Evaluation of the urban form in the mobility of medium-sized cities in Brazil

Avaliação da forma urbana na mobilidade de cidades de médio porte no Brasil

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ABSTRACT
The article evaluates urban configuration attributes considered to promote urban mobility: high densities, mixed uses, continuity and connectivity of the urban structure. The morphological analysis used simulations based on the Theory of the Social Logic of Space in medium-sized Brazilian cities of similar socioeconomic contexts and sizes and different urban structures to measure commuting times in order to have the impact of each of the attributes. As a result, the relevance of the attributes is confirmed, which enables the adoption of intervention scenarios for the urban configuration and road system regarding the elaboration of Mobility Plans.

Keywords: sustainable mobility, urban morphology, spatial syntax, brazilian medium cities.

RESUMO
O artigo avalia atributos de configuração urbana considerados promotores da mobilidade urbana: altas densidades, usos mistos, continuidade e conectividade da estrutura urbana. A análise morfológica utilizou simulações baseadas na Teoria da Lógica Social do Espaço em cidades médias brasileiras de contextos e portes socioeconômicos semelhantes e diferentes estruturas
urbanas para medir os tempos de deslocamento, a fim de se ter o impacto de cada um dos atributos. Como resultado, confirma-se a relevância dos atributos, o que permite a adoção de cenários de intervenção na configuração urbana e no sistema viário para a elaboração de Planos de Mobilidade.

**Palavras-chave:** mobilidade sustentável, morfologia urbana, sintaxe espacial, cidades médias brasileiras.

1 INTRODUCTION

This article starts from a theoretical-methodological review about the morphological elements that act in mobility with investigation of geometric and topological attributes that impact commuting. It aims to evaluate how the shape of the road structure and the urban configuration - high densities, mixed uses, continuity and connectivity of the urban structure and can favor/hinder the performance of mobility.

The chosen attributes are applied in a case study on the urban expansion of two medium-sized Brazilian municipalities. Today, medium-sized cities have shown a higher rate of population growth than large metropolises and are under great pressure in all their systems: infrastructure, housing and mobility, in addition to the socioeconomic aspects associated with health, education and employment. Some studies point out that, as there is a fragility of urban management in these locations, there is a risk of repeating the same disorderly and exclusionary processes that marked Brazilian urbanization in the 1970s and 1980s. (Bezerra, Chaer 2021).

The choice of cities prioritized independent areas (not belonging to a conurbation) and that have opposite urban forms: Rolim de Moura (Rondônia), with strong regularity (chessboard, compact, regular and connected mesh) and Viçosa (Minas Gerais), of expressive irregularity (organic, fragmented and dispersed mesh). The cities were selected due to similarities in socioeconomic characteristics and number of inhabitants, and when evaluating average travel times, they are differentiated. While Rolim de Moura has average commuting times to reach services, home, or work of 5 to 30 minutes, in Viçosa these average at 30 minutes (IBGE, 2012; Denatran, 2020).

Rolim de Moura represents a city with some planning of its initial road network, which results from the colonization movement from Ji-Paraná, which occurred in the Amazon region in the late 1970s. The city was established as municipal headquarters in 1983 and has since had
a regular urban structure maintaining the morphological characteristics. According to the IBGE (2020) the city reached 55,407 inhabitants.

Viçosa's urban history began at the turn of the 18th century as a village of a small agglomeration resulting from the donation of land to the Catholic Church (Marx, 1991). The urban area underwent a more significant change in the 19th century, starting in the 1930s, when the city expanded due to the installation of higher education activities, which today comprise the Federal University of Viçosa (UFV). The expansion was gradual and rapid, with strong fragmentation, a result of the city's topographic limitations, reaching an estimated 79,388 thousand inhabitants on 07/01/2021, according to IBGE.

The case study was conducted using descriptive techniques of morphological analysis on the use and occupation plans of the municipalities, relating them to the expansion of the urban area interpreted through the Theory of the Social Logic of Space (Hillier and Hanson, 1989; Medeiros, Barros and Oliveira, 2011; Medeiros and Holanda, 2013). The analysis took into account aspects such as the process of commuting in the urban center and diachronic variations in measures of compactness, connectivity, integration, choice and intelligibility, using the average value of these attributes for Brazilian cities as a basis for comparison, according to Medeiros (2013).

2 THEORETICAL AND METHODOLOGICAL ASPECTS

In Brazil, today, municipalities have the obligation to prepare a Mobility Plan by Law 12,587/2012, in which there is an approach strongly linked to urban transport, reproducing methodologies used in transport engineering. Based on these observations, Marques, Bracarense and Sousa (2015) point out that the inclusion of configurational analysis as part of the elaboration of mobility plans constitutes a diagnostic and decision-making tool that would make the Plans more effective by integrating the various dimensions present to range of mobility.

2.1 SUSTAINABLE MOBILITY AND URBAN CONFIGURATIONAL ASPECTS

In Brazil, only in the last two decades have studies been developed on how the morphology of the city affects sustainable mobility. These are studies that follow the path explored by researchers from other countries for longer (Rogers and Gumuchdjian, 2001; Owens, 1992; Newman and Kenworthy, 1989). Urban densification seems to be the common aspect of
the various investigations and figures as one of the guidelines for promoting urban sustainability both in academic works and in public policies (Brazil, 2001). Despite this, the model of urban sprawl experienced by Brazilian cities still prevails and continues to reproduce itself, as discussed by Medeiros (2013) and Gentil (2015).

The mix of uses is another aspect of particular interest in these same studies and its action on mobility is also demonstrated. Serra et al. (2004), on the subject, listed distances between the demographic and functional centers of large metropolises in the world such as Brasília, London and Jakarta, and pointed out diversity of uses, fragmentation and compactness as the priority axes that interfere in the efficiency of urban mobility.

From a dimensional perspective, the compact city has shown a positive performance in these dimensions as it allows high densities and mixed uses, based on a better-connected network (Bezerra and Gentil, 2013; Dias, 2014; Gentil, 2015). If the city has these aforementioned characteristics, there is potential for more economic use of the road infrastructure, resulting in shorter distances and shorter travel times compared to dispersed cities. Rueda (2002) argues that keeping the urban area dense and compact optimizes land use and that large integrating axes tend to attract commercial development. The high density and close and varied uses, in turn, affect the co-presence dimension, by stimulating interaction and social connection and, to a certain extent, the continuous use of space in time (Medeiros and Holanda, 2010).

Extending the evaluation of the urban configuration further, Bezerra and Gentil (2013) point out, in addition to density and mixed land uses, the continuity of the urban fabric and the connectivity between the different elements of the road system. In turn, Dias (2014) reinforces, among configurational aspects, topological accessibility, that is, the different ways of articulating path networks in an urban system: the more vascularized the network, the greater the potential capacity for distributing flows of people and goods. Barros (2014) mentions the high intelligibility of the road system as a positive aspect, which measures how easily the urban space is to understand in a certain road configuration, which influences the quality of the paths for pedestrians. When it comes to an assessment of sustainable mobility, the apprehension of space is important because the existence of inviting routes for pedestrians and users of non-motorized vehicles favors the adoption of active modes of transport associated with sustainable mobility.

According to Kohlsdorf & Kohlsdorf (2017) the decoding of morphological performance allows a clearer understanding of the relationship between space and society, and for this they
recommend the interpretation of cities in six dimensions: bioclimatic, functional, economic, co-presential, topoceptive and expressive-symbolic. (Table 1).

Table 1. Dimensional attributes that favor sustainable urban mobility

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Attribute Favorable to Sustainable Urban Mobility</th>
</tr>
</thead>
</table>
| Co-presential      | • Greater findability  
                    | • Better configurational integration  
                    | • Better articulation between urban fractions                                                                  |
| Functional         | • Use multiplicity  
                    | • Compact cities                                                                                               |

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Benefit of Sustainable Mobility</th>
</tr>
</thead>
</table>
| Economic  | • Low fuel consumption  
                    | • Low cost of infrastructure                                                                    |
| Bioclimatic | • Low pollutant emission  
                     | • Low land use  
                     | • Low soil sealing                                                                                   |
| Expressive-symbolic | • Favoring of intelligible settings  
                               | • Favoring of highly visually pleasing settings                                                  |
| Topoceptive | • Greater walkability  
                    | • Greater orientability and identifiability                                                      |

Source: Authors' collection

It is worth noting that authors who emphasize ecological aspects in the urban structure tend to question the compact city. To Romero (2016), other morphological properties such as roughness, porosity, compactness, conformation and type of soil and vegetation cover are important variables to consider for the quality of the urban structure. This can lead to certain contradictions: there are studies that, in favor of what is called environmental quality, advocate in favor of a more dispersed urban fabric, with distancing of stretches of the urban area (Burton, 2000). What is certain is that the effects of this pattern are being discussed more and more, even from an ecological perspective using as an argument the increase in the ecological footprint of extensive urban fabrics.
Table 2 shows a summary of the morphological attributes recurrently investigated in the literature that influence urban mobility.

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Geographic Attributes</th>
<th>Topological Attributes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Co-presencial</td>
<td>• High density</td>
<td>• Low space depth</td>
</tr>
<tr>
<td>(Gentil, 2015)</td>
<td>• High dispersion of uses</td>
<td>• High connectivity</td>
</tr>
<tr>
<td>Functional</td>
<td>• High density</td>
<td>• High accessibility</td>
</tr>
<tr>
<td>(Gentil, 2015)</td>
<td>• High dispersion of uses</td>
<td>• High connectivity</td>
</tr>
<tr>
<td>Bioclimatic</td>
<td>• Low compacticity</td>
<td>• High integration</td>
</tr>
<tr>
<td>(DPP, 2011; Rueda, 2002; Litman, 2003)</td>
<td>• Low density</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Mixed uses</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• High density</td>
<td></td>
</tr>
<tr>
<td>Economic</td>
<td>• High density</td>
<td>• High accessibility and choice</td>
</tr>
<tr>
<td>(DPP, 2011; Litman, 2003)</td>
<td>• High density</td>
<td></td>
</tr>
<tr>
<td>Topoceptive</td>
<td>• High intelligibility</td>
<td></td>
</tr>
<tr>
<td>(Barros, 2014)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: Authors’ collection

In addition, it is important to highlight that urban mobility is a social construct. For this reason, it is observed that research usually relates morphological issues with social aspects. Dias (2014), for example, linked the issue of mobility to income and the spatial distribution of jobs, while Gentil (2015) articulated schooling and chosen mode of transport.

2.2 SYNTAX OF SPACE FOR URBAN MOBILITY ASSESSMENT

Mobility with an emphasis on urban morphology has been using the Spatial Syntax – SS approach as an analysis strategy (Dias, 2014 and Gentil, 2015, Medeiros, 2013). This is due to the various possibilities for simulating the road network, such as axis modeling (axial map) and segment modeling (segment map) used to assess the dynamics of cities. In this perspective, the most frequently adopted variables are, among the geometric ones, compactness and number/size of axes and segments, and, among the topological ones, integration (INT), connectivity (CONN), intelligibility and normalized choice (NACH) (Medeiros, 2013; Gentil, 2015; Bezerra and Gentil, 2013; Dias, 2014; Barros, 2014). In general, higher values of these attributes would be related to better potential mesh efficiency for commuting.

3 EMPIRICAL STUDY: SELECTION OF CITIES AND ANALYSIS CRITERIA

For the selection of cities to be studied within the universe of Brazilian municipalities with a population between 50 and 100 thousand inhabitants (a range understood as already presenting sufficient complexity to result in challenges for urban mobility planning), two cities
were chosen that, despite similar in population, had opposite spatial arrangements regarding the
degree of urban dispersion and continuity. Additionally, socioeconomic characteristics (IBGE, 2012) and average commuting time were evaluated, the latter being adopted as a mobility assessment criterion. Initial measurements of this attribute were based on home to work commuting time data, with considerations for population (IBGE, 2012). The table of municipalities by population was crossed with that of commuting times from home to work, with the objective of obtaining the cities located at the two extremes: the locations with the highest and lowest percentage of time in which the population commutes to the service location.

Separating those that, at the same time, had a higher percentage of the population that managed to commute to work in less than 30 minutes and a lower percentage of the population that took longer than that to commute and excluding, after visual inspection of the cities Google Earth satellite images, the municipalities that had a relationship with another city in terms of mobility, the output of the operation was generally municipalities with a continuous and regular form. The process was repeated but separating the lowest percentages of movement within 5 minutes and the highest percentages between 6 and 30 minutes to find municipalities with the highest commuting times. In this arrangement, the return was almost always from isolated municipalities, with an urban morphology more dispersed than compact and presenting discontinuities in the urban area.

Cities either conurbated or close to large urban structures were also discarded, as they would affect the evaluation of commuting. This resulted in cities of relative independence in relation to the network of cities. Next, a visual inspection was carried out regarding the general characteristics of the urban form, considering the density, connectivity and continuity of the road system, evaluated by checking the most recurrent intersections, in "T" or "X". In the end, the cities of Viçosa, in Minas Gerais, and Rolim de Moura, in Rondônia, were selected.

In line with the literature explored in items 2.1 and 2.2, the investigation was based on the discussion on a) land use and density, through the interpretation of zoning data, b) topography and c) diachronic configuration, according to the investigation of geometric configurational variables (area, number of lines and segments, length of line and segments, ratio between segments and lines, compactness A and compactness B) and topological (connectivity, global integration, local integration, intelligibility, synergy, NAIN and NACH), extracted from axial and segment maps (Medeiros 2021 definitions based on syntactic analysis theory).
With regard to the parameter *land use and density*, there was an analysis of the current distribution of activities and the relationship between numbers of inhabitants per hectare in the urban areas defined in the respective Master Plan. Data was spatialized on satellite images with Google viewer place labels, within the QGIS geoprocessing program. The evaluation of the use zones and density of occupation was carried out by superimposing the zoning plan of each municipality on its current map of axes (linear representation, according to the Space Syntax), highlighting the maximum density of each zone in function of its location (Figure 1). The relationship between the current urban form of the cities and the topography was carried out using the base map of the Open Street Map layer superimposed on the axes of the urban area.

Figure 1. Above, zoning maps according to the maximum number of floors allowed superimposed on the road network of each municipality; below, point distribution map that represents traffic generating activities.

Source: Viçosa and Rolim de Moura zoning laws, effective in 2020, with adaptations.
Regarding the diachronic configurational reading of urban expansion, the methods of modeling and morphological analysis recommended by Medeiros, Barros and Oliveira (2011) were applied. To this end, for the city of Rolim de Moura, the road axes for 1984, 1998, 2008 and 2020 were designed using the Digital Globe database; and in Viçosa, the road axes of 1815, 1923 and 1970 were represented from the historical cartography survey present in Mello (2002) completed with the road axes of 1984 and 2020 with the Digital Globe base. (Figure 1). The processing of the axial and segment maps was done in the QGIS program, using Space Syntax Toolkit complement and the DepthmapX software, which allowed obtaining the selected geometric and topological variables (Figure 3).

Figure 2. Expansion diagram of the urban area of Viçosa and Rolim de Moura, with superimposition of the configurational axes of the municipalities on their elevation maps.

Source: Open Street Maps, with adaptations.
3.1 RESULTS AND DISCUSSION

The execution of the research procedures and the configurational modeling of the cities allowed the achievement of a set of results. Figure 2 shows the perimeters of the urban areas of the two cities at different times, according to the collected data. From the diagram it is possible to observe that, unlike Viçosa, Rolim de Moura continued throughout its existence conditioned by a rigid layout based on the original settlement, with significant expansions after 2008. Viçosa,
on the other hand, experienced a process of growth conditioned by the topographical and territorial limitations, implying a more discontinuous and fragmented system, although in flatter areas it is possible to identify a mesh that approaches the chessboard model and/or regularity, as occurs in the region of UFV.

As for the analysis of the impact of land use on mobility, it can be said that both Viçosa and Rolim de Moura have a robust centrality, with densification conferred by the gauge that the respective areas have, which can be verified in Figure 1 by the overlapping of the city roads in occupation zones; in the diagram, the areas in lighter tones are those of greater density and verticality. With regard to the urban layout, a more heterogeneous structure can be seen in Viçosa, as opposed to Rolim de Moura, which has a checkered road network that corresponds to the continuous expansion of the original layout with verticalization in the central area. Comparing the two cities, the zones of Viçosa and its discontinuous layout led to a larger occupied area, however with a greater concentration of functional activities in the territory, a condition that usually works against efficient mobility (Bezerra and Gentil, 2013).

In Viçosa, traffic-generating activities are found around the city center while in Rolim de Moura they are more dispersed throughout the urban system, which results in a kind of sparse and linear centrality, in the shape of a cross, following the RO- 010 and RO-479. Moreover, there are horizontal residential condominiums in some peripheral regions in the extreme north and south of Viçosa, a typology that, in Rolim de Moura, was not observed. According to Medeiros and Holanda (2010), horizontal condominiums, despite partially filling some urban voids, in general do not contribute to the improvement of urban articulation and hardly increase the integration or decrease the fragmentation of the system, factors that would be important for the efficiency of the mobility.

In relation to the geometric (Chart 3) and topological (Chart 4) configurational variables, interpreted according to the diachronic modeling, the results express the differences in the urban structure of the cities and in the respective expansion processes. For the entire analysis interval, Rolim de Moura expands 2.10 times in 36 years (between 1984 and 2020), while Viçosa expands 148.23 times in 207 years. The pace of expansion of the latter in recent years, however, has slowed down: considering only from 1984 onwards, Viçosa grew 1.42 times, therefore at a slower pace than Rolim de Moura. The variables number of lines and number of segments also account for this distinction. Observing only the period between 1984 and 2020 for both, Rolim de Moura
expands 3.19 times while Viçosa reaches 1.84 – if we consider that the layout of the first is regular and the second tends to irregularity, it becomes even more evident a process of reduction of the rhythm of growth in Viçosa, contrary scenario to that of Rolim de Moura.

Similar performance is found in the number of segments: 1.53 compared to 1.65, however when we observe the length of the axes, the regularity scenario for Rolim de Moura is evident: although currently the axes reach 460.2m, between 1984 and 2008 the tendency was lines above 700.0m (Table 3 and 4). In Viçosa, however, the axes today reach 111.52m, which expresses the organic nature of the layout, something noticeable over time – only in 1923 were the lines longer than 200.0m.

The ratio between number of segments and number of lines is a relevant indicator to assess the degree of regularity. The higher the result, the greater the tendency for systems to be gridded. The smaller, the characteristics of an organic structure stand out. Over time, a relatively high value prevails in Rolim de Moura: although in 2020 it was 3.62, in previous periods it had always been above 5.00. In Viçosa, on the other hand, the scenario is reduced: until the beginning of the 20th century it was higher than 2, but since 1970 it has been below, always in a slight decrease.

As for the evaluation of density, the degree of regularity between these cities from very different contexts is also revealing. Taking into account only the intervals from 1984 onwards, the number of lines per km2 (compactness A) in Rolim de Moura has grown, reaching in 2020 the value of 30.15. Viçosa, on the other hand, goes from 134.89 in 1984 to 163.05 in 2020. Despite the distance between the two values, in both cases the number of lines per unit has increased, which is an indication of increased density. For compactness B, which concerns the length of lines per km2, there is a certain stability in Rolim de Moura, despite the sensitive and gradual decrease (which indicates, on the other hand, expansion of empty areas), and an increase in Vicosa.
### Table 3. Geometric configurational variables for Rolim de Moura/RO and Viçosa/MG.

<table>
<thead>
<tr>
<th>Year</th>
<th>Area (Km²)</th>
<th>Number of Lines/Axis</th>
<th>Average Lines/Axis Length (m)</th>
<th>Number of Segments</th>
<th>Average Length of Segments (m)</th>
<th>Number of Segments/Number of Lines</th>
<th>Compactness A (Number of Lines/Axis per Km²)</th>
<th>Compactness B (Length of Lines/Axis in Km per Km²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rolim de Moura</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1984</td>
<td>14.76</td>
<td>294</td>
<td>749.18</td>
<td>1522</td>
<td>134.48</td>
<td>5.18</td>
<td>19.92</td>
<td>14.92</td>
</tr>
<tr>
<td>1998</td>
<td>18.26</td>
<td>315</td>
<td>854.05</td>
<td>1849</td>
<td>137.02</td>
<td>5.87</td>
<td>17.25</td>
<td>14.73</td>
</tr>
<tr>
<td>2008</td>
<td>20.75</td>
<td>416</td>
<td>721.58</td>
<td>2214</td>
<td>129.28</td>
<td>5.32</td>
<td>20.05</td>
<td>14.47</td>
</tr>
<tr>
<td>2020</td>
<td>31.14</td>
<td>939</td>
<td>460.2</td>
<td>3398</td>
<td>120.61</td>
<td>3.62</td>
<td>30.15</td>
<td>13.88</td>
</tr>
<tr>
<td></td>
<td>Viçosa</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1813</td>
<td>0.13</td>
<td>33</td>
<td>157.92</td>
<td>68</td>
<td>70.55</td>
<td>2.06</td>
<td>253.85</td>
<td>40.09</td>
</tr>
<tr>
<td>1923</td>
<td>1.18</td>
<td>135</td>
<td>208.71</td>
<td>295</td>
<td>87.08</td>
<td>2.19</td>
<td>114.41</td>
<td>23.88</td>
</tr>
<tr>
<td>1970</td>
<td>2.90</td>
<td>538</td>
<td>128.92</td>
<td>1047</td>
<td>60.44</td>
<td>1.95</td>
<td>185.52</td>
<td>23.92</td>
</tr>
<tr>
<td>1984</td>
<td>12.64</td>
<td>1705</td>
<td>120.35</td>
<td>3162</td>
<td>58.76</td>
<td>1.85</td>
<td>134.89</td>
<td>16.23</td>
</tr>
<tr>
<td>2020</td>
<td>19.27</td>
<td>3142</td>
<td>111.52</td>
<td>5597</td>
<td>56.59</td>
<td>1.78</td>
<td>163.05</td>
<td>18.18</td>
</tr>
</tbody>
</table>

Source: Authors' collection

### Table 4. Topological configurational variables for Rolim de Moura/RO and Viçosa/MG.

<table>
<thead>
<tr>
<th>Year</th>
<th>Connectivity</th>
<th>Global Integration Rn</th>
<th>Local Integration R3</th>
<th>Ineligibility</th>
<th>Synergy</th>
<th>NAIN</th>
<th>NACH</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rolim de Moura</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1984</td>
<td>5,959</td>
<td>1,721</td>
<td>2,320</td>
<td>0.592</td>
<td>0.888</td>
<td>1.667</td>
<td>1.027</td>
</tr>
<tr>
<td>1998</td>
<td>6,653</td>
<td>1,888</td>
<td>2,441</td>
<td>0.662</td>
<td>0.886</td>
<td>1.816</td>
<td>1.082</td>
</tr>
<tr>
<td>2008</td>
<td>6,096</td>
<td>1,880</td>
<td>2,492</td>
<td>0.494</td>
<td>0.875</td>
<td>1.777</td>
<td>1.078</td>
</tr>
<tr>
<td>2020</td>
<td>4,379</td>
<td>1,342</td>
<td>2,091</td>
<td>0.258</td>
<td>0.803</td>
<td>1.382</td>
<td>0.99</td>
</tr>
<tr>
<td></td>
<td>Viçosa</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1813</td>
<td>2,666</td>
<td>0.926</td>
<td>1.324</td>
<td>0.475</td>
<td>0.902</td>
<td>1.291</td>
<td>0.893</td>
</tr>
<tr>
<td>1923</td>
<td>2,962</td>
<td>0.931</td>
<td>1.450</td>
<td>0.313</td>
<td>0.700</td>
<td>0.936</td>
<td>0.862</td>
</tr>
<tr>
<td>1970</td>
<td>2,747</td>
<td>0.578</td>
<td>1.324</td>
<td>0.140</td>
<td>0.364</td>
<td>0.695</td>
<td>0.854</td>
</tr>
<tr>
<td>1984</td>
<td>2,672</td>
<td>0.365</td>
<td>1.280</td>
<td>0.053</td>
<td>0.144</td>
<td>0.540</td>
<td>0.817</td>
</tr>
<tr>
<td>2020</td>
<td>2,599</td>
<td>0.327</td>
<td>1.226</td>
<td>0.041</td>
<td>0.120</td>
<td>0.487</td>
<td>0.814</td>
</tr>
</tbody>
</table>

Source: Authors' collection
The geometric reading points out that cities seem to expand, however they also experience a process of densification of the road network, which may be related to the filling of voids or consolidation of urban areas not yet occupied. In addition, the polarized position in terms of urban form is clearly translated by the variables, which account for the regularity of Rolim de Moura, a product of global planning that includes choosing a site conducive to this pattern, as opposed to Viçosa, a structure formed and contained by the most accentuated topographic characteristics, resulting in a kind of maximization of the spatial occupation in the different fractions that can be occupied.

The topological configurational variables (Figure 4) account not for the scale or proportions in terms of size, but for the relationships between the constituent elements of the urban network. The results obtained clarify the effect of regularity (or lack thereof) in both scenarios: in Rolim de Moura, where “X” intersections (with crossings) predominate, the average connectivity is high, above 4 in the entire interval, with emphasis on for the period from 1984 to 2008, when it is around 6. Viçosa, on the other hand, has in more recent decades a scenario around 2.5, a product of the predominant “T” crossings (that is, the lanes often end when they catch up with each other, which results in a low degree of crossing). The effect of connectivity lies in the offer of routes and paths for commuting – thus, it is verified how much the regulated route of Rolim de Moura is able to offer more options for commuting as opposed to Viçosa, which will interfere in the performance for mobility, potentially reducing average travel times. The interpretation dialogues with what Gentil (2015) argues, when recording that higher connectivity favors commuting in urban space.

From the connectivity values derive the integration measures. Therefore, the scenario described above also ends up affecting the network's ability to offer better configurational accessibility, observable from the measures of global integration, local integration, NAIN and NACH. For a perspective of the whole system (global integration), in Rolim de Moura the averages are above 1.000, reaching 1.342 in 2020, the lowest value in the historical series for the city. Viçosa, however, although it reached values close to 1 in the first years, currently only reaches 0.327, making it possible to assume different performances of the networks for the commuting. Furthermore, in the case of Viçosa, recent years have been marked by the effects of real estate expansion and housing relocation policies (Mello, 2002), which contributed to the spread of the system.
The definition of syntactic centrality measures (including integration) informs how commuting occurs in the system, since a low performance means that commutes will be longer due to the weakly articulated network. Local integration and the NAIN variable (resulting from segment map processing) are another way of reading this performance, but for another group of numerical intervals. In the case studied, the set of more integrated axes in Viçosa results in a clearly demarcated center – the integration nucleus stands out in the urban area, which tends to reinforce the agglomerating character of this region, which contributes to the central activities developed there. Rolim de Moura, on the other hand, has a center distributed along axes, which are state highways, which tends to disperse the flow to these axes, not reaching a clear center demarcation.

The next evaluations refer to the syntax variables: intelligibility and synergy. Here the maps inform us that both cities have been experiencing declines in readability over time which is somewhat natural in an urban system as the city grows. The scale itself affects the overall understanding of the network of paths and the city itself: we tend to understand settlements in pieces, the larger they are. However, when observing the intervals, it is clear how much Rolim de Moura's performance is superior to that of Viçosa, which points to the effects of a more irregular plot for a labyrinthine impression. It is worth mentioning, however, that the organic character does not necessarily result in low performance – an example comes from the map of Viçosa in 1813, when it reached a synergy of 90.2%.

These evaluations indicate that the form of Rolim de Moura is potentially more favorable for vehicle driver orientation, on a global scale, due to its more direct and linear paths than those of Viçosa. In the pedestrian context, however, it is necessary to develop complementary studies related to the quality and visibility of space (Barros, 2014). It is thus reinforced that the network tracing is a facilitator of commuting.

4 FINAL CONSIDERATIONS

The results show that Rolim de Moura, a more compact and regular structure, has a better distributed diversity of uses and obtained better performance in all studied variables, corroborating its lower intra-urban travel times. Its expansion took place in a continuum of expansion-consolidation of urban areas. On the other hand, Viçosa expands without internal filling, leaving empty spaces and a fragmented road structure. This layout is sometimes due to
the conditions imposed by the site, sometimes due to phenomena such as the creation of gated communities as a result of urban decisions and territorial planning that made it possible for the urban limits to move away from the consolidated territories. Everything leads to Viçosa having a worse performance in all the studied variables and, as a consequence, having a longer intra-urban commute.

The study carried out validates the variables as representative of the relationship between urban structure and mobility with regard to the commuting time within the city, having the relevance that it can be used through simulations of possible interventions in the road system and in the configuration of the cities. Thus, it is possible to create scenarios and predict what best meets the expectations of population commuting. From there, we return to the previously mentioned discussion of constituting a method to be used in the urban mobility plans of Brazilian municipalities.
REFERENCES


