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Explorando tipologias intraurbanas em João Pessoa, Paraíba: implicações para o Plano Diretor municipal

Explorando tipologías intraurbanas en João Pessoa, Paraíba: implicaciones para el Plan Maestro municipal

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Abstract

Latin American cities are marked by processes of socio-spatial fragmentation, which manifest themselves in their urban fabric, generating different morphological patterns. Several studies have already pointed out the effectiveness of lacunarity and inhabitability in distinguishing these patterns in the city, the first has proven to be sensitive in recognizing different concentrations of urban open spaces, and the second, of population and household conditions. These measures use remote sensing images and census data, obtained widely and free of charge. The use of algorithms, aided by geoprocessing software, has spread the application of methodologies that associate this data with each other. The city of João Pessoa, located in the state of Paraíba (Brazil), presents the particularity of a complex urban fabric, whose morphological patterns are the result of interaction with the Atlantic Forest in an extensive coastal strip, in addition to humid and mangrove areas. The crossing of lacunarity and inhabitability measures generated nine classes of intra-urban typologies, which are distinguished from each other by socio-spatial pattern. By relating these classes to the Master Plan zones, this research contributes to urban planning by applying an alternative method of physical-territorial reading.

Keywords: Urban fragmentation; Urban morphology; Master Plan; Intra-urban typologies.

Resumo

As cidades latino-americanas são marcadas por processos de fragmentação socioespacial que se manifestam em seu tecido urbano, gerando diferentes padrões morfológicos. Estudos já apontaram a eficácia das medidas da lacunaridade e da habitabilidade em distinguir esses padrões na cidade: a primeira demonstrou-se sensível em reconhecer diferentes concentrações de espaços livres urbanos, e a segunda, de condições populacionais e domiciliares. Essas medidas utilizam imagens de sensoriamento remoto e dados censitários, obtidos de modo amplo e gratuito. O uso de algoritmos, auxiliados por *softwares* de geoprocessamento, tem difundido a aplicação de metodologias que associam entre si esses dados. A cidade de João Pessoa, situada no estado da Paraíba (Brasil), apresenta a particularidade de um tecido urbano complexo, cujos padrões morfológicos são resultantes da interação com a Mata Atlântica em uma extensa faixa litorânea, além de áreas úmidas e de mangue. O cruzamento dos indicadores de lacunaridade e habitabilidade gerou nove classes de tipologias intraurbanas, que se distinguem entre si pelo padrão socioespacial. Ao relacionar essas classes às zonas do Plano Diretor da cidade, esta pesquisa contribui com o planejamento urbano na aplicação de um método alternativo de leitura físico-territorial.

Palavras-Chave: Fragmentação urbana; Morfologia urbana; Plano Diretor; Tipologias intraurbanas.

Resumen

Las ciudades latinoamericanas están marcadas por procesos de fragmentación socioespacial, que se manifiestan en su tejido urbano, generando diferentes patrones morfológicos. Varios estudios ya han señalado la efectividad de la lacunaridad y la habitabilidad para distinguir estos patrones en la ciudad, el primero ha demostrado ser sensible para reconocer diferentes concentraciones de espacios abiertos urbanos, y el segundo, de condiciones de población y hogar. Estas medidas utilizan imágenes de teledetección y datos censales, obtenidos de forma amplia y gratuita. El uso de algoritmos, ayudados por *software*s de geoprocesamiento, ha extendido la aplicación de metodologías que asocian estos datos entre sí. La ciudad de João Pessoa, ubicada en el estado de Paraíba (Brasil), presenta la particularidad de un tejido urbano complejo, cuyos patrones morfológicos son resultado de la interacción con la Mata Atlántica en una extensa franja costera, además de áreas húmedas y manglares. . El cruce de medidas de lacunaridad y habitabilidad generó nueve clases de tipologías intraurbanas, que se distinguen entre sí por un patrón socioespacial. Al relacionar estas clases con las zonas del Plan Maestro, esta investigación contribuye a la planificación urbana aplicando un método alternativo de lectura físico-territorial.

Palabras clave: Fragmentación urbana; Morfología urbana; Plan maestro; Tipologías intraurbanas.

1 Introduction

Socio-spatial segregation has marked the growth of cities with greater intensity since the end of the nineteenth century. According to Cavalcanti and Araújo (2017), this process assigns different social classes to live in different urban spaces. In this sense, the poorest have occupied the least healthy places in the city, with precarious infrastructure and difficult access to basic urban services, while the richest occupy the most privileged ones. The correlation between social characteristics and the quality of the built space is high, according to Secchi (2019, p. 21): "social injustices are increasingly revealed in the form of spatial injustices".

Historically, several models have tried to represent the distribution of socio-spatial patterns in cities; however, the fragmented model stands out in representing the current reality of emerging cities in the Global South, as is the case of João Pessoa. Limonad (2011) points out that this model has prevailed over the traditional center-periphery model, a dual understanding that predominated during many decades of the twentieth century and is explained when the main centrality of infrastructure and services is occupied mainly by the high-income population, while the poor mostly occupies peripheral areas precariously supplied with infrastructure and services.

Sposito and Sposito (2020) carried out an important literature review on socio-spatial fragmentation, and conclude that the expression is polysemic and multidimensional, which means that it has different meanings and can be analyzed in many dimensions (urban, cultural, sociopolitical, etc.). In addition, they highlight its socio-spatial and procedural characteristics, resulting from new practices and forms of separation in the city, and the need for research that explores its empirical dimension.

In this sense, this paper is interested in how fragmentation is recognizable in urban space. According to Sobreira (2002), fragmentation can be manifested by a combination of two movements: dispersion and compaction. Dispersion can be characterized as a tendency of expansion of the city center towards the edges, under a low-density and poorly optimized occupancy pattern. On the other hand, compaction as a tendency to occupy the edges towards the center, resulting in the occupation of urban open spaces and an increase in density (Sobreira, 2002). Both rich and poor participate in each of these movements, making the fragmentation even more complex due to the morphological particularities of each occupation; this factor has brought together geographically different social groups in multiple locations of the city, whether central or peripheral.

These groups produce different forms of land occupation, which, according to De La Mora (2008), can be based on four different logics: business, state, spontaneous and social. The high-income strata tend to occupy under the business logic, based on typologies produced and marketed by the real estate market, such as buildings (of various sizes), residences in gated communities, which occupy large plots of land in the peripheries, or residences inserted in valued neighborhoods that are true urban refuges. In addition, they strictly comply with the rules of land occupation, preserving the minimum amount of setbacks and soil permeability within the lot.

Historically, the lower income strata occupy urban space following the spontaneous logic and, rarely, the social one. The first is marked by self-building, when the residents themselves use their resources and time to build or expand their own housing. It is present in a significant part of the urban fabric in Brazil and has incremental characteristics. This type of settlement can or cannot produce slums and is characterized by spontaneity, according to Dovey *et al*. (2020), can lead to densification with an incremental loss of light, air, public spaces and accessibility. When combined with a lack of urban planning and public infrastructure, these settlements can bring environmental and health risks due to the poor quality of the built environment. Jacques (2001) adds that the lack of project results in the absence of predetermined forms and conclusion of the constructions, maintaining their unfinished aspect. Despite the simplicity of their buildings, the uncontrolled self-construction of slums and the relationship with the characteristics of the site – such as topographical slope, water bodies and vegetation – can result in settlements with huge spatial complexity.

The state logic, on the other hand, refers to Social Interest Housing (HIS, as in the Portuguese acronym) built by the state and accessible by the low-income population through subsidies. In terms of their morphology, they usually present more regularity by conforming to the formal rules of land occupation; however, they can also be self-built and have a high density of housing. The social logic also refers to HIS, but differs from the state logic due to an inverse logic of conception and occupation, specifically, with the strong participation of residents in the process. However, it is difficult to differentiate this logic at a spatial level in the city, without previous knowledge of the conditions that preceded the construction of this type of habitat.

Considering these multiple forms of land occupation, it is up to the urban planner to understand the complexity of the contemporary fragmented city, since the poor are no longer confined to the peripheries and neither are the rich in the central and more integrated areas, but the fragments have different morphological patterns and compose a wide urban mosaic. In this sense, understanding the morphological, populational and household characteristics of the fragments, as well as their distribution in the city, can be a powerful resource that supports good territorial planning policies.

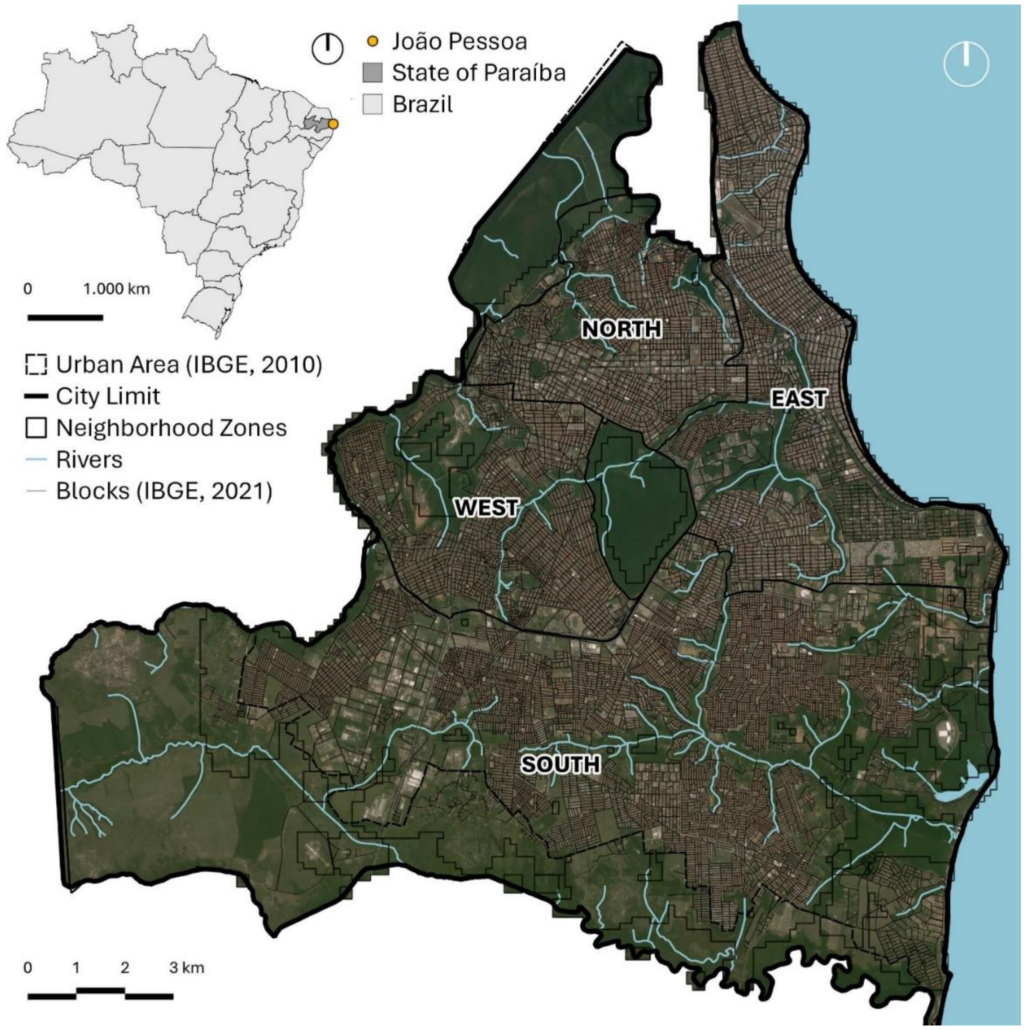
In order to understand urban morphology, a spatial approach based on Fractal Theory is adopted. This theory, developed from studies by Mandelbrot (1982), was subsequently applied to urban analysis (Frankhauser, 1997; Batty; Longley, 1994). In it, traditional Euclidean geometry is questioned as to its ability to represent the spatial complexity of cities, and fractal characteristics like non-homogeneity, fragmentation, roughness, hierarchical organization and repetition of patterns at multiple scales were highlighted in the urban scope. In this context, various metrics have emerged with the objective of distinguishing different morphological patterns and predicting future scenarios, such as fractal dimension and lacunarity, the focus of this paper. Lacunarity has the particularity of being more sensitive than fractal dimension in distinguishing texture patterns in urban digital images from remote sensing. This texture can be associated with different distributions of urban open spaces and, in the literature, has been used to differentiate human settlements with different standards of inhabitability (Barros Filho, 2006).

When it comes to understanding population characteristics, one should start with the concept of inhabitability. This term is very wide and describes, in short, the conditions of a given environment for the maintenance and reproduction of human life. The United Nations (UN) has established the universalization of adequate and sustainable living conditions in cities as a Sustainable Development Goal (SDG 11 – Sustainable Cities and Communities). Therefore, evaluating inhabitability starts from both a population dimension, since a quality urban space leads to better longevity and income-generating opportunities, and a household dimension, since space is socially constructed. The way in which inhabitability and the lacunarity were calculated will be better described in the methodology of this paper.

2 Intra-urban diversities in the municipality of João Pessoa, Paraíba

The study area is within the urban perimeter of the municipality of João Pessoa, located on the coast of the state of Paraíba, Brazil. This area has approximately 833,932 people and 210.044 km^2, resulting in a demographic density of 3,970.27 inhabitants/km^2, according to the Brazilian Institute of Geography and Statistics (IBGE, as in the Portuguese acronym) in 2022[1]. The first occupations of the city took place on the banks of the Sanhauá River. Its urbanization intensified at the end of the nineteenth century, mainly due to the development of cotton production (Gonçalves *et al.*, 1999). Figure 1 shows the location of João Pessoa in Brazil, highlighting its neighborhood zones and the relationship between the occupied area and the seafront, rivers and vegetated areas.

Figure 1: Location map of João Pessoa, Paraíba.



Source: Authors, 2023.

Figure 1 shows that the city has several morphological patterns, one of which is composed of riverine settlements close to water bodies. Such settlements, since the Code of

[1] See these and other demographic data for João Pessoa on the IBGE Cidades portal. Available at: https://cidades.ibge.gov.br/brasil/pb/joao-pessoa/panorama. Accessed on: July 22, 2024.

Postures that marked their urbanization (establishing laws and decrees since the 1970s), have been dispossessed to peripheral areas, under the discourse that unhealthy housing represents a risk to its urbanization – intensified at the end of the nineteenth century – mainly due to the development of cotton production central areas of the city, both for moral order and for the transmission of diseases, as well as for not obeying the supposedly desired standard. The norms of land occupation – which established patterns of setbacks, openings and gardens – contributed to a new morphological pattern, which was only experienced by the population with greater purchasing power.

The high demand for housing, combined with permissive urban planning in terms of urban expansion and the demand for low-cost land, gradually increased the city's urban macrozone and allowed for greater intensification in the occupation of the land and new land uses. Thus, the southern area of the city began to be intensely dense, following the interests of the real estate sector, which stimulated the opening of new roads and the deforestation of green areas, in many cases under the sanction of the State. In this way, the morphological patterns of the peripheries have changed, and many open spaces have been filled; however, there are still relevant differences between the historic center and the seafront, which have been intensively occupied since the 1970s (Martins; Maia, 2019).

3 Methodology

The proposed methodology consists of four steps, structured according to the following logic: The initial stages refer to the procedures for obtaining and processing data in a GIS environment (see sections 3.1; 3.2; 3.3). Subsequently, the analysis stages are presented (see sections 3.4; 3.5), which sought to validate the cross-referencing of data based on typological analysis and correlated indicators. Finally, the relevance of this method in city planning is discussed using zoning that has been applied since the 1990s.

The first stage aimed to build a lacunarity map of the urban occupied areas of João Pessoa. In the second stage, an inhabitability map was elaborated through the calculation of an index, developed by Barros Filho (2006) and adapted by Anjos (2013), from a database made available by the IBGE Census and, later, linked to the census tracts. The maps of these stages were interpolated through Ordinary Kriging[2].

The third stage combined the results of the two previous maps. Each of them was individually classified into three classes (low, medium, and high), and the crossover resulted in a map with nine classes. The formation of the classes is based on a classification using the quantile method, which divides the data set into equal parts. In this case, each class contains 33.3% of the data. This method was chosen because of the subsequent crossing stage, making it important to form equally balanced classes. Its disadvantage consists of the possibility of separating similar cells into different classes. However, the intermediate class mitigated this problem by preserving the characteristics of cells with extreme characteristics.

This map for João Pessoa is a refinement of the map that was generated for Campina

[2] Kriging is an interpolation method, which involves constructing a new set of data based on georeferenced point data. There are many different methods of interpolation (IDW, TIN, etc.) and Kriging (simple, ordinary, co-kriging, universal and indicative). It differs from the others in that it is based on pre-selected models of semivariograms, allowing for more precise estimates, based on the directions of the variability of the data (Barros Filho, 2006). In this article, ordinary kriging was used, and its particularity is in the assumption of a constant variance between the interpolated points.

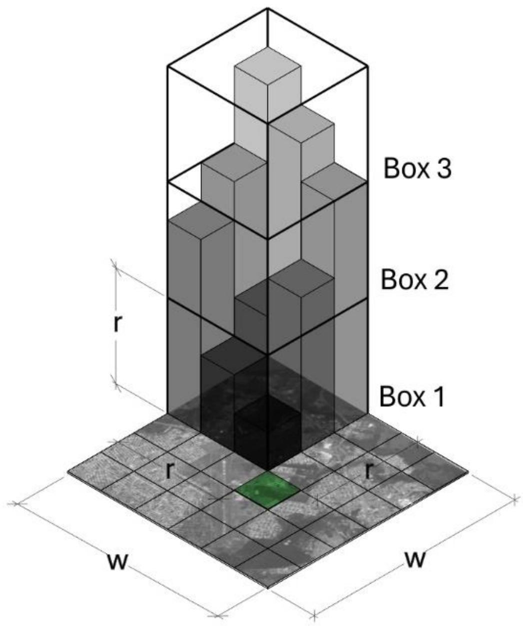
Grande with the crossing of four classes (Simões; Barros Filho, 2022). The first applied in a coastal capital that has almost twice the population and a much more complex socio-spatial structure than the second.

The fourth and final stage consisted initially of the analysis of the intra-urban typologies of the nine classes resulting from the crossing, based on a random selection of representative samples of each of them. Each sample has a dimension of 250 m x 250 m, and was analyzed from aerial images extracted from Google Earth and from ground images captured from Google Street View. Subsequently, it analyzed the relationship of the intra-urban typologies with the macro-zones defined in the current Master Plan (Prefeitura Municipal de João Pessoa, 2009) and with the Special Zones of Social Interest (ZEIS, as in the Portuguese acronym) of the city.

Before explaining in detail how the maps were developed, it is important to explain the two metrics used in this research, the first of which is morphological (lacunarity) and the second of which is socio-spatial (inhabitability).

Lacunarity is a complementary metric to fractal dimension, which can be used to identify areas with different distribution patterns of urban open spaces. Lacunarity is considered a metric for measuring texture patterns, with higher values indicating more heterogeneous textures, characteristic of areas of dispersed occupation; while lower values (closer to 1) indicate more homogeneous textures, characteristic of areas of more dense occupation (Barros Filho, 2006). The algorithm used for digital images with 256 shades of gray (8 bits) is Differential Box Counting (Dong, 2000), illustrated in Figure 2 below:

Figure 2: Schematic of the Differential Box Count algorithm.



Source: Authors, 2023.

In this algorithm, the gray levels of an image are represented by columns whose heights vary depending on their values, and cubic sliding boxes with different sizes n_r pass through the image, considering the differences $n_r(i,j)$ between the maximum v and minimum u values of these columns. This generates the mass M of the image and its probability distribution $Q(M,r)$. The equations for the calculation are shown as follows:

$$\boldsymbol{L}\,(\boldsymbol{r}) = \frac{\sum_{M} (\boldsymbol{M}^2)\boldsymbol{Q}(\boldsymbol{M},\boldsymbol{r})}{[\sum_{M} \boldsymbol{MQ}(\boldsymbol{M},\boldsymbol{r})]^2} \tag{1}$$

$$\boldsymbol{M_r} = \sum_{i,j} \boldsymbol{n_t}(\boldsymbol{i},\boldsymbol{j}) \tag{2}$$

$$\boldsymbol{n_r}(\boldsymbol{i},\boldsymbol{j}) = \boldsymbol{v} - \boldsymbol{u} - \boldsymbol{1} \tag{3}$$

Where:
M = Grayscale image mass
(M,r) = Probability distribution of mass
(i,j) = Relative height of column *i* and *j*

The inhabitability index was calculated using indicators from the latest Demographic Census, from 2010[3]. This index, developed by Barros Filho (2006) and adapted by Anjos (2013), calculates the indicators for the census sectors: (i) Sanitation, defined by combining data on water supply, waste collection and sanitation; (ii) Typology, given by the number of bathrooms in the households; (iii) Occupancy, generated by the contractual conditions of land tenure, giving more weight to security of tenure; (iv) Income, considering the average nominal income of those responsible for the households; and (v) Longevity, based on the age groups of the residents. The variables used are detailed in Anjos (2013) and Barros Filho (2006). The average of sanitation, typology and occupation resulted in the Household Index, while the average of income and longevity resulted in the Population Index. Finally, the average of these indices resulted in the Inhabitability Index. Thus, the final construction of the index follows the formulas below:

$$Household\ Index = \frac{Sanitation + Typology + Occupancy}{3} \tag{4}$$

$$Population\ Index = \frac{Income + Longevity}{2} \tag{5}$$

$$Inhabitability\ Index = \frac{Household\ Index + Population\ Index}{2} \tag{6}$$

3.1 Elaboration of the lacunarity map

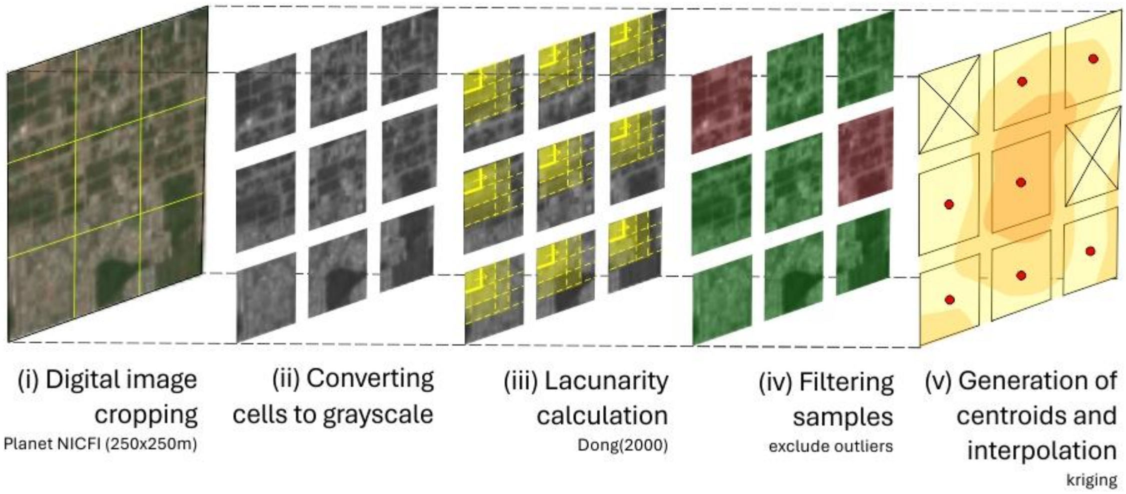
The calculation of lacunarity was carried out using a Python algorithm that crops the entire digital image into a grid of cells (i), as shown in the diagram in Figure 3. Each of the cells is automatically converted into a grayscale and then the calculation proposed by Dong (2000) is carried out (ii). The image selected was from the Planet sensor, made available free of charge by Norway's International Climate & Forests Initiative (NICFI) for monitoring forests in South America and Africa, whose spatial resolution is 5 meters and the mosaic provided (Google Earth Engine) does not contain clouds. The cell size chosen was 250 m x 250 m and a 50% overlap was applied to increase the number of samples (Simões, 2022).

After calculating the lacunarity in each cell (iii), it was necessary to filter out non-occupied samples (iv), because the results of this methodology are very dependent on the classification method, and extreme values (outliers) are to be expected. This process consisted of spatially associating building features with the cells, made available through Google Earth Engine, and samples without buildings were not considered.

[3] For more data from the 2010 Demographic Census, refer to the IBGE website. Available at: https://www.ibge.gov.br/estatisticas/sociais/populacao/9662-censo-demografico-2010.html. Accessed on: July 22, 2024.

Finally, the map was finalized by interpolating a cloud of points generated from lacunarity (v), corresponding to the centroids of the 250 m x 250 m cells. This was done using the logarithmic Ordinary Kriging method, whose values were obtained from the analysis of semivariograms applied to the data set.

Figure 3: Stages for creating the lacunarity map.



Source: Authors, 2023.

3.2 Elaboration of the inhabitability map

The inhabitability calculation was carried out in a spreadsheet, the values obtained were associated with the centroids of João Pessoa's urban census sectors and then ordinary kriging was carried out. To enable cross-referencing, both maps had to be represented in raster format.

The advantage of using census data is that it is freely available and covers the entire country, allowing this methodology to be replicated in other cities. The 2010 Census was used as the data for the 2022 Census is not yet available. Despite the time gap, an analysis of satellite images over the decade shows that the morphological characteristics of the urban fabric have not changed drastically in this time interval, which leads to the assumption that there has been a certain maintenance of the city's socio-spatial segregation patterns.

3.3 Crossing the lacunarity and inhabitability classes

The classes of the lacunarity and inhabitability maps were cross-referenced using the Raster Calculator function, available in the GIS software. As a result, the three classes of each map gave way to nine, namely: Low Low (LL), Medium Low (ML), High Low (HL), Medium Low (ML), Medium Medium (MM), Medium High (MH), High Low (HL), High Medium (HM) and High High (HH). In terms of representation, a matrix with primary and gradual colors was adopted for better class distinction.

3.4 Typological analysis of classes

Initially, this analysis consisted of the random selection of a satellite image sample from each of the nine classes of the cross-referenced map, representing different combinations of lacunarity and inhabitability levels. Then, two Google Street View images were selected from these samples, and their typologies were analyzed in terms of road layout, average number of pavements, presence of setbacks, vegetation cover, building sizes, and roofing materials.

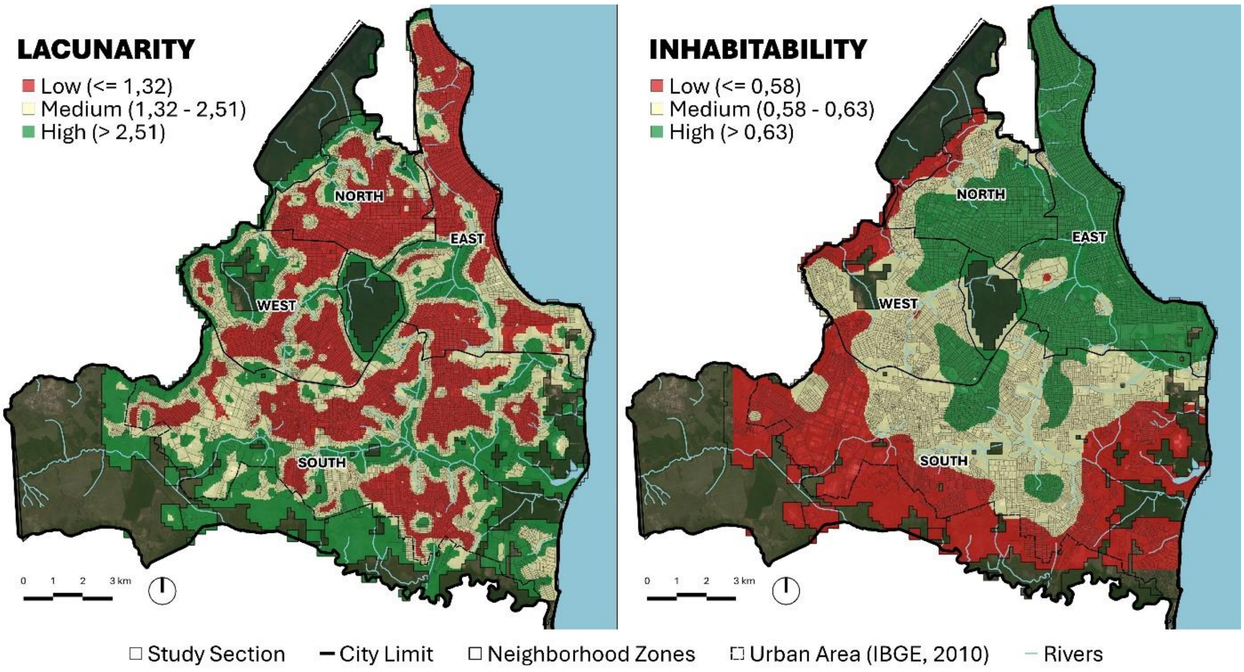
3.5 Typological analysis of ZEIS and macrozoning

Subsequently, the three zones (Priority Densifiable Zone, Non-Priority Densifiable Zone, and Non Densifiable Zone) of João Pessoa Master Plan (Law No. 6.499/2009) were investigated considering the typological classes resulting from the previous stage. Then, the boundaries of the ZEIS of João Pessoa (PB) were superimposed and, through the Zonal Statistics function of a GIS software, and ZEIS were classified according to their levels of lacunarity and inhabitability. These procedures were essential for the detection of different urban fabrics and their relationship with the degrees of consolidation, with important consequences for the city planning.

4 Intra-urban typologies and their implications for planning in João Pessoa, Paraíba

The spatial distribution of the Inhabitability Index in João Pessoa shows high values on the seafront (East Zone), and these values remain high until they approach the city center (West Zone). These results show a timid advance in the South Zone, which mostly presents a trend of reduced inhabitability (Figure 4). In general, areas with high inhabitability levels have good infrastructure and are home to the most varied urban services, as well as commercial and leisure facilities.

Figure 4: Lacunarity and inhabitability maps of João Pessoa.



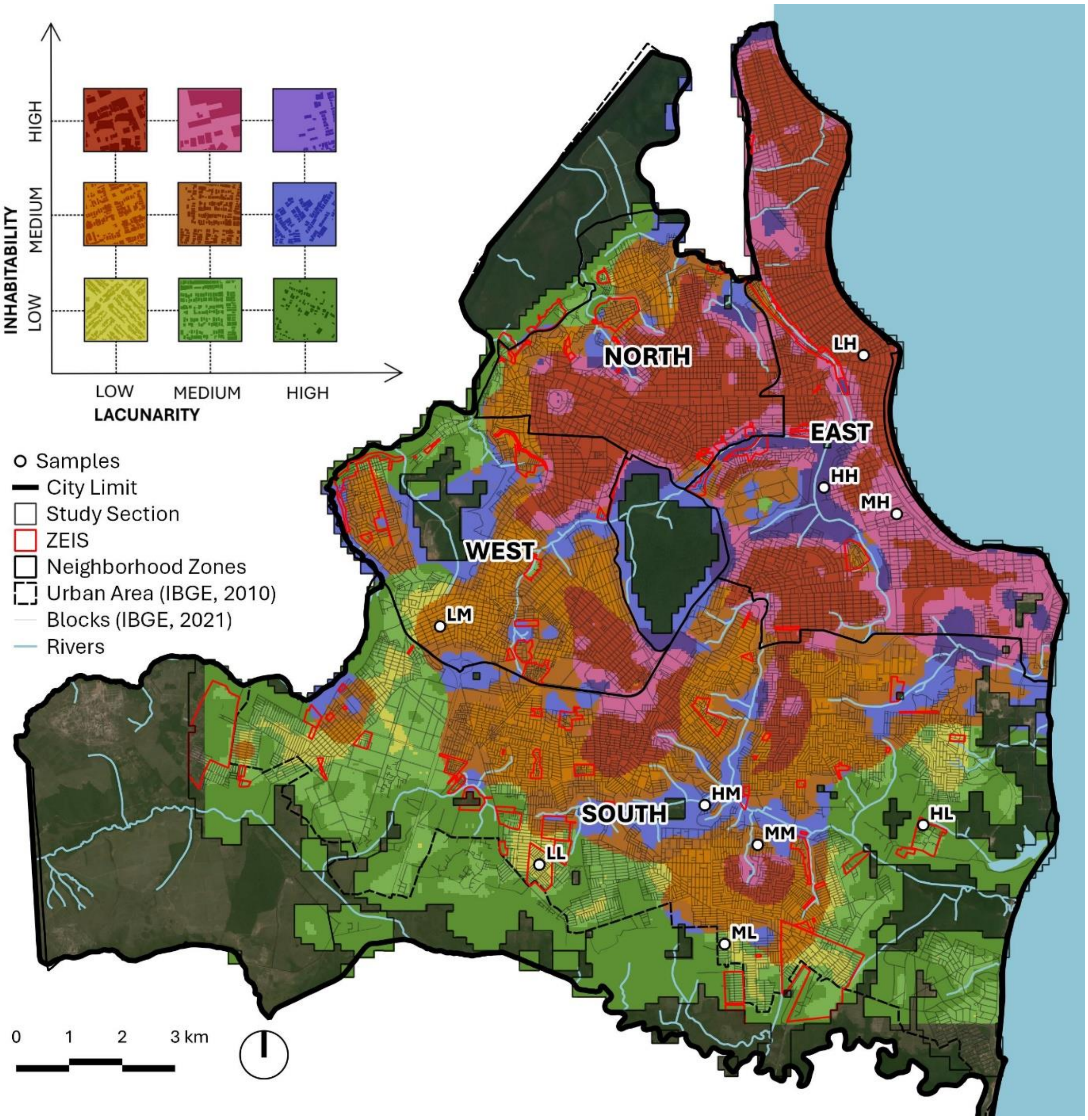
Source: Authors, 2023.

The areas with average inhabitability levels, located predominantly in the South and West Zones, comprise the first neighborhoods occupied by the poorest population during the city expansion, but which have received infrastructure investments over the last decades. This occurs mainly near the BR 101 highway that connects João Pessoa to Recife, being an inducer of urban expansion. Overall, inhabitability classes decrease in value as they move away from the coast. According to IBGE (2017), "some bays have become privileged loci for the emergence and development of urban centers, due to their position [...] Areas along the sand strips are generally more valued, and as you move away, living conditions decrease".

While the inhabitability levels are influenced by the edge, the spatial distribution of the lacunarity levels is more heterogeneous and does not seem to have a centrality or radial behavior (Figure 4). It can be seen that the Lacunarity Index is a measure that allows us to characterize the urban occupation model, which can vary from a compact model, concentrated in a single patch, to a dispersed model, composed by non occupied intervals and multiple nuclei, also known as "leapfrog development" (Hall, 2016).

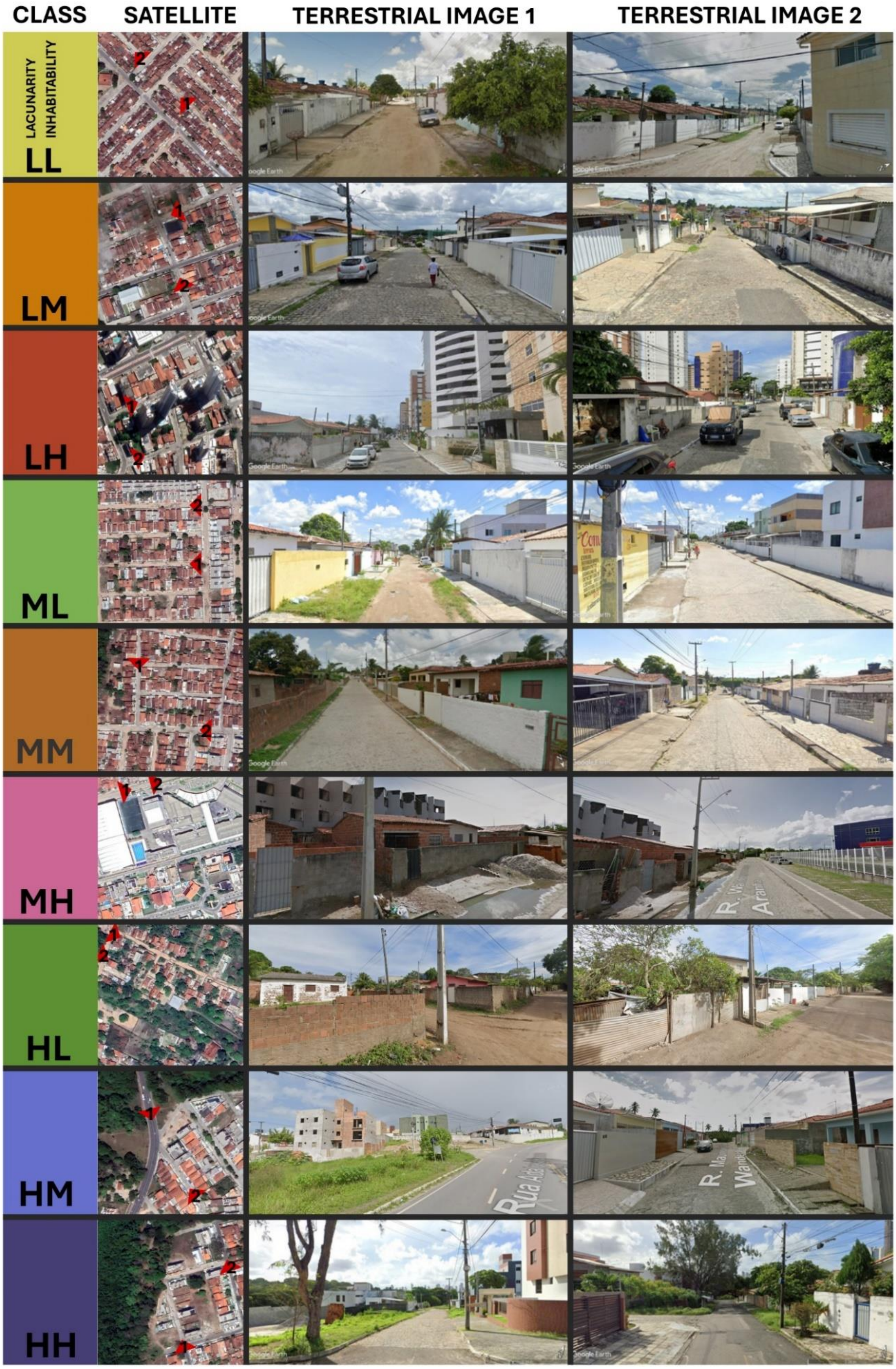
Based on these analyses, the study overlaps the classes of lacunarity and inhabitability, resulting in nine groups represented in Figure 5. The typological pattern of each class is presented in Figure 6, based on a satellite image extracted from Google Earth and two recent terrestrial images (from 2019) captured from Google Street View.

Figure 5: Lacunarity and Inhabitability classes of the crossing-referenced map of João Pessoa.



Source: Authors, 2023.

Figure 6: Satellite and terrestrial images of the lacunarity and inhabitability classes of João Pessoa.



Source: Authors, 2023.

Table 1 shows the predominant morphological characteristics observed in the image samples of each Intra Urban Typology class. Before analyzing each one, it is necessary to clarify that the nine resulting classes do not represent homogeneous urban areas, and it is possible to find precarious settlements even in classes with high inhabitability levels, as well as gated communities in classes with low inhabitability levels. This heterogeneity within the classes occurs, firstly, due to the size of the census tracts, some of them are very large and can homogenize a greater number of patterns, generating values that are neither representative for the poorer resident population, nor for the richer population. Secondly, the census data used for the Inhabitability Index calculation is from 2010, and the Google Street View images were captured between 2019 and 2021. In this sense, it is expected that the urban areas represented in the terrestrial images are more occupied than those represented in the satellite images.

Table 1: Predominant morphological characteristics in the samples of each class.

Class	Road layout, width, pavement	Building height (floors)	Setback quantity	Vegetation intensity	Building size	Roof materials
LL	regular, narrow, unpaved	1, 2	> 2	sparsely	small	ceramic
LM	regular, narrow, paved	1, 2	1 to 2	sparsely	small	ceramic
LH	regular, mixed, paved	1, 2, 3, 4	1 to 2	sparsely	small, big	ceramic, fiber cement
ML	irregular, narrow, paved	1, 2	1 to 2	sparsely	small	ceramic, fiber cement
MM	mixed, mixed, paved	1, 2	1 to 2	heavily	small	ceramic, fiber cement
MH	mixed, mixed, paved	1, 2, 3	1 to 2	heavily	small, big	aluminum, ceramic, fiber cement
HL	irregular, narrow, unpaved	1, 2	> 2	heavily	small	ceramic
HM	mixed, wide, paved	1, 2, 3, 4	> 2	heavily	small	ceramic, fiber cement
HH	regular, wide, paved	1, 2, 3, 4	1, > 2	heavily	small, big	ceramic

Source: Authors, 2023.

Class LL corresponds to urban areas located in the South and West Zones, close to industries. These areas are densely occupied and sparsely vegetated. They present a regular layout with narrow and unpaved roads. As for the houses, there is a predominance of those between 1 and 2 floors, many of them are social housing whose residents have increased their size (losing the original setbacks) as well as their walls, which hinders visibility to the street. The main difference between this class and the LM class is that in the latter the roads are usually paved with cobblestones and the facades of the buildings are covered with nobler materials, usually ceramic.

Class LH is already more different from the previous ones, as it corresponds to extremely valued areas on the seafront and in the city center (East and North Zones). Most of the roads are paved and tree lined, just like the other classes with low lacunarity levels, it is difficult to find vacant lots. However, if previously this phenomenon was linked to self-construction or state-owned housing developments, in this case it refers to the performance of the real estate market, which has intensively occupied these areas since the 1950s.

In addition, LH class has many high buildings with a wide variation of heights; however, near the waterfront, the building heights tend to decrease, due to the parameters established by the local Master Plan (João Pessoa, 2009, p. 10) which limits their heights as they approach the waterfront. Observing the patterns of open and built spaces found in a sample of each class represented in the matrix in the upper left corner of Figure 5, it can be seen that the size of buildings increases as the levels of inhabitability become higher, due to the larger presence of buildings with 4 or more floors.

The medium lacunarity classes (ML, MM and MH) are located in areas between low and high levels of inhabitability; It is not common to combine lacunarity and inhabitability classes with extreme levels, indicating that both quantities are gradually reduced, even in a small transition area. As for the inhabitability classes, the images show that there is a greater probability of finding vacant lots, even if they are few. In addition, the infrastructure of the roads improves considerably in the samples of greater inhabitability, as already noted. To this set of classes, the MH stands out, its chosen sample consists of a road in which, on one side, there is a precarious occupation around an abandoned building, while on the other side, there is a private school used by high-income people. The context becomes clearer when analyzing the class as a whole (Figure 5), and the precarious settlement detected is shown to be an exception, surrounded by a valued area and mostly of high income. On the other side of the private school, there are luxury residences in a gated community, and images of their internal streets are unavailable on Google Street View.

Lastly, we have three classes with a high lacunarity level. The areas of class HL are located at the extremities and correspond, mostly, to precarious areas with very sparse occupation that are close to an area of dense vegetation. The roads tend to be irregular, narrow and unpaved, with deviations conditioned to physical aspects of the relief. The houses are small and with a simple rectangular shape; However, despite having a rural appearance due to the nature of the surroundings, it is still common to find houses that follow the typology of detached house on a delimited lot, protected by high walls.

It is not common to find areas of medium and high inhabitability levels in peri-urban areas, so classes HM and HH refer to well infrastructured urban areas in which predominate empty lots or that are close to large environmental preservation areas. João Pessoa has many highways that surround or enter environmental reserves, which are commonly interconnected to housing areas in the process of densification, and these classes are located in these areas. Many residences of class HH differ from those found in Class HM, due to the nobler materials of their high-income dwellings.

In 2017, IBGE classified the intra-urban typologies using weighting areas and clustering techniques by a non-hierarchical k-means method, identifying 11 typologies named alphabetically from A to K. Several household data were used, such as: garbage collection, water supply, housing density, presence of brick masonry, and existence of computer with internet and washing machine; as well as householders data, such as income, education, number of dependents (under 15 years of age).

The samples collected were also associated with three IBGE intra-urban typologies, with very similar characteristics that validate those detected using the Inhabitability Index. Table 2 shows the numerical data of each sample analyzed, along with the typological classes defined by IBGE.

For urban areas from the low inhabitability class, Typology H was predominant in low and medium lacunarity classes, being characterized by "having good, medium or bad results depending on the theme evaluated [...] they make up large portions of the main urbanized area, but they also form, in some cases, a myriad of urbanized fragments that orbit the main one" (IBGE, 2017). In other words, these may be areas inhabited by a low-income population, but which, however, have already received sanitation and urbanization services and have social housing complexes that ensure the permanence of that population and better construction conditions.

Table 2: Lacunarity Indices, Inhabitability Indices, and intra-urban typology of the nine selected samples.

Lacunarity		Inhabitability		Inhabitability Indicators					IBGE
Class	**Index**	**Class**	**Index**	**Sanitation**	**Income**	**Typology**	**Occupation**	**Longevity**	**Typology**
Low	1.08	Low	0.57	0.99	0.20	0.80	0.88	0.31	H
Low	1.25	Medium	0.61	0.87	0.31	0.83	0.84	0.43	G
Low	1.30	High	0.74	1.00	0.62	0.90	0.87	0.50	C
Medium	1.31	Low	0.57	0.86	0.24	0.81	0.85	0.34	H
Medium	2.23	Medium	0.58	0.92	0.23	0.80	0.88	0.35	G
Medium	2.27	High	0.73	0.90	0.63	0.92	0.94	0.44	C
High	2.98	Low	0.54	0.70	0.25	0.76	0.83	0.36	G
High	3.51	Medium	0.58	0.81	0.27	0.79	0.92	0.36	G
High	5.47	High	0.68	0.89	0.52	0.88	0.88	0.45	C

Source: Authors, 2023. “IBGE Typology” refers to the typological classification established by the survey "Intraurban Typology: Spaces of socioeconomic differentiation in Urban Concentrations in Brazil", carried out by IBGE in 2017.

The samples of the class with medium inhabitability were mostly associated with Typology G, presenting greater oscillations in the results, because "they have, in general, the characteristic of being located interspersed in the urban fabric, next to the main urbanized area, between the best and worst types" (IBGE, 2017). Finally, the areas of high inhabitability were associated with Typology C, characterized as "areas with good living conditions [...] They are close to the richest areas of large urban concentrations or in the most important intra-urban subnuclei" (IBGE, 2017).

It is worth noting the limitations of this comparison, as it considers only three of the eleven intra-urban typologies of IBGE. Despite this, a clear similarity was perceived in this approach. Information from census surveys, such as the Inhabitability Index and the Intra-urban Typologies (IBGE, 2017), extract relevant information about household and population characteristics.

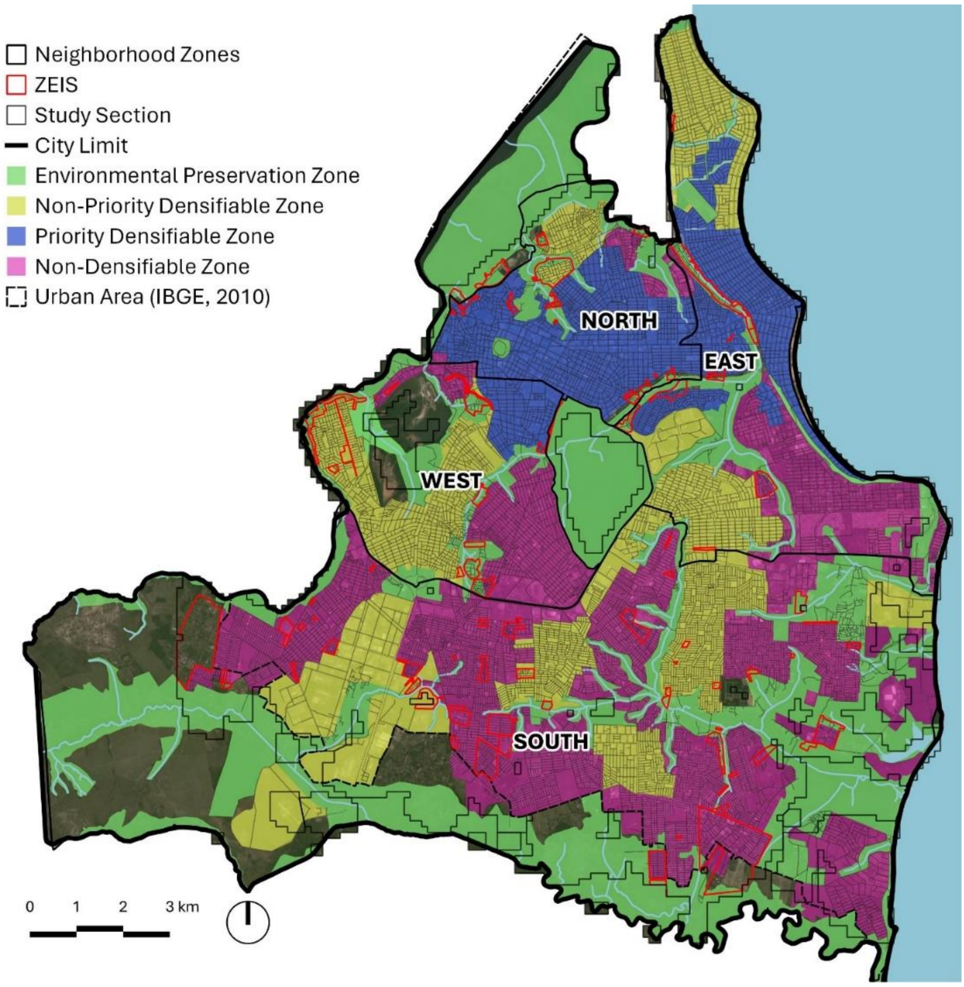
However, there is a range of other data available from public institutions and research agencies, which can be cross-referenced with morphological variables to generate useful information for regional urban planning. In the case of lacunarity, it makes it possible to assess land occupation patterns, which cannot be deduced by looking only at housing density, because very verticalized areas can have a high density of this type, but be surrounded by unoccupied open spaces, so that this occupation pattern may not promote urban vitality, compared to the scenario of high housing density in non-verticalized areas.

In this sense, only by linking spatial data that extract information about the relationships of open spaces with green areas, built areas, urban infrastructure, among others, can the quality of the built environment be more accurately assessed. Such information is fundamental in the design of zones for municipal master plans, in which various urban planning guidelines and instruments can be applied for the regulation of land use and occupation.

Finally, the socio-spatial patterns of three zones of the municipal Master Plan (Law No. 6,499/2009) were investigated. In this analysis, it was assumed that areas with high lacunarity have more open spaces, however, the density capacity depends on the degree of inhabitability, as well as the quality of the infrastructure, which may not be suitable for high densities. The combination of morphological (for example, lacunarity) and infrastructural (for example, inhabitability) attributes can help to define the capacity of a given area to stimulate or restrict occupation. Urban areas with low lacunarity do not have the capacity to increase the land occupation rate, however, depending on the degree of inhabitability, this capacity can be expanded through the verticalization of areas already occupied. The class LH (see Figures 5 and 6) is located in areas where it can be stimulated, as they have infrastructure and several underutilized buildings that can undergo renovations. On the other hand, some areas of classes HH and HM which have many open spaces and good inhabitability conditions can house new developments in financing programs. However, many social housing complexes tend to be built in areas of class HL, due to the cheaper price of land, allocating the population to areas that are poorly integrated into the infrastructure network.

In this sense, analyzing socio-spatial patterns is fundamental in the formulation of macro zoning for master plans. In this paper, three of four zones of João Pessoa Master Plan were analyzed: the Priority Densifiable Zone; the Non-Priority Densifiable Zone; and the Non-Densifiable Zone. The Utilization Index (UI) is a number that, multiplied by the area of a lot, determines the maximum built-up area allowed on this lot. In these zones, the UIs are 4, 2, and 1, respectively. This means that the construction potential of the Priority Densifiable Zone doubles in relation to the Non-Priority Densifiable Zone, while the latter doubles in relation to the Non-Densifiable Zone. Therefore, the possible impacts generated by the land occupation in these zones will be quite different. The Environmental Preservation Zone, highlighted in green in Figure 7, was not included in this study.

Figure 7: Administrative and Densifiable Zones of João Pessoa.



Source: Authors, 2023.

The Priority Densifiable Zone (Figure 7, in blue) is located in the area of highest inhabitability, but with a small amount of open space. The class that most describes this zone is the one with low lacunarity and high inhabitability (70.9%), followed by the medium lacunarity and high inhabitability class (17.3%). This situation may be a cause for an upward trend in the price of the built square meter, and a pressure from the real estate sector to demolish single-family residences for the construction of multi-family buildings. Based on the assumption that there are Special Zones within this area that limit the construction power, as is the case of the regulation of the height of buildings in the 500 meters distance from the waterfront (Law No. 6,499/2009, p.10), in addition to restrictions in areas of heritage and environmental importance. The scarcity of open spaces, in this context, can lead to a pressure for the loosening of protective legislation, in addition to an expansion of this Zone to areas that do not have the same high level of public infrastructure. This zone had the highest levels of inhabitability, especially on the eastern seafront (Table 3).

Table 3: Socio-spatial patterns by Macro Zones of the João Pessoa Master Plan (João Pessoa, 2009).

Class (%)	Priority Densifiable	Non-Priority Densifiable	Non-Densifiable
LL	0.0	7.4	3.6
LM	5.5	20.3	22.3
LH	70.9	27.5	11.3
ML	4.0	18.2	20.3
MM	0.0	1.8	9.4
MH	17.4	9.2	12.3
HL	0.3	9.8	13.1
HM	0.5	4.4	5.1
HH	1.4	1.4	2.6

Source: Authors, 2023.

Therefore, the Non-Priority Densifiable Zone (Figure 7, in yellow) presents a great diversity of intra urban typologies, represented by classes LH (27.5%), LM (20.3%) and ML (18.2%). In general, this is a zone of low lacunarity, but different inhabitability levels (Table 3). This variation is explained by the large number of occupied peripheral areas, where real estate products with a similar occupation pattern have been distributed in mostly peripheral areas, enabling the real estate market to act in the occupation of voids for the construction of popular buildings for the middle and lower classes.

As for the Non-Densifiable Zone (in magenta in Figure 7) it is possible to draw the following findings: (i) in the lacunarity map in Figure 1, it can be seen that many areas of this zone are already densified, since they are predominantly of low lacunarity, when they should be of high lacunarity (see Table 3), in this sense, it can be understood that these are the priority areas by the government for an increase in inhabitability conditions, with the improvement of urban infrastructure. Added to this, the current occupation situation may weaken the discourse of the Government in avoiding greater density; (ii) the bordering areas between the Priority Densifiable Zone (in blue) and Non-Densifiable Zone (in magenta) require greater effectiveness of the instruments to control land use and occupation, since dense and poor areas, close to high-income areas, are more prone to attempts that promote housing evictions and gentrification; and (iii) the ZEIS (in red in Figure 7) under these conditions deserve greater attention. The current Revision of the Master Plan (2021-2022), under the pretext of building ecological parks with a tourist bias, may stimulate densification in unsuitable areas with low infrastructure.

Although low inhabitability is predominant, the Non-Densifiable Zone has a great variation in terms of lacunarity, and areas with high values are full of natural resources. The

Utilization Index of 1 also allows the occupation of these areas for tourism purposes and luxury villas, as is the case of large resorts and gated communities, which, because they are located on large plots, become flexible for different types of occupation. The southern coast is vulnerable to this trend, being able to reproduce enclaves of wealth in an area that is mostly poor, lacking infrastructure and occupied by traditional populations that are at risk of removal.

This analysis becomes even more complex when considering the multiple Special Zones within the Macro Zones of João Pessoa. Taking into account their data, Spearman's coefficient was calculated in an attempt to understand the behavior of the quantities. The value obtained was -0.33, indicating a weak negative correlation. In this sense, the ZEIS with a greater amount of open spaces have a lower inhabitability, and these are commonly located on the periphery or close to water bodies.

The weak correlation confirms the assumptions that there is a diversity of morphological patterns in precarious settlements. And considering its different levels of inhabitability, we take into account the complexity of cross-referencing data of different types. Therefore, the methodology proposed for the detection of intra-urban typologies can help both in the delimitation of Macro Zones and Special Zones, as well as in the evaluation of master plans after implementation, based on relevant information regarding the real estate market and land conflicts.

5 Conclusion

This paper revealed the ability of the combination of lacunarity and inhabitability measures to detect various intra-urban typologies. The complexity of this analysis was the application in a large city, which reverberated in the observation of singularities in the varieties of classes generated with different levels of inhabitability and lacunarity. Methods such as this can help in the analysis of urban fragmentation, based on the distribution of socio-spatial patterns in the territory, as well as identifying which areas of the city can be densified or restricted.

The detection of low inhabitability areas with diverse morphological patterns, by the lacunarity values, contributes to understanding the diversity in precarious settlements, as well as the diverse morphological patterns in high-income areas. The presence of precarious areas with different levels of inhabitability helps in the identification of areas that have already undergone urbanization processes.

As main limitations, the lack of three-dimensional and infrastructural data for the entire city makes the methodology dependent on Google Street View images, which present a temporal gap in relation to the satellite image, as well as the census data used. In general, there is a difficulty in obtaining quality local data, in addition to political barriers that make it difficult to make it available. Furthermore, it should be noted that the classes generated in the intersection may vary depending on the classification and interpolation methods used, which may require geostatistical tests in search of more balanced classes.

Finally, this analysis proved to be useful to support studies of zoning, macro zoning and post implementation evaluation of master plans. Although the relationship of densification and non-densification has been coherent in the face of the distribution of infrastructure in João Pessoa, this relationship is not so simple and should not be seen with causality, due to other political, social and environmental constraints. The replication of this methodology to evaluate the master plans of other cities could reveal inconsistencies that threaten the right to the city and urban sustainability.

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