Analysis of Pedestrian Mobility in Three Different Urban Configurations – Case Study in Lisbon

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ABSTRACT

This paper presents a probability analysis of some variables – syntactic, morphological, land uses and proximity to public transport – being more or less significant for the act of walking. In order to obtain the first type of variables mentioned (syntactic), the Theory of Social Logic of Space or Space Syntax was used, which is based on a relational view among parts. The study was implemented in three neighborhoods on the city of Lisbon, with different morphosyntactic aspects. For the probability analysis, it was used the Poisson model, and the results showed the proximity to the subway as the most likely factor to be chosen for people, then (but negatively) the presence of stairs, and third the integration index, in other words, configurational aspects. The findings show that Space Syntax Analysis can be used in mobility studies of pedestrians, in order to contribute to the development of more friendly spaces for people.

1. INTRODUCTION

At present, any discussion about the act of walking entails exploring the key point of urban mobility, a theme that is in itself recurrent, exhausting and to a certain extent, worn out. As cities gather an increasingly higher proportion of the world's population, their growth and the problems arising from the scale of human settlements have made public transportation unviable in a most places – that is, when these places do have public transportation to begin with. In addition, with the invention of the automobile after the Industrial Revolution, the displacements on foot have been undergoing a process of mythfication in favor of the motorized comfort. If on the one hand, walking has become the exception (as if walking were not part of the natural human logic of displacement), on the other, urban spaces are most times conceived with the perspective of motorized transportation in mind, and not the pedestrian's.

In addition, motorized transportation seems to be inherent to carrying out several human activities, which leads to a persisting (but not new, according to Gondim, 2013) and increasingly greater problem in the urban centers: the changes in the built environment, that further pushes away the human scale in order to favor the scale of motorized transportation. The growth of cities, aligned with the culture of 'consumerism and status', has led to a uncontrolled use of the car in the urban centers worldwide. Thus, the implementation of a street infrastructure to cope with this increased demand grows, based on the erroneous idea that such demand should be met. On the other hand, the infrastructure for pedestrians and cyclists is either neglected or pushed aside. This situation shows how most cities loose the space that was once awarded to human scale and embrace the scale of the motorized transportation, thus failing to provide a more pleasant urban life, in which cities are made for people and not for cars (Gehl, 2010; Gehl, 2011).

Apparently, this change in scale can be understood in terms of the different urban geometries and topologies, as we seek to comprehend the shapes and the relations between the elements that form a city, exploring how the transition from the human scale to motorized scale affect, or may affect, the act of walking.

This article aims at analyzing the probability of some variables being more or less influential in a displacement on foot. Such variables may be morphological (or geometric, related to the components of the sidewalks), syntactic (or topological, taken from the Space Syntax), of land use (related to the information of use and occupation of the soil) and the proximity to public transportation (which refers to the time spend when going to public transportation sites).

Therefore, three neighborhoods in the city of Lisbon, whose street network are different among them, were chosen as the case study in point. The first one, Graça, presents an irregular, rather organic street network; the second, Campo de Ourique, presents a chessboard grid pattern; and finally, Telheiras, with a predominance of a contemporary design of its street network.

It is important to highlight that this paper is a part of a larger research in progress, whose objective is to verify to which extent the urban form interferes in the way people move in the space of cities.

2. THEORETICAL BACKGROUND

2.1 Urban Mobility

According to the Ministry of Cities (2005), urban mobility is the interaction of the flows of displacement of people and assets in the urban structure, involving both motorized and non-motorized flows. It is a feature of cities determined mostly by social and economic aspects, by the way people appropriate the space and the technological evolution, while public transportation refer strictly to the services and the means of transportation used in the displacements within the urban space.

Summarizing, in 2006, the Ministry of Cities presented an amendment to the concept, by which mobility became an attribute, a feature of cities, dealing with how easy it is for people and assets to move within the urban structure. These displacements entail vehicles, streets and the whole infra-structure that enables this daily ‘coming and going’, resulting from the interaction between the displacement of both people and assets in the city.

ANTP (2002) adds the variable “dimension of the space” to the concept of mobility, incorporating, however timidly, the principles of urban form: “mobility is an asset of people and of economic agents, as they seek to ensure the displacement they need, taking into account the dimensions of the urban space and the complexity of the activities that take place in it”. In addition, it includes several individuals and how they move around the space (pedestrians, cyclists, drivers and users of public transportation), correlating it with the variables income, age and gender.

Vasconcellos (2001), in turn, adds to these factors the variables ‘occupation’ and ‘school level’, and states that the availability of a car in the residence has great impact, which can be measured according to the variable ‘income’. He also believes that, in general, man travel more than women, and the ones who have reached adulthood and are part of the economically active population travel more than the young and the elderly. People with a higher school level also move around more often than those with lower intellectual knowledge. In addition, he states that the distinctions in mobility are followed by differences in the use of forms of transport and the use of motorized transportation depends highly in the position one occupies in the family structure.

2.2 Morphossyntax (Morphology and Urban Syntax)

2.2.1 Morphology

The approach of urban morphology has been increasingly more utilized not only in studies about architecture, but also about urban mobility. However, the approach to urban mobility differs from the one used in architecture. Amâncio (2005) and Handy (2007), for example, both used this approach to evaluate displacements ‘on foot’. However, on the one hand, Amâncio (2005) carried out a case study only about the city of São Carlos, which means he used only one type of configuration. The analysis was based in the division of territory made by the Brazilian Institute of Geography and Statistics for data collection, not taking into consideration determining variables for analyzing the micro scale, such as the declivity of the street. Handy (2007), on the other hand, used three different kinds of morphological characteristics of the city of Austin (based on six neighborhoods) and reached the conclusion that the urban form is the second most encouraging factor for displacements on foot.

Cervero and Kockelman (1997) made a rigorous analysis and concluded that the 3 Ds (Density, Diversity and Design) are important variables for analyzing displacements on foot. Thus, is it possible to notice another indication that the design of spaces presents certain relevance in thinking about these spaces and for this reason it cannot be ignored. However, this variable – Design – is not approached by the authors from a relational point of view.

Reid and Cervero (2010) made a meta-analysis in which they gathered over fifty papers, reporting quantitatively how the characteristics of the built environment influence patterns of mobility. However, these studies do not encompass the morphology/urban form as understood by Holanda (2012), who sees it from the perspective of the relation between parts. Thus, there doesn't seem to be an understanding that the factors associated to the way the street grid structure is articulated contribute to the process of displacement and circulation in a city.

In turn, Rodrigues (2013) does not consider the morphological approach (name used by Holanda) to space or, as we use here, Space Syntax; he does however use terms such as "configuration" and "topology" when studying the influence of urban design in the likelihood of trips made on foot.

2.2.2 Syntax/Configuration

The adoption of the so-called configurational approach to the investigation of the relationship between the built form of cities and their corresponding dynamics has also been growing. As the literature shows (Kohlsdorf, 1996, Holanda, 2002; Barros, 2006; Medeiros, 2010; Costa, 2008; Pires, 2008; Dias, 2011), there is a close relationship between the causes and effects of the built environment for the act of living in places. It is assumed that the spaces are the product of human intentions, that is, a product of clearly established interests, either resulting from global planning actions (with a perspective broader initiative) or local initiatives (point gestures). Nevertheless, these spaces bring consequences for human dynamics that often diverge from what was originally planned.

In this regard, when analyzing architecture understood as the space socially used, Kohlsdorf (1996) and Holanda (2002) qualify it as both a dependent variable - ie, the product of human intentions and desires - and independent one - because its consequences can be different from those previously conceived.

In view of this, Hillier and Hanson (1984) believe that there is a virtuous cycle for the explanation of the law of natural movement (Figure 1), in which the spatial configuration has as a primary effect the generation of movement (whether of people or vehicles) in spaces. And as a secondary effect, this movement generated by the configuration fosters the emergence of uses (ie, the attractors and generators of movement). And finally, as tertiary and quaternary effects, the reverse process occurs, the uses foster the movement and, therefore, interfere with the configuration of the spaces.

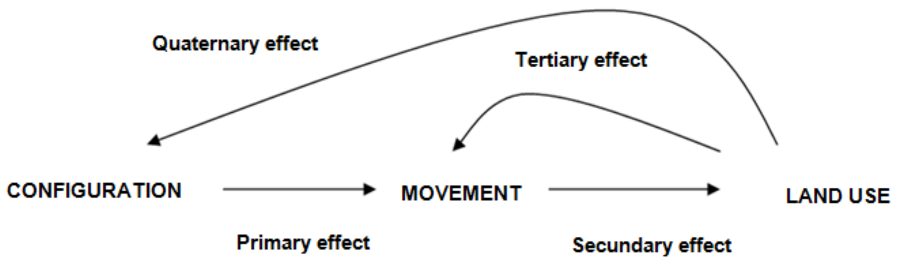

Figure 1 - Virtuous cycle of natural movement
Source: Medeiros (2010)

2.2.3 Morphossyntax

Morphosyntax is used in grammar as the interconnect study of morphological and syntactic aspects of the words, and according to Cipro Neto and Infante (1998), it is only in this way that the morphological classification can be done efficiently. It is based on this statement and the finding that studies of urban mobility do not address the relational aspects, that this study incorporates this concept, replacing 'words' with 'cities' to form the concept of morphosyntax as being the interconnected study of morphological and syntactic aspects of cities. This concept, therefore, consists on analyzing the urban space from the perspective of the morphological/geometric aspects (to include: width of the roads/ sidewalks, height of buildings, etc.) and syntactic/topological ones - study of the relations between the parts that compose the urban form (in this case, the relationship between built environment and empty spaces).

Therefore, the word morphosyntax in this paper is used in an attempt to emphasize the need for researchers in the field of Transportation Engineering - that claim to work with the morphology of spaces, however they do not like in the field of Architecture and Urbanism - to include the relational aspect (topological) of urban form in studies of urban mobility. It is believed, therefore, that such studies have treated only the geometric/ morphological (morph), but would need to add the topological/syntactic aspect (Syntax), that is why, the idea of binding the terms to generate the name morphosyntax has arisen.

3. METHODOLOGY

3.1 Characterizing the Area under Study

The areas chosen for this study were three neighborhoods (Graça, Campo de Ourique and Telheiras) located in the city of Lisbon (Figure 2), because (a) the micro data needed to perform the analysis in question was available and (b) because there are differences between their morphosyntactic characteristics.

Such characteristics can be seen in Figures 2, 3 and 4 (in the next topic) in which:

(a) Graça (Figure 3A) has a predominantly irregular grid, resulting from a specific process of adaptation to natural site. The design of the streets is similar to the traditional Portuguese way of designing cities, a peculiar way of settling the land. The area presents mostly T shaped crossroads and the blocks present no regularity, either in shape or size.

(b) Campo de Ourique (Figure 3B) presents a chessboard grid pattern – with X shaped crossroads and very regular blocks in terms of shape and size – which increases the number of possible routes and trajectories. However, although such configuration optimizes the relations of flow and movement, it also has a tendency to turn the neighborhood into a labyrinth, once each space is very similar to another.

(c) The neighborhood of Telheiras (Figure 4) has a very peculiar layout in relation to the others, since it results from contemporary design experiences based on modern ideologies. Its grid does not present a clearly defined pattern, because sometimes it resembles a chess grid, like Campo de Ourique, whereas in other places it appears to have an 'ordered' irregularity: T and X shaped crossroads are constant, and the presence of excessively long blocks is frequent (also with no regularity in terms of shape and size).

3.2 Data collection about Morphosyntactic aspects, of land use and of accessibility to public transport

For this analysis, we used (a) morphological/geometric data (the width of sidewalks, presence of stairs, declivity) and syntactic/topological ones (integration index, connectivity, street compactness) obtained by means of axial maps derived from Space Syntax.

Such characteristics can be seen in Figures 2 and 3, in which:

(a) The neighborhood of Graça (Figure 3A), due to the aspects mentioned above, presents a global average integration index of 0.39 and connectivity 2.78 (Table 1);

(b) Campo de Ourique (Figure 3B) presents the highest global average integration index from the sample (0.74 – Table 1) and also the highest average connectivity (2.81 – Table 1), revealing a predisposition for being 'easy to read' by the users. This is because the chessboard grid patters increases the number of possible routes and trajectories, optimizing the relations of flow and movement.

(c) Finally, the neighborhood of Telheiras (Figure 4), once it has a different layout in comparison to the others (as described above), presents a global average integration index of 0.48 and average connectivity of 2.62 (Table 1).

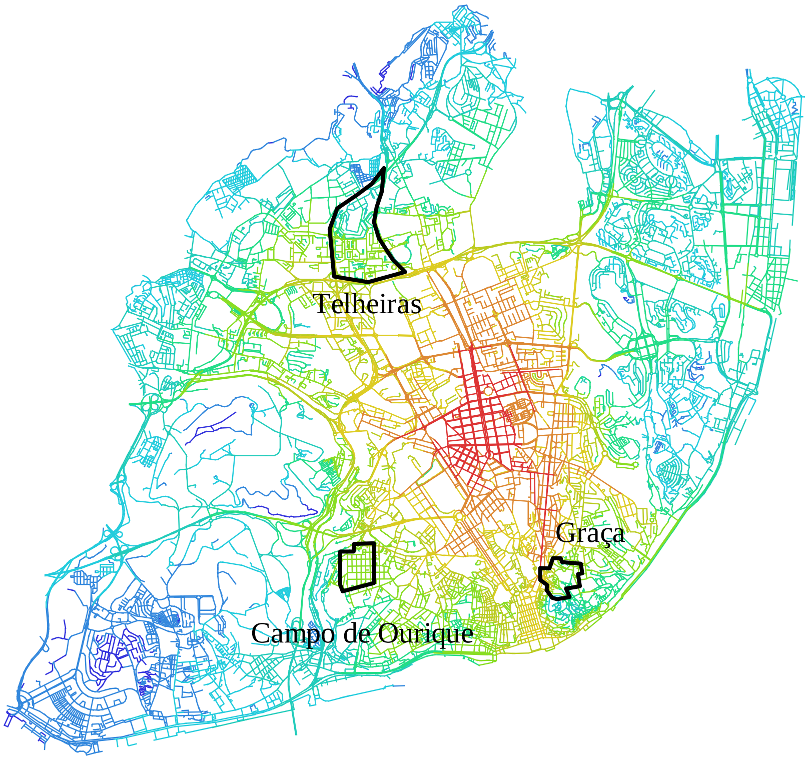

Figure 2 - Axial Map R*n* of Lisbon with the location of the neighborhoods under study (based on the transport network).

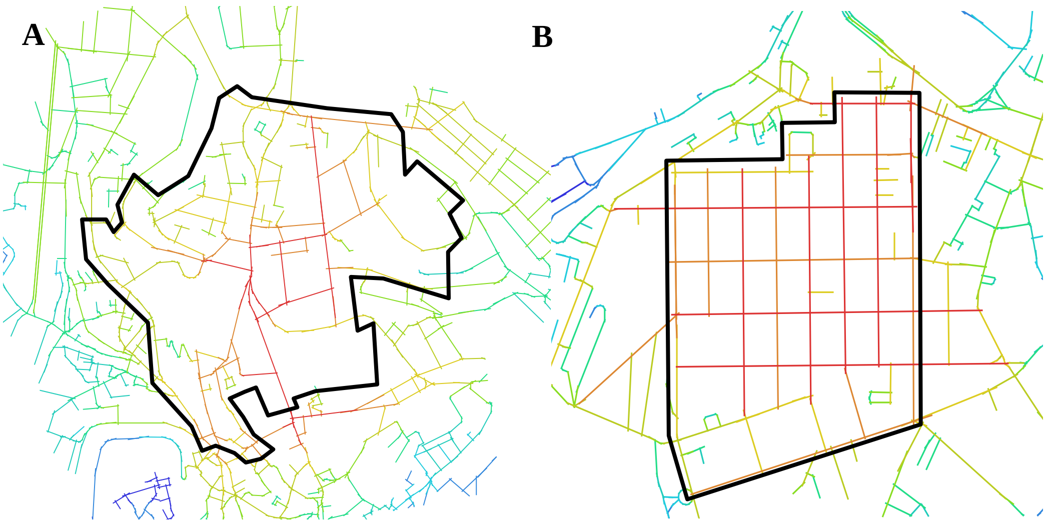

Figure 3 - Axial Map (integration R*n*) of Graça (A) and of Campo de Ourique (B) – scale not mentioned.

Figure 4 - Axial Map (integration R*n*) of Telheiras – scale not mentioned.

Neighborhood	Average Integration R*n*	Average connectivity
Graça	0.39	2.78
Campo de Ourique	0.74	2.81
Telheiras	0.48	2.62

Table 1 - Syntactic Index

Additionally, data about activities (originating from the data about land use), and accessibility (regarding the time it takes to access public transport, ie the proximity to public transport) were collected.

Table 2 presents the statistical characteristics (mean values and standard deviations) of the independent variables to be tested in the model, grouped as: syntactic, morphological, of land uses and proximity to public transport.

Variables	Average	Standard deviation
Pedestrians per hour (peak hour - morning)	55.36	91.42
Syntactic		
Integration Index (HH)	0.54	0.19
Connectivity	5.59	0.80
Street compactness (m via/hectar)	6.70	2.50
Morphologic		
Width of the sidewalk (narrow – width < 1.5 m)	0.14	0.35
Presence of stairs	0.03	0.16
Presence of trees (more than 5 trees per each 100 m of street)	0.39	0.49
Declivity (elevated – declivity > 5%)	0.08	0.26
Land use		
Area of commerce (1000 m^2)	0.99	1.09
Area of education (1000 m^2)	0.20	0.52
Area of food and leisure (1000 m^2)	0.40	0.66
Entropy index (added values of the entropy index of Cervero for streets with less than 30 m of each gate)	0.72	0.49
Number of doors (less than 30 m from each gate)	10.96	10.38
Proximity to public transport		
Gates less than 5 min walking from a bus stop	0.17	0.38
Gates less than 10 min walking from a subway station	0.02	0.14
Number of bus lines that stop near the gate (< 30 m)	0.54	1.31

Table 2 - Variables of the model

3.3 Counting – Gate Method

For counting pedestrians, the Gate method was used (cf. Grajewski and Vaughan, 2001). The first step consists in choosing the gates (imaginary lines crossing the street from one side to another) for counting in a particular area. Later, after at least two visits to the area under study, the route to be conducted is decided, so that it covers all gates in an interval of 2h. The counting time should be 2.5 min, however, if the counting takes into account both pedestrians and vehicles, it should be of 5 minutes (2.5 min for pedestrians and 2.5 min for vehicles) so that it does not interfere with reliability of the results.

3.4 Poisson Regression Model

To understand how the different factors affect the movement of pedestrians, we used an explanatory model of the displacements done on foot through a Poisson regression analysis because it is an appropriate formulation for modeling independent events.

However, the base formulation is only suitable for low probability events, whose likelihood function leads to values similar to the expected value and the variance. When these conditions are not met, it is necessary to formulate alternative models such as the negative binomial model, or introduce derivations of the base model (Poisson) which would allow overdispersion of the sample data, requiring additional estimation of the overdispersion parameter.

After the observation of the variables applied to the pedestrian flow counting, it was verified that the sample had a high overdispersion (expected value of 55.36 and variance of 8357.62), requiring an adjustment of the base model. After numerous tests, we could see that the overdispersed Poisson model would lead to better estimates of the ρ2 value, significance of the independent variables coefficients and the prediction capability.

4. APPLICATION

After several tests for specification of the model, a satisfactory configuration of the overdispersed Poisson model was achieved, including most of the tested explanatory variables. The calibrated model features a high quality adjustment with a value of ρ2 = 0.50 and significant Omnibus test, most of variables included being significant for reaching a level of significance of 0.05 (except Food and Leisure variable). The results are shown in Table 3.

In general, the coefficients of the explanatory variables presented the expected signs, impacting negatively or positively the intensity of pedestrian flows. It was possible to see that the variables of land use and accessibility positively impact the flow of pedestrians, while morphological variables that influence pedestrian comfort (e.g. presence of narrow sidewalks or stairs) present an adverse impact on pedestrian mobility. Regarding the syntactic variables, they reveal that the integration index has a very positive impact on fostering mobility, while the presence of a very dense grid (high levels of street connectivity and compactness) hinder pedestrian movement.

Variables	**Coef.**	**Stand. Coef.**	**Stand. Error**	**Wald Chi^2**	**Sig.**
(Independent term)	3.926	3.926	0.398	97.196	0.000
Integration Index (HH)	0.685	0.394	0.232	8.748	0.003
Connectivity	-0.242	-1.352	0.060	16.034	0.000
Street compactness	-0.071	-0.476	0.033	4.637	0.031
Narrow sidewalks	-0.360	-0.051	0.197	3.340	0.068
Presence of stairs	-0.771	-0.019	0.289	7.143	0.008
Presence of trees	0.285	0.112	0.122	5.464	0.019
High declivity	-0.566	-0.043	0.276	4.192	0.041
Area of commerce	0.179	0.177	0.041	18.970	0.000
Area of education	0.209	0.043	0.084	6.131	0.013
Food and leisure	0.116	0.046	0.101	1.311	0.252
Entropy	0.387	0.279	0.162	5.688	0.017
Number of doors	0.035	0.384	0.006	37.086	0.000
Proximity to bus stop	0.306	0.052	0.144	4.494	0.034
Proximity to subway station	1.534	34.279	0.375	16.756	0.000

Bus line	0.200	0.108	0.050	16.349	0.000
(Overdispersion parameter)	48.140				

Table 3 - Results of the model

It should be noted that in Table 3, the presence of some variables such as connectivity, street compactness, presence of narrow sidewalks, stairs and declivity present negative values. This fact reveals that the presence of these factors may condition the existence of pedestrian flows. However, there are other variables in the pedestrian environment that can far outweigh these negative effects such as proximity to the subway station and integration index, which are crucial factors in correlation movement (pedestrian flows).

One can also see that among the variables studied, those that stand out (positively or negatively) are: (a) the proximity to the subway station (1.534), (b) the integration index (0.685), (c) the presence of stairs (-0771) and steep declivity with (-0566). This evaluation can be complemented by the values of the standard coefficients which are presented in Table 3. It is therefore possible to see that, with the exception of the integration index, the other variables are those that commonly have significant importance for the displacements, as in the case of the search by Cervero and Kockelman (1997), which by not having performed a detailed analysis, achieved coinciding results with respect to aspects of comfort (width of sidewalks, etc..) and the flow of people.

It is noteworthy that even variables of land uses show much lower overall impacts than the global integration – entropy (mixture of land uses), with a standard coefficient of 0.279; the number of doors, with a standard coefficient of 0.384; and the factors of geometry or comfort for walking, such as the presence of narrow sidewalks with a negative impact of -0.051. Therefore, the fact that the integration index presents the second highest positive standard coefficient (0.394), shows that the configuration of space (that is, how the spatial structure is interconnected) makes the space more or less favorable for walking.

It is important to highlight that the quality of the estimates obtained from the calibrated model show a good fit with the pedestrian counting during the morning peak hour, resulting in a correlation coefficient of 0.77, which ensures the reliability of the results obtained by the model.

In order to illustrate the results shown in Table 3, one can check on Figure 5 that the prediction of pedestrian flow generated by the model was quite similar to the actual recorded flows registered on the morning peak hour. Moreover, if it is confronted with the axial maps of the neighborhoods under study (Figures 3A, 3B and 4), one can also see the similarity with the results of the integration indices, derived from the syntactic analysis of the space.

Figure 5 - Relation between the pedestrian counting and the predictions of the model for morning peak hour: (A) Graça, (B) Campo de Ourique and (C) Telheiras.

5. FINAL CONSIDERATIONS

It is possible to observe that most aspects linked to the comfort of walkability (such as width of sidewalks and the presence of stairs) are not considered essential factors to explain the movement of pedestrians on the streets. The results indicate that syntactic aspects have greater significance for walking than some elements considered paramount for fostering pedestrian mobility cited in the literature. Other factors such as proximity to transport systems (subway stations and bus stops) and the intensity and diversity of land uses, were found to be of greater importance than geometric factors that influence pedestrian comfort.

It should be emphasized that the present study attempts only to measure the impact that the different elements of the pedestrian environment cause over the generation of flows and not on the quality of the movement, provided by the presence of favorable geometric/comfort characteristics.

A mixture of both elements and the absence of disaggregated models with the presence of syntactic variables led to the conclusion that the comforts for movement and the intensity and diversity of land uses were the most prevalent elements in fostering pedestrian mobility. However, this study demonstrates that the configuration of the urban structure in which a route is inserted, strongly determines the possibility of promoting pedestrian flows. Moreover, when it is associated with favorable characteristics of comfort and intensity and diversity of activities, it should generate spaces where the presence people would be even higher.

The findings also confirm that the component of accessibility to public transport is considered a key factor in explaining the flow of people on the streets.

The results confirm the existence of the virtuous cycle of natural movement which Hillier and Hanson (1984) claim to be inherent in the urban process. But not only the result serves to demystify the spatial relations existing between the full (private space / built environment) and empty (open space / parks / streets) which have long been analyzed (but not confirmed statistically) by scholars of Space Syntax, it also proves it is a fallacy.

Thus, it is inferred that the space syntax has significant relevance in terms of walking and should be considered in planning the mobility of the cities, so as to provide better public spaces for people who use it, or will use it, enabling urban spaces to be designed for people and not for cars.

ACKNOLEDGEMENTS

The main author would like to thank her advisor professors and co-advisor professors (who are also co-authors of this paper), Portuguese friends (Ana Galelo, Joana Ribeiro, Liliana Magalhães, Luís Caetano, Luís Filipe and Tomás Eiró) who helped perform the counting in Telheiras and, finally, Capes for the financial support during the 4 years of development of this research.

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