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How urban form promotes walkability?

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Abstract

This paper presents the results of a part of a doctorate thesis whose aim is to check how the form of spaces interferes in displacements on foot. The methodology here presented is only part of what was carried out in order to answer such questions. Therefore, in order to find out which factors interfere in generating trips in three neighborhoods with distinct urban forms (organic, orthogonal and contemporary), the model of trip generation by people counting was used. It was verified that the presence of a subway station (which was present in only one of the three neighborhoods), the urban form (represented by the integration index) and the presence of stairs and slopes are the most relevant factors, that is, the ones which better explain the presence of people in the points for counting in the three neighborhood under study.

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Keywords: Urban form; Walkability; Space Syntax.

1. Introduction

According to Cervero and Kockelman (1997), the variables which most influence walkability are the three Ds: design, density and diversity, being the 'design' factor the most relevant among them. In other words, the urban form is important to displacements. In a study conducted by Handy (1996), the urban form was used only like a different urban grid, but the systemic conception of urban form wasn't approached.

In order to try to fill this gap, the Space Syntax Theory was used, because it is based on a systemic conception which allows understanding the interrelations more broadly.

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Hence, this paper aims to present the results of a thesis that aimed at understanding how the urban form interferers on displacements on foot, from a systemic viewpoint.

2. Theoretical references

2.1. Urban Form

It is assumed that the act of walking facilitates a coherent apprehension and experience of the city, for reasons explained by different disciplinary fields. The act of walking around a city can be interpreted according to the points of origin and destinations, or the ability of the places to become routes or points of arrival, as discussed by Hillier (2008). There seems to be a logical process in the organization of urban spaces that affects the choice of paths, which expresses the preference of individuals for one route or another.

Discussing the organization of spaces implies not only considering the urban structure, perceived as a system of interdependencies, but also understanding how the form of the city interferes on the act of walking. This component may play a greater role than we think, actively conditioning the flow of pedestrians.

Urban form is understood here as a geometric composition of the elements that make up the city (streets, buildings, blocks, facades, street furniture, vegetation, etc.), in terms of their dimensions and proportions (geometric framework). Furthermore, it is important to explore the concept in light of how the elements that make up the urban space are arranged and relate to each other, either from a bi or three-dimensional perspective. As relations are paramount to this study (because they result in hierarchical variations), we intended to carry out a reading of the topological context.

In the literature, urban form has historically been categorized by the differences in layout. In his work "Wanderlust: a history of walking", Solnit (2001) depicts poetically and accurately, the distinction between traditional urban forms (cohesive) - or pre-modern (Holanda, 2013) - and contemporary (isolated) – post-modern (Holanda, 2013).

When discussing this issue, Medeiros (2013) emphasizes the two kinds of urban form mentioned by Kostof (1992); Kostof (2001) – the irregular/organic one and the regular/orthogonal/chess board grid – when comparing a sample of Brazilian and international cities. Nevertheless, in a reading that considers the articulation between the urban fabrics and their impact over displacements, the author highlights that the issue is not the presence of one type or another, but the articulations that take place in the city. Aspects such as seam, connection and relation between the main axes seem to be more relevant than the layout itself. Therefore, the urban forms that more closely resemble a 'quilt' would be a more negative scenario for urban mobility, even for walking: the apparent planning expressed by the regularity of the layout comes undone by the absence of a global intention that prevents coherent levels of articulation between the parts.

For urban mobility, understanding the form entails understanding the geometrical and topological aspects simultaneously, focusing on relations. The reading of the articulations of the city elements – such as the street grid layout or the degree of compactness of buildings and population, the primary mode of transportation or the distances to overcome - is an axis of interpretation that deserves attention, for they seem to have a substantial influence over the processes of displacement of individuals in space.

2.2. Space Syntax

In regard to the study of the built environment, the Theory of Social Logic of Space or Space Syntax (Hillier and Hanson, 1984; Hillier, 1996; Holanda, 2002; Medeiros, 2013) contributes substantially to the debate, when aligned with the reading strategies of urban form whose bases are derived from the systemic view (where parts of the city should be linked to create an integrated whole – Derridá, 1971; Foucault, 1971; Capra, 2003).

The main objective of Space Syntax is to investigate the relationship between the built environments – the building or the city, roughly referred to as architecture – and society – seen as a system of possibilities of encounters (Holanda, 2002).

The theory offers techniques for understanding and representing space, including the structure of the street network, providing materials that allow the researcher to investigate the city through its urban articulations.

According to Hillier (2001), by placing an object here or there within a spatial system, certain predictable consequences affect the spatial configuration of the environment. These effects are quite independent of human desires or intent, but can be used by humans to achieve the spatial and social effects.

In view of this, Hillier and Hanson (1984) believe that there is a virtuous cycle that explains the law of natural movement (Figure 1), in which the spatial configuration has the primary effect of generating movement (whether of people or vehicles) in spaces. As a side effect, this movement generated by the configuration fosters the appearance of uses (i.e., the attractors and generators of movement). Finally, as tertiary and quaternary effect, the reverse process occurs: the land uses foster movement once again, and thus interfere with the configuration of the spaces. Therefore, the configuration can be understood as an explanatory factor for the functional distribution in cities, acting directly on aspects of movement.

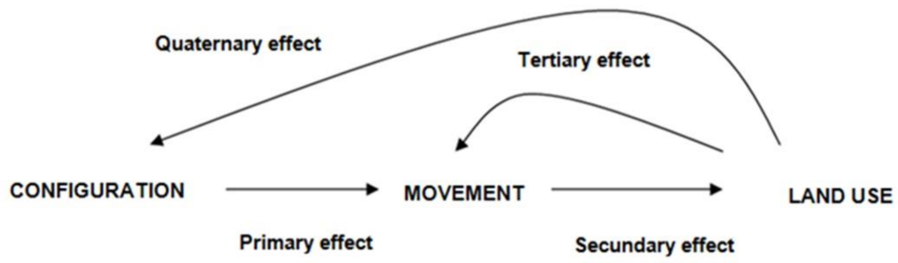

Fig. 1. Virtuous cycle of natural movement. Source: Medeiros (2013).

Amongst the representation techniques recommended by Space Syntax for configurational studies, two are of particular interest for this research: visual fields (map of visibility) and lines (axial maps).

The linear representation of the axial maps (Figure 1) is obtained by tracing the street network in the form of lines, based on the cartographic resources available, in order to reach the minimum number of lines that represent direct access throughout the urban fabric. After processing these lines, it is possible to generate a matrix of intersections, from which the representative values of its axial interrelationships are calculated using the Depthmap® software.

This procedure results in the calculation of the total matrix of intersections of the system, which takes into account all the connections from all axes. We obtain a value called Rn, where R is the radius (how many axes we want to consider from another axis in the system) and n is the unlimited number of connections. The values obtained from the representation and quantification of urban space at the desired level are called value or potential of integration. These values can be represented numerically or by a chromatic scale or gradient, ranging from red (most integrated), to blue (more segregated).

More integrated axes are those more permeable and accessible in urban areas, from which all the other axes are more easily accessible. They usually entail topologically shorter paths that can be reached from any axis of the system.

3. Data & Methodology

Some indicators (integration, connectivity, etc.) of the Space Syntax Theory were used and fed into the database, that is composed of four types of factors: (a) geometric; (b) syntactic; (c) transport accessibility; and (d) activities.

Three neighborhoods in Lisbon were chosen as the case study, due to their different urban form/urban fabric: (a) Campo de Ourique (orthogonal grid – a regular grid designed with blocks of equal dimensions and a predominance of “X” crossings); (b) Graça (organic fabric – an irregular grid with blocks of different dimensions and a predominance of “T” crossings); and (c) Telheiras (contemporary fabric – with a mixture of orthogonal grid and organic fabric, but with isolated buildings).

The modelling used was the Trip Generation Analysis with flow counting of people (based on Gate Method very common in Space Syntax researches) of the three neighborhoods.

This model aims at exploring the variables which batter explain the flow of people, based on the countings and on the pre-existing data from the data banks, and further taking into account the data about urban form (here represented also by the integration index). The Poisson regression model was chosen instead of Linear Regression, because it was more adequate to analyze discrete and non-negative countings. In addition, such analysis is the most suitable to explore the meaning and the intensity with which certain variables of a group have the power to explain a phenomena (in the present case, the pedestrian countings).

Once the statistical distribution of the variables under analysis presents discrete or non-existing values (zero), it is not possible to use normal distribution as a function of the dependent variable. Analyzing the literature for the representation of similar phenomena (Fernandes, 2010), it was possible to identify that the Poisson Regression would be an adequate formulation to model the phenomena under analysis. This is because the Poisson distribution does not present negative values and presents a discrete ordering.

The main goal of this model is to identify which variables are more relevant to better explain the flow of people present in the gates and to answer the question: "What is the impact of the factor urban form in the trips generation for displacements on foot?"

The base formulation of the model is only suitable for events with reduced probability and whose probability function leads to values similar to the value expected and the variance. Value expected is the one generated by the model itself. Variance is a deviation between something observed and the mean, which can be decomposed as a 'deviation from observation' (the values observed in the countings, the real data) in relation to the 'value adjusted by the regression' (which are the values expected, generated by the model) added to the deviation of the adjusted value in relation to the mean.

When these conditions are not present, it is necessary to formulate alternative models such as negative binomial or introduce derivations of the Poisson model (such as the Poisson with overdispersion - used in this research) in order to allow the overdispersion of the sample data, requiring the additional estimation of the (overdispersion) parameter. This parameter is fixed with value 1 in the case of traditional Poisson, and above 1, for Overdispersion Poisson, as it can be observed in the 'value of scale' present in Table 2, with the presence of overdispersion in all models, that is, with values above 1.

In order to build the model, only countings carried out at the morning peak time were used, because in Lisbon the morning peak time is the time when both schools and most jobs in commerce and service start. The same does not happen in the afternoon peak time, once the time people leave their jobs and the time children leave schools differs greatly. Some schools finish at 16h30, others at 18h00 and a few even finish at 19h00, which renders the analysis unfeasible.

In addition, the set of data used in the research included: (a) morphological/geometrical data such as width of the sidewalk, presence of stairs, slopes, etc.; (b) syntactic/topological data such as integration index, connectivity, street compactness, etc., obtained from the axial maps of Space Syntax,; (c) data about activities, based on land use information and (d) accessibility data, regarding the proximity of public transport (buses, metro and taxi). In table 1, the statistical characterization of these variables is presented (average values, standard deviation and variation coefficients). The variables will be tested in the models.

It is important to highlight that only the variables integration, connectivity and street compactness, related to the syntactic variables, and the entropy index and the number of doors, related to the 'land use' variables, do not present great variability in the counting points: its variation coefficient - relation between the standard deviation and the average - are below 1.00. The other variables presented greater variability of data, because their values are above 1.00. It is important to highlight that the behavior does not represent something good or bad, it only expresses the variation degree in relation to the average of variables in the counting points.

After the observation of the variables of the pedestrian flow countings, it was possible to observe that the sample presented a high overdispersion for the pedestrian model (average/expected value of 55.36 and variance - which is the square potency of the standard deviation - of 8357.52, which requires an adaptation of the base model).

After several tests of specifications for the models, a model configuration was reached with the overdispersion Poisson, because it led to the best estimates of Ro ($\rho 2$) value, meaning of the coefficients of the independent variables and the model's prediction capacity.

Table 1. Variables of model.

Variables	Average	Standard Deviation	Variation coefficient
Pedestrian flow per hour (morning peak time)	55.36	91.42	1.65
Syntactic variables			
Integration index	0.54	0.19	0.35
Connectivity	5.59	0.80	0.14
Street compactness (m street/hectare)	6.70	2.50	0.37
Morphologic variables			
Width of the sidewalk (narrow - <1.5m)	0.14	0.35	2.50
Barriers 1 (presence of stairs)	0.03	0.16	5.33
Trees 1 (more than 5 trees per 100m stretch of road)	0.39	0.49	1.26
Slope 3 (high - slope >5%)	0.08	0.26	3.25
Land use variables			
Commerce (1000 m^2)	0.99	1.09	1.10
Education (1000 m^2)	0.20	0.52	2.60
Food and leisure (1000 m^2)	0.40	0.66	1.65
Entropy index (a sum of Cervero's entropy index for the streets at less than 30m distance from each gate)	0.72	0.49	0.68
Number of doors (at less than 30 m distance from each gate)	10,96	10,38	0.95
Proximity to Public Transportation			
Gates at less than 5 minutes walking from a bus stop	0.17	0.38	2.24
Gates at less than 10 minutes walking from a subway stop	0.02	0.14	7.00
Number of bus lines that stop near the gate (< 30 m)	0.54	1.31	2.43

The calibrated model presented high adjustment quality, with Ro (ρ2) value of 0.50 and meaningful Omnibus test, most of the variables being considered significant for the level of significance 0,05. The results obtained based on the variables are presented in table 2

It is important to highlight that, for each explanatory variable, there are two orders of magnitude. The first is the explanatory power (given by coefficient 'B', if all these explanatory variables have been standardized), which means the expected change in the explanatory variable by each unit of change in the independent variable (in this case, the countings). The second is the degree of significance, which represents the statistical soundness of this relation (an inverse measure to the margin of error in the estimation of that coefficient B - Sig.), that is, it represents the probability of the real value of that coefficient being zero. The justification for the use of coefficient 'B' and not 'standard B' is the importance of knowing how much more pedestrian flow is generated with 1m2 more of commerce, for example. The second coefficient is used to compare the magnitude of the effect of the independent variable over the dependent variable.

4. Results

In order to understand the behavior of the most renowned syntactic variable in the literature of configurational studies - the 'integration' - we performed a regression of this variable with pedestrian counting.

A good performance of the model was observed, since all variables (15 - Tables 2 and 3) presented satisfactory significance, with values ranging below 0,100, including 'integration', with score 0,002 (Table 2).

Table 2. Estimates of the variables for the regression model between integration and pedestrian counting in the morning

Variable Estimates							
Variables	B	Standardized Error	95% Wald Trust Interval		Assumption test		
			High	Low	Wald Chi-Squared	df	Sig.
(Intercepto)	3.870	.4007	3.085	4.656	93.290	1	0.000
Integration	.716	.2289	.268	1.165	9,795	1	.002
Connectivity	-.243	.0603	-.362	-.125	16.303	1	.000
Entropy	.464	.1596	.093	.719	6.481	1	.011
Doors	.034	.0058	.023	.046	35.536	1	.000
Proximity to bus	.311	.1446	.027	.594	4.622	1	.032
Proximity to subway	1.515	.3709	.788	2.242	16.690	1	.000
Commerce	.178	.0416	.097	.260	18.408	1	.000
Education	.209	.0837	.045	.373	6.222	1	.013
Stairs	-.785	.2881	-1.350	-.221	7.434	1	.006
Bus stop	.194	.0497	.097	.292	15.240	1	.000
Trees	.330	.1222	.090	.569	7.292	1	.007
Slope	-.550	.2735	-1.086	-.014	4.039	1	.044
Width of the sidewalk	-.355	.1975	-.742	.032	3.230	1	.072
Compactness	-.067	.0328	-.131	-.003	4.200	1	.040
Food and leisure	.119	.0996	-.076	.314	1.432	1	.232
(Scale)	47.900						

Dependent variable: Pedestrians_morning
Model: (Intercepto), Integration, Connectivity, Entropy, Doors, Proximity to bus, Proximity to subway, Commerce, Education, Stairs, Bus Stop, Trees, Slopes, Width of the Sidewalk_1, Street Compactness_ha, Food_Leisure
(a. Computed based on the Pearson chi-square).

Table 3. Omnibus test or Chi-squared test

Omnibus Test[a]		
Proportion between likelihood ratio and chi-squared	df	Sig.
395.377	15	0.000

Dependent variable: Pedestrians_morning
Model: (Intercepto), Integration, Connectivity, Entropy, Doors, Proximity to bus, Proximity to subway, Commerce, Education, Stairs, Bus Stop, Trees, Slopes, Width of the Sidewalk_1, Street Compactness_ha, Food_Leisure[a]
(a. Compares the fitted model against the intercept-only)

Table 4. Fit test of quality model

Evaluation of the Quality of the Model[a]			
	Value	df	Value/df
Deviation	15711.351	342	45.940
Standard deviation	328.002	342	
Pearson Chi-squared	16381.871	342	47.900
Standard Pearson Chi-squared	342.000	342	
Log Likelihood Ratio	-8577.751		
Standard Log Likelihood Ratio	-179.075		
Akaike's Information Criterion (AIC)	17187.502		
Information Criteria for the Corrected Finite Sample AIC (AICC)	17189.097		
Bayesiana Information Criterion (BIC)	17249.591		
Consistent Akaike's Information Criterion AIC (CAIC)	17265.591		
Dependent variable: Pedestrians_morning Model: (Intercepto), Integration, Connectivity, Entropy, Doors, Proximity to bus, Proximity to subway, Commerce, Education, Stairs, Bus Stop, Trees, Slopes, Width of the Sidewalk_1, Street Compactness_ha, Food_Leisure[a]			
(a. Information criteria are in small-is-better form).			
(b. The full log likelihood function is displayed and used in computing information criteria).			
(c. The log likelihood is based on scale parameter fixed at 1).			
(d. The adjusted log likelihood is based on an estimated scale parameter and is used in the model fitting omnibus test).			

In terms of their relevance in interfering with pedestrian flow, the variables can be ranked as follows: (1) ‘proximity to the subway station’ with value 1,515; (2) ‘stairs’ with -0,785; (3) ‘integration’ with 0,716; (4) ‘slope’ with -0,550; (5) ‘entropy’ with 0,406; (6) ‘width of the sidewalk 1’ (no sidewalk) with -0,355; (7) ‘trees’ with 0,330; (8) ‘proximity to bus lines’ with 0,311; (9) ‘connectivity’ with -0,243; (10) ‘bus stop’ with 0,194; (11) ‘commerce’ with 0,178; (12) ‘food and leisure’ with 0,119; (13) ‘street compactness’ with -0,067 and (14) ‘doors’ with 0,034. The variables - stairs, slope, width of the sidewalk 1, connectivity and street compactness - presented negative values, however, they displayed intense influence in the flow of pedestrians by preventing people from walking.

Fig. 3. Relation between pedestrians counting and model forecast in the morning peak: (A) Graça, (B) Campo de Ourique and (C) Telheiras

In order to illustrate the results of the regression, presented in table 2, it is possible to check in Figure 3 that the prediction of pedestrian flow generated by the model was very similar to the real flow counted at morning peak time.

This allowed us to see that the urban form - translated mainly by the syntactic variable 'integration' - is the third most important variable (Table 5) - only behind the variable of 'time to access subway' (positive) and 'presence of stairs' (negative) - in explaining the flow of pedestrians going by the gates established to this research. Even there being other explanatory variables, its performance was more significant than land use, which strengthens the Natural Movement premise defended by Hillier et al. (1993), when presuming that the configuration of spaces would be the most relevant factor for conditioning the flows in the city.

Table 5. Variables (positives and negatives for the walkability) presents in the first model.

Variables	Model 1	Value
Food and leasure	green	0,119
Trees 1 (streets with a lot of trees)	green	0,33
Commerce	green	0,178
Education (Educational Institutions)	green	0,209
Entropy 4 (mixture of uses)	green	0,406
Integration	green	0,716
Bus stop	green	0,194
Number of doors	green	0,034
Access time to subway	green	1,515
Access time to bus stop	green	0,311
Barrier 1 (streets with stars)	red	-0,785
Street Compacity	red	-0,067
Connectivity	red	-0,243
Slope 3 (up to 5%)	red	-0,55
Sidewalk width 1 (without sidewalk)	red	-0,355

*in red: negative impact (discourage pedestrians flow) and in green: positive impact (stimulate the pedestrians flow).

5. Conclusions

The results show that urban form (integration indicator) is the second factor that better explains the presence of people in the neighborhoods (in the counting gates). In addition, the presence of stairs and slopes, two other relevant factors, are also a part of the urban form factors. It is important to highlight that, according to this study, the most relevant factor is the presence of subway station (transport accessibility). However, since such variable was only present in one of the neighborhoods under study, this must be confirmed by further studies.

In terms of methodology, the Trip Generation Model with syntactical variables was an innovation. Since there are no models with the same types of urban form variables specification that allow identifying deeply the impact of such attributes.

Therefore, in order to answer the question “What is the impact of the factor urban form in the trips generation for displacements on foot?” based on the analysis presented, it was possible to conclude that the urban form affects the generation of walking displacements with significant importance. This demonstrates, therefore, that urban form is one of most important factors to promote walkability in the cities. Based on the evidence presented, it is paramount to re-think the way public space in cities is designed: do we want to create spaces for cars or for people?

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