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The Common Axis:

Configuration and Social Patterns in Brazilian Cities

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ABSTRACT

The study is part of an ongoing research project and seeks to investigate geometric (and topological) aspects in Brazilian cities, from an exploratory perspective. It intends to answer three research questions: 1) what is the effect of urban form/structure on topological accessibility patterns (Space Syntax measures)?; 2) to what extent do the modeling developed according to Space Syntax express the real movement flow?; and 3) how did the diachronic transformation of configurational aspects (geometric and topological) take place in Brazilian cities? The conceptual framework is based on Space Syntax, employing axial and segment maps developed according to updated satellite images (QGis© and Depthmap©). The sample consists of 43 Brazilian cities (different sizes, dates of foundation, and geographic locations), from which 275 models of various stages of urban expansion of the settlements result. The findings reflect the importance of urban design and planning that considers global relationships and the extent to which fragmentation ends up negatively influencing aspects of urban life, legible through configuration.

KEYWORDS

Space Syntax, Topological Accessibility, Brazilian Cities, Diachronic Analysis

1 INTRODUCTION

The research is morphological and seeks to understand geometric and topological aspects of the Brazilian city based on the investigation of its spatial structure, synchronically (currently) and diachronically (over time). The study integrates the project *"Uma herança do ultramar: análise da configuração urbana em cidades lusófonas"* (Medeiros, 2020), developed at PPG/FAU/University of Brasília since 2010, in successive stages. The action, conducted under the *Laboratório Configurar*, is the result of the collaboration of researchers and students at various levels (undergraduate and graduate: scientific initiation, master's, doctoral) and disciplines related to the area of urban morphology and urban planning and design, that progressively contribute to the expansion of the database and development of the analysis.

The project addresses the configurational aspect in urban settlements, comparatively analyzing cities in countries from the former Portuguese colonial network around the world. The intentions of the study are: (a) to strengthen previously investigated morphological aspects (Medeiros, 2013), (b) to discuss new configurational variables, and (c) to extend the analysis of the samples. It is aimed at comparing configurational features - applying instruments of reading and representation of space, by means of the Theory of the Social Logic of Space (Space Syntax; Hillier and Hanson, 1984; Hillier, 1996; Holanda, 2012), and geoprocessing resources - in order to identify an urban typology in the sample settlements, if there are any. In addition, it is intended to advance the conceptual, methodological, and instrumental discussion of Space Syntax, according to vast empirical evidence. Underlying the theme are debates on (1) Portuguese urban know-how; (2) the consolidation of the Portuguese overseas urban network; (3) the processes of expansion and creation of cities, after colonial rule; and (4) the form-space of these cities.

By providing a selection of results for a sample of Brazilian cities that are part of the aforementioned project, this article seeks to contribute to the understanding of the spatial reality in the country, observing how physical transformations can be linked to the national urbanization process, in its various phases or structuring milestones. Although the results cannot be assumed as definitive, due to their exploratory nature, they allow us to trace a set of interpretations on the structure of the city in Brazil that dialogue with the national urban history, advancing to the contemporary scenario.

As a means to conduct the argument, the study is organized around three research questions concerning cities in Brazil: 1) what is the effect of urban form/structure on topological accessibility patterns (Space Syntax measures)?; 2) to what extent does the modeling developed according to Space Syntax express the real movement flow?; and 3) how did the diachronic transformation of configurational aspects (geometric and topological) take place in Brazilian cities?

To that end, the paper is structured in four sections, besides the introduction. Section 2 - *methodological aspects* - explains the following: a) the references for the approach adopted, b) the construction process of the sample, in three groups, and c) the variables chosen. Section 3 - *results and discussion* - seeks to evaluate the effects of a) the shape (structure) on the configurational accessibility, b) the configurational accessibility on the usual average travel time, and c) the course of time in the configuration. Last, Section 4 presents the final considerations.

2 METHODOLOGICAL ASPECTS

The study is based on the Theory of the Social Logic of Space or Space Syntax (Hillier and Hanson, 1984; Hillier, 1996; Holanda, 2012). The approach is founded on the notion of movement, understood as the strategy of spatial reading based on the investigation of the relations between parts of a settlement. Space Syntax (SS) seeks to identify the links between space and society to discuss the social meaning inherent in spatial structures.

Supported by systems thinking, SS seeks to understand the effects of movement patterns for urban dynamics through configuration - i.e., the set of interdependent relationships between the constituent elements of a system. It is assumed that different spatial arrangements produce different potential effects on the movement of people, favoring or restricting the choice of certain routes (Figure 1).

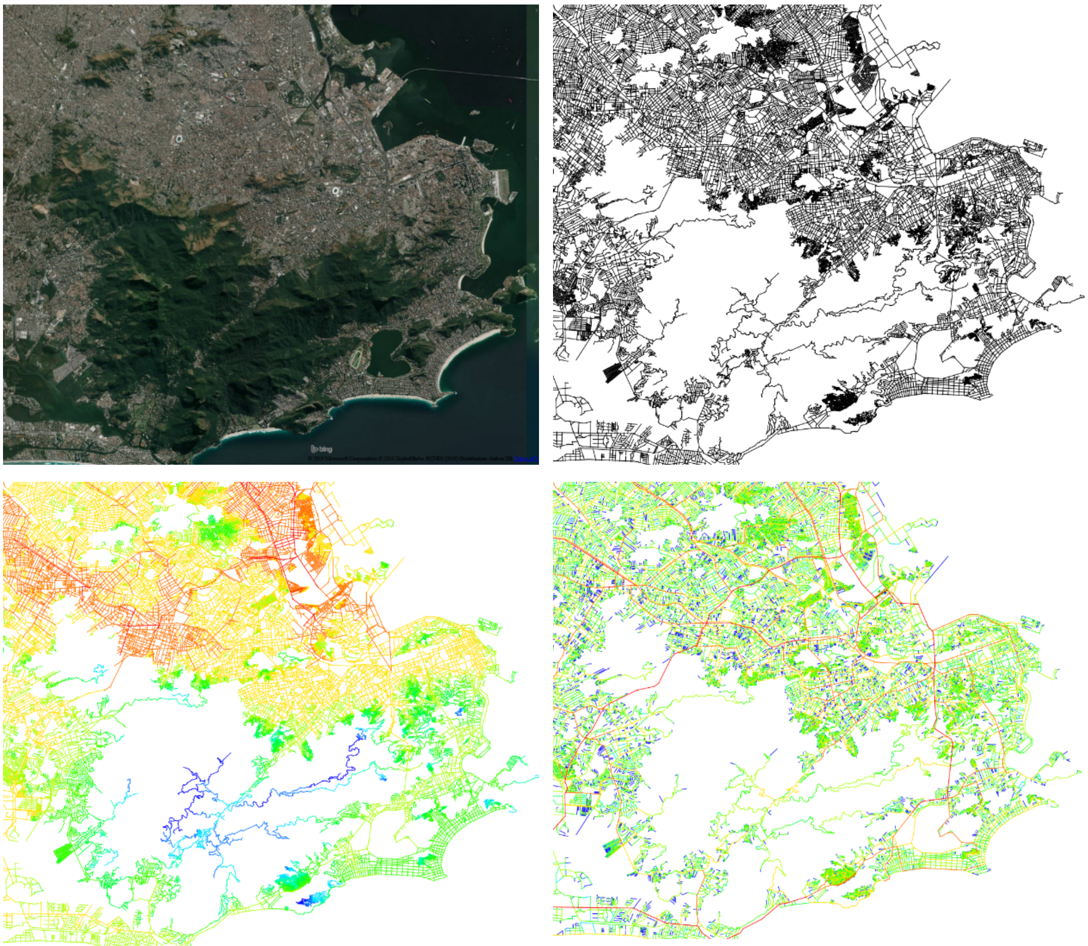


Figure 1. Configurational modeling according to Space Syntax for the city of Rio de Janeiro (excert) in 2017, developed in QGIS software: a) satellite image from the *Bing* platform (top left), b) linear representation (top right), c) axial map for the global integration variable (HH Rn) (bottom left), and d) segment map for the variable NACH (normalized angular choice) (bottom right). Credit of the Linear Representation: Juliane Medeiros.

This premise justifies why there is greater movement on some streets and not others. Although there are several factors influencing the flows throughout the city (such as land use, presence of magnets, civil restrictions, etc.), the approach postulates that the very form of the city read by its configuration is a relevant aspect to be considered, as proven by empirical studies developed around the world (cf. the set of proceedings of the international Space Syntax symposia, initiated in 1997, biennially, available in full at: < http://www.spacesyntax.net/ symposia/ >).

Here, the movement per se is not the object of interest, unless the investigation focuses on a traffic (transportation) perspective, it is rather the set of urban attributes that are associated with movement, such as activity distribution, centrality, segregation, preservation, vitality, etc. Movement should be assumed not as a mere metaphor of urban dynamics, but a mobile morphological component, as opposed to the ones usually catalogued (lots, blocks, streets, etc.), which are fixed (Gondim, 2014).

For this research, linear representations are adopted as tools of Space Syntax, processed as axial and segment maps, whose execution procedures are widely illustrated and discussed in the literature (cf. Holanda, 2012; Medeiros, 2013; Torres, 2017; Loureiro, 2017; Cerqueira, 2017; Rocha, 2017; Coelho and Medeiros, 2019; Loureiro and Medeiros, 2019; Rocha and Medeiros, 2019; Torres and Medeiros, 2019). From the modeling, configurational variables are obtained, which are later confronted with other data, including, for example, those of a socioeconomic nature (Hillier, 2008; Oliveira and Medeiros, 2016; Oliveira, Medeiros, and Corgo, 2020) (Figure 1).

2.1 Sample

For the research, modeling was performed for 43 Brazilian cities (global sample), organized into 3 groups: sample 1 (medium-sized cities), sample 2 (diachronic analysis) and sample 3 (form, structure and accessibility analysis). The modeling, in view of the political-administrative scenario in the country, comprises municipal headquarters, primarily representing the urban area of the settlement. In conurbation situations, the maps extrapolate the political boundaries in order to capture the spatial reality of the structure.

Sample 1 (Medium-sized cities)

Sample 1 was composed of 15 cities whose configurational modeling was developed during the course *Estudos Especiais em Desenho Urbano I e II (EEDU I e II/2019.1)*. Roughly speaking, they are medium-sized cities, with populations varying between 100,000 and 500,000 inhabitants, according to the IBGE's Population Estimate for July 1st, 2020: Anápolis/GO, Betim/MG, Cascavel/PR, Imperatriz/MA, Luziânia/GO, Parauapebas/PA, Petrópolis/RJ, Rio Branco/AC, Rio Verde/GO, Santa Luzia/MG, Trindade/GO, Uberaba/MG, and Vitória da Conquista/BA.
In addition, due to the interest of the participating students, Ribeirão Preto/SP, with a population of almost 700,000 inhabitants, and Planaltina de Goiás/GO, with less than 90,000 people, were included. Although sample 1 covers the 5 major Brazilian regions, it is heterogeneous and includes both state capitals (Rio Branco), and municipalities in the periphery of metropolitan

structures, such as (a) Betim and Santa Luzia, in relation to Belo Horizonte; (b) Luziânia and Planaltina de Goiás, in relation to Brasília; and (c) Trindade to Goiânia.

Sample 2 (Diachronic Analysis)

Sample 2 was produced for the diachronic interpretation of the configurational measures and was based on the construction of axial and segment maps that expressed the expansion process of the settlements over time. In addition to the 15 cities comprising sample 1, the following were included: (a) 6 cities executed by the students in the edition of *Estudos Especiais em Desenho Urbano I e II (EEDU I e II/2018.1)* (Florianópolis/SC, Oeiras/PI, Mogi-Mirim/SP, Foz do Iguaçu/PR, Altônia/PR, Paracatu/MG); (b) Rio de Janeiro, produced by Juliane Cruz *(EEDU 2017.2)* (Medeiros, 2020a); (c) 12 cities of interest for heritage preservation produced by Raquel Egídio for the thesis *"A hospitalidade invertida: o papel das relações configuracionais do espaço urbano turístico"* (Silva, 2017) (Alcântara/MA, Cachoeira/BA, Cidade de Goiás/GO, Congonhas/MG, Diamantina/MG, Icó/CE, Laguna/SC, Ouro Preto/MG, Paraty/RJ, São João del Rei/MG, Serro/MG, and Tiradentes/MG); (d) 8 medium-sized cities included in the dissertation *"Cidades médias brasileiras: que perfil é esse?"* (Bogniotti, 2018) (Londrina/PR, Chapecó/SC, Passo Fundo/RS, Dourados/MS, Marília/SP, Campina Grande/PB, Mossoró/RN and Marabá/PA); and (d) Uberlândia/MG, produced by Brenda Oliveira in her undergraduate thesis *"Estrutura espacial e mobilidade urbana: o caso de Uberlândia"* (Oliveira, 2017). In total, 275 modelings were performed for 43 cities, with the oldest dating back to 1567, for Rio de Janeiro.

The set of 275 maps coming from sample 2 was categorized according to 17 historical periods, with progressively shorter intervals, as it gets closer to the present time: (a) 1-century intervals (1501-1600, 1601-1700, 1701-1800), (b) 50-year intervals (1801-1850, 1851-1900), and (c) 1-decade intervals (1901-1910, 1911-1920, 1921-1930, 1931-1940, 1941-1950, 1951-1960, 1961-1970, 1971-1980, 1981-1990, 1991-2000, 2001-2010, 2011-2019). The heterogeneous division of the intervals resulted from the interest in obtaining more precise information for the most recent scenarios, as well as from the scarce availability of maps for the first centuries of Portuguese rule over Brazilian territory.

Sample 3 (Form, Structure and Accessibility Analysis)

Sample 3 comprised the cities from sample 2, except for Rio de Janeiro/RJ. The set of 42 samples was evaluated exclusively in their most recent available maps - 2014: Cachoeira/BA; 2015: Alcântara/MA and Icó/CE; 2016: Cidade de Goiás/GO, Congonhas/MG, Diamantina/MG, Laguna/SC, Ouro Preto/MG, Paraty/RJ and Serro/MG; 2017: Altônia/PR, Campina Grande/PB, Chapecó/SC, Dourados/MS, Londrina/PR, Marabá/PA, Marília/SP, Mossoró/RN, Passo Fundo/RS, São João Del Rei/MG, Tiradentes/MG, and Uberlândia/MG; 2018: Florianópolis/SC, Foz do Iguaçu/PR, Mogi-Mirim/SP, Oeiras/PI, and Paracatu/MG; and 2019: Anápolis/GO, Betim/MG, Cascavel/PR, Imperatriz/MA, Luziânia/MA, Parauapebas/PA, Petrópolis/RJ, Planaltina de Goiás/GO, Ribeirão Preto/SP, Rio Branco/AC, Rio Verde/GO, Santa Luzia/MG, Trindade/GO, Uberaba/MG, and Vitória da Conquista/BA.

The sample was used to investigate the relationship between configurational centrality (via NAIN: see next item) and a set of qualitative geometric and topological variables regarding the characteristics of the structure of linear representation (in its original situation or processed as axial and segment map). The intention was to understand to what extent the shape and structure of the city affect the potential accessibility relationships, readable from the normalized integration measure.

2.2 Variables

The linear representations referring to the different sample groupings (from 1 to 3) were processed, and, from the modeling, qualitative and quantitative configurational variables were extracted. The quantitative variables were geometric and topological, whereas the qualitative variables are as follows: 1) area of the system (km2), 2) number of lines/axes, 3) average length of lines/axes (m), 4) number of segments, 5) average length of segments (m), 6) compactness a: number of lines/axes per km2, 7) compactness b: length of lines/axes (in km) per km2, 8) connectivity, 9) global integration (Rn), 10) local integration (R3), 11) synergy, 12) intelligibility, 13) NAIN, 14) NACH, 15) continuity of the urban area, 16) predominant form of the linear representation, 17) predominant intersection type, 18) pattern of the linear representation, 19) existence of global lines, and 20) function of the most integrated lines (Charts 1, 2, and 3).

Since the Theory of the Social Logic of Space is related to the evaluation of the potential movement arising from the network of paths comprising a settlement, the information of variable 21) average travel time to work was used for the validation, at least for part of the cities investigated, based on data collected by the 2010 Census, from IBGE.

Chart 1. List of quantitative geometric configurational variables, with performance interpretation.

ID	Variable	Category	Explanation/Interpretation
1	Area of the System (Area)	Order of Magnitude	*It indicates the area of the metropolitan area corresponding to the linear representation, in km2 (it does not represent the official area of the city, but rather the area extracted from the polygon that contains the representation).*
2	Number of Lines/Axes (N. Axes)	Order of Magnitude	*It indicates the number of lines in the system, which will be a product of the configurational characteristics (greater or lesser regularity affect this measurement). Regardless of the size of the system, it is worth considering that cities with greater regularity tend to have a smaller number of lines, since a few straight axes can cover most of the territory.*
3	Average Length of Lines/Axes (T. Axes)	Order of Magnitude	*It represents the average length of the lines in the system in meters and it serves as a parameter to evaluate the average size of streets (estimate). It is relevant to compare with the previous measurement,*

			taking into consideration the discussion over the degree of regularity.
4	Number of Segments (N. Seg)	Order of Magnitude	*It indicates de number of segments in the system. See item "Number of Lines/Axes".*
5	Average Length of Segments (T. Seg)	Order of Magnitude	*It shows the average length of segments in the system, in meters, and it serves as a parameter to evaluate de average size of blocks (estimate).*
6	Compactness A: Number of Lines/Axes per Km^2 (Comp. A)	Order of Densification	*It is a measure of the density of the system, associating the number of existing lines in units of area (in km^2). The greater the regularity in a city, the lower the measurements. The more irregular, the higher the measurements.*
7	Compactness B: Length of Lines/Axes (in Km) per Km^2 (Comp. B)	Order of Densification	*It is a second measure of the system's density, associating the total length of lines (in km) by unit of area (in km^2). This variable allows us to make more refined observations when compared to the previous measurement because it points to the "length of street" per area, regardless of regularity.*

Chart 2. List of quantitative topological configurational variables, with performance interpretation.

ID	Variable	Category	Explanation/Interpretation
8	Connectivity (CON)	Topological Accessibility	*It indicates de average number of connections of axes in the system. This measure is directly associated to the number of routes and trajectories available for displacement in a city. Systems with high average connectivity are more accessible because they offer a greater number of possibilities of paths. The regularity associated with the chessboard grid also leads to higher values. Irregular grids tend to decrease average connectivity, which compromises potential accessibility.*
9	Global Integration (Rn) (INT Rn)	Topological Accessibility	*Integration is a measure of centrality that indicates the lines that can be most easily reached from the others in the system. More accessible lines tend to concentrate uses and activities that benefit from this potential movement, such as commerce and services, which highlights the coincidence with active urban centers. This measure can be globally evaluated, highlighting the integration core, which corresponds to the set of most integrated axes. Alternatively, local assessment (analysis in radius 3) points to local centers, as seen in the literature. The most integrated lines are those that function as a "destination".*
10	Local Integration (R3) (INT R3)	Topological Accessibility	*See previous item.*
11	Sinergy (SIN)	Topological Perception (Legibility)	*Indicates the correlation between global and local integration of the system. The higher its value, the greater the synchrony between global and local properties (a good synergy means that axes that are more globally integrated are also more integrated when analyzed at the local scale).*
12	Intelligibility (INTEL)	Topological Perception	*Indicates the degree of legibility of the system. The higher its value, the better it meets the expectation that*

		(Legibility)	*the most connected lines are also the most integrated globally.*
13	NAIN	Topological Accessibility	*(Normalized Integration) NAIN is a centrality measure calculated from the global angular analysis (radius n) (segment map), which considers the angle of direction changes to construct the smallest angular path, i.e., the one that minimizes the angle of direction changes (Coelho, 2017).*
14	NACH	Topological Accessibility	*(Normalized Choice) (NACH) is the normalized measure of choice obtained from the global angular analysis (radius n) (segment map) associated with the distribution of the path network across the system (Coelho, 2017). Choice indicates how much the paths/axes/segments are used, which signifies the evaluation of the role as a "path". The measure is relevant for exploring road hierarchy issues, due to the correspondence between the potential of the configuration and the actual movement.*

Chart 3. List of qualitative configurational variables, with performance interpretation.

ID	Variable	Category	Explanation/Interpretation
15	Continuity of the Urban Area	Form and Structure	*It indicates whether the urban area is "continuous" or "discontinuous", that is, it assesses the presence of significant voids or interruptions in the build-up area.*
16	Predominant Form of the Linear Representatio n	Form and Structure	*It indicates whether the linear representation is predominantly "regular", "mixed" or "irregular" according to its form.*
17	Predominant Type of Intersection	Form and Structure	*It indicates the predominant type of intersection: "X", "T" or "mixed",*
18	Linear Representatio n Pattern	Form and Structure	*It indicates the predominant pattern of linear representation: "chess board grid", "mixed" or "organic".*
19	Presence of Global Lines	Form and Structure; Topological Accessibility	*It records the presence ("yes") or absence ("no") of red lines, both on the axial map and on the segment map, that cross from the integration core to the peripheries of the urban system.*
20	Function of the Most Integrated Lines	Form and Structure; Topological Accessibility	*It evaluates the role of the reddest lines, both on the axial map and on the segment map, in relation to their coverage on the map: whether "global", i.e., if they cut across the entire system, from the center to the peripheries, or "local", if they cover only small fractions of the system.*

3 RESULTS AND DISCUSSION

3.1 Effects of the Form (Structure) on Configurational Accessibility in Brazilian Cities

The first research question concerns the understanding of the effect of urban form on topological accessibility patterns, in the case of Brazilian cities. To evaluate this accessibility, we used as reference the variable NAIN (normalized integration), a measure of centrality derived from the segment map. In this analysis, the characteristics of urban structures that affect the supply of paths in urban systems are observed. The results obtained indicate that, for sample 3 (Figure 2):

a) Irregular systems, that is, of complex geometry and implicit structuring logic (cf. Loureiro, 2017; Loureiro and Medeiros, 2019) are less accessible, while regular systems, of simpler geometry and explicit logic, are more so. The behavior is similar for continuous or discontinuous grid, with the difference that, in the case of the former, the averages are always higher than for the latter. More regular urban networks increase the number of possible travel routes and paths, which facilitates potential accessibility. Mixed grids are in an intermediate position in any continuity scenario.

b) In relation to the linear representation pattern, in clear dialogue with the previous results, chessboard grids present higher NAIN averages (1.035) than mixed (0.845) and organic (0.471) grids. The significant disparity is a product of the irregularity of the organic grid that, although commonly containing a clearer hierarchy, has reduced connectivity and provision of routes, which compromises the number of possible paths.

c) The evaluation of the predominant type of intersection is carried out by comparing the proportion of "T" intersections, i.e., with more streets that end when they reach others (which is more common in organic grids), and "X" intersections, when streets cross those with which they meet, a recurrent situation in chessboard grids. For the sample, when there is a predominance of intersection in "X", the average NAIN values are significantly higher (0.961) than those with a predominance of "T" (0.556).

d) When processing the representations in the format of axial or segment maps, a relevant criterion is the existence of global lines, that is, those that establish the connections between the morphological center and the peripheries of the system. The model pointed out in the literature as the most advantageous in terms of accessibility is the "deformed wheel" (Hillier and Hanson, 1984; Hillier, 1996), composed of a central structure from which rims emerge that follow in all directions and function as connective axes.

However, the existence of at least one global line already indicates a local-global, inside-outside articulation, although the ideal theoretical situation would imply having such axes covering all the quadrants of the system, in several directions. The existence of one global line or more, by itself, is already capable of favoring articulation precisely because of this aspect. For the sample, systems that contain global lines are significantly more accessible in topological terms (1.009) than those that do not have them (0.653), which points to the labyrinth effect in compromising the topological accessibility of the systems.

e) If these lines cross all the quadrants of the settlement, or most of them, accessibility becomes even higher, as can be seen in the variation of the averages: 1.034 for the existence of global lines that cross the entire system, compared to those that do not present this extended crossing (0.805).

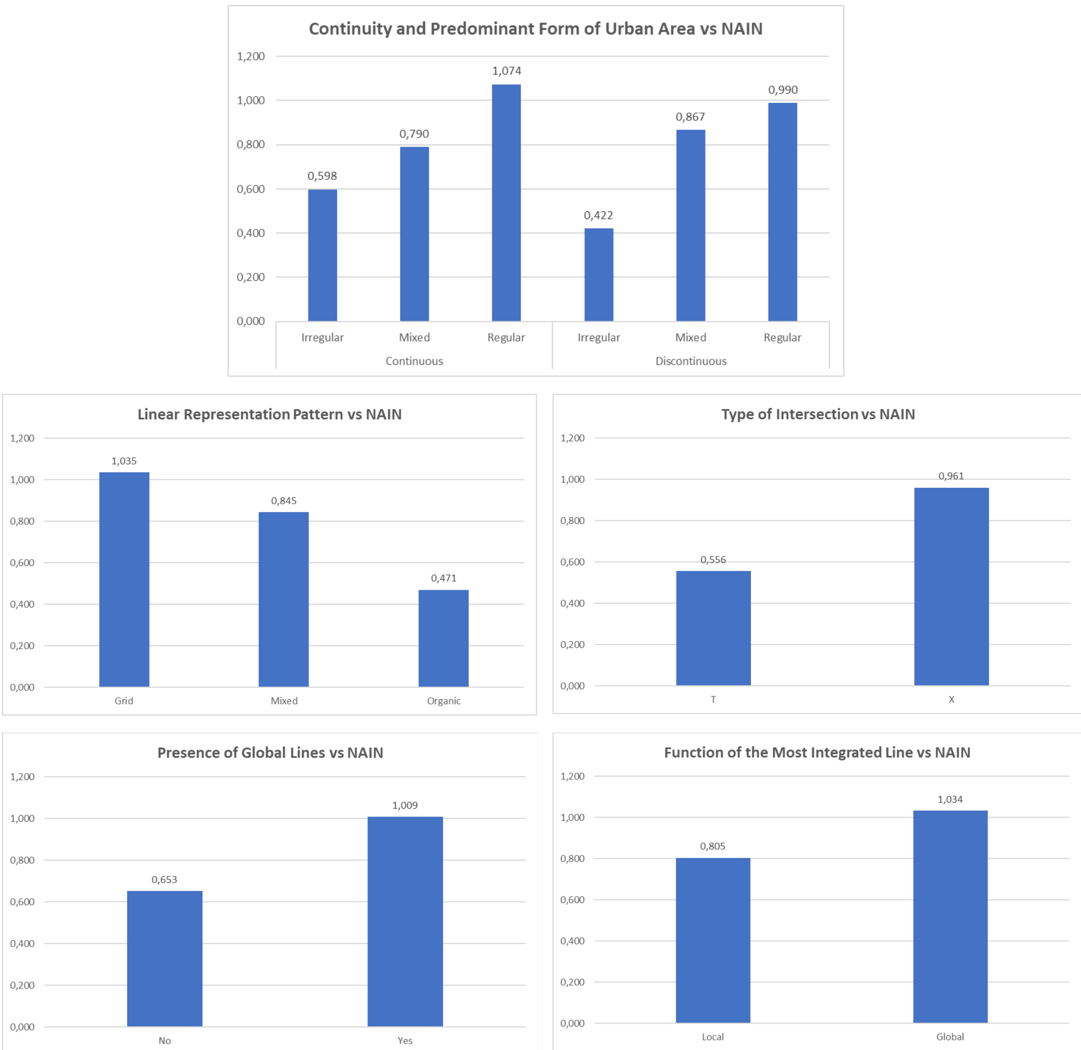


Figure 2. Association between qualitative variables of form characterization and potential accessibility from the NAIN measure (normalized angular integration extracted from the segment map).

3.2 Effects of Configurational Accessibility over Average Travel Time

It is common to question the validity of the modeling associated with Space Syntax in relation to the actual flows of movement in the city. Axial maps and segment maps are potentials, that is, they indicate the potential for movement arising from the urban form, in what Hillier and Hanson (1984) call "natural movement". They are not, in fact, reality. Despite this, the literature, including that conducted in Brazil in recent years (Barros, 2014; Arrais, 2015; Cerqueira, 2017; Rocha, 2017; Torres, 2017; Coelho and Medeiros, 2019; Rocha and Medeiros, 2019; Torres and Medeiros, 2019), has shown a robust correspondence between accessibility potentials, noticeable from measures such as global integration, local integration, NAIN and NACH, and the actual movement of people.

If the goal of the research is the adoption of the maps as movement simulation, it is necessary to validate the modeling. This means confronting the actual flow of movement with the potential flows coming from the axial and segment maps, in the present situation or in a context where consistent data exists. The aim is to scrutinize this aspect that supports the research question "to what extent do the modelings developed according to the Space Syntax express the actual flow of movement?"

There are specific procedures that appear in the Space Syntax Observation Manual (Grajewski and Vaughan, 2001) in order to count the actual flow of movement. Recent studies developed at *Universidade de Brasília* have demonstrated high degrees of correspondence (Cerqueira, 2017; Rocha, 2017; Torres, 2017), in places as distinct from one another as Goiânia/GO, Recife/PE, and Afuá/PA.

Due to the scope of the research, it would not be feasible to validate the maps based on actual counts. However, it would be possible to evaluate the effect of form on movement, or its synchrony, considering the *average travel time* data inventoried by IBGE in the 2010 Census. To this end, topological variables were correlated with *average travel time /ATT* for sample 1, composed of relatively homogeneous settlements, classified as medium-sized.
By means of simple regression, the coefficients of determination (R^2) were obtained, which correspond to the measure of the proportion of variability of a variable explained by the variability of the other, one being independent and the other explanatory (Medeiros, 2013). With the intention of facilitating the interpretation, we adopted the *Cohen Scale*, which is an auxiliary tool for explaining the intensity of the R^2 from the correspondence between the numerical value obtained and a rating scale from nonexistent to perfect (Cohen, 1988; Hopkins, 2002): non-existent (0.0 to 0.009), small (0.01 to 0.08), moderate (0.09 to 0.24), large (0.25 to 0.48), very large (0.49 to 0.80), almost perfect (0.81 to 0.99) and perfect (1).

The results obtained (Figure 3) show that:

a) If we consider the correlation between *connectivity* (average number of connections in an urban system, read from the axial map) and the percentage of inhabitants who spend, daily, from 30 min to 1 hour in their average travel time, we observe that the relation is inversely proportional, with a large determination coefficient (0.47), according to Cohen's Scale. It means that, for similar systems like the ones in sample 1, the lower the average connectivity, that is, the worse the system is articulated, the higher the percentage of population that takes this amount of time to commute daily. The higher the connectivity, on the other hand, the lower the percentage, since most of the population would probably commute in a shorter time, below 30 minutes.

b) This performance repeats itself, always inversely proportional, for the correlations with *integration Rn HH* ($R^2 = 0.49$, in the threshold between large and very large), coming from the axial map, and *NAIN* ($R^2 = 0.62$, very large), product of the segment map. There is no correlation, however, with *NACH* ($R^2 = 0.003$).

c) If we consider the correlation in the lower time interval - average travel time of 6 min to 30 min - the associations become directly proportional, that is, the better the performance of the configurational variable, the higher the percentage of the population in this range of average travel time. For *connectivity*, the coefficient of determination is 0.17, moderate according to Cohen's Scale. As for *integration Rn HH*, there is a drop in value, but it is still classified as moderate (0.11). However, it rises to 0.25 with *NAIN* (at the lower threshold of large). Similarly, only a tenuous correlation was found with *NACH* (R2 = 0.05).

d) The data obtained, to consider the common grouping of settlements, provide evidence of how much the structure of the path network can affect everyday commuting. The greater the *connectivity* of a system, the greater the *integration* and *NAIN*. The effect is an increase in the percentage of the population that commutes in the 6 min to 30 min daily range, and a drop in the percentage of those who take 30 min to 1 hour. In other words, if the system is configurationally better articulated, it will also be more fluid, so the actual commute measurable via the ATT variable is facilitated.

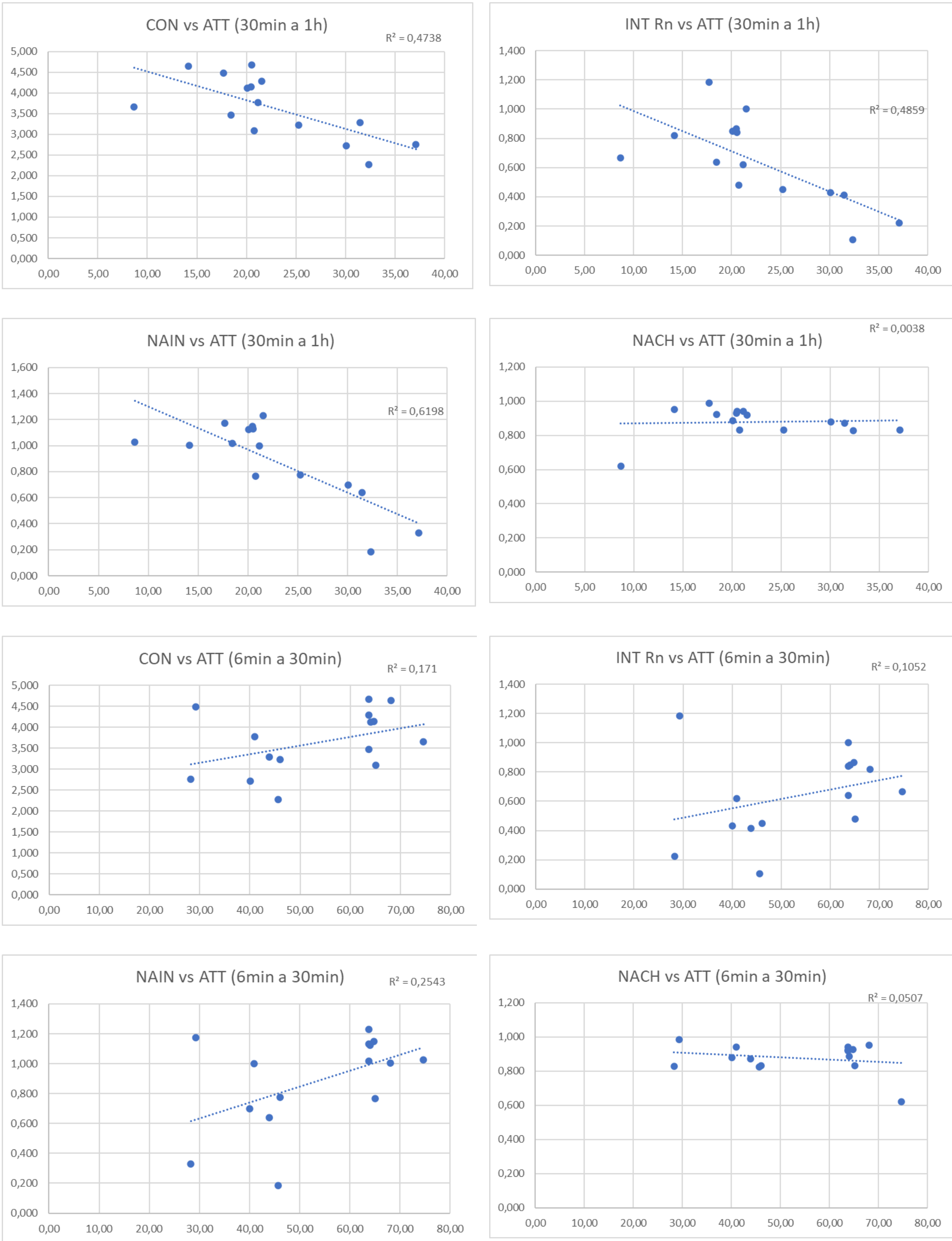


Figure 3. Correlations between configurational variables (*connectivity, integration, NAIN and NACH*) and *average travel time* (6min to 30min; 30min to 1h), according to the 2010 Census (IBGE).

3.3 Diachronic Discussion on Brazilian Cities

Once the effects of form (structure) on configurational accessibility and of the latter on the usual commuting time were understood, a third research aim was to explore how the diachronic transformation of the configurational aspects (geometric and topological) in Brazilian cities took place.

For this phase, the main objective was the configurational characterization of the country's settlements in a diachronic perspective. The results obtained pointed out that (Figure 4, Table 1 and Table 2):

a) Throughout the colonial period, the urban structures are reduced, and hardly exceed 1,00km^2, an area that is only surpassed in the beginning of the 19th century. Despite the growth from then on, it is only after the third decade of the 20th century that the limit of 6,00km^2 is effectively surpassed. Considering the acceleration of urban growth in the country from the 1940s onward, the figures grow continuously. In each decade the dimensions increase by 50% in relation to the previous period, until reaching, in the last interval of analysis, an average of 142km^2, which would be equivalent to a square urban area with a side of approximately 12 km.

b) As expected, the *number of lines* follows the growth of the area: low values throughout the colonial period and a rupture especially between the 1930s and 1940s, a landmark for the beginning of accelerated urbanization in the country. If in colonial Brazil the cities had, on average, less than 100 routes (this range will only be exceeded from the second half of the 19th century onwards), the value reaches the level of approximately 6,000 lines in the final interval (2011-2019), a 60-fold increase.

c) Street size, which can generally be interpreted based on the average length of the lines, has a wave-like behavior: the values alternately rise and fall, which is believed to be related to phases of rapid expansion of the urban area and subsequent filling of the territories between the original settlement limits and those resulting from the expansion. If this assumption is correct, it can be assumed as expansion phases the first half of the nineteenth century, which is related to the arrival of the Portuguese Royal Family in Brazil in 1808 and the implementation of a set of policies and institutions that were, to some extent, responsible for stimulating urban growth.

Of special interest in this period is the *Opening of the Ports*, in 1810, which promoted the dilatation of the urban limits, by generating the expansion of the upper city to the lower city, the focus of trade due to the port. In the 20th century, the beginning of the acceleration of urbanization, in the 1940s, also corresponds to the period with the highest value of the variable: streets reaching an average of 547.13m.
From that moment on, the decline is successive, starting the 21st century at the same level as the beginning of the 20th century. The explanation for this phenomenon is perhaps associated with an expansion of the urban limits linked to long streets built to

reach these new frontiers in the 1940s. However, the continuous filling of the voids resulted in the contemporary measure. On the other hand, the changes in the variable "in bursts" reinforces the notion of waves of expansion and filling that seem to characterize the Brazilian city.

d) The *average block size*, which can, by analogy, be extracted from the variable *average length of segments*, presents a decreasing behavior, however without the significant oscillations of the average line length. Here we observe a scenario in which the peak of 126.14m (in the interval 1931-1940) decreases, until it stabilizes in the 90m range. The value, if confronted with literature in favor of promoting urbanity (Jacobs, 2000; Fernandes, 2011; Holanda, 2013; Gehl, 2013), legitimizes the interpretation that at least in this measure there is performance in favor of better spatial quality.

e) However, the variables that account for density aspects, such as *compactness A and B*, have inverse performance. Although a city becoming progressively more dense and compact would be desirable, what is verified in the diachronic reading is that, especially throughout the 20th century, there has been a reduction in the amount of axes and in the total length of axes per km^2. It means that: (a) urban voids have been growing, (b) associated with the expansion of the boundaries of urban metropolitan areas that tends to be more rarefied as one moves away from the old center. The ongoing path is oriented toward a dispersed city.

f) If the previous variables provide geometrical features, regarding the order of magnitude, the topological measures associated with accessibility express how the relationships between parts of the urban structure in Brazil have behaved. If we understand that the average number of crossings on city streets is an indicator of better urban mobility, since it would mean a greater supply of routes and paths between any pair of origin and destination, we see that *connectivity* in the country, from the colonial period until the 1940s, grew, despite slight moments of decline.

The result may be an indication of the transformation from a more irregular or organic urban fabric (Reis Filho, 2000; Reis Filho, 2001; Teixeira, 2012), in the first moments of the colonial period, to another one primarily based on the chessboard grid or, as will happen in the eighteenth century, with the set of cities founded by the Portuguese Empire in the Brazilian Amazon, according to the orders of Marques de Pombal. The regularity of the grid would be associated to moments when occupation needed to occur quickly, or else in a clear counterpoint to the colonial structure.

However, as of 1940, the values suffer a slight reduction, falling from 4.65 in this interval, to the current 3.55. Although it remains at a high level in view of the timeline, the drop (with a tendency to stabilize in the final phase), points to a loss of articulation of the urban path network, which can also be understood as responsible for the compromise in the circulation condition in the cities of the country.

g) The performance of the *integration* measures dialogues with the panorama described above. However, if in the case of *connectivity*, the drop has not yet reached the lowest values, for *integration* the scale factor (the excessive growth of urban areas) seems to contribute so that potential accessibility, which measures the displacement factor, is currently the lowest of the entire period analyzed, reaching 0.697.

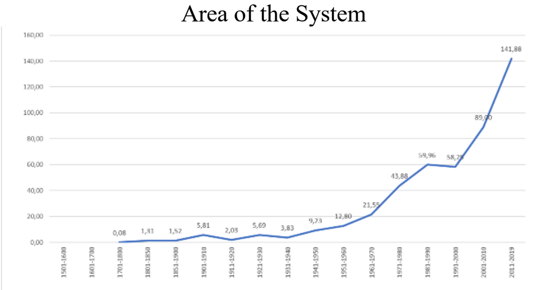
This number is even lower than the one verified by Medeiros (2013), of 0.764. Although the drop in connectivity has not been sharp, the cities have grown under a model based also on horizontal growth, promoting urban voids and long distances, which ultimately compromises the relationships between parts. Here we also identify the "burst" scenario, with alternating rises and falls.

h) Local measures, however, apart from an initial moment of oscillation, remain constant. If locally the properties are maintained and globally, they decline, one can understand that the city loses its global properties, preserving, however, the dynamics of the neighborhoods and local centers. The whole is lost, the part remains.

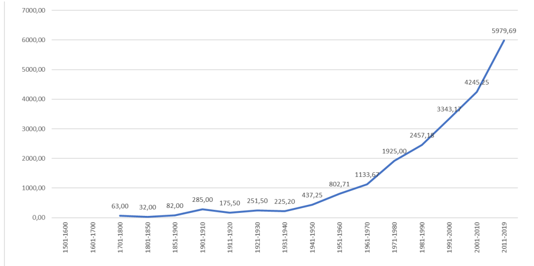
i) The previous findings affect issues of perception and legibility. As expected, the growth, fragmentation, and discontinuity of urban fabrics in Brazilian cities result in loss of properties that allow a better spatial understanding (Medeiros, 2013; Silva, 2017; Bogniotti, 2018). Both *synergy* and *intelligibility* decline, in a sequential and progressive reduction, until they reach the worst level of the sample in the last intervals. The very expansion of structures can be reputed to cause the loss of global understanding, either by the expectation that global properties remain at the local scale (*synergy*), or that the most connected routes are also the most integrated (*intelligibility*). It is relevant to note that these two variables, interpreted according to the coefficient of determination, reach averages below 40%, which is still high for synergy, but low for intelligibility, at just under 14%.

j) Finally, the normalized *NAIN* and *NACH* measures, derived from the segment map, are used to interpret the angular reading of the movement. The performance of *NAIN* is close to that of the *global integration*: the lowest value of the historical series occurs at present, with 0.867, which indicates the compromise of the relational properties as Brazilian cities have grown. The *NACH* variable, on the other hand, proved to be of little use for comparison - apparently the normalization process proceeded with the choice ends up almost eliminating the difference between the systems, resulting in almost constant values. The variable, it seems, is more relevant to be analyzed in terms of lane-by-lane variation over time, or else to provide information with strong equivalence to the road hierarchy within a system.

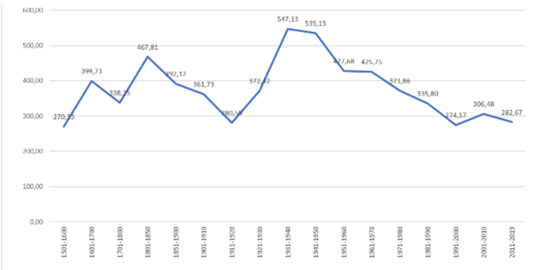
Area of the System



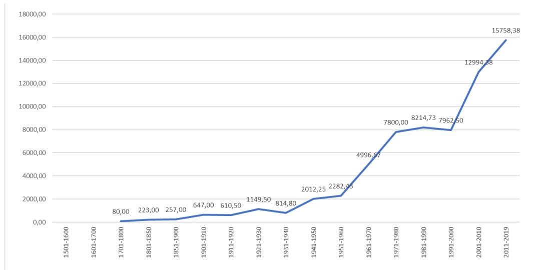
Number of Lines/Axes



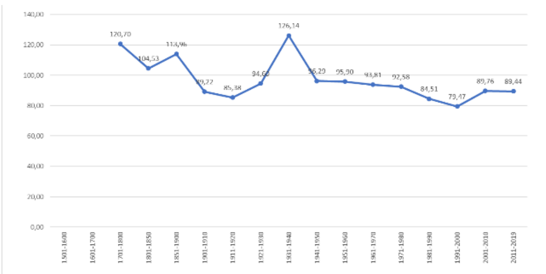
Average Length of Lines/Axes



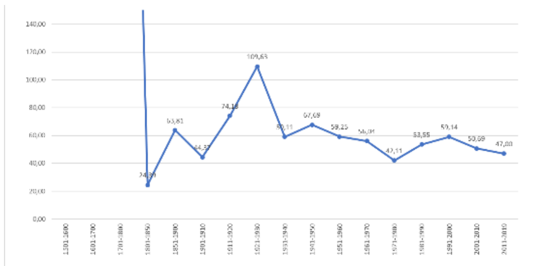
Number of Segments



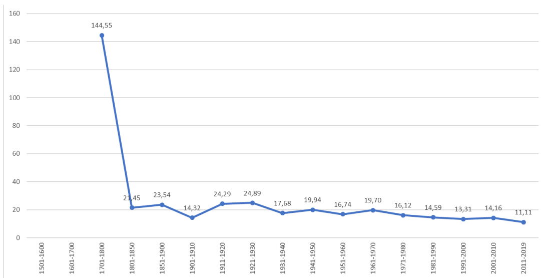
Average Length of Segments



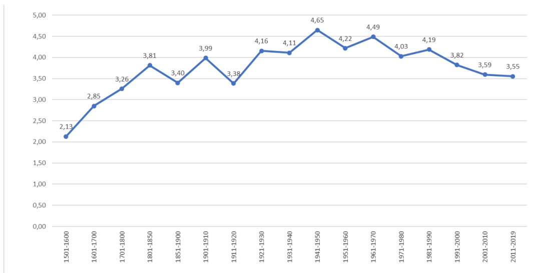
Compactness A



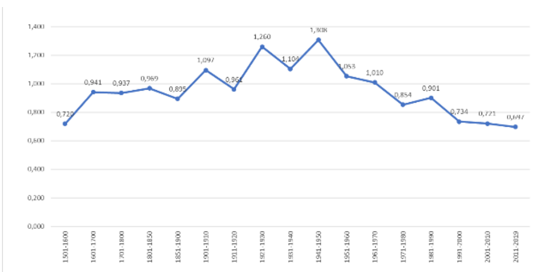
Compactness B



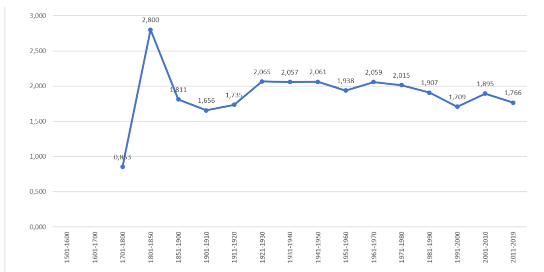
Connectivity



Global Integration (Rn)



Local Integration (R3)



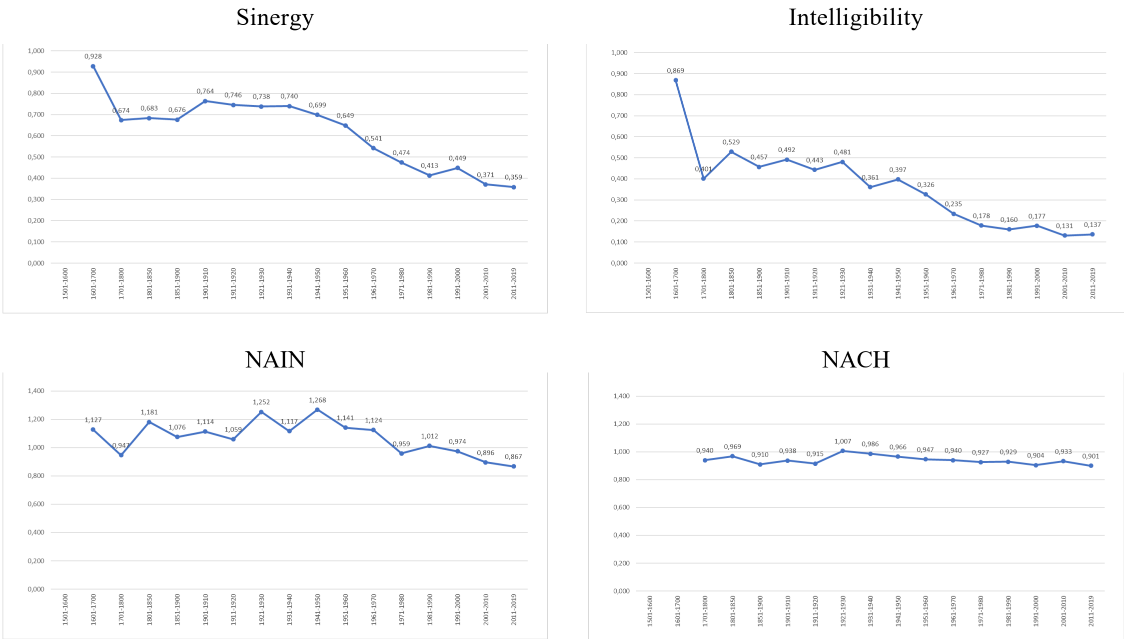


Figure 4. Diachronic performance of configurational variables for the sample of Brazilian cities.

Table 1. Results for the quantitative geometric configurational variables, according to the periods analyzed.

Periods	Area	N. Axes	T. Axes	N. Seg	T. Seg	Comp. A	Comp. B
1501-1600	-	-	270,33	-	-	-	-
1601-1700	-	-	399,73	-	-	-	-
1701-1800	0,08	63,00	338,25	80,00	120,70	787,50	144,55
1801-1850	1,31	32,00	467,81	223,00	104,53	24,39	21,45
1851-1900	1,52	82,00	392,12	257,00	113,96	63,81	23,54
1901-1910	5,81	285,00	361,73	647,00	89,22	44,37	14,32
1911-1920	2,03	175,50	280,59	610,50	85,38	74,18	24,29
1921-1930	5,69	251,50	372,42	1149,50	94,60	109,63	24,89
1931-1940	3,83	225,20	547,13	814,80	126,14	59,11	17,68
1941-1950	9,23	437,25	535,15	2012,25	96,29	67,69	19,94
1951-1960	12,80	802,71	427,68	2282,43	95,90	59,25	16,74
1961-1970	21,55	1133,67	425,75	4996,67	93,81	56,04	19,70
1971-1980	43,88	1925,00	371,86	7800,00	92,58	42,11	16,12
1981-1990	59,96	2457,18	335,80	8214,73	84,51	53,55	14,59
1991-2000	58,25	3343,17	274,17	7962,50	79,47	59,14	13,31
2001-2010	89,00	4245,25	306,48	12994,38	89,76	50,69	14,16
2011-2019	141,88	5979,69	282,67	15758,38	89,44	47,00	11,11

Table 2. Results for quantitative topological configurational variables, according to the periods analyzed.

Period	CON	INT Rn	INT R3	SIN	INTEL	NAIN	NACH
1501-1600	2,129	0,720	-	-	-	-	-
1601-1700	2,849	0,941	-	92,80%	86,90%	1,127	-
1701-1800	3,259	0,937	0,853	67,38%	40,11%	0,947	0,940
1801-1850	3,814	0,969	2,800	68,32%	52,86%	1,181	0,969
1851-1900	3,398	0,895	1,811	67,63%	45,68%	1,076	0,910
1901-1910	3,989	1,097	1,656	76,35%	49,15%	1,114	0,938
1911-1920	3,384	0,961	1,735	74,57%	44,28%	1,059	0,915
1921-1930	4,156	1,260	2,065	73,81%	48,09%	1,252	1,007
1931-1940	4,109	1,104	2,057	74,03%	36,14%	1,117	0,986
1941-1950	4,651	1,308	2,061	69,91%	39,71%	1,268	0,966
1951-1960	4,218	1,053	1,938	64,87%	32,60%	1,141	0,947
1961-1970	4,490	1,010	2,059	54,14%	23,45%	1,124	0,940
1971-1980	4,028	0,854	2,015	47,44%	17,84%	0,959	0,927
1981-1990	4,190	0,901	1,907	41,29%	15,99%	1,012	0,929
1991-2000	3,823	0,734	1,709	44,88%	17,71%	0,974	0,904
2001-2010	3,592	0,721	1,895	37,06%	13,08%	0,896	0,933
2011-2019	3,552	0,697	1,766	35,85%	13,68%	0,867	0,901

4 CONCLUSIONS

This article, part of the research *"Uma herança do ultramar: análise da configuração urbana em cidades lusófonas"* (Medeiros, 2020), sought to understand geometrical and topological aspects of Brazilian cities based on the investigation of their structure, synchronically (currently) and diachronically (over time). The study, based on a sample of 43 cities, for which 275 maps of urban expansion were created, was developed in order to answer three research questions: *1) what is the effect of urban form/structure on topological accessibility patterns (Space Syntax measures)?; 2) to what extent does the modeling developed according to Space Syntax expresses the real movement flow?; and 3) how did the diachronic transformation of configurational aspects (geometric and topological) take place in Brazilian cities?*

In summary, the results obtained show that:

a) The Brazilian city seems to experience stages of development "in bursts", with phases of perimeter expansion and enlargement of interstitial voids, and subsequent filling of these spaces, which generates variations in density, especially throughout the twentieth century;

b) The period between the 1930s and 1940s is a landmark in the configurational performance of the settlements. Roughly, since then, the measures express a continued decline, possibly a product of the speed of the urbanization process and the absence, weakness and/or inadequacy of urban policies that could maintain an adequate relationship between the parts of the city. It seems that the settlements, in their horizontal and vertical growth, have weakened as interconnected systems, which certainly contributed to the contemporary urban crisis that has mobility as one of its main problems;

c) The city design substantially affects the configurational performance read through the accessibility variables - if the Brazilian city can be synthesized as a "grid", as explored by Medeiros (2013), the low performance or the identified decline reinforce the "patchwork" problem: despite the regularity that, in theory, increases the amount of intersections between parts of the city, the set of chessboards of distinct angles ends up resulting in a labyrinth, which justifies the drop in measures and should also be associated with the scale factor; and

d) The results linking *average travel time* with configurational measures are an indication of the role of form in constraining or facilitating commuting.

The findings, besides answering the questions, a) strengthen morphological aspects previously investigated (Medeiros, 2013), b) allow exploring recent configurational variables, such as *NAIN* and *NACH*, c) broaden the understanding of diachronic transformation in Brazilian cities, d) as well as the role of form in conditioning displacement relations.

Moreover, they reinforce the relevance of the configurational approach through the Theory of the Social Logic of Space to understand the spatial reality of cities in the country and provide inputs to think the urban form and its "*effects*" on everyday life (such as the one on *average travel time*). Investigating these "effects" is also a challenge. If on the one hand, we must move away from the deterministic outlook, very much associated with the modern movement, which sometimes believed that architecture and urbanism were able to transform society, on the other hand we cannot ignore that space "affects" us.

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