THE IMPACT OF URBAN STREET PLAN DESIGN IN SUSTAINABLE URBAN MOBILITY

BARROS, Ana Paula; University of Brasilia and Technical University of Lisbon; anapaulabgb@gmail.com

MARTÍNEZ, Luis Miguel; Technical University of Lisbon; martinez@civil.ist.utl.pt

VIEGAS, José Manuel; Technical University of Lisbon; viegas@civil.ist.utl.pt

SILVA, Paulo Cesar; University of Brasilia; paulocmsilva@gmail.com

ABSTRACT

The paper analyzes the performance of different street plans to determine which variables are present in each type, as first step to creating a walkability index. Three neighbourhoods of Lisbon are used as case studies: (a) Campo de Ourique - with a grid-based street plan - (b) Graça – with irregular roads - and (c) Telheiras - with a contemporary street plan. It was found that the grid-based street plan has more road homogeneity, a lower straightness index and a higher average integration index. The contemporary street plan performs the worst, while the organic street plan is ranked in the middle.

Key words: Urban Form, Spatial Configuration, Space Syntax, Walkability, Lisbon.

INTRODUCTION

The discussion about mobility in large urban centers has been a recurring theme in the studies and researches aimed at the individual's displacement patterns in space. In the field of transport, the focus of the approach has essentially been motorised vehicles, maybe because this means of transportation corresponds to most trips in large urban settlements worldwide. Despite this scenario, however, the energetic crisis, as well as the debates around sustainability, have shifted the focus of attention to other displacement strategies, including walking, since they are an important part of the urban mobility system and, according to Vasconcellos (1998), they affect all individual.

Based on this premise, the focus on walkability is part of the studies which involve the fostering of conditions to encourage the pedestrians to walk their routes, thus improving the quality of the space for such. While the literature focusses on the quality of the space (such as Rutz et al.,2007; Rutz et al., 2010; e Lwin and Murayama, 2011), by observing the physical conditions of sidewalks and footpaths, it is interesting to explore different variables, that bring into the discussion a configurational standpoint.

THEORETICAL AND METHODOLOGICAL PREMISSES

Urban Syntax and Form

Several researchers, among which Ferraz and Torres (2004), believe that the urban configuration conditions the existing transport system, and interfere in the individual's displacement process. Naturally, there are other factors, once the city's dynamics incorporate a series of levels of information that condition the comings and goings in the urban space. Ferrari (1991), for example, interprets the movement as being relational, which derives from studies of biology and ecology, referring to the "study of human, spatial and temporal relations, as affected by selective, distributive and adaptive forces, in the environment".

According to Hillier (2001), if we place an object here or there within a spatial system, then certain predictable consequences will affect the configuration of space in the environment and, as a consequence, the displacement relations happening there. These effects are highly independent of desires or human intent, but can be used by the human beings in order to achieve social or spatial effects.

Therefore it means that the possibility of managing the space configuration can be converted into an attribute for interpreting human mobility, once it will affect the flows in the city. The space is not a passive element; it is also an independent variable.

Based on such premises, this research employs the Theory of the Social Logic of Space, also called Space Syntax – henceforth referred to as SS - (Hillier and Hanson, 1984; Hillier, 1996), a theory which relies on systemic and structuralist thinking, once Hillier and Hanson (1984) were concerned that "[...] the theories [in architecture] have been extremely normative and not analytic enough".

The approach encompasses techniques for understanding and representing the space, enabling the researcher to investigate it with a focus on the urban articulations and at the same time, describe possibilities of interaction and contact derived from possible different flows of people or vehicles. Space Syntax, with its methods and techniques, establishes relations among attributes of two kinds: (a) the space organised for human ends (buildings or cities); and (b) the social structure, the means of interaction between individuals and groups, social cleavage and power structure (Holanda, 2002).

At the core of all this, is the premise that in order to understand a city or a building in its full social-cultural complexity, it is necessary to understand the underlying laws of the built/urban object and how it relates to society (cf. Hillier, 2001): (1) the laws of the object itself, which refer to how the constructions can be placed or understood in space, through a volumetric and spatial standpoint; (2) the laws of society for the urban form, that is how society uses and adapts the laws of the object in order to give a spatial form to the different kinds and patterns of social relations; (3) the laws of the urban form for society, which translate how the urban form affects society, that is, the answers that the urban form, or built form give to society; and, to complete the cycle we could add a fourth law: (4) the laws of society itself about its own social relations with the social arrangement systems.

What Space Syntax proposes is a fundamental relationship between the space configuration in a city and the way it works. The analysis of the space in relation to its configurational properties, or syntactic properties, allows us to determine some aspects of urban functioning that other approaches fails to provide.

The theory offers a set of tools for the configurational analysis of space, in which aspects such as potential flow, circulation and movement are investigated (Hillier e Hanson, 1984). Holanda (2001) adds that the approach is not only a set of tools but also "a theory that encompass a methodology, in addition to a set of techniques".

Among these techniques, the axiality is adopted in this study, for it is indicated to work linearly with the potential movement flows in a given urban space, which allows us to interface with aspects of urban mobility.

Research Methodology

Bearing in mind the theoretical premises recommended for this research, a preliminary analysis of the city of Lisbon and the areas subject to investigation was carried out, beginning with a construction of a linear representation and its corresponding axial map (cf. procedures outlined in Barros, 2006 and Medeiros, 2006). From this analysis, the configurational variables discussed in the study were derived: (a) integration, corresponding to the potential for topological accessibility of a street or an urban system; (b) connectivity, encompassing the existing number of connections of a street or an urban system; (c) intelligibility, associated to the degree to which the system can be understood from the correlation between integration and connectivity values; and (d) synergy, as a product of the correlation between the global and local measurements of the axial map (global integration and local integration). Next, for each arch of a street, geometrical information was collected, such as: street inclination, the street compactness index and the percentage of public spaces, thus configuring two groups of variables to be explored.

The following step was to carry out a Cluster[1] Analysis with the purpose of aggregating the similar variables in order to identify the extent to which the arches (streets, links) present similar characteristics and from then on, characterise the typology of the neighbourhoods studied.

Such characteristics result from the following final variable, selected from the set under study: (a) integration index – potential for movement; (b) street compactness index – calculated based on the amount of streets/arches per Km²; (c) inclination – the inclination of each arch; (d) width of the sidewalks – taking into account the existing obstacles; (e) percentage of public spaces in relation to build spaces – calculated based on the immediate surroundings links (a 50 meters buffer zone).

At last, in order to refine the results of the Cluster Analysis, an additional evaluation of the impact of the network spatial configuration of the urban street plan in the pedestrian movement was performed. A shortest path analysis was carried out, in which the shortest path between all the centroids of the links/streets/segments was estimated. The result was an Average Straightness Index of streets, based on the ratio between the shortest network path and the straight distance between the corresponding origin and destination points.

[1] "The Cluster Analysis is a series of statistical procedures used to classify objects and people by observing the similarities and differences between them. The information gathered is then organised into relatively homogenous groups (called Clusters). The analysis can thus be described: given a set of *n* individuals, for which there is information about *p* variables, the analysis groups the individuals in function of the existing information, so that the individuals in a groups are as similar as possible, and always more similar to the elements in the same group than to the elements in the other groups. In this analysis there shouldn't be a dependency among the variables, that is, the groups are set without it being necessary to define a cause relation between the variables used. Among the methods used in Cluster Analysis, the method used in this paper was the Hierarchical Clustering, in which a matrix of similarities or differences between two cases is built. In this process, a standard measure of each variable ($(X-\mu)/\sigma$) was used, so that the influence of the different scales of the variables was taken out of the equation. As a means to aggregate the cases, the Ward method was used, which prove to be the most efficient, being characterised by the mitigation of variation of the indicators within each group formed. The aim was to reach a hierarchy of partitions *P1, P2,…Pn* of the total set of the *n* objects in *n* groups. The Hierarchical Method have dendrograms as outputs. The analysis of these dendrograms allows us to evaluate what is the number of clusters to consider as input to our optimization methods" (Source: adapted from https://dspace.ist.utl.pt/bitstream/2295/49184/1/Clusters.pdf).

ANALITIC ASPECTS

The exploration of the variables resulted in the analysis of the three scenarios chosen for the case study, with the intention to explore aspects of the urban form, affecting the relations of displacement within the city.

Characterization of the Areas under Study

The case study consists of three neighbourhoods of the city of Lisbon – Portugal (Figure 1), characterised by different urban fabric designs, resulting from peculiar occupation processes. Campo de Ourique (Figure 2) exemplifies a remarkably regular grid-based, similar to a chess board: the grid-based is rigid and based on a strong regularity urban tissue solution, with mostly perpendicular crossings. Graça (Figure 3) represents a strategy of accommodating the urban fabric to the physical characteristics of the site: the irregularity of the streets derives from the approximation to the conditions of the terrain. Telheiras (Figure 4) presents a urban tissue based on modernist urbanistic premises, adapted according to solutions seen in many contemporary cities: large empty spaces, presence of secondary and internal streets, circulating rings, cul-de-sacs.

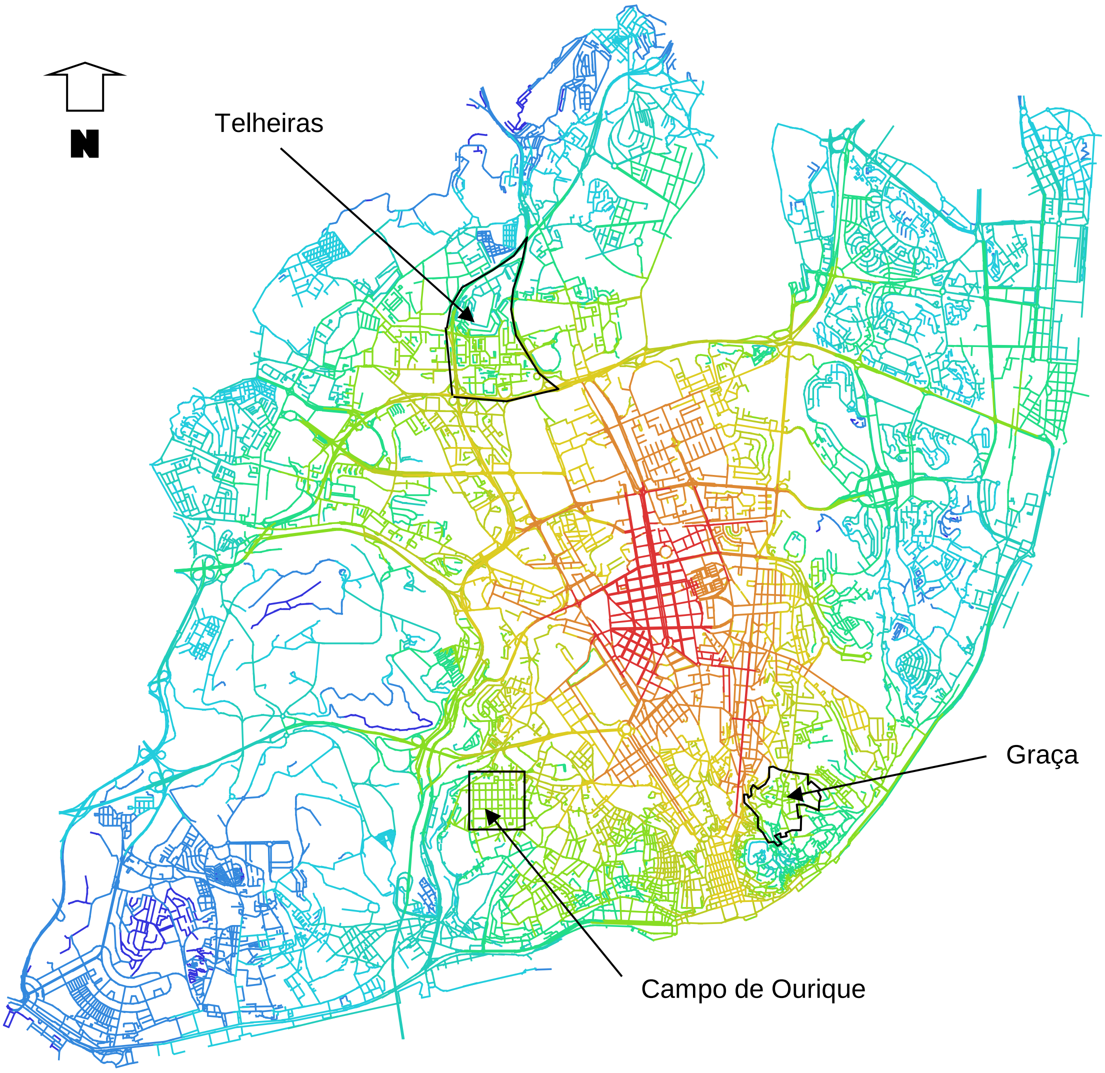

Figure 1 – Axial Map R*n* of Lisbon with the location of the neighbourhoods.

Syntactic Characterization of the Three Types of Urban Tissue

Regular Street Plan

The area of Campo de Ourique is characterised by an essentially regular grid-based, with X-intersection. Consequently, the blocks resulting from this design are very similar in their sizes and proportions. The chessboard like urban fabric tends to maximize the possible number of routes between origin and destination, which usually results in more elevated configuration values (Figure 2).

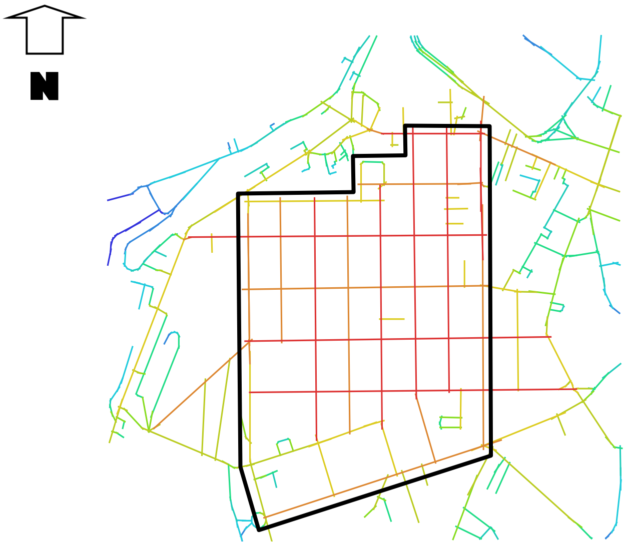

Figure 2 – Axial Map R*n* of Campo de Ourique with its surrounding – scale not indicated

As it could be predicted, Campo de Ourique (Table 1) presents the highest global integration average in the sample (0,743) and the highest spatial intelligibility (0,262), revealing a tendency to be easily understood by the users. This is because the chessboard urban fabric layout increases the number of possible routes and trajectories, optimising the flow and movement relations. The neighbourhood is also the one which presents the highest values for synergy (0,646), which reveals a good articulation between the global and local properties.

Table 1 - Syntactic Indexes

Neighbourhood	**Average Integration R*n***	**Average Integration R3**	**Average Connectivity**	**Intelligibility**	**Synergy**
Campo de Ourique	0,743	1,305	2,813	0,262	0,646

Irregular Street Plan

On the other hand, Graça has a predominantly irregular urban tissue, resulting from an specific process of occupation. The design of the streets follows what is called ‘the Portuguese way of making cities’, inherited from a very peculiar urbanistic view of how to occupy a territory. The area mainly presents T-intersection and the blocks are irregular both in terms of size and form. Such characteristics are reflected in the indicators, as seen in Figure 3.

Figure 3 – Axial Map R*n* of Graça with its surrounding – scale not indicated

In Table 2 it can be observed that Graça has the lowest average integration R*n* (0,390) in the sample, even if compared to Telheira (Table 3 – 0,477). This occurs because the urban street plan almost resembles a labyrinth (Medeiros, 2006), due to the ups and downs of the terrain, which reduces the possible routes and trajectories. The values of intelligibility, however, are higher than those of Telheiras, because the traditional structure serves better the relation between the integration potential of the streets and their connectivity. Still those values are lower than those of Campo de Ourique.

Table 2 - Syntactic Indexes

Neighbourhood	Average Integration Rn	Average Integration R3	Average Connectivity	Intelligibility	Synergy
Graça	0,390	1,266	2,784	0,131	0,160

Contemporary Street Plan

At last, Telheira has a very distinguished design if compared to the previous ones, due to the contemporary modernist experimentations. The urban tissue does present a well-defined clear pattern, sometimes resembling Campo de Ourique, sometimes deriving from an apparently 'organised' irregularity: X-intersection and T-intersection are frequent, as well as elongated block (again, with no regularity as to form and size). Such features promote lower integration values, as seen in Figure 4 and Table 3.

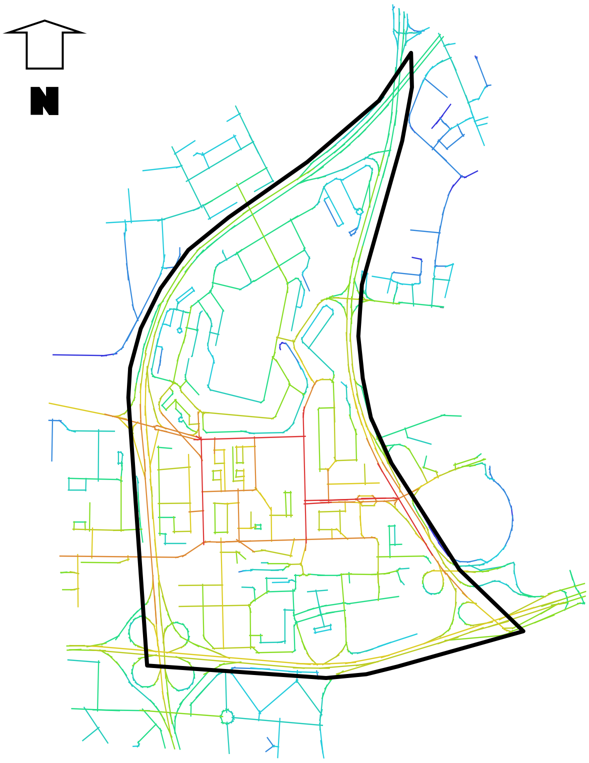

Figure 4 – Axial Map R*n* of Telheiras with its surrounding – scale not indicated.

It can be observed that Telheiras (Table 3) present an average global integration slightly higher than Graça (0,477), because there are streets which cross the area from east to west, making it more accessible. On the other hand, intelligibility is very low (0,065), significantly lower in relation to the other neighbourhoods, compromising spatial reading.

Table 3 - Syntactic Indexes

Neighbourhood	Average Integration R*n*	Average Integration R3	Average Connectivity	Intelligibility	Synergy
Telheiras	0,477	1,207	2,626	0,065	0,265

Categorising the Street Links – Cluster Analysis

The Cluster Analysis applied to the study aims at establishing the classification of the streets by similarity of features (according to the attributes of analysis), allowing us to form groups of similar characteristics. Therefore, in order to identify the characteristics of the streets in the three neighbourhoods, six clusters were created in the analysis (Figure 5).

In Cluster 1, there is a predominance of average integration, high street compactness, average size sidewalks and low inclination. These characteristics are identified in some of the streets of Telheiras. Cluster 2 presents streets with low integration, low street compactness, average inclination, large sidewalks and an average percentage of public spaces. These characteristics are strongly present in

Telheiras and some are present in Graça. Cluster 3 has streets with low values for integration and street compactness, average sidewalks and percentage of public spaces, and very high inclinations. This category of features is somewhat present in Graça. Cluster 4 presents high values of integration, average sidewalks, basically no inclination and a percentage of public spaces and low street compactness. The features are strongly present in all streets of Campo de Ourique. In Cluster 5, there are low levels of integration, average inclination, average sidewalks, high percentage of public spaces and average street compactness. These characteristics can be found mostly in Graça and somewhat in Telheiras. Finally, Cluster 6 has average integration values, average inclination, very narrow sidewalks, high percentage of public spaces and average street compactness. These features exist only for the highways that surround Telheiras.

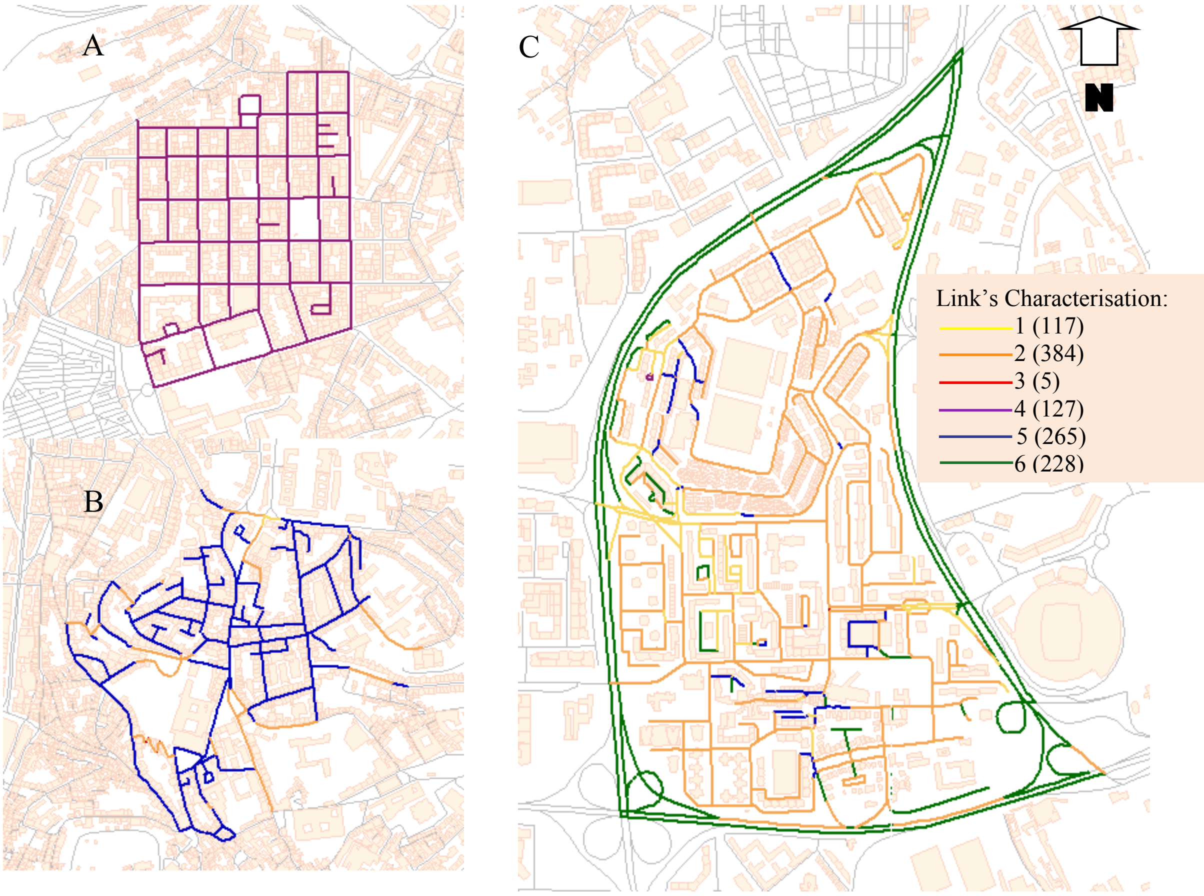

Figure 5 – Characterisation of the urban street plan of the neighbourhood (A) Campo de Ourique, (B) Graça e (C) Telheiras – scale not indicated

From the findings and values obtained, it is possible to verify that the neighbourhood Campo de Ourique (Figure 5A) is more homogenous in terms of street characteristics, once all the streets in it belong to the same cluster. In Graça, however, the streets are spread across three different clusters, although cluster 5 is more present (Figure 5B). Telheiras, in turn, presents the highest variation in terms of the features of its streets, being part of 4 out of 6 clusters, which shows heterogeneity as to the features studied (Figure 5C).

Categorising the Walkability Indexes – Shortest Path Analysis

In order to complement the Cluster Analysis, a Shortest Path Analysis was developed, based on the simulation of all possible trajectories in each neighbourhood, originating in all arches and going to all arches. Later, the lowest value for the Average Straightness Index was verified to be that of Campo de Ourique, 1,34 (Table 4). Such value, therefore, can only derive from the most regular grid-based, which was only possible due to the regularity of the place where it is located (Figure 6)

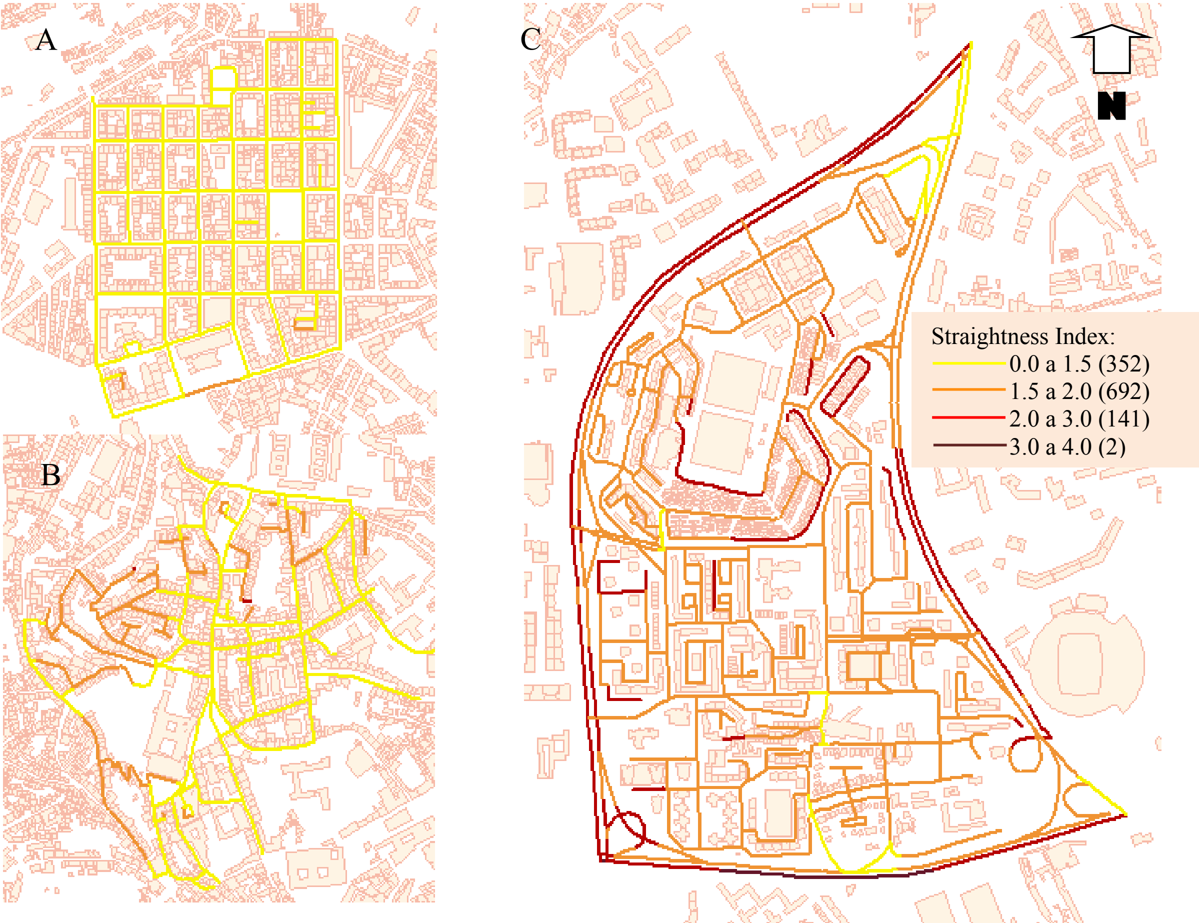

Figure 6 – Average straightness index in the neighbourhoods (A) Campo de Ourique, (B) Graça e (C) Telheiras – scale not indicated

In Graça, the average straightness index is of 1,47 (Table 4), which shows greater difficulty in reaching certain destinations, as compared to Campo de Ourique (Figure 4), once there is the need of a higher number of conversions (turns) as shown in cluster 5 (Figure 5).

Telheiras presents a 1,76 average straightness index, the highest in the sample. This means that there is a higher number of necessary conversions (turns) to reach the destinations, on average.

Table 4 - Average street straightness in the neighbourhoods

Index	Campo de Ourique	Graça	Telheiras
Average straightness index of street	1,34	1,47	1,76

In face of the facts previously exposed, it is possible to infer that the regular grid-based (in this study exemplified by the neighbourhood of Ourique) presents a significant homogeneity, as it can be observed by the street features related to cluster 4. In addition, these features – even because of the high level of integration – foster a better displacement in the neighbourhood as a whole, due to the high number of connections in this kind of urban tissue and to the way the various axes intersect each other, which leads to a greater offer of possible routes in each pair.

On the other hand, the other kinds of urban fabrics (exemplified by the neighbourhood of Graça – irregular – and Telheiras – contemporary) present higher heterogeneity in terms of the features of the streets, as it was shown in the Analysis of Cluster. The same is true about the way the displacements happen in these neighbourhoods, because it has a lower number of connections between the axes and it leads to a lower number of possibilities of routes. In Campo do Ourique, it also means that this street configuration tends towards a labyrinth configuration (Medeiros, 2006). The average straightness index (Table 4), to some extent, confirms this aspect: in Graça it is 1,47; in Telheiras, 1,76; and in Campo do Ourique, 1,34.

FINAL CONSIDERATIONS

The research, despite it exploratory nature, encompassed a set of experiments in order to identify the relations between configurational aspects and other variables for the interpretation of urban mobility with a focus on the pedestrian. The results of the Cluster Analysis and the Shortest Path Analysis have demonstrated that the distinguished characteristics of the urban street plans directly affect the performance of the space.

The findings confirm that the street plans, similar to a chessboard, present lower conversion rates for the displacements. On the other hand, a street plan with extremely irregular features tends to require more conversions, due to its labyrinth like nature. The results also show that the contemporary street plan performs the worst.

Therefore, we can infer that the displacement of people in the case study neighbourhoods was affected by the characteristics of the urban design. The features to be considered are inclination of the terrain, street compactness, the form and size of blocks, the ratio between public and private spaces, the width of the sidewalks and the way the streets in the system relate to each other. It then becomes possible to create guidelines for a walkability index, whose variables would take into account the form of urban spaces.

As future perspectives, it is recommended that such analysis be applied to other examples of the street typologies here analysed (different scales, such as: neighbourhoods and cities). Furthermore, we suggest that other typologies (such as radial, semi-radial, quilt, etc.) be tested as well.

ACKNOLEDGEMENTS

The lead author would like to thanks CAPES for the financial support during the doctorate done in IST-UTL (Lisbon/Portugal) under the supervision of Professor José Manuel Viegas and co-supervision of Professor Luis Miguel Martínez, for all the support granted.

REFERENCES

Barros, A. P. (2006) Estudo exploratório da Sintaxe Espacial como ferramenta de alocação de tráfego. Dissertação de Mestrado. Faculdade de Tecnologia. Departamento de Engenharia Civil e Ambiental. Universidade de Brasília. Brasília, 171p.

Ferrari, C. (1991). Curso de Planejamento Municipal Integrado. 2ª Ed. Livraria Pioneira. São Paulo.

Ferraz, A. C. P. e Torres, I. G. E. (2004). Transporte Público Urbano. 2ª Ed. Editora Rima, São Carlos.

Hillier, B. and Hanson, J. (1984). The Social Logic of Space. University Press: Cambridge.

Hillier, B. (1996) Space is the Machine. Cambridge University Press, Londres.

Hillier, B. (2001). A theory of the city as object, or how the spatial laws mediate the social construction of urban space. In: 3rd International Space Syntax Symposium. Proceedings of 3rd International Space Syntax Symposium. A. Alfred Taubman College of Architecture and Urban Planning, University of Michigan, Atlanta - EUA, 7-11 May 2001.

Holanda, F. (2001) Teoria do Conhecimento e dos Espaços Construídos. Notas de Aula do Curso de Mestrado em Arquitetura e Urbanismo da Universidade de Brasília. PPGT/FAU/UnB

Holanda, F. (2002) Espaço de Exceção. EdUnB: Brasília.

Lwin, K.; Murayama, Y. (2011). Modelling of Urban Green Space Walkability: Eco-frindly Walk Score Calculator. Journal of Computers, Environment and Urban Systems. 35/408-420.

Medeiros, V. A. (2006). *Urbis Brasiliae* ou Sobre Cidades do Brasil: inserindo assentamentos urbanos do país em investigações configuracionais comparativas. Tese de Doutorado. Programa de Pesquisa e Pós-Graduação da Faculdade de Arquitetura e Urbanismo. Universidade de Brasília. Brasília, 520p.

Rutz, N.; Merino, E.; Prado, F. (2007). Determinação do índice de caminhabilidade urbana. 16º Congresso Brasileiro de Transporte e Trânsito. Anais do 16º Congresso Brasileiro de Transporte e Trânsito - ANTP. Maceió, 1-8 Outubro 2007.

Rutz, N.; Merino, E.; Santos, C. (2010). Determinação de indicadores de caracterização física das calçadas. 4º Congresso Luso-Brasileiro de Planejamento Urbano Regional Integrado e Sustentável. Anais do Congresso Luso-Brasileiro de Planejamento Urbano Regional Integrado e Sustentável - PLURIS. Faro, 6-8 Outubro 2010.

Vasconcellos, E. (1998). O que é trânsito. Coleção Primeiros Passos. N. 162. 3ª ed. Ed.:Brasiliense, São Paulo.