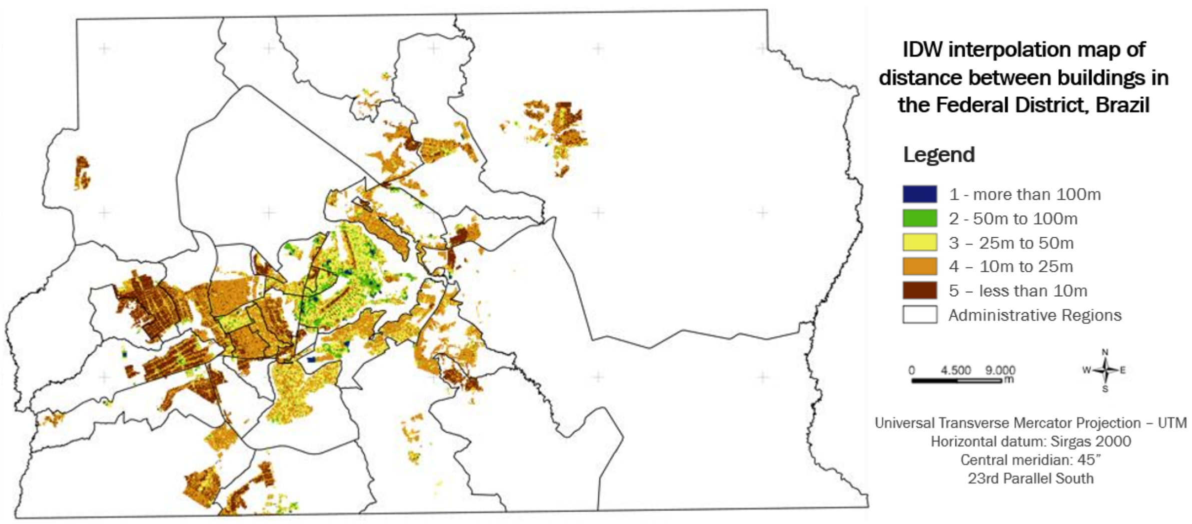


Figure 3. IDW Interpolation map of lots size in the Federal District, Brazil



The 3 classified raster results were then combined by means of a weight average. The distance between building received weight 3, while the other metrics, lot size and occupation rate, received weight 1. The weights were defined after other combinations tests, and it is estimated that in the case of the federal district this factor has a greater influence on the description of the urban configuration due to the large amount of open spaces between isolated buildings in areas of modernist layout. The weighted average of the combined raster was than classified again in 5 classes, from the least compact to the most considering visual observations. The five groups includes values: (1) between 0 an d 1.8; (2) between 1.8 and 2.6; (3) between 2.6 and 3.4; (4) between 3.4 and 4.2; (2) between 4.2 and 5. After this process the tool Majority Filter was applied 19 times in order to obtain more homogenized areas. The results can be seen in the Figure 5.

The result shows a concentration of category 5, of lower availability of open spaces, mainly in regions of low socioeconomic power, what may indicate environmental injustices regarding the access to public open spaces in the city. Furthermore, the classification shows a concentration of open spaces supply closer to the center, an issue related mainly to the modernist preserved region and its green belt and to suburbs areas of high income located vey close to the city center.

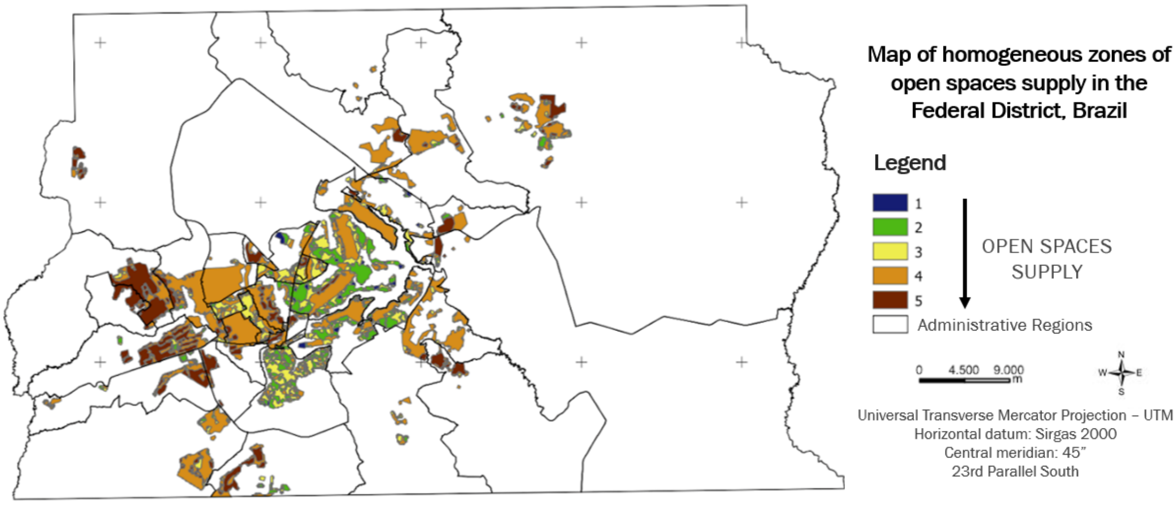


Figure 5. 5 Classes of homogeneous zones of open spaces supply in the Federal District, Brazil

CONCLUSIONS

The methodology results demonstrate its ability to organize large amount of data in a simple and rapidly way into homogenous regions consistent with intuitively understood regional differences. Whereas, the statically generated regions of the methodology arrive in finer divisions, highlighting local conditions gradients. For example, some of the administrative regions, shows up to four different classes of open spaces supply, that would be otherwise lost calculating indicators based on these administrative regions.

It is important to highlight that, although the methodology can be reproduced in other regions and contexts, during the calibration process of the geostatistical tools, general good practice is to evaluate singular parameters, checking results in order to assess whether or not results are sensible to the specific reality being analyzed (Mubareka et al., 2011).

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