A STEP FURTHER:
segment analysis for comparative urban studies

030

Valério Augusto Soares de Medeiros
Universidade de Brasília
Frederico Rosa Borges de Holanda
Universidade de Brasília

Keywords:

Space syntax
Segment analysis
Configurational study
Comparative urban study

Valério Augusto Soares de Medeiros
Universidade de Brasília,
SQN 406, Bloco I, Apto. 202,
Asa Norte, Brasília – DF, Brasil
CEP 70847-090
+55 (0) 61 349-6798
vaugusto@digi.com.br
Frederico Rosa Borges de Holanda
Faculdade de Arquitetura e Urbanismo, Programa de Pesquisa e Pós-Graduação em Arquitetura e Urbanismo, Universidade de Brasília – Caixa Postal 04431, CEP: 70919-970
Fax: (+55) (61) 3274 - 5444
Phone: (+55) (61) 3307- 2454
fredhol@unb.br

Abstract

This paper discusses an exploratory research aiming at investigating segment analysis in order to evaluate its usefulness in comparative urban studies. Research procedures considered an urban database composed of 164 axial/segment maps: 44 from Brazil; 76 international maps available at SSL; 33 obtained from researchers around the world and 11 drawn from urban raster images. Cities were distinguished according to the world region: Brazil, Europe, Latin America, North America and Asia/Pacific. Space syntax tools and geoprocessing techniques have been applied intending to foster spatial analysis and create an integrated urban database.

Segment analysis approach is recent and under development: variables are being tested and new empirical researches are requested to assure certain categories. Studies exploring properly output data available at Depthmap® software are necessary to proof, or deny, the assumption that segment analysis gives a refined picture when compared to a traditional axial map.

Explored database revealed some important comparative results. The segment/axial lines ratio is higher for orthogonal layouts: North American and Latin American cities reach 4.76 and 5.02 values, respectively. Figures are lower for other regions: 3.37 (Europe), 3.27 (Arab States), 3.21 (Brazil), 2.83 (Asia Pacific) and 2.77 (Portugal). The more organic or labyrinthine is an urban structure, the lower the ratio will be.

A general trend was found for total length of lines: an average loss from 14% to 16% when converting an axial to a segment map was identified. For North and Latin American cities, with orthogonal layouts, values were lower: 12% and 10%. In Portugal, where organic patterns are more common, the figure reached 18%.

Future empirical explorations are demanded, mainly concerning metric radius and normalized mean depth values related to the size of the system. Findings so far obtained indicate that segment analysis seems to be a powerful configurational step toward integration of fields, once it allows a better association with transportation, contributing for movement investigation.

Foreword

The development of the Depthmap® software at the UCL enabled the exploration of a new configurational technique: the segment map (Turner, 2003; Turner, 2004). Unlike traditional axial maps, where one

030-02

searches for the construction of the lowest number of the largest straight lines, the segment map consists of the disposition of lines between each node of an urban grid, resembling the node-link binomial, common for traffic engineering models. The software enables the generation of the segment map based on a usual axial map, allowing researchers to compare results and find out of which situation one technique or another would present better applicability. The Depthmap® software promotes the automatic conversion by breaking all axes in places where there are crossings of lines or connections. A single straight line may be transformed into countless segments, depending on the number of intersections present in the line. According to Hillier (2006), the advantage on the use of this technique would be its more refined output data in relation to the integration value in a single line, thus allowing the visualization of different mean depth values for the same axis. The idea is a counterpoint to the problem identified for the axial map in revealing axes potentially powerful in the flow generation that, indeed, are only strongly busy in some parts.

For this research, all segment maps were generated based on pre-existing axial maps, and the Depthmap® default option of excluding line fragments with dimension below 25% of the origin axis length was maintained. The analysis classes applied to the samples included: (a) total length of lines, (b) total length of segments, (c) segments/axes ratio, (d) loss when converting an axial into a segment map, (e) number of axes, (f) number of segments, and (g) depth (mean, maximum and minimum).

The Sample

The variables were explored for two samples. Firstly, only Brazilian cities were investigated and subdivided into two groups. In a second moment, Brazilian cities were inserted into a world urban sample, thus enlarging the scope of this research.

The Brazilian Sample

Brazilian cities sampling included two stratums of specific features:

Group 1 – cities classified as A, with population over 500,000 inhabitants and B, with population from 300,000 to 499,999 inhabitants (Populational Estimative for 2005 - IBGE/Brazilian Institute for Geography and Statistics). Most examples are coincident with state capitals and/or large urban centres of regional relevance. The following cities belong to group A: São Paulo, Rio de Janeiro, Salvador, Recife, Fortaleza, Brasília, Manaus, Goiânia, Porto Alegre, Belém, São Luís, Maceió, Teresina, Natal, João Pessoa, Uberlândia, Cuiabá and Aracaju. Group B included: Florianópolis, Porto Velho, Pelotas, Anápolis, Vitória and Palmas.

Group 2 – or cities classified as C, is the group composed of settlements presenting heritage urban areas or areas containing building sets or monuments of heritage interest. Moreover, these areas maintain features that expressively bring them back to the territory occupation process and consolidation of the urban space of the country, including cities awarded with the World Heritage Site title by UNESCO. The following cities were included in this study: Alcântara, Antônio Prado, Aracati, Belém, Brasília, Cachoeira, Cuiabá, Diamantina, Florianópolis, Fortaleza, Goiás, Icó, João Pessoa, Lençóis, Manaus, Mariana, Mucugê, Natal, Oeiras, Olinda, Ouro Preto, Parati, Pelotas, Penedo, Petrópolis, Pirenópolis, Porto Alegre, Porto Seguro, Recife, Rio de Contas, Rio de Janeiro, Rio Grande, Salvador, São Luís, São Paulo, Tiradentes and Vitória.

From the groups above, we have reached the following situation:

(a) 50 Brazilian cities have population over 300,000 inhabitants. This study included 24 of them, what results in a sample proportion equivalent to 48%.

(b) There are 81 urban sites of heritage interest in Brazil, according to Roll of Priorities of the Monumenta Program/IPHAN (Brazilian Institute for Heritage Preservation); where 37 of them have been included, what corresponds to 46%.

There is a superposition in both classes, once there are cities of heritage interest with population above 300,000 inhabitants. Examples are Salvador, Recife, Olinda, Belém and others. Therefore, 44 is the total figure of investigated settlements (Figure 1).

Figure 1:

Investigated Brazilian cities

World Sample

The Brazilian sample was enlarged by means of the incorporation of world settlements with the objective of searching for regional peculiarities and features according to the urban grid pattern.

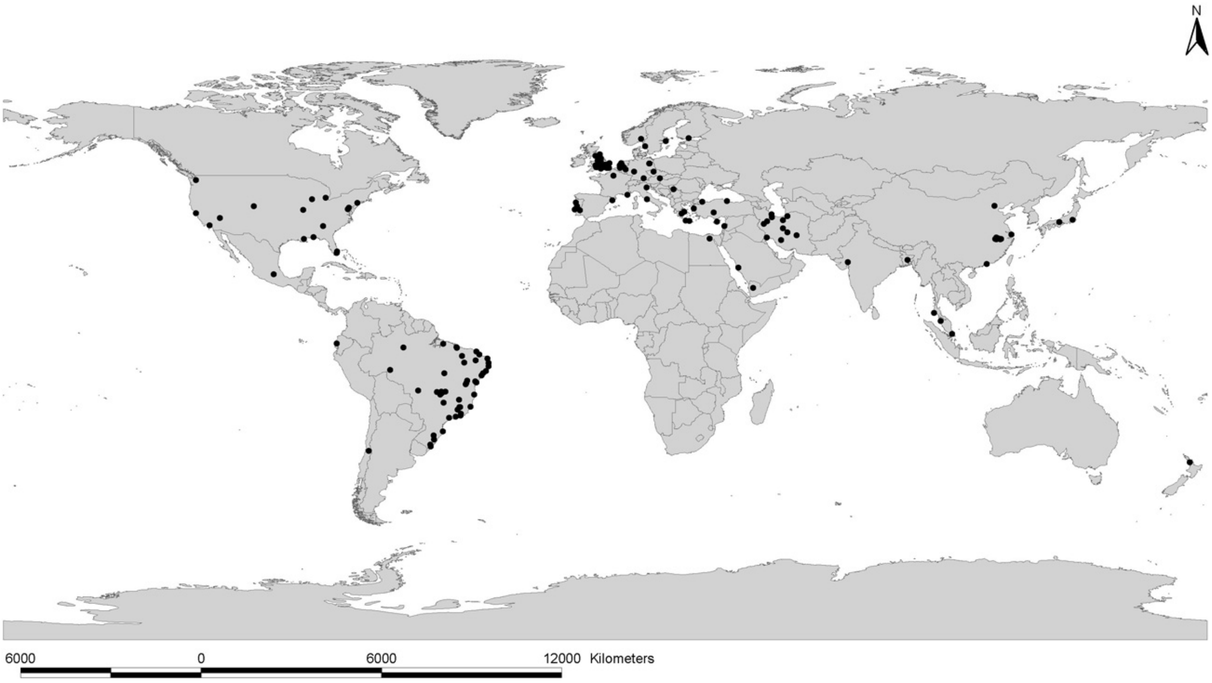
The world cities were distinguished according to region based on classification adopted by UNESCO (available at www.unesco.org). For the international organism, the globe interpretation is given by the fractioning into the following parts: (1) Latin America and The Caribbean/LAT; (2) North America/NOR; (3) Europe/EUR; (4) Asia and Pacific/ASP; (5) Arab States/ARA and (6) Africa/AFR.

Since the main focus of this work was the Brazilian cities, a group called BRA was created. Analogically, searching for the counterpoint between Brazilian cities and their European colonial matrix, the Portugal group – POR – was also created. Oppositely, due to the inexistence of axial maps for African cities, the Africa group – AFR – was excluded.

The resulting global database was composed of 164 cities: (1) 44 Brazilian cities selected according to criteria previously established (Medeiros, 2006a); (2) 76 axial maps found at the urban database from the Space Syntax Laboratory in London (Medeiros, Hillier & Figueiredo, 2006); (3) 33 maps, sent upon request by researchers from several universities worldwide, who participate in the space syntax mailbase (Medeiros, 2006c); and (4) 11 maps based on cartographic databases in raster format (images) obtained from the Internet (Figure 2).

Figure 2:

Investigated world cities



Analysis of Variables

The variables include geometric and topologic aspects, dealing with quantitative, distribution and accessibility.

Brazilian Cities

Total length of axes

Information on the total length of axes of the axial map reinforces the geometric feature of the Brazilian sample, guaranteeing the discrimination of the Brazilian cities as large and small settlements (Cf. Medeiros & Holanda, 2005).

Of course, the larger the system is, the larger the total sum of the axes will be. Figure 3 reveals the following premise: systems presenting the highest values are the cities of São Paulo, Rio de Janeiro and Porto Alegre. Rio de Contas is on the opposite pole, once it presents the status of smallest city in the sample in terms of area and number of lines.

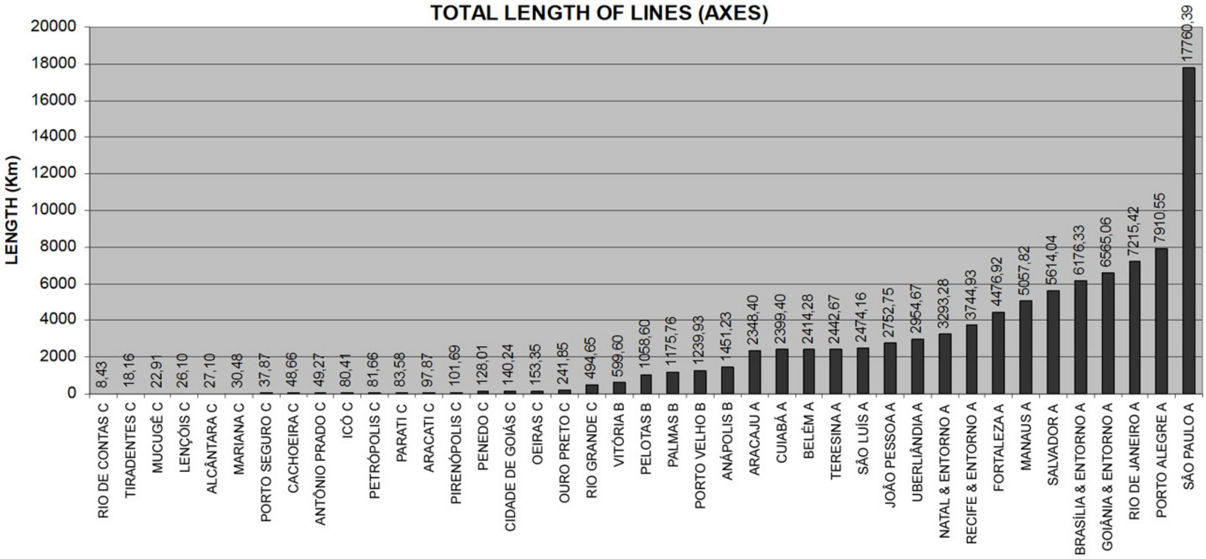
The general average for Brazilian settlements is 2,214.87 km: 86% of cities from group 1 are above this average, while 100% of C is found below. The median corresponds to Pelotas, with total value of 1,058.60 km.

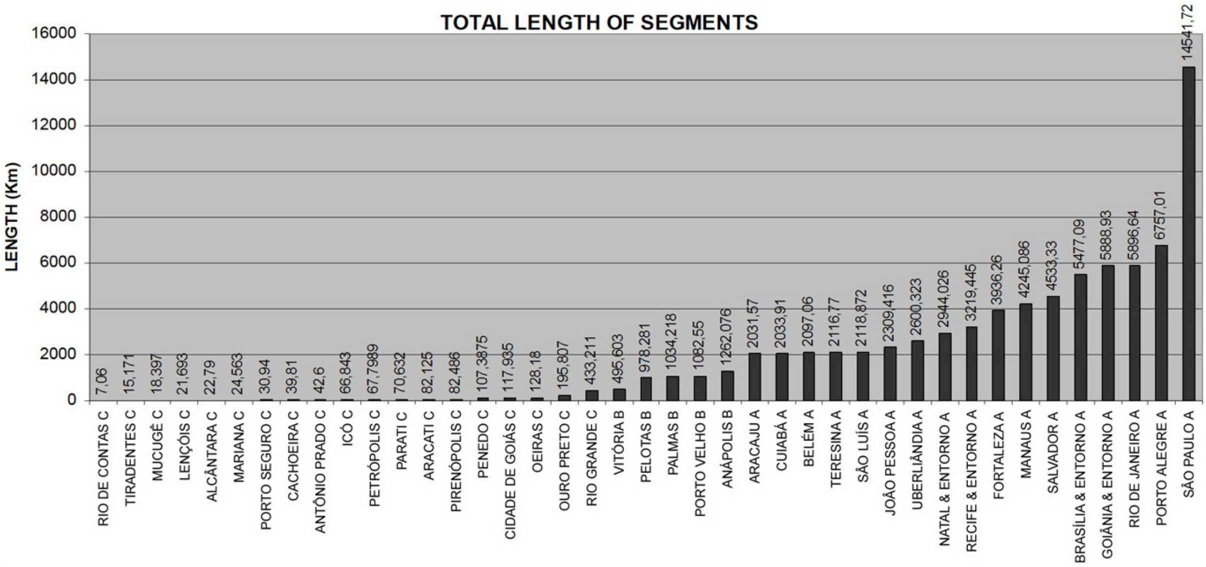
Total length of segments

Reflecting indications for the total length of axes, when we evaluate the sum of segments, the characterization of samples among large and small systems consolidates and practically there is no significant alteration in the position of cities considering the increasing size order (Figure 3). The average value found was of 1,885.65 km, with median also in Pelotas (978.28 km). 78% of cities from group 1 presented sum above the average, while 100% of settlements from group 2 remained below this value.

Figure 3:

Total length of lines and segments for the Brazilian sample





The comparison of data between the total length in the axial map and in the segment map revealed some aspects. For instance, it is possible comprehending how the arrangement of a given urban structure is more or less economic.

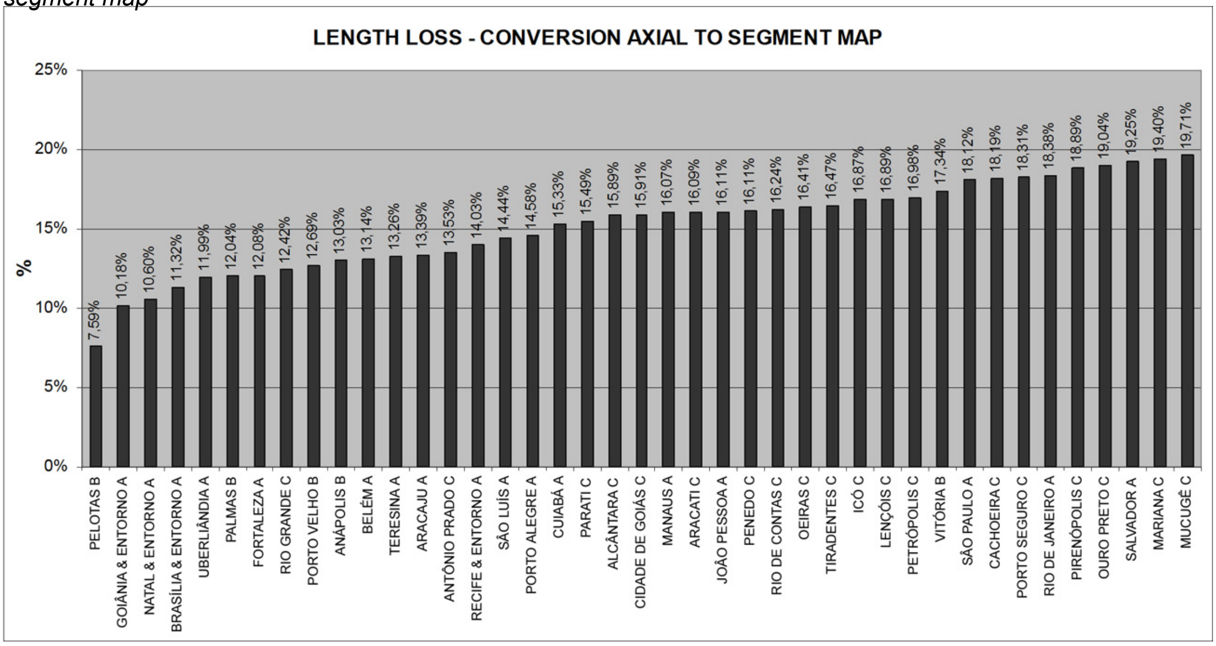
For example, at the moment of the automatic conversion of an axial map into a segment map, the researcher may determine the exclusion of all segments smaller than a given length of the origin line (default value is 25%). This strategy is useful to avoid that prolongations of axes purposely drawn by the researcher to guarantee the connection between lines in a given axial map be considered as a segment.

Figure 4 demonstrates that the average loss is of 15%. The median is equivalent to Cidade de Goiás, with loss of 16%: 74% of cities belonging to group 2 are at the right side of the median, with higher values, while 73% of cities from group 1 are at the left side. Therefore, the larger a city is, the smaller the loss percentage will be, what also seems to be associated to a higher regularity in such settlements. The

Figure 4:

Average length loss when converting an axial map to a segment map

opposite is observed for small-size cities, once there is a larger amount of examples of irregular grids or grids that tend to be organic, where “T” shape intersections prevail, what increases the occurrence of line prolongations to guarantee the connection.



It could be illustrated by the tendency that the more orthogonal a given system is, the lower the loss at the conversion moment will be: the axes are proportionally larger, cross most part of the systems and the connection guaranty aspect is minimized by the “X” shape connection. That is why cities such as Pelotas, Goiânia, Brasília and Uberlândia are at the lower pole, with losses below 12%. On the other hand, the more irregular, the higher the loss will be, considering an urban structure full of complications, what accentuates the item connection guaranty, reason why Mucugê, Mariana, Salvador and Ouro Preto are at the maximum pole, with losses above 19%.

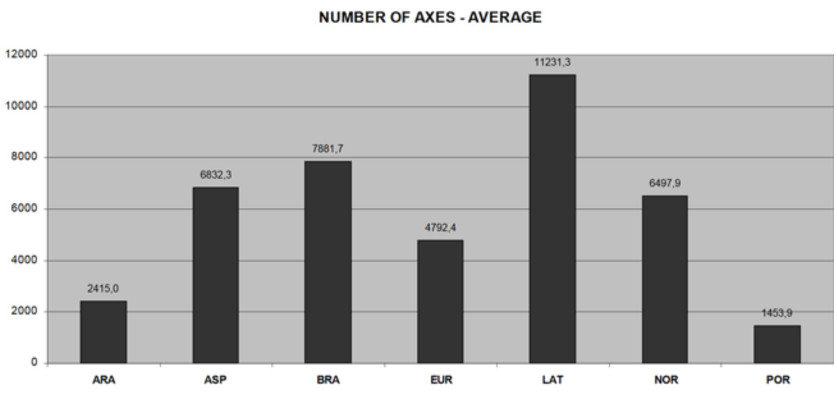
Global Sample

Amount of lines/axes

The first variable to be explored for world settlements was the average number of axes found in axial maps for each region. Considering the existence of only three Latin American examples, data have been distorted, once the city of Santiago do Chile, with 28,623 lines, is one of the largest systems ever drawn in that region.

Figure 5:

Number of lines per world region



The world average reaches 5,872 lines (Figure 5): Brazilian, Asiatic and North American cities are above this average. From the fourteen largest cities, those presenting number of axes above 20,000 lines

(9% of the sample), eleven of them (79%) are placed in these world regions (Goiânia; Seattle; Beijing; Kyoto; Manaus; Johor Bahru; Santiago; Chicago; Salvador; Tokyo and São Paulo). Exceptions are Istanbul; Athens and Gothenburg, all in Europe.

Except for Latin settlements, the Brazilian cities are those that reached the highest average value, with 7,882 axes, although this sample has presented distinct poles such as São Paulo (79,740) or Rio de Contas (46). Similar situation seems to occur with Asiatic cities (average of 6, 832), including Tokyo (73,719) and Yuliang (88). For North American cities, the average is similarly high (6,498), which is the effect of an enlarged grid in suburban areas, in the typical characterization of USA settlements.

European cities are in intermediate situation, with 4,792 axes. Arab cities are below the average value, with 2,415 axes, followed by Portuguese cities, with 1,454 lines. These regions correspond to lower quadrants, indicating areas especially composed of small settlements: Portugal is structured in an urban network focused on the city of Porto at north and by Lisbon at middle-south. Both cities altogether correspond to 69% of the total axes in the country: if we counted them out, the average would drop to 573 lines.

Number of segments

The investigation on the number of segments aided the comprehension on the articulation mode of the urban compass, leading to the exploration of the following variables: (1) average number of segments; (2) segment/axial lines ratio; and (3) loss in total length of axes at the conversion moment – similarly to what has been performed for the Brazilian sample in separate. The analysis of variables validated findings on the existence of a more organic or regulated urban tissue.

One believes that the transformation of axes into segments will be capable of indicating grids with higher or lower regularity. Grids where “X” shape connections prevail would be those of higher orthogonality. Here, there is a tendency to maximize the number of segments per axis, once one line will be transformed into several segments, depending on the coverage degree of the axis in the system. On the other hand, grids where “T” shape connections prevail would correspond to those of lower regularity and derive to organic standards, once here routes would tend to be closed when reaching those of higher hierarchic importance in a capillarity profile.

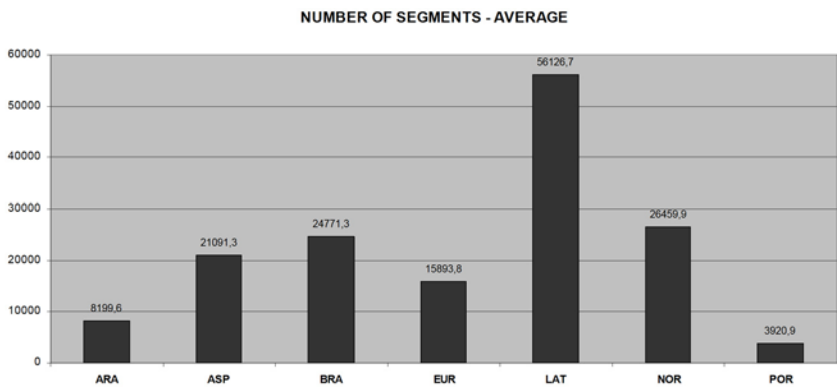


Figure 6:

Average number of segments per world region

Figure 6 presents the mean number of segments. The comparison with Figure 5 reveals that the distribution order remains similar, with only one alteration: North American cities took over the second position (26,460) and Brazilian ones dropped to the third position (24,771 segments). The global average is of 22,352 and, except for Latin American cities; only Brazilian and North American settlements are above the average. In case we excluded the Latin group, the average would be reduced down to 16,723 lines, and the Asia Pacific cities would be added to the group above the average.

Figure 7 presents the number of segments/axes ratio: the segment map has 3.6 times more lines than the axial map, on average. Individually, North American cities that account for 58% of the 12 settlements in this condition are among cities with higher ratio, above 5. New York is the pole, reaching 8.88 segments/axes, and is a product of the extremely regulated feature of Manhattan; followed by Denver (also in the USA, with 6.75), Mexico City (which reports the Spanish colonial grid, with 6.60) and Athens (6.20).

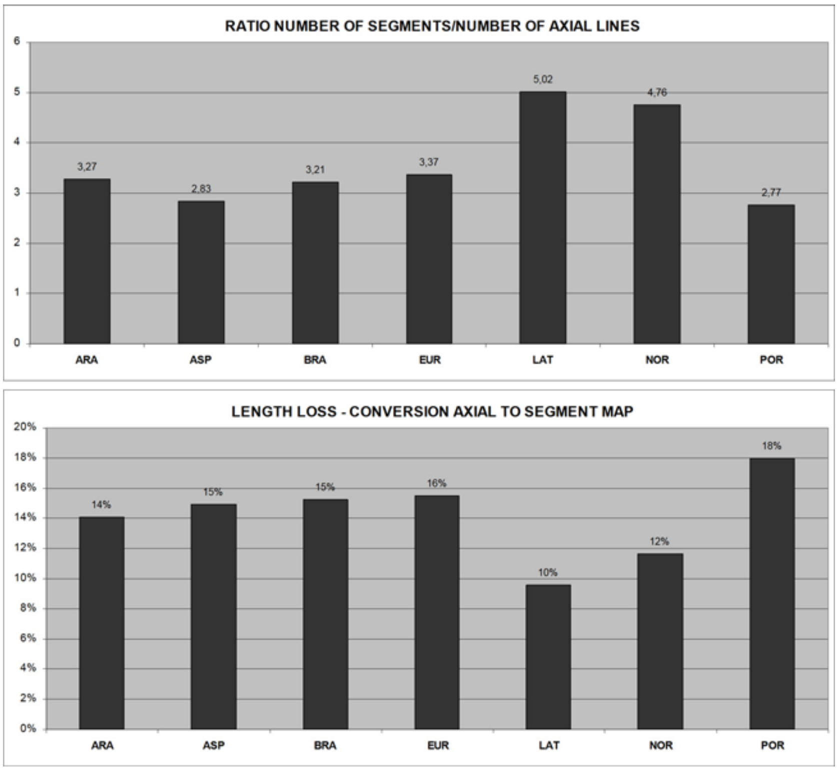


Figure 7:

Average ratio segment/axis (top) and length loss when converting an axial to a segment map (world sample)

The graphic distribution provides relevant inferences on the urban configuration. The initial argumentation has been confirmed: settlements of strong orthogonality, corresponding to Latin American (5.02) and North American cities (4.76) are in the top of the distribution and the only cities above the average. European (3.37), Arab (3.27) and Brazilian (3.21) settlements are in intermediate position. Asiatic (2.83) and Portuguese (2.77) examples are found at the lower pole.

The distribution is indicative when those low-order or more organic form-spaces are coincident with those of lower value for the segments/axes ratio: it is the situation found in Asiatic or Portuguese cities, where the maximum available space is used in an economic occupation inherited from the Guerra da Reconquista and of a defense-based urban scheme. The product obtained was an extreme dense space with irregular grid in places of accented terrain conditions: Óbidos, Porto, Lisbon, Coimbra and Évora confirm this inference.

If we associated data on the loss of length of line from the conversion on axes into segments (Figure 7), we will identify that the following tendency is also observed: (1) the more orthogonal a given system is, the lower the loss at the conversion moment will be, once the axes are proportionally greater and cross most part of the systems, and the connection guaranty aspect is minimized by a “X” shape connection, reason why Latin American and North American cities correspond to the minimum pole, with 10% and 12% of loss, respectively; (2) on the other hand, the more irregular, the higher the loss will be, considering a low-regularity urban structure – Portuguese cities are those presenting the highest loss (18%), followed by European (16%) and Brazilian cities (15%).

Mean depth

The investigation of attributes related to the variable of segments considered information in relation to depth only. Since the axes are sectioned in their intersections, all segments will only have a reduced number of connections, what makes the connectivity variable not much significant. In the case of the city of Adaban in Iran, the connectivity for an axial map ranges from 1 to 47, and when converted into a segment map, this range goes from 1 to 6. The same condition is observed for Lisbon, from 1 to 33 and from 1 to 7, respectively. Other examples are Santiago (1 to 152 and 1 to 12) or Phuket (1 to 30 and 1 to 6). This behaviour is observed for the entire sample.

For data of mean, maximum and minimum depth (Figure 8), the following results were found:

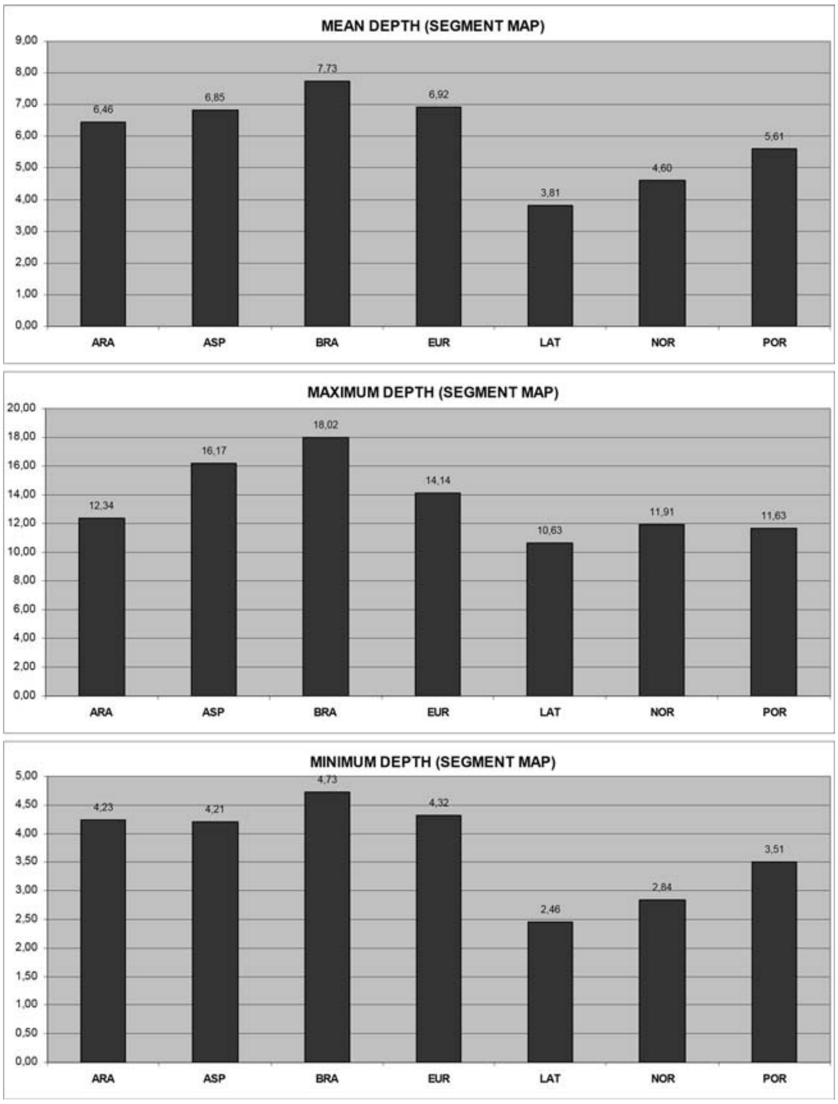


Figure 8:

Mean, maximum and minimum depth values (world sample)

Cities with more orthogonal characteristics are those of lower mean depth, such as Latin American and North American settlements (3.81 and 4.00, respectively, for an average of 5.99). These settlements are also those presenting the lowest maximum and minimum depth, what validates the statement that the systems become shallow, as the orthogonality feature is more present and uniform in the urban grid.

Arab cities, although tending towards the highest depth quadrant, are not the deepest systems, unlike a renowned labyrinthine impression could indicate.

Asiatic settlements, comparatively, present more reduced depths, always below the mean (mean depth of 5.61, for the mean of the sample of 5.99, maximum of 11.63; for the mean of the sample of 13.54, and minimum of 3.51, for 3.76). It is one more evidence, considering the reduced number of axes and segments for such settlements, than a shallower feature itself, once a more parsimonious urban form-space would tend to indicate higher depth.

The Brazilian cities always corresponded to the maximum poles of the graphic, which is an evidence of their labyrinthine feature and the patchwork pattern that increases depth and hence decreases the integration for axial maps. It is an evidence of the low permeability degree in the urban grid in settlements of this country.

Conclusions

The exploration of the previous variables allowed the identification of features according to the world region in which settlements occurred. The cities were particularized into some of their predominant geometric and topological features. The spatial distribution associated to some characteristics in the form-space – such as the Latin American orthogonal grid or the parsimonious standard of Portuguese cities – have allowed a topological interpretation, addressing to precise spatial characteristics.

The exploration of correlations for the entire sample gave raise to some observations:

1 – Invariably, the higher the number of axes in a given system is, the higher the number of segments will be. The coefficient of determination of 94% and the Pearson's r of 97% indicate that the association between variables is almost perfect.

2 – However, there is no association between the number of axes of a system and the loss of length of line at the conversion moment of an axial map into a segment map (r is equivalent to - 4% and R2 to 0.1%). The situation seems to indicate that other factors affect these variables and we are inclined to believe that the configurational studies are those of main interference.

3 – The analyses indicate that orthogonal systems tend to present reduced loss, once lines pass over one another, and there is no noise of exceeding segments; low-order systems or those that tend to organicity present large amounts of "T" shape connections, and to guarantee the connections, the researchers usually draw the axial map and make large trespasses at the crossing moment in order to guarantee the connection: these line segments are not considered at the conversion moment, what leads to a higher loss.

4 – The process that transforms axes into segments allows identifying grids with higher or lower regularity, either large or small urban structures. The predominance of "X" shape connections would indicate higher orthogonality (and smaller number of segments), and in "T" shape connections, higher organicity (and higher number of segments).

5 – The segment/axis ratio reinforces previous forecasts. The higher proportions are associated to orthogonal settlements, and lower are

associated to those more organic or large or labyrinthine ones (Asiatic and Portuguese cities).

Considering the aspect that the segment map presents a more refined situation in relation to the axial map, findings have pointed a peculiar situation: keeping equal ranges of colours for segment and axial maps, the picture seems to be refined, in the sense of urban hierarchy, for the segment when in irregular urban structures. When cities have an orthogonal predominance, results for segment are worse, once almost all lines tend to be concentrated in the same red band. Therefore, refinement situation for segment is true for organic structures, but in regular, axial maps – despite the Manhattan question, are more precise.

The set of attributes investigated, although only initially approached, presents valid contributions for the process that consolidate the segment analysis in configurational studies.

The construction logics associated to segments based on nodes in an urban net is close to that adopted in traffic studies, allowing a higher integration of data between knowledge areas – what will lead to a better incorporation of the configurational variable in the understanding of flows and movements in urban spaces. This fact intends to be a powerful link between knowledge fields. Studies have already been conducted, and the first findings present robust correlation between vehicle counting and the potential flows based on axial maps and, even better, when based on segment maps (Cf. Barros, 2006).

Finally, we would like to make clear that the output results in relation to the segment analysis are in mean depth and the variable corresponding to the integration value has not been developed so far. It means that the numerical mean depth indexes obtained from segment maps still need to be calibrated in order to consider the size of the systems, what effectively will guarantee the comparison between the investigated urban examples.

References

Barros, A., 2006, “Estudo Exploratório da Sintaxe Espacial COMO Ferramenta de Alocação de Tráfego”, *MSc thesis*, Universidade de Brasília, Brasília.

Hillier, B., 2006, “Personal Communication”, 01 February.

Medeiros, V., Hillier, B., Figueiredo, L., (Eds.), 2006, “Space Syntax Laboratory Urban Form Database”, Bartlett School of Graduate Studies, University College London, London.

Medeiros, V., Holanda, F., 2005, “Urbis Brasiliae”, A. van Nes (Ed.), *Proceedings*, 5th International Space Syntax Symposium, Delft University of Technology. Delft, v.1, pp. 331-339.

Medeiros, V., (Ed.), 2006a, “Brazilian Urban Form Database”, DIMPU Research Group, Universidade de Brasilia, Brasilia.

Medeiros, V., (Ed.), 2006c, “World Urban Form Database”, DIMPU Research Group, Universidade de Brasilia, Brasília.

Turner, A., 2003, “Depthmap: A Program to Perform Visibility Graph Analysis”, J. Peponis, J. Wineman, S. Bafna (Eds.), *Proceedings*, 3rd International Space Syntax Symposium, Georgia Institute of Technology, Atlanta, pp. 03.1-06.09.

Turner, A., 2004, “Depthmap 4: A Researcher’s Handbook”, Bartlett School of Built Environment, University College London, London.