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THE USE OF SPACE SYNTAX IN URBAN TRANSPORT ANALYSIS: limits and potentials

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Abstract

This paper explores the potentials of applying Space Syntax on transport performance analysis. The case study is the Federal District (Brazil) and its 19 Administrative Regions, considering its urban road system. Based on Simple Linear Regressions, the study investigates the effects of urban configuration (different integration degrees) on the average time spent in car trips. Integration measures are calculated using traditional configurational procedures as well as topo-geometric ones. Findings point that while regular topological measures have produced low regressions, topo-geometric measures have shown much better results. Finally, it is suggested that more integrated and compact road systems (in topological and geometrical terms) tend to provide an urban configuration more efficient regarding urban motorized transportation performance.

1. INTRODUCTION[1]

Many large urban systems are facing growing transportation problems today. Because of that, several studies are seeking to address this issue of population spatial mobility, including those related to Space Syntax approach (henceforth SS), associating urban/built space configuration to spatial patterns of movement. This paper intends to contribute in this field, aiming at exploring the potentials and limits of applying SS to the analysis of urban configurations so as to provide scenarios with greater transportation efficiency. The case study is based on micro data from the Origin-Destination Survey conducted in the Federal District (Brazil), in 2000.

In general, the SS theory defines a city's structure by its road system as seen from a topological perspective, taking into account the existing connections seen from a relational or systemic perspective.

The capability of SS to indicate the potential distribution of flows on the various routes of the urban grid has been widely explored (Hillier et al 1993; Hillier, 1996; Major, 1997; Holanda, 2002; Medeiros, 2006). However, little has been written about its contributions to urban transport studies. Is it possible, for example, to use SS as a tool to evaluate the degree of efficiency of different urban configurations with respect to the performance of car trips? Would SS's methodological and theoretical instruments be suitable to explore the performance of urban transport? What are the limits and potentials of SS to do so?

The answers to these questions will play an important role for future researches exploring the effects of street grid layout on urban transportation performance – which is understood here in terms of travel time spent by individual motor vehicles in urban trips (involving cars, utility vehicles and taxis).

Following this introduction, the article presents a literature review of SS and raises some questions about SS methodological limitations regarding transport studies. In sections 3 and 4 there is a brief discussion of the methods used and the obtained results. Finally, the article presents concluding remarks and addresses the research questions previously noted.

2. LITERATURE REVIEW

2.1 Space Syntax – General Theory

SS theory was developed in the 1970s by a group led by Bill Hillier and Julienne Hanson at the University College London (UCL/London - England) in collaboration with researchers from several countries, including Brazil. The *ethos* of SS is based on how built space configuration affects the way the city works, influencing urban dynamics (Hillier et al 1993; Hillier, 1996). SS theory aims to study the social implications of architectural space:

[...] in a few words, it aims to establish a relationship between the spatial structure of cities and buildings, the spatial dimension of social structures, and broader social variables. It seeks to reveal both the logic of architectural space at any scale and the spatial logic of societies (HOLANDA, 2002, p. 92).

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Studies that articulate SS in order to discuss the relationship between urban configuration and spatial mobility of pedestrians have focused their analyses on axial maps, which include a simplified representation of the street grid and its integration values resulting from barriers and permeabilities. Axial maps are fundamentally based on a relational approach of the set of streets making up the road system of a city. This approach allows considerations on the topological attributes that each street establishes with its nearby streets (local connections) or with the whole system to which it pertains (global connections) .

The studies of Hillier *et al*. (1993) and Hillier (1996) suggest that the amount of movement which occurs on each street is substantially influenced by its configuration. In this respect, the topological characteristics of a road system might be conceived as a system of possible routes and it embed a kind of probability field in which it becomes possible to identify routes that are potentially more likely to be traveled.

Space Syntax theory understands that the spatial distribution of flows through the city as an essentially morphological and topological question, that is, a functional result of the urban configuration[2]. This type of approach, less emphasized in more traditional theories of transport and traffic management, is precisely the contribution SS makes to transport and urban mobility studies (Hillier *et al*., 1993; Cybis *et al*., 1996; Barros *et al*., 2008).

2.2 Configurational Studies About Urban Mobility and Transportation

Generally, studies of urban mobility and transportation that use SS theory have concentrated efforts on what Hillier calls the degree of predictability of the urban configuration. The notion of predictability comes from the idea that in every spatial system, each urban street has a potential attraction of trips that depends on its level of integration with the street network as a whole. Thus, the degree of predictability of a particular configuration is related to the degree of correlation between the topological integration of each street and the actual flows that access these streets (measured in number of pedestrians or vehicles). This index is obtained *a posteriori* by a simple correlation measure (Pearson's R) or by a simple linear regression – ordinary least squares (OLS) between topological degree of integration of each unit of the road system and the number of people or cars that pass through these axes during a given period.

In a large study conducted in 1993, Hillier *et al*. presented a synthesis of three case studies that examined the predictability of the configuration of some areas of London regarding pedestrian movement. Nearly all of the analysis presented by the authors in this work found a significant degree of correlation between these two elements. Such results empirically support the authors' ideas regarding the role of urban configuration in the spatial patterns of mobility.

In one case study, for example, the author conducted fieldwork to count and map pedestrians presence in 239 sections of streets near King's Cross railway station in London. Field surveys were developed at several times of day, and the rate of pedestrian movement was normalized by street lengths. A simple linear regression analysis between the number of pedestrians and the index of topological integration for each of the street sections observed indicated a coefficient of determination (R^2) of 0.238. When the analysis was repeated considering the natural logarithm of the rates of pedestrian movement, the authors obtained an R^2

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[2] For Hillier *et al*. (1993, p. 32) these results do not mean that natural movement is not a cultural phenomenon. On the contrary, existing spatial configurations are cultural "product result" that reflect a specific spatial logic for each society and involve different degrees and types of probabilistic fields of encounter and avoidance between several social roles (inhabitants, foreigners, men, women, teenagers, adults, children, rich, poor, etc.).

value of 0.547, indicating that 54.7% of the variation in rates of pedestrian traffic would be captured by the variation in the level of topological integration of the streets where pedestrians circulate[3].

When the same analyses were performed separately for each subarea of analysis, the effects were even stronger (R² values between 0.617 and 0.798). However, the authors conclude that it is not possible to say precisely how much of this effect is due exclusively to the configurational factor because of methodological limitations. In an attempt to minimize this problem, the analyses were repeated after removing streets with malls from the regression. The results changed considerably, featuring an R² value from 0.66 to 0.824.

An interesting work that applied SS in the Brazilian context is the study by Holanda (2002). Given the great morphological diversity among satellite cities of the Federal District (FD), the author attempts to characterize their urban configurations. This study also establishes relationships between the spatial patterns of these areas and how pedestrians tend to use them. To achieve this goal, the author has also used primary data collected during field surveys in a variety of spatial contexts. The obtained results indicate a relatively high correlation for those areas "[…] in which the average integration showed similar values to those found in traditional urban areas [...]" (HOLANDA, 2002, p. 338). This was the case for Planaltina, Southern Commercial District (*Setor Comercial Sul*) and Paranoá Novo, where the correlation between measures of global integration and pedestrian co-presence was, respectively, 0.34, 0.42 and 0.49. The analysis performed at SQS 405/406 (Superblock South 405/406) and Guará I, on the other hand, showed very low correlation values.

According to the author, this result indicates a nonlinear relationship between integration and co-presence. Holanda concludes that even in spatial configurations with integrated street grids, the indices of co-presence would be under a stronger influence from local attributes such as historical land use factors or the location of magnets than from factors such as the global topological integration of the road system itself. He claims that, "[...] it seems that both extremes of the integration spectrum tend to impair predictability" (HOLANDA, 2002, p. 331).

Cybis *et al*. (1996) produced a pioneering work in the application of SS to the study of motorized transport systems in Brazil. The objective was to compare the road hierarchy provided by a traditional model of traffic allocation (AX-I-MAGIC) to the hierarchy based on analysis of topological integration measures for roads in the system.

The study referred to the São José neighborhood in the city of Aracaju (Brazil), with 102 intersections. The results indicated that the hierarchy of roads obtained by the two models showed very different results. However, it is emphasized that the authors based the results strictly on a visual comparison between the axial map and the traffic allocation maps (generated from several scenarios of origin-destination demand), which did not allow an objective determination of the size of this discrepancy.

Barros *et al*. (2008) also analyze the potential of SS to define parameters of road hierarchy and speed limits. They analyze the road system of Plano Piloto in Brasilia (Brazil) using a different methodology than Cybis *et*

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[3] According to Hillier *et al*. (1993, p. 44), several studies of space syntax have found that the level of topological integration has more predictive power for movement when we consider the logarithmic rate of movement. According to the authors, this occurs because the presence of shops (as an attraction element for pedestrian movement) transforms the basic linear relationship that exists between movement and integration into a logarithmic relationship (Hillier *et al*., 1993, p. 48). This would exist because mainly because stores act as multipliers in a logarithmic pattern of movements defined by the configuration, and *ii*) there would be an overall logarithmic effect on the relationship level between the sub-analyses.

al. (1996). Although the authors suggest the configurational analysis has a low capacity for defining speed limits, the results indicate some potential for SS in defining road hierarchy.

In another work, Barros, Silva and Holanda (2007) attempt to verify the potential application of the theoretical and methodological configuration framework on traffic allocation studies. The authors investigate the degree of predictability of the Plano Piloto street configuration in Brasília (Brazil). Analyses are performed using vehicle counts conducted by the Federal District Department of Transit (DETRAN/FD), and the level of road integration is calculated by both the axial map and segment map techniques.[4]

The first results showed a Pearson correlation coefficient of 0.53 between the vehicle count and the integration level calculated by the axial map. For the integration level calculated by the segment map, the correlation reached -0.62[5]. A simple linear regression analysis reveals R^2 values for the axial maps and segment maps of 30% and 40%, respectively. This percentage means that the variability in the integration level of these maps capture, respectively, approximately 30% and 40% of the variability of the vehicle count on those routes.

After log transforming the data (base 10), the same analysis shows improved results. The Pearson's R^2 values for axial and segment maps reached 44% and 61%, respectively. Although the authors do not clearly define the level of significance obtained in the analyses, the correlation levels calculated could be considered high, suggesting a high degree of predictability in the urban configuration of the road system in Plano Piloto, Brasilia.

Furthermore, the authors identify some uses for the application of SS in the first steps of transportation planning when comparing it to analyses performed using the Simulation and Assignment of Traffic to Urban Road Networks (SATURN) application[6]. The authors suggest that SS easily allows a heuristic view of the road systems, thereby enabling a low-cost mapping of the way in which these systems react to a specific road intervention. Traditional models of transport, in turn, would require more resources, including large amounts of data and time.

This brief literature review intended to revisit some international and Brazilian studies that have demonstrated the existence of a potential use for SS in the study of population spatial mobility and urban transport. These studies frequently indicate that the potential distribution of the movement flows shows a good correlation with the actual distribution of people and cars on the road system.

On the one hand, SS has shown an ability to clarify the spatial distribution pattern of flows on different streets in the urban grid. On the other hand, there are few studies that explore its capacity for analyzing the performance of these trips. What are its limits and capabilities? The next section attempts to summarize

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[4] The segment map involves a derivation of the axial map. Although the axial map represents the smallest number of major lines passing through the urban system, the segment map involves the fragmentation of each line into several segments, according to the nodes existing in the urban grid. Thus, there would be further integration between the representations from SS and those traditionally adopted in traffic engineering based on links (segments) and nodes (connections/crossings).

[5] Contrary to the axial map, which serves as the basis for calculating the degree of topological integration, the segment map is the basis for calculating the degree of mean depth of the road grid. As long as more integrated routes tend to be frequently used, deeper routes (more segregated) tend to be less used. Therefore, the correlation between depth and presence of movement tends to be negative.

[6] SATURN is a program of traditional network analysis adopted for transportation engineering. Developed at the Institute for Transport Studies, University of Leeds, England, it consists essentially of two functions that work toward different goals: the traffic assignment module – which chooses the route of the road network to be used – and the simulation module, which models the behavior of intersections in the road system.

some of the limits established in the literature for the implementation of configurational analysis in this type of study.

2.3 SS Limits for Studies of Urban Transport Performance

During the first years, the uses and methods of SS were mainly concentrated in studies on urban configuration. Over time, new investigations have further developed the theory and corresponding techniques while simultaneously stimulating reflection on some of the limitations of the approach for novel applications.

According to Stegen (1997), for example, although macro-traffic structures have an important effect on global urban circulation, specifically within large urban centers, these elements are not captured by the concept of urban configuration as represented by the techniques of SS.

Another important issue is that techniques for analyzing urban configuration (axial maps and segment maps) were not initially created in a way that considers certain essential street features. By focusing mainly on the topological characteristics of urban street networks, configuration analysis fails to consider some street features that greatly influence urban transportation performance, such as road capacity (in terms of numbers and width of lanes), direction of traffic flows, or pavement conditions. Thus, different parts of the road system can exhibit the same level of topological integration but have different capacities in terms of lanes. Therefore, they would show different performance characteristics in terms of vehicular flow rate and average speed[7].

Three-dimensional information, such as reliefs, topographic variations, the presence of obstacles on the roads (i.e., pedestrian crosswalks, traffic lights, and speed bumps), and certain road characteristics such as geometric dimensions of distance are also disregarded.

In that way, two large hypothetical avenues possessing the same level of topological integration could exhibit completely different average vehicle speed, depending on the presence or absence of obstacles such as traffic lights and speed bumps. Another recurring critique of the use of SS in transportation studies is that techniques traditionally employed in configuration analysis do not consider the geometric aspects of reality. A topological analysis of urban configuration is clearly a one-dimensional approach to the road system (CYBIS *et al*., 1996; RATTI, 2004a, 2004b; MEDEIROS, 2006). For example, aspects such as topography are not incorporated directly in the analysis, although they would be indirectly captured if topographically steep areas had distinct street grid patterns compared to flat regions.

In addition to disregarding the geometrical properties of streets such as length, size and number of lanes, traditional configuration analysis based on topological integration also ignores the global extension of the road system as a whole. Take as an example the two hypothetical street networks represented in figure 1. Both road systems are comprised of identical uniform street grids, except with respect to size. The extension of each street in the “a” system is five kilometers, while the extension of each street in system “b” is ten kilometers. Therefore, although the diagram of both road networks is the same, the metric extension of road system “b” is twice the one in system “a”.

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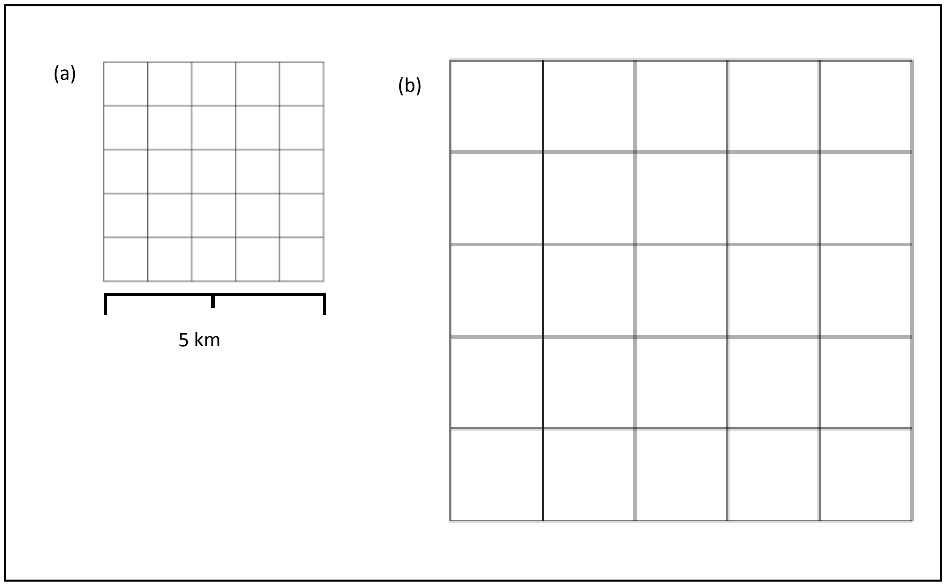
[7] Most likely, SS research techniques will incorporate these new aspects in the coming years.

In this example, for any given equivalent origin-destination pairs traveled by a vehicle in each system, it is natural to expect that the average travel time be different according to the difference between traveled distances. Obviously, the average travel time for road system "b" tends to be greater than for system "a". Despite this difference, both road configurations would show the same global topological integration value (Rn), equal to 3.13374 in the SS methodology.

FIGURE 1
Hypothetical Road Grids



The fact that SS disregards geometrical properties in different urban configurations could be a limiting factor for its application to transportation studies. Hence, one can expect that the relationship between topological integration and travel time will not be so simple and mechanical in comparative studies analyzing road systems with very different geometrical dimensions.

Therefore, a strictly topological measure of integration would represent a limited proxy for the potential transportation performance of those roads in terms of average travel time. This issue brings more attention to the need to calibrate configuration analyses with geometrical features (RATTI, 2004a, 2004b) and prompts new studies to investigate both the relations between topological and geometrical measures (MAJOR, 1997) and to find new topo-geometrical measures (HILLIER *et al*., 2007). As a result of these concerns, the UCL team adapted its analysis software for configuration analysis (Depthmap®) to enable the analysis of topo-geometrical measures.

These new topo-geometrical measures enabled by Depthmap® will be tested in the data analysis section of this study. Further explanations regarding the methods used in this study will be presented in the next section.

3. METHODOLOGY

The present study explores the potential use of SS for analyzing the performance of urban transportation. We take the Federal District (DF – Brazil) and its 19 Administrative Regions (ARs) as a case study to analyze the possible correlation of the configurational characteristics of the respective road systems with the performance of motorized transport. Thus, it is critical to be clear regarding what is meant by "urban configuration" and "performance of urban transportation" as well as to introduce a method of operationalization of these variables in the sense that they are understood here.

3.1 Configurational Variables

In order to develop the concept of urban configuration and the identification and measurement of the relevant configuration features, we turn to the traditional technique of data processing from configuration studies known as axiality. The application of this technique initially involves the graphic representation of the urban street network based on the cartographic information of the area. This linear representation of space should be achieved using the smallest possible number of straight lines over the existing streets. From an axial map, it is also possible to build a “segment map”, which segments each axial line at its intersections, allowing an analysis of street segments. Then, the constructed axial representation is run in Depthmap software for the calculation of the connectivity matrix and configurational measures. Axial maps of the street network of the Federal District and of the 19 ARs were built separately (see maps in appendix 1).

After obtaining a series of indices, several correlation tests were performed using simple linear regression between the configurational variables (taken as explanatory variables) and the performance of urban transportation in each RA and the FD as a whole. The degree of significance of these regressions and the explanatory power of the configuration characteristics of the road systems on the average travel time in these systems gives some indication of the limit/potential of using SS for this type of study.

One of the configurational measures used is the mean depth index. The degree of depth of a street is inversely related to its degree of integration in relation to all other roads in the system (from a global perspective), or in relation to the topologically nearest streets (from a local integration perspective). This degree of integration can be thought of in different radii of action. In a global radius of action, for example, the degree of integration is calculated by taking into account the whole system. In a local radius of action, the degree of integration is calculated in relation to a limited number of conversions, defined as a “step” using Depthmap®.

If we imagine a topological radius equal to three and a given street “a”, its integration can be calculated by the number of streets one can reach from “a” with only three conversions (for example, streets “x”, “y”, “z”, “w”). Its mean depth could be calculated by the ratio between its degree of integration (e.g., at the three conversion levels) and the average integration of streets “x”, “y”, “z” and “w” (in the same example at the three conversion levels). According to Medeiros (2006, p. 357), this measure “[...] clarifies the average degree of difficulty or ease of reaching an axis, and allows the comparison of means values between distinct road systems”.

It is worth remembering that the topological radius of action does not account for the metric distance (road extension in linear meters) but refers instead to the topological distance (number of conversions). Concerning previous criticism about possible limitations generated by using this perspective alone, the present study also analyzes other topo-geometric measures using the improvements made to the Depthmap® software.

In addition to analyzing the mean depths with the global topological radius Rn and local topological radius R3, other configurational characteristics, such as mean metric radius depth, were also analyzed. This indicator has the same calculation logic as the potential number of accessible lines used in the index mean depth; however, in this case, the limit of the action radius is given in metric rather than topological terms. As the delimitation of this radius can be arbitrary, we attempted to use several radius specifications as an analysis of sensitivity. The present study investigates metric mean depth levels of the following sizes, in meters: 100, 500, 1,000, 5,000, 10,000 and 50,000.

We also used the integration index (also known as topological accessibility or permeability), which constitutes one of the most traditional measures of SS. The integration level of a road system can be calculated both as a function of the integration radius of the system as a whole (using the global integration index with topological radius Rn) or as a function of a local radius involving the integration level of each road with its surroundings (using the local integration index with topological radius R3, R5 or R7, etc.). This index is obtained as a function of the minimum number of axial lines that must be travelled, on average, to go from a given position in a city to another one. According to Holanda (2002, p. 103), this means that in a highly integrated system, one would have to make few turns, on average, to go from one street to any other place in the system.

In the following analysis, the global integration index with topological radius Rn and the local integration index with topological radius R3 were used. It is worth noting that these indicators also use a strictly topological notion of distance in the road system.

Recognizing that these indicators could be limited by using a strictly topological notion of distance, some topo-geometric measures were also included as alternative variables in the present study. These measures exhibit the same logic of the traditional integration measures but are calculated by Depthmap® by weighting the topological integration of an urban configuration by the length of its streets in linear meters. We have the following indicators: global topo-geometric integration Rn (weighted by segment length) and local topo-geometric integration R3 (weighted by segment length).

As a first step for the analysis in the next section, the values of the respective configurational characteristics were calculated for all 19 ARs and for the FD. These values are displayed in table 1.

TABLE 1

Configurational characteristics of the road systems from the Federal District and its ARs – 2000

(a)

Administrative Region	Configurational Variables						
	Mean depth with Global topological radius Rn	Mean depth with Global topological radius Rn (weighted by segment length)	Mean depth with Local topological radius R3	Mean depth with Local topological radius R3 (weighted by segment length)	Mean depth (100 meter radius)	Mean depth (500 meter radius)	Mean depth (1,000 meter radius)
Brasília	7.3417	1.2902	6.8973	1.2380	0.8167	1.9589	2.9113
Brazlândia	5.9761	1.3116	5.7040	1.2929	0.9717	2.0343	2.6477
Candangolândia	3.4512	1.1735	3.4845	1.1494	0.3544	2.0413	2.9054
Ceilândia	7.4319	2.5936	5.4700	1.1504	0.9255	0.3594	2.6295
Cruzeiro	8.8064	2.3582	6.2673	1.2051	1.0950	2.6367	3.6043
Gama	5.6291	1.2516	5.6209	1.2030	0.9185	2.0686	2.9540
Guará	8.5475	1.2519	8.2774	2.2398	0.8201	2.0059	3.0149
Lago Norte	6.6010	1.1525	6.3177	1.1356	0.7484	1.4649	1.9679
Lago Sul	8.1071	1.3623	7.9176	1.3092	0.6612	1.7156	2.4050
Núcleo Bandeirante	5.7685	1.1634	5.7446	1.1230	0.6690	1.4218	1.8948
Paranoá	3.9471	1.2058	3.9334	1.1732	0.9583	2.2718	3.0395
Planaltina	5.2889	1.1624	5.3065	1.1527	0.7470	1.6054	2.1091
Recanto das Emas	4.3444	1.2129	4.3505	1.1811	0.8207	1.7934	2.4779
Riacho Fundo	6.8449	1.1946	6.5265	1.1680	0.8313	1.8616	2.5747
Samambaia	6.2172	1.2245	6.0171	1.2018	0.9971	2.2803	3.1952
Sobradinho	6.8159	1.2827	6.0949	1.2537	0.6599	1.5909	2.2331
São Sebastião	7.3834	1.1886	7.4130	1.1545	0.7250	1.5406	2.1907
Santa Maria	5.5741	1.2056	5.5799	1.2019	0.8283	1.9399	2.7047
Taguatinga	7.1741	1.2064	7.0975	1.1851	0.7963	1.8045	2.5191
Total (DF)	**9.8651**	**1.2274**	**9.5925**	**1.1973**	**0.8617**	**1.9259**	**2.6985** ....

(b)

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Administrative Region	Configurational Variables						
	Mean depth (5,000 meter radius)	Mean depth (10,000 meter radius)	Mean depth (50,000 meter radius);	Global Integration with topological radius Rn	Rn Topo-geometric Global Integration (weighted by segment length)	Local Integration with topological radius R3	R3 Topo-geometric Local Integration (weighted by segment length)
Brasília	5.8928	6.6247	7.3544	0.8100	1.4217	11.4286	2.3450
Brazlândia	5.5620	1.3116	5.9761	0.9578	2.0419	7.3469	2.3441
Candangolândia	3.4512	3.4512	3.4512	1.3232	1.8765	4.5004	2.3747
Ceilândia	4.7905	5.3050	5.4638	1.3200	2.2402	7.5502	2.6057
Cruzeiro	6.4102	6.6084	6.6084	0.8844	1.4879	8.3714	2.3347
Gama	5.5932	5.6036	5.6290	1.2338	1.9387	7.4747	2.4799
Guará	6.7496	8.0792	8.5476	0.7293	1.5851	11.6888	2.2882
Lago Norte	5.2253	6.3462	6.0092	0.6944	1.5471	10.4270	2.3061
Lago Sul	4.9877	6.1891	8.1074	0.5697	1.4577	14.6433	2.3645
Núcleo Bandeirante	3.7676	5.0410	5.7684	0.8784	1.7930	8.2012	2.3162
Paranoá	3.9321	3.9471	3.9471	1.3294	1.7543	5.2050	2.4703
Planaltina	4.4185	4.9660	5.2889	0.9746	2.0539	8.2709	2.4338
Recanto das Emas	4.0213	4.3400	4.3445	1.0695	1.9253	6.9863	2.4754
Riacho Fundo	4.6969	6.3325	6.8448	0.7524	1.8257	9.2724	2.3573
Samambaia	5.7274	6.1638	6.2172	1.0097	1.8353	9.4060	2.4851
Sobradinho	4.7760	6.0491	6.8155	0.9372	1.7149	9.0187	2.3950
São Sebastião	4.7495	6.7225	7.3834	0.6839	1.7045	10.7908	2.3160
Santa Maria	4.3179	4.8948	5.5741	0.9007	1.8600	9.1825	2.3839
Taguatinga	5.3459	6.2771	7.1741	0.8021	1.7921	11.8022	2.4523
Total (DF)	5.**0408**	**6.2993**	**9.4359**	**0.6775**	**1.7913**	**18.3768**	**2.4425**

3.2 The "Urban Transportation Performance" Variable

Among the many options for analyzing urban transportation performance, such as costs of operation and systems maintenance, social costs of accidents, road maintenance costs, or emission of pollutants, travel time is a measure widely accepted in the literature (LIMA, 1991; ROBERTS; THUM, 2005).

In the present study, we define the urban transportation performance variable as the average travel time spent on urban trips. For comparative purposes, however, we will only consider trips made by individual motorized transport (including cars and taxis). We will not consider trips made by bus or subway. The existence of these services and their routes can fluctuate significantly between the ARs that will be analyzed and could, therefore, distort the travel time data. Trips on foot will also not be considered in this study. This is because, as stated by Holanda (2002, p. 321), the urban syntax in the Federal District is markedly different from the perspective of the pedestrian and driver.

The database used consisted of the Origin-Destination Survey conducted in the Federal District in 2000 by the Development Company of the Brazilian Highlands (CODEPLAN, 2002). For each trip performed in a typical working day of the reference year, it is possible to identify the mode of transport used, the travel time spent, and the origin and destination. Thus, it was possible to filter the data to count only the average travel time for trips within each AR and the Federal District by mode of transportation.

According to the survey, there were 520,642 trips performed by car, utility vehicle and taxi within each AR on a typical work day in 2000. Including trips between ARs, the Federal District had approximately 1,000,198 internal trips on a typical work day made by the previously mentioned modes of transport[8]. The average travel time for the trips is presented in table 2. The regression results will be explored in the next section.

TABLE 2 Total number and average travel time (in minutes) for trips made by car, utility vehicle and taxi within each AR on a typical day in the Federal District

Administrative Region	**Performance Variable**	
	Average Time	**Number of trips**
Brasília	14.41	267,826
Brazlândia	8.38	4,988
Candangolândia	6.43	1,713
Ceilândia	10.56	29,538
Cruzeiro	7.86	13,093
Gama	9.53	28,788
Guará	11.77	37,498
Lago Norte	13.80	3,678
Lago Sul	13.14	7,682
Núcleo Bandeirante	8.40	4,433
Paranoá	11.98	687
Planaltina	10.58	10,621
Recanto das Emas	12.70	2,496
Riacho Fundo	7.85	1,738
Samambaia	10.34	9,083
Sobradinho	9.28	18,281
São Sebastião	13.93	2,223
Santa Maria	11.10	2,457
Taguatinga	12.42	73,819
Total (DF)	**19.31**	**1,000,198**

Source: Author's elaboration with Codeplan data – Household Origin-Destination Survey, 2000.

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[8] To refine the data quality, we removed those observations in which the interviewee identified the travel time as an outlier. We considered as outliers those trips that had a declared duration of at least six times the standard deviation of the original data distribution (equal to 8.17 minutes), thereby ignoring 270 trips, representing approximately 0.06% of observations.

4. ANALYSIS AND RESULTS

Table 3 shows the results of a simple linear regression analysis on several configurational characteristics of the road systems analyzed (taken as independent variables) and the average travel time for internal trips made by car on a typical work day (taken as the dependent variable). It is important to keep in mind that the analysis is limited to 20 observations (19 ARs and the Federal District – see the maps in Appendix 1), which may reduce the significance of the regression analysis in some cases.

TABLE 3
Results of simple linear regressions between configurational and performance variables

Configurational variables	Performance variable	Statistics	
		R^2(%)	**P-value**
Mean depth with Global topological radius Rn	Average Travel Time	21.8	0.0380
Mean depth with Global topological radius Rn (weighted by segment length)	Average Travel Time	38.9	0.0033
Mean depth with Local topological radius R3	Average Travel Time	3.8	0.4094
Mean depth with Local topological radius R3 (weighted by segment length)	Average Travel Time	0.3	0.8060
Mean depth (100 meter radius)	Average Travel Time	1.0	0.6801
Mean depth (500 meter radius)	Average Travel Time	1.3	0.6339
Mean depth (1,000 meter radius)	Average Travel Time	2.7	0.4848
Mean depth (5,000 meter radius)	Average Travel Time	2.1	0.5402
Mean depth (10,000 meter radius)	Average Travel Time	14.5	0.0978
Mean depth (50,000 meter radius)	Average Travel Time	30.5	0.0115
Global Integration with topological radius Rn	Average Travel Time	22.0	0.0370
Rn Global topo-geometric Integration (weighted by segment length)	Average Travel Time	58.0	0.0001
Local Integration with radius R3	Average Travel Time	8.5	0.2128
R3 Local topo-geometric Integration (weighted by segment length)	Average Travel Time	0.5	0.7664

Source: Author's elaboration using Depthmap®.

Contrary to global measures, local measures had very unsatisfactory results. Both depth and integration measures and the local metric radius measures (up to 5.000 meters) had a very high p-value and a very low R^2. Considered on its own, this result might support the emphasis placed by the SS theory on the global characteristics of the urban configuration as an explanatory dimension of the spatial mobility pattern.

The mean depth variables and the Global Integration index (all of them calculated using topological radius) showed similar results. They both had explanatory powers (R^2) between 21.8% and 22.0% and p-values between 0.038 and 0.037. Thus, in addition to showing acceptable levels of significance (less than 4%), the variation of these indices is able to capture approximately 22% of the variation in average travel time spent on the road systems analyzed.

Perhaps the most important result of this study concerns the application of topo-geometrical measures to the analysis of urban transportation. Initially, we highlight the results obtained for mean depth variables with metric radius. Although these variables demonstrated highly unsatisfactory results, there is an improvement in the results as the radius of action expands. The measure with a metric radius of 50 km, for instance, showed a p-value of 0.0115 and an R^2 of 30.5%, even higher than the R^2 obtained by more traditional global topological measures (such as Rn depth average or Rn global integration).

It is also worth mentioning the analyses that have used topo-geometric versions of more traditional global measures. It was observed that the use of topological measures weighted by the street length parameter produced surprisingly improved results. The mean depth with global topological radius Rn (weighted by segment length), for example, achieved a R^2 of 38.9% with a low p-value. However, the topo-geometric version of the global integration measure (Rn global topo-geometric integration weighted by segment length) had an R^2 of 58%, with a p-value of 0.0001. This means that 58% of the variation in average travel time for each territorial unit analyzed is captured by the variation of the global topo-geometric integration levels of their road systems.

It should also be noted that some preliminary analyses of this study showed a significant improvement, approximately 10%, in the R^2 values of these regressions when the travel time calculations were restricted to trips made for work-related issues or during rush hour (periods between 7am and 9am and between 6pm and 8pm). The reasons leading to this higher correlation in these cases still require further investigation.

Finally, it is important to highlight that the results obtained here exhibit coherence as they indicate an inverse relationship between integration level and travel time. Road systems with more integrated configurations support motorized trips with shorter durations, on average, thereby promoting increased efficiency of urban transportation. In contrast, we observed that deeper, less integrated road systems tend to be less efficient, resulting in longer trips.

5. FINAL REMARKS

The aim of this study was to explore the potential application of the theoretical and methodological tools of SS to the study of the performance of urban transportation. To this end, we took the urban configuration road system of the Federal District and its 19 ARs as a case study. After the construction of axial and segment maps of these systems, we used the Depthmap® software to identify their configurational features according to traditional variables from SS studies, including local and global mean depth measures and local and global topological integration measures. We also calculated some topo-geometric characteristics from those road systems, such as depth measurements with different metric radii and topo-geometric versions of traditional indicators recalculated to weight their values by the metric length of the routes comprising the systems analyzed.

Configurational variables were used in simple linear regression analyses as explanatory variables of average travel time spent on urban trips made by individual motorized transport in those territorial units. The travel time data were obtained based on microdata from the Origin-Destination Survey conducted in the Federal District in 2000.

The results obtained are provocative in the sense that they *i*) suggest that global configurational characteristics, rather than local characteristics, are important for urban spatial performance; *ii*) indicate that there is a low potential for the application of more traditional topological measures from SS to investigate the effects of street configuration on urban transportation performance; *iii*) suggest that this potential can be widely expanded by using topo-geometric measures to characterize urban street configuration; and *iv*) suggest that more integrated and compact road systems (in topological and geometrical terms) tend to provide an urban configuration more efficient for the performance of urban motorized transportation with lower average travel time. This conclusion reinforces the idea that the more compact and integrated road systems tend to be also more economically efficient and less environmentally damaging in terms of energy use and pollutant emissions.

There is also a range of configurational measures that could be explored such as the compactness of urban configuration, the degree of grid efficiency by other integration and depth measures, and different radii of action. The degree of *intelligibility* of different urban configurations also appears to have promising potential in this type of analysis. According to Stegen (1997), this variable would be important because, together with the integration measure, it is one of the qualities that promote the "efficient" behavior of individuals. This is because the degree of intelligibility of a configuration contributes enormously to the degree of predictability of the configuration. In Hillier's words, "*virtual communities can only become real, and be predictable, if spatial environments are intelligible*" (HILLIER *et al*., 1993 *apud* STEGEN, 1997, p. 37.04).

In agreement with the discussion provided by Hillier *et al*. (1993), some methodological limitations prevent us from stating precisely what proportion of the results are exclusively due to the configurational factor of the areas analyzed. Given the limited number of observations in the regression analyses performed in this study, using a multivariate analysis method would have compromised statistical validity. The advancement of this study depends on the replication of this type of study in other metropolitan areas with a greater number of cities. We would expect to find more consistent results with the help of analysis that can control a number of other factors that may influence travel time, such as the number of traffic lights in each system, the speed limits of its routes, and road grid capacity in terms of lanes. Other statistical analysis techniques may also provide more consistent results. For example, performing multilevel analyses that consider the time spent on each trip rather than the average of all trips in each city or neighborhood would be informative.

If the findings obtained in this study are corroborated by future studies in other urban agglomerations, then the following ideas will be reinforced: *i*) studies of SS may complement the theoretical and methodological fields of urban and transportation studies; *ii*) recommendations on road interventions in large cities should be directed at increasing the global permeability level of their transportation systems; and *iii*) urban development of cities should prioritize denser, less dispersed configurations.

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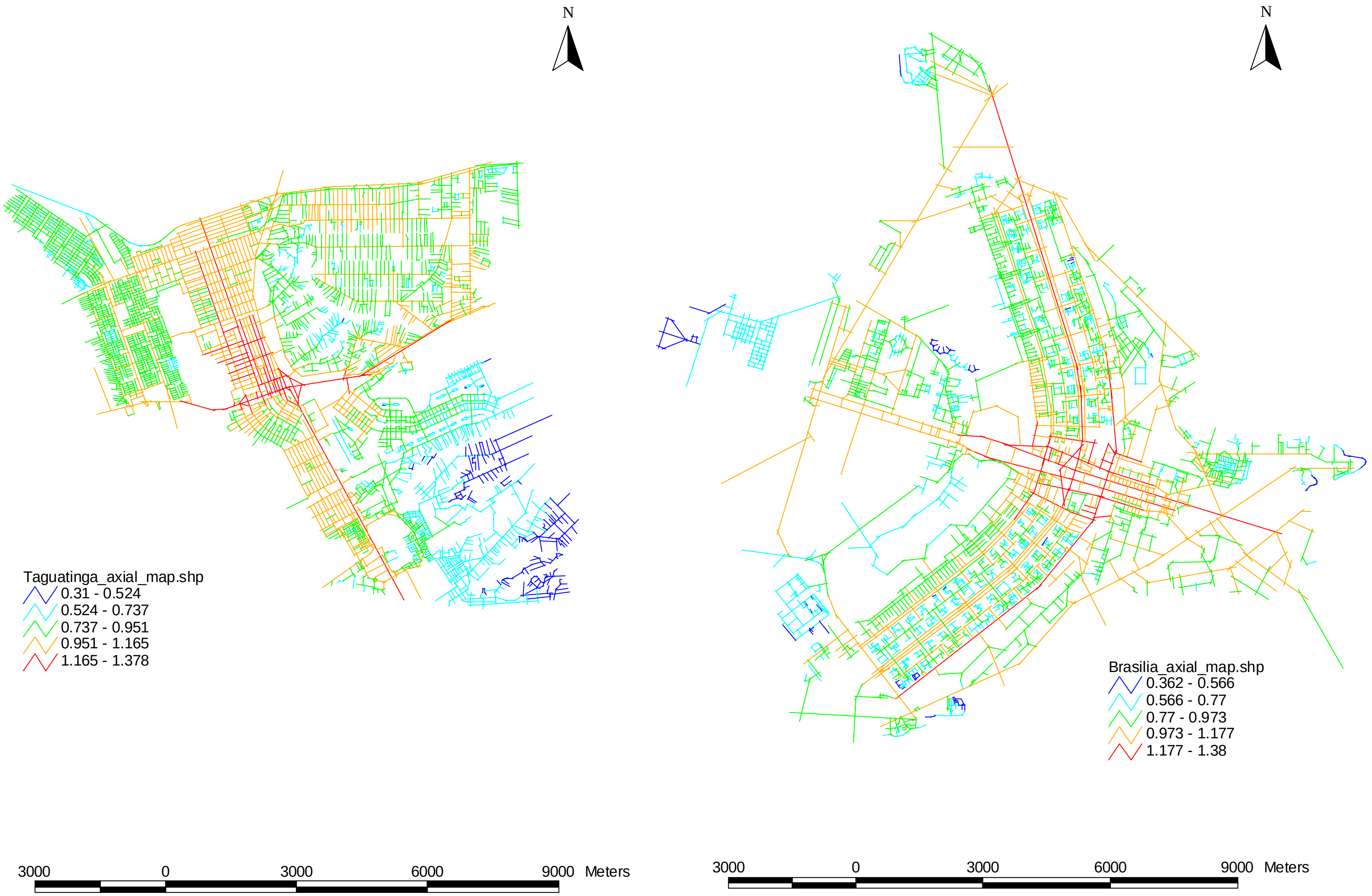
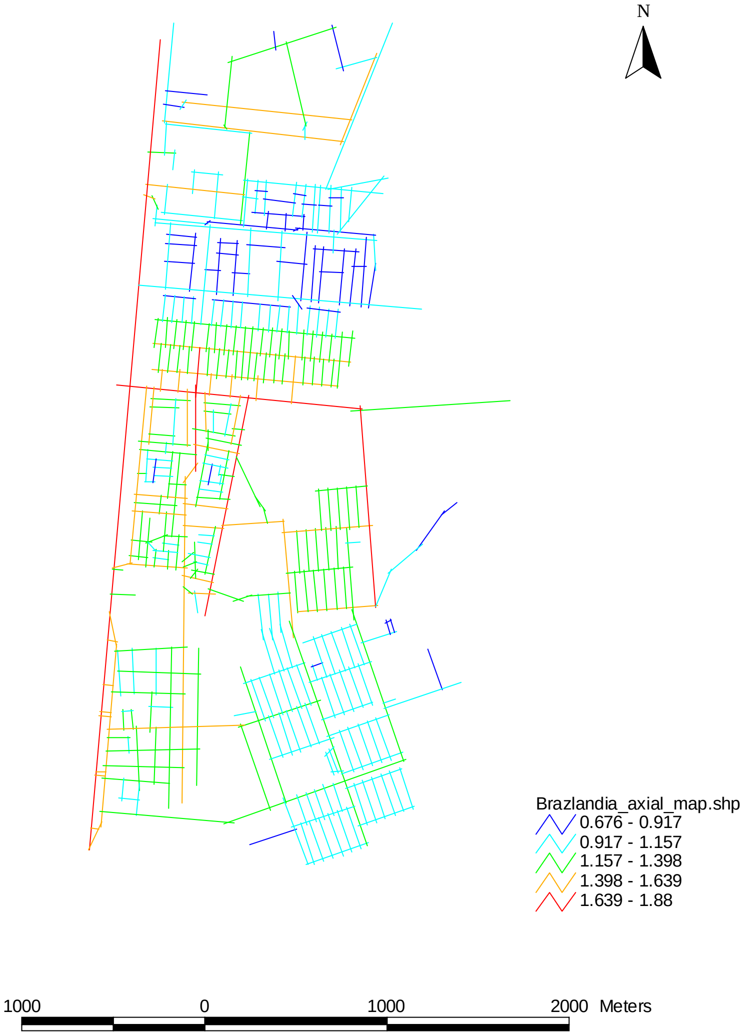
APPENDIX 1

MAP 1

Axial maps of global topological integration (Rn) from the Federal District and its ARs – 2000

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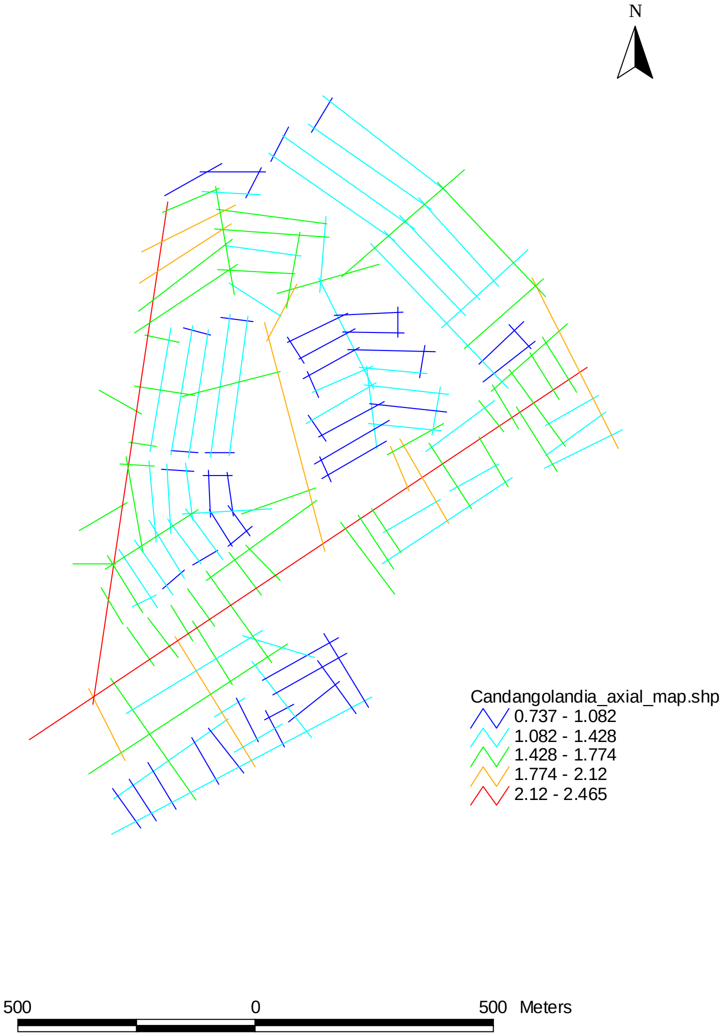
1000
2000
Meters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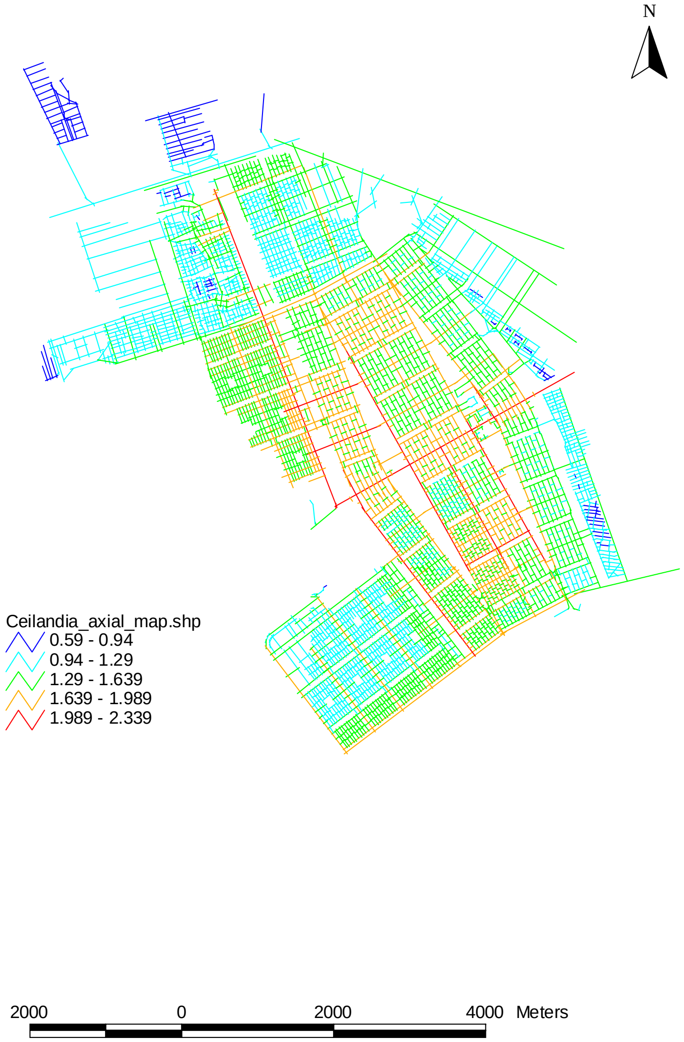
500
0
500
Meters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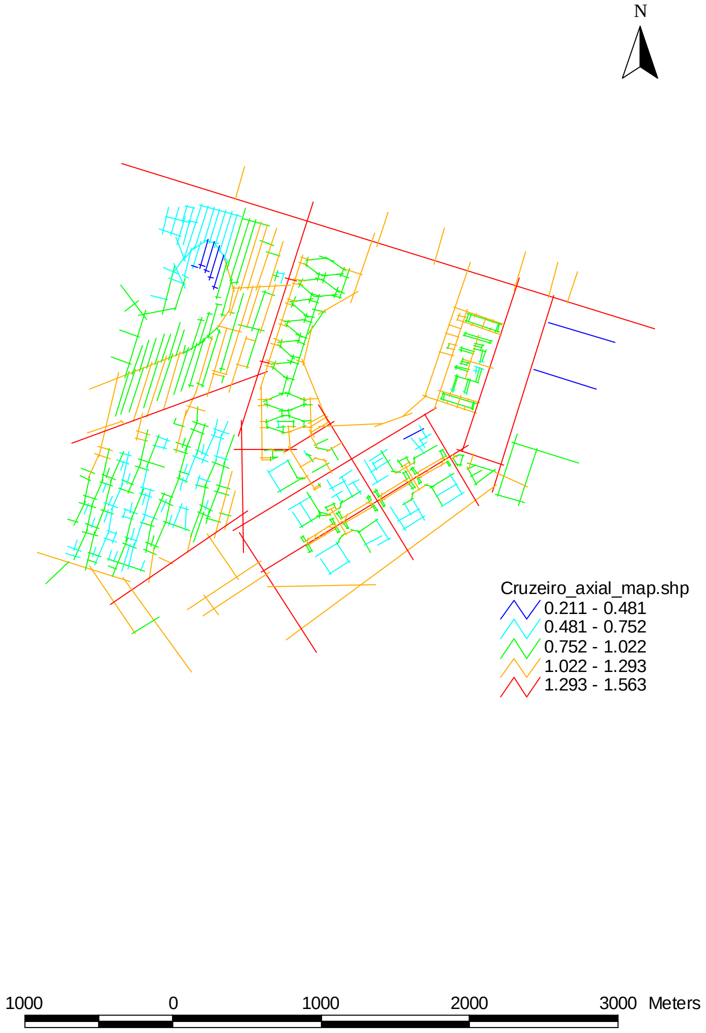
0.94 - 1.29
1.29 - 1.639
1.639 - 1.989
1.989 - 2.339
2000
0
2000
4000
Meters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Cruzeiro_axial_map.shp
0.211 - 0.481
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0.752 - 1.022
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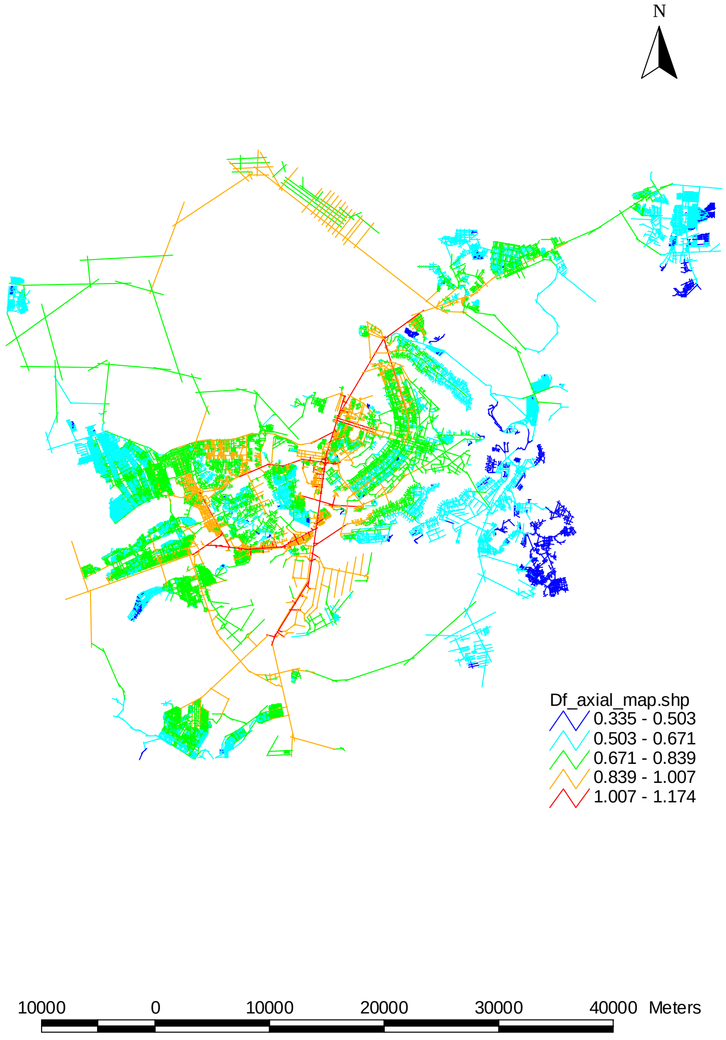
1.293 - 1.563
1000
0
1000
2000
3000
Meters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0.335 - 0.503
0.503 - 0.671
0.671 - 0.839
0.839 - 1.007
1.007 - 1.174
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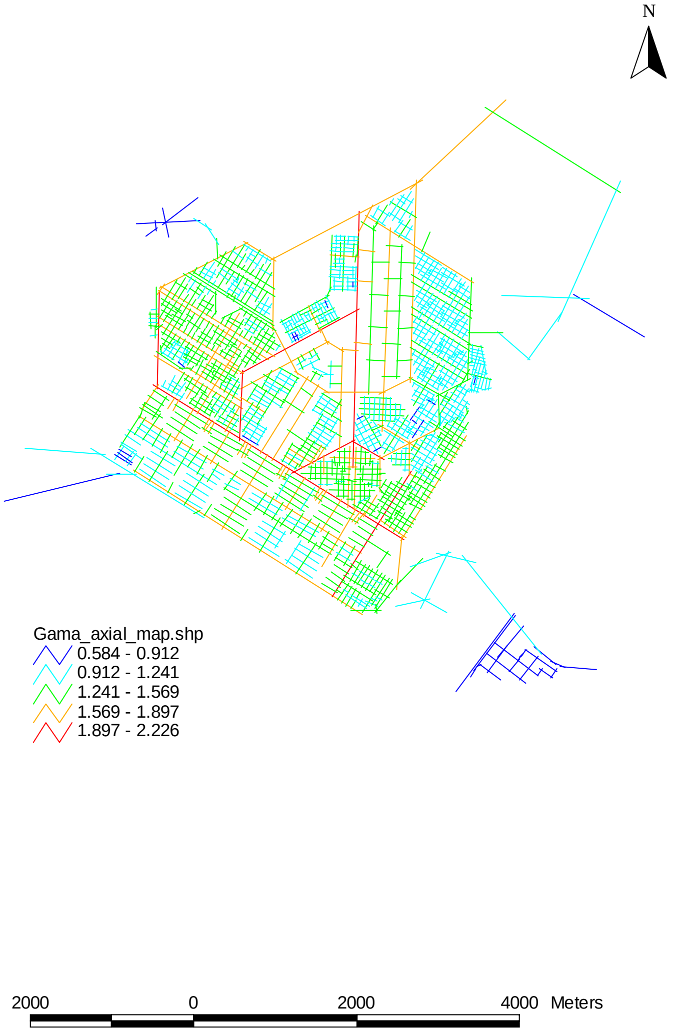
10000
20000
30000
40000
Meters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0.584 - 0.912
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1.241 - 1.569
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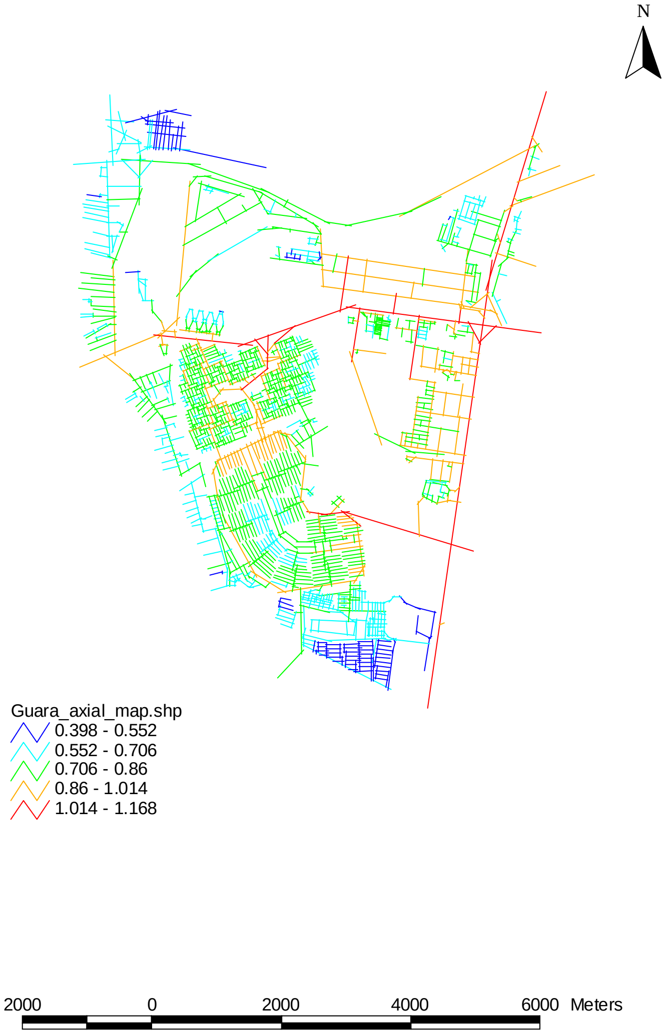
2000
0
2000
4000
Meters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Guara_axial_map.shp
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0.706 - 0.86
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1.014 - 1.168
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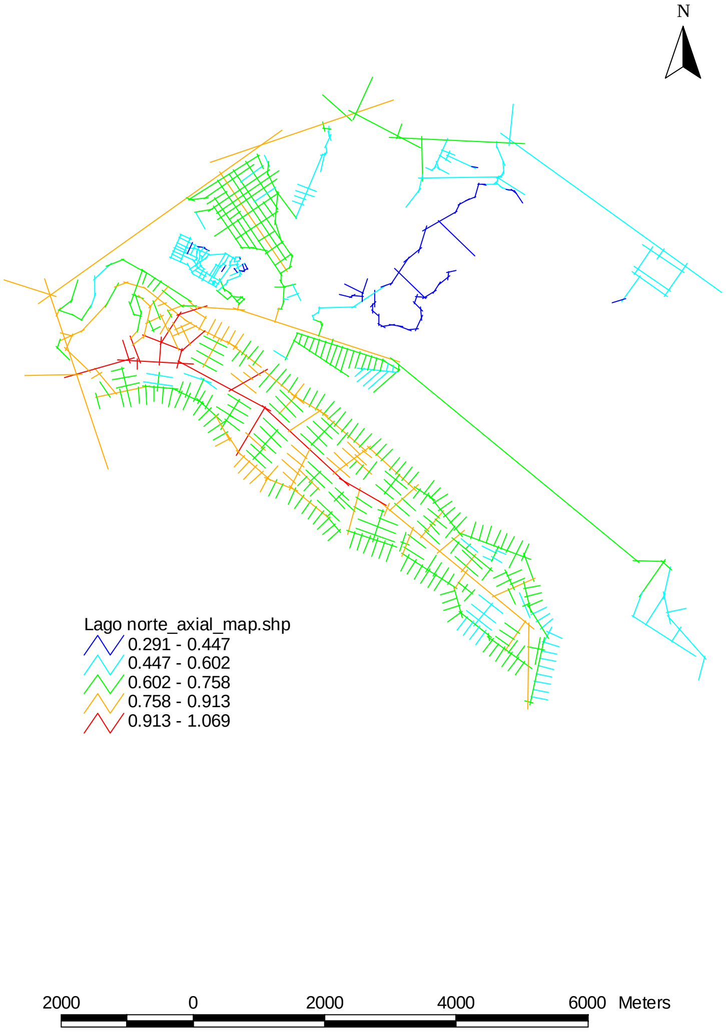
0
2000
4000
6000
Meters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0.602 - 0.758
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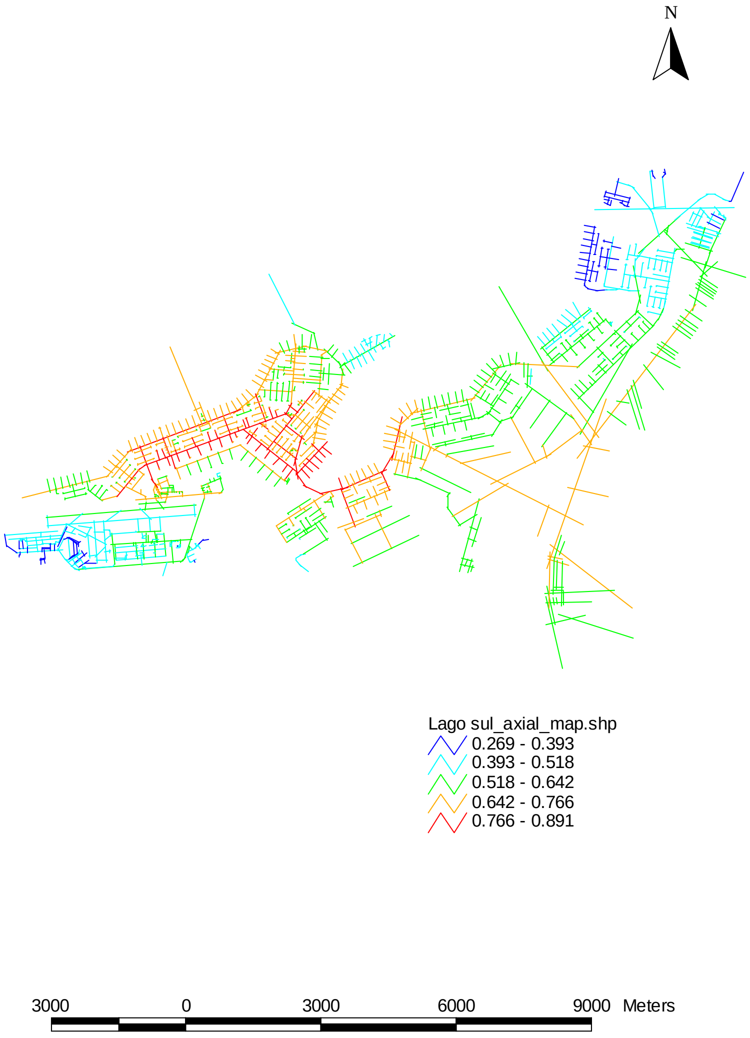
0.913 - 1.069
2000
0
2000
4000
6000
Meters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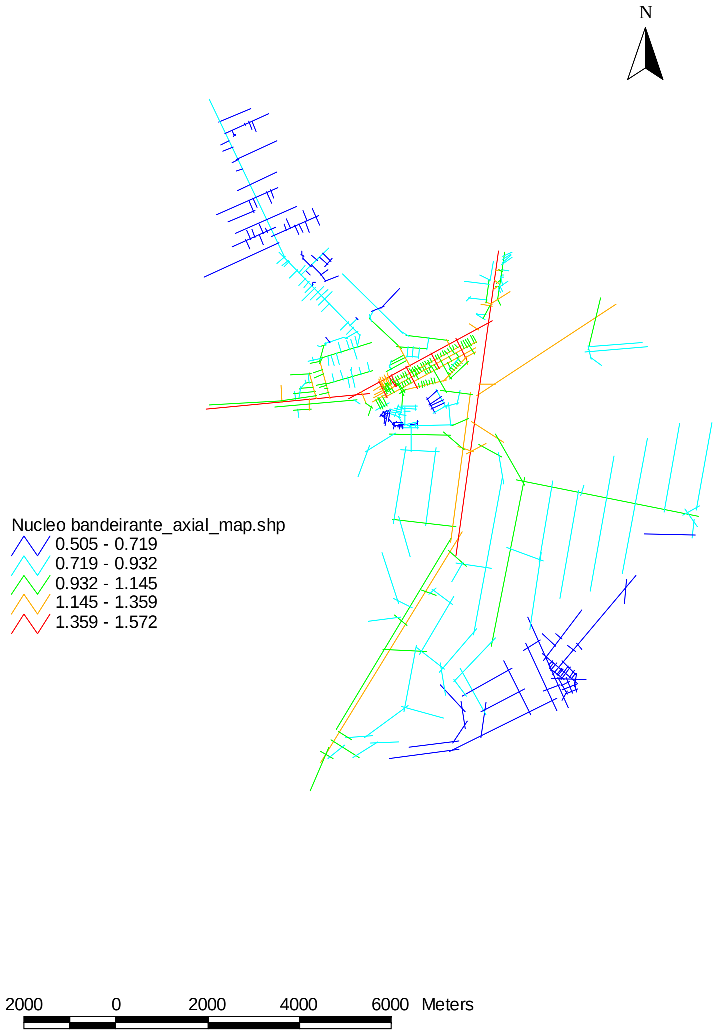
3000
0
3000
6000
9000
Meters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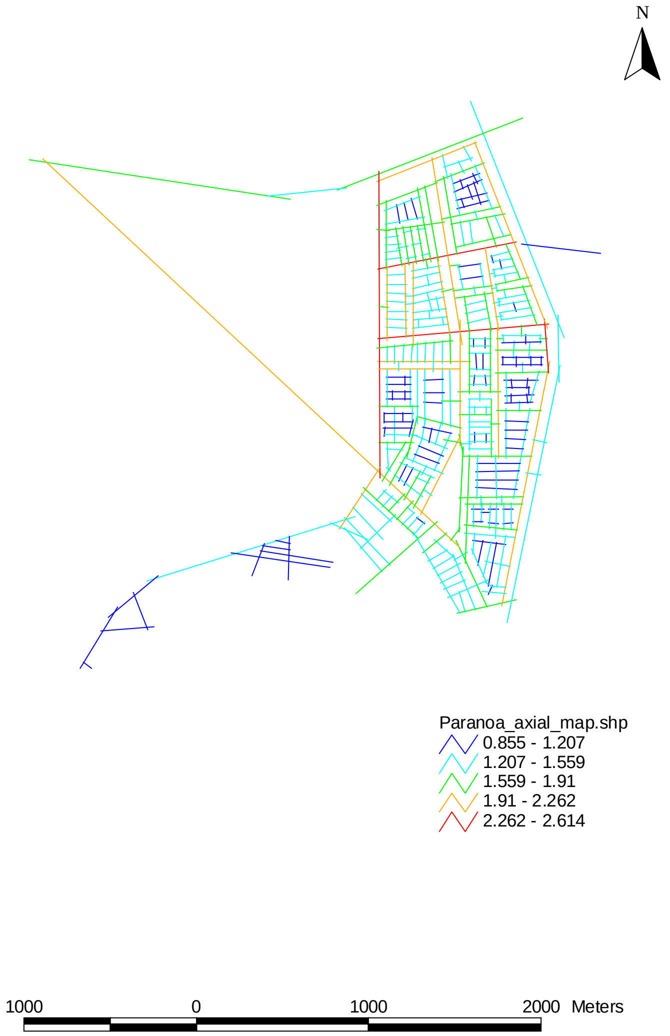
2000
0
2000
4000
6000
Meters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1.559 - 1.91
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2.262 - 2.614
1000
0
1000
2000
Meters


N
Planaltina_axial_map.shp
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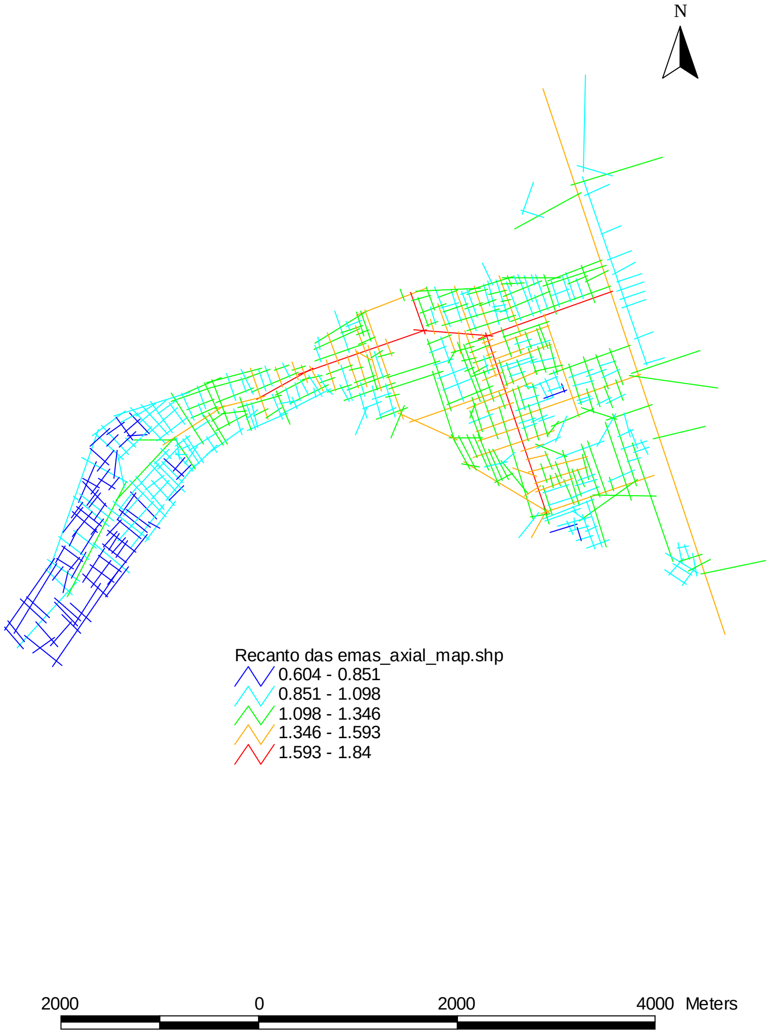
0.967 - 1.2
1.2 - 1.433
1.433 - 1.667
3000
0
3000
6000
Meters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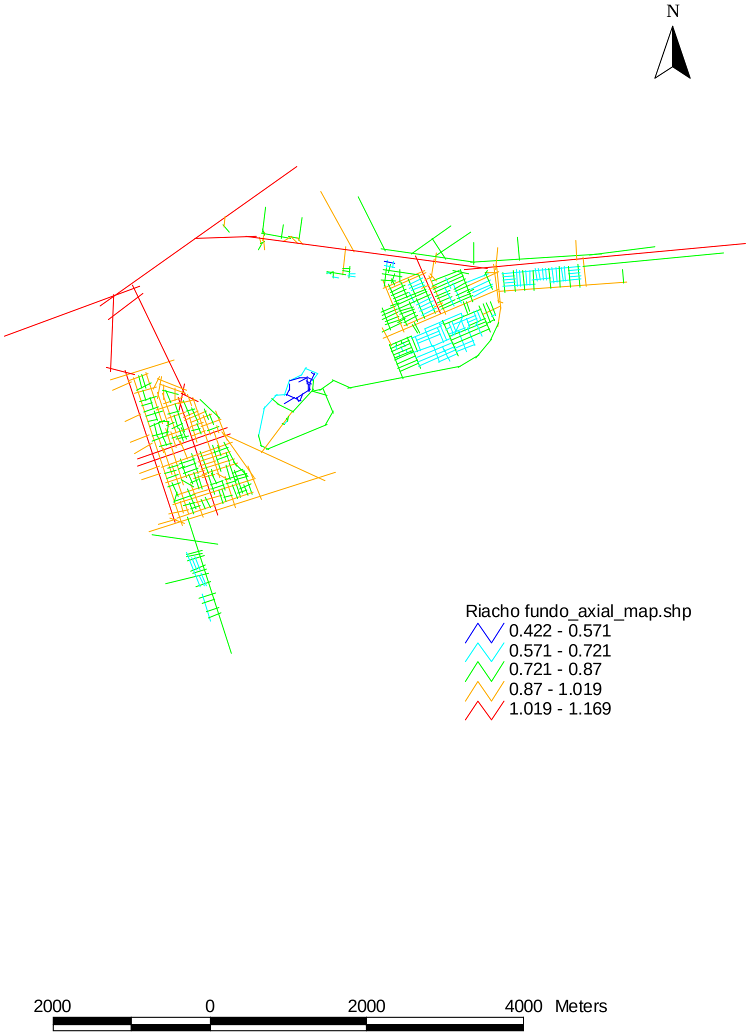
4000
Meters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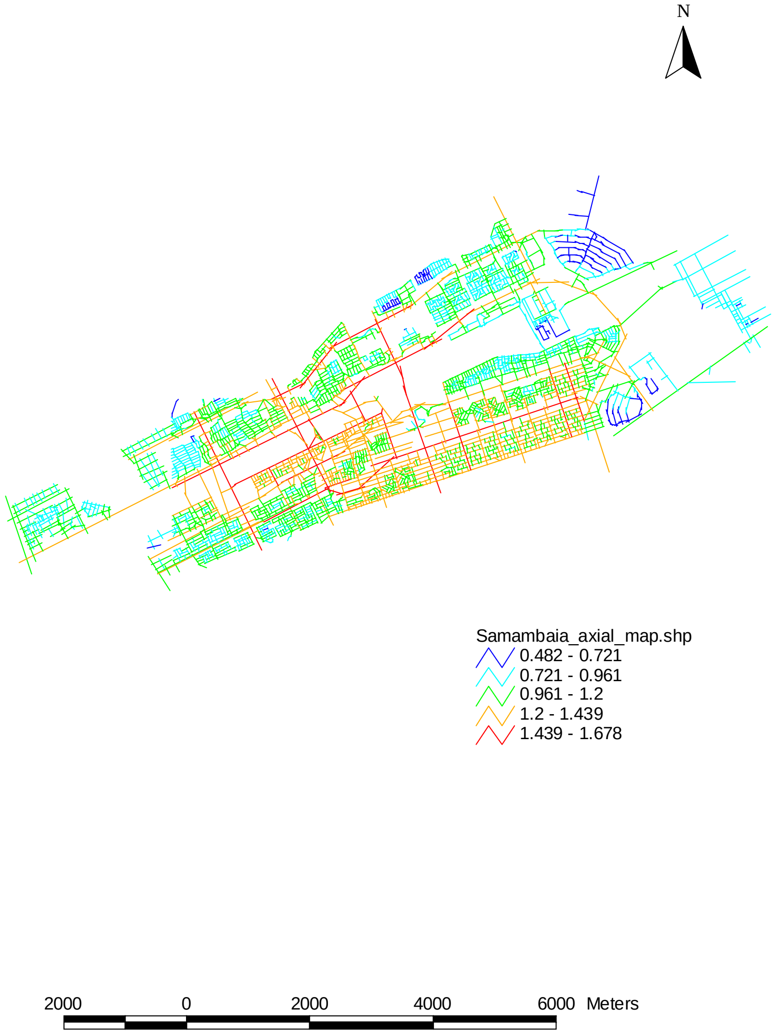
1.019 - 1.169
2000
0
2000
4000
Meters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Samambaia_axial_map.shp
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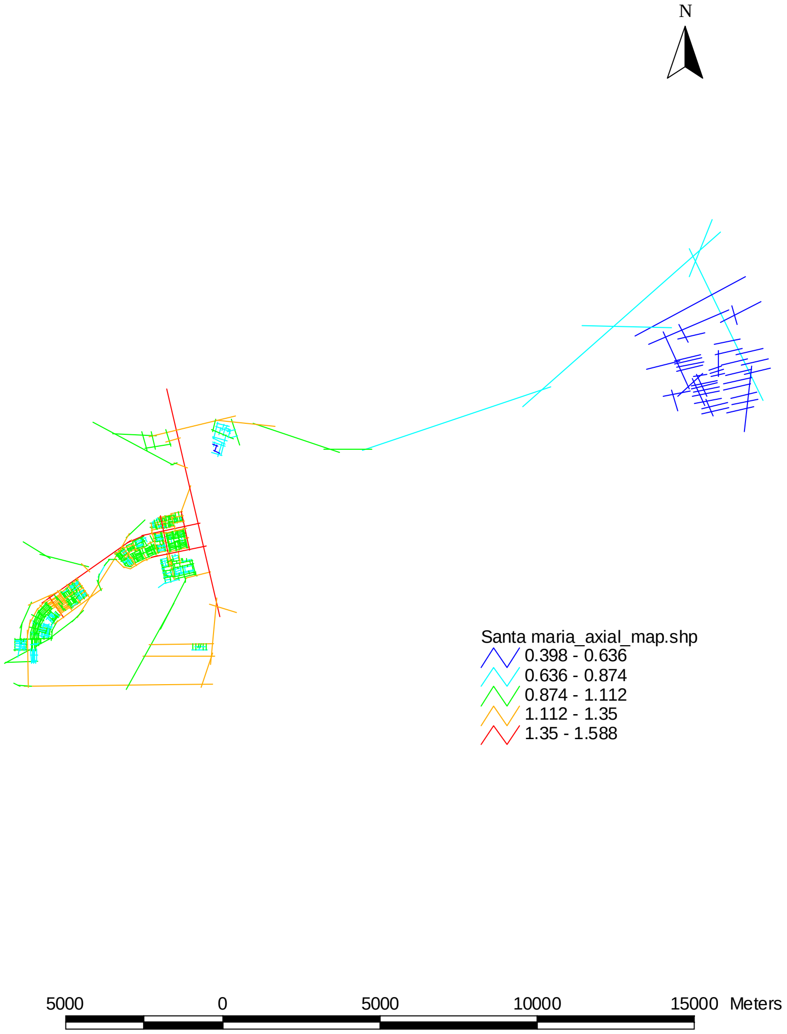
2000
0
2000
4000
6000
Meters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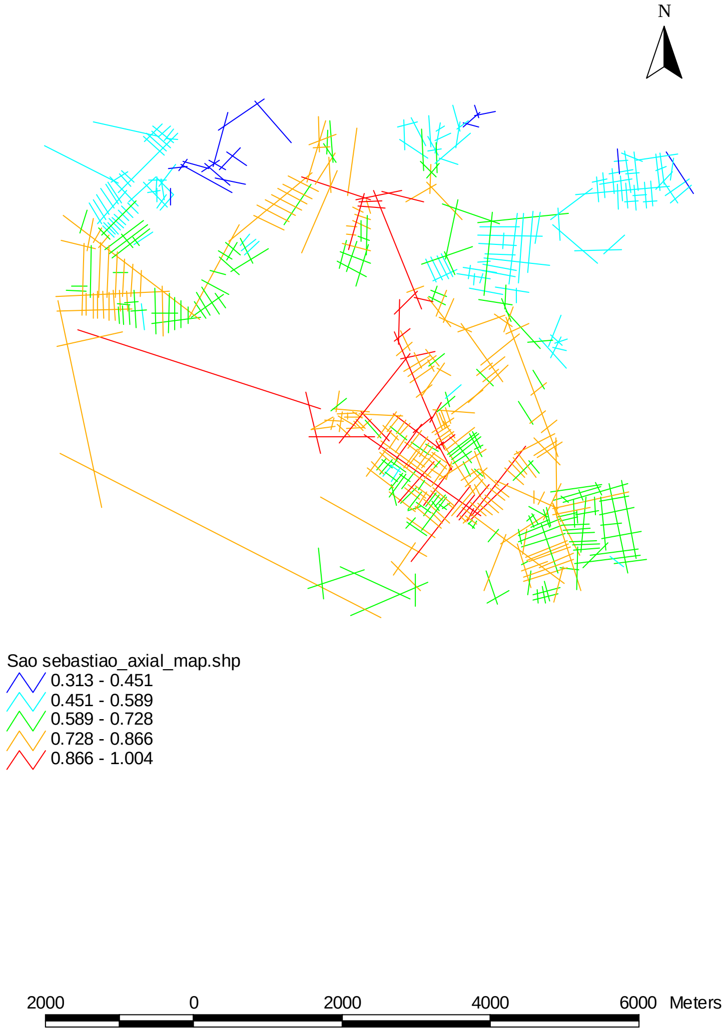
1.112 - 1.35
1.35 - 1.588
5000
0
5000
10000
15000
Meters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Sao sebastiao_axial_map.shp
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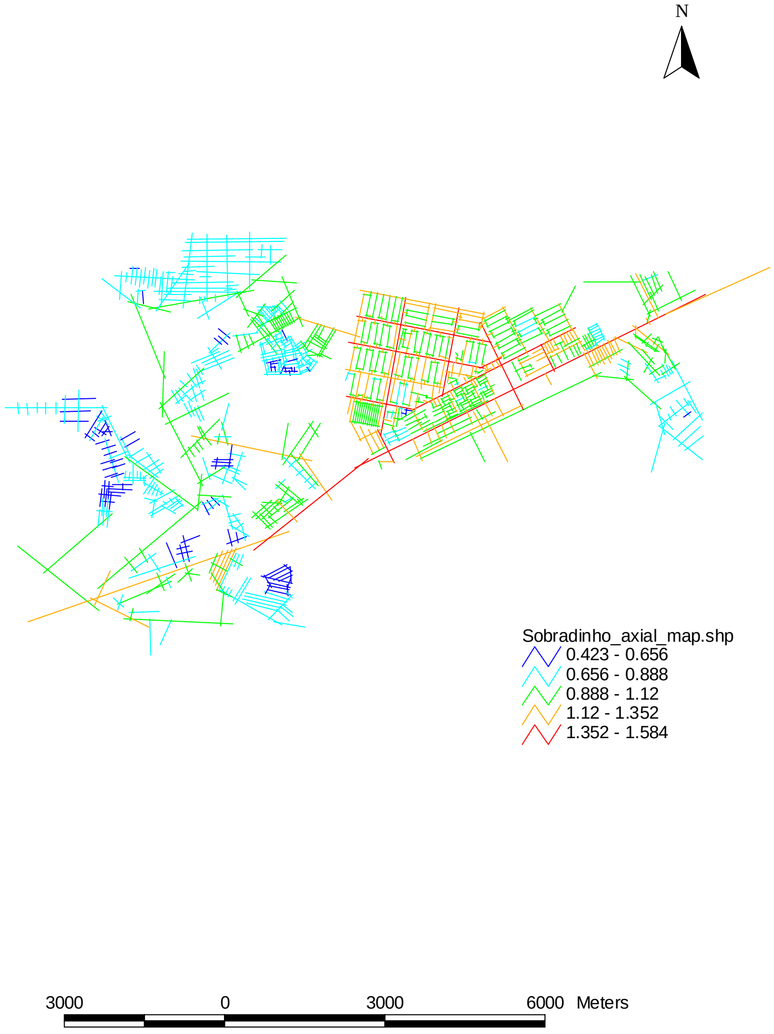
0.451 - 0.589
0.589 - 0.728
0.728 - 0.866
0.866 - 1.004
2000
0
2000
4000
6000
Meters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0.423 - 0.656
0.656 - 0.888
0.888 - 1.12
1.12 - 1.352
1.352 - 1.584
3000
0
3000
6000
Meters