Introduction of non-topological costs in syntactic analyses: the case of Gulbenkian estate.

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Abstract:

Space syntax is a set of theories and techniques for analysing urban settlements and buildings. Focused on the study of the configuration of convex spaces, space syntax is based on the concept of topological depth, that is, in the number of steps to go from some space (or axial line) to every other space in a spatial complex. Typically, non-topological costs like stairs, ramps, accentuated slopes or walls are not considered in space syntax analyses, or are incorporated in an insufficient fashion, namely, with the arbitrary introduction of axial lines in order to increase depth. This article proposes an innovative method to deal with these costs that uses logic programming with Prolog language. In this way, it is possible to better understand the relative segregation of the Gulbenkian estate within its urban environment, the city of Odivelas near Lisbon (Portugal), noting that it was the largest public housing estate built within the scope of the resettlement plan for those displaced by the great floods of November 25-26, 1967, established by the Ministry of Public Works and the Calouste Gulbenkian Foundation in the late 1960s.

Keywords: Space Syntax, Non-topological costs, Liveability, Logic Programming, Public housing estates, Great Lisbon's floods of 1967.

INTRODUCTION

Space syntax is a set of techniques for analysing urban settlements and buildings, as well of theories linking space and society founded on Architecture, Engineering, Mathematics, Sociology, Anthropology, Ethnography, Linguistic, Psychology, Biology and Computer Science. It was developed originally by Bill Hillier, Julienne Hanson and colleagues at the Bartlett School of Architecture and Planning, University College of London (UCL), since the 1970s. Their innovative approach was condensed in three landmark books: *The Social Logic of Space* (Hillier and Hanson, 1984), *Decoding Homes and Houses* (Hanson, 1998) and *Space is the machine: a configurational theory of architecture* (Hillier, 2007).

Space syntax is mainly concerned with the study of the relations between *convex spaces*. Convexity exists when straight lines can be drawn from any point in a space to any other point in it without going outside of the space itself (Hillier and Hanson, 1984: 97-98). In fact, convex spaces rather that concave stimulate social interaction in the sense that everyone sees everybody within that kind of space. Thus, the starting point of a syntactic analysis is typically a *map* of the fattest *convex* and open (or permeable) *spaces* that cover the settlement (or building) in question. Eventually, this framework can be represented by an *axial map* with the smallest set of straight lines that pass through all convex spaces or by a map of segments. Then, several syntactic measures can be computed to explore the *connectivity* between spaces and lines or the angular deviation between segments in order to evaluate the degree of asymmetry (or integration) and distributeness of each convex space/line/segment or of the whole system (Heitor and Pinelo Silva, 2015: 154-164).

Thus, space syntax aims to find and explain the relation between spatial configurations and social activities. *Configuration* is a concept addressed to the whole of a complex (settlement or building) rather than to its parts that captures how the relations between two spaces, say A and B, might be affected by a third space C (Hillier, 2007: 23-24). For instance, if A and B are adjacent or permeable, then they have a symmetric configuration in the sense that, if A is neighbour of B, then B is neighbour of A, as illustrated by the left-hand side of figure 1.

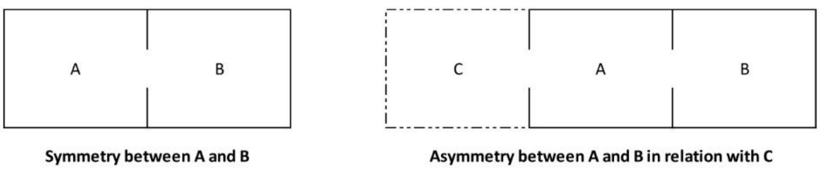

Figure 1: Basic configurations. Adapted from Hillier (2007: 24).

However, if only A is connected with a third space C, as in the right-hand side of the same figure, A and B become asymmetrical in relation with C, because we have to go through A to get to B from C, but we do not have to go through B to get to A from C. Thus, *asymmetry* relates to *depth* or *topological distance*, that is, to the number of spaces (or steps) to go from some space, say C, to another space, A (1 step), B (2 steps), and so on.

If we count the number of steps to go from some space to every other space in a complex, we can get a measure of its total depth (TD), or of its mean depth (MD), by dividing that total by the number of spaces in the complex minus one (Hillier and

Hanson, 1984: 108) (Hanson, 1998: 27-28). In the previous example, the total depth of C is 3 which is the sum of steps to reach A and B (1+2) from that origin. This is also the case of B, but the total depth of A is 2, noting that this (central) space is directly connected with both B and C spaces (1+1). Thus, the mean depth is 1 (2/2) for A, and 1.5 (3/2) for B and C, noting that the number of spaces minus one in this simple complex is 2 (3-1).

Now, suppose that we have a *non-topological cost*, namely, a ramp or stairs, between the spaces C and A. Obviously, the depth between C and A or B should increase. How can we incorporate this additional cost in space syntax measures? In the classic gamma analysis of the English cottage, Hillier and Hanson (1984: 156) considered two halls linked by internal stairs, instead of a single hall, as a simple strategy to increase the depth between spaces located in different floors. This would be equivalent to split the illustrated space C into two spaces C_1 and C_2, so that to go from C_1 to A (or B), we must pass through C_2 (and A).

However, this strategy lacks flexibility. For instance, if we have a ramp instead of stairs, the 'distance' between C and A might be different in order to express a smaller non-topological cost. This kind of practical difficulties can become cumbersome in the case of an alpha analysis of urban settlements. A good example is Maiden Lane, the public housing estate near King's Cross station in London studied by Hillier et al. (1989) and described by Hillier (2007: chapter five). There, 'clusters' of axial lines had to be introduced in every point with stairs, ramps, walls and similar non-topological costs (that are common in that estate) in order to increase depth artificially, resulting in a rather complex axial map.

Here, we propose a different, elegant method to deal with that kind of costs, based on the implementation of space syntax measures in Prolog, a logic programming language. Then, we apply our method to a public housing estate in Portugal (Bairro Gulbenkian) which is accessed by several stairs and ramps, resulting in a quite introvert neighbourhood.

METHOD

Our approach is a simple development of the method described in Fernandes (2022). Space syntax with Prolog (SSWP) requires a knowledge base, or a dataset, with the description of the connections between spaces, namely,

```
connected(C, A, 1).
connected(A, B, 1).
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where 1 in the third argument of the complex term 'connected' is the cost of going from some space to another space. This is the dataset for the right-hand side of figure 1. Having a ramp between C and A, we can replace the first fact by connected(C, A, 2).

Noting that the cost associated with climbing stairs is greater than the one concerned with ramps, we can assume that A is accessible from C by stairs with cost 3, that is,

connected(C, A, 3).

With small adaptations, the predicates described in Fernandes (2022) can deal with this kind of complex terms, computing mean depth and integration in the presence of non-topological costs. The key issue is the predicate depth/3 that was adapted to control symmetric adjacencies with costs 1, 2 or 3, that is,

```
depth(X, Y, 1) :- adjacent1(X, Y, 1).

depth(X, Y, 2) :- adjacent1(X, Z, 1), depth(Z, Y, 1), dif(X, Y).
depth(X, Y, 2) :- adjacent2(X, Y, 1).

depth(X ,Y, 3) :- adjacent1(X, Z, 1), depth(Z, Y, 2), dif(X, Y).
depth(X ,Y, 3) :- adjacent2(X, Z, 1), depth(Z, Y, 1), dif(X, Y).
depth(X ,Y, 3) :- adjacent3(X, Y, 1).

depth(X ,Y, 4) :- adjacent1(X, Z, 1), depth(Z, Y, 3), dif(X, Y).
depth(X ,Y, 4) :- adjacent2(X, Z, 1), depth(Z, Y, 2), dif(X, Y).
depth(X ,Y, 4) :- adjacent3(X, Z, 1), depth(Z, Y, 1), dif(X, Y).
…
```

where the symbol ':-' means 'if' and the predicate dif(X, Y) assures that the space X is always different from Y. For example, the last predicate declares that the depth between X and Y spaces is 4 if, namely, X is adjacent to other space Z with cost 3, that is, they are linked by stairs and Z is one-step way from Y.

CASE STUDY

We illustrate our method with Bairro Gulbenkian, a public housing estate built in the late 1960's in Odivelas, Portugal, more precisely in a plot with 28,500 squared meters reserved for the Ministry of Public Works (M.O.P.) by the master plan of Quinta do Mendes (Fernandes, 2015: 110), see figure 2. This case corresponds to the greater estate built with the financial and technical support of the Calouste Gulbenkian Foundation in a special resettlement plan to deal with the homeless of the great flood of November 25-26, 1967, in the Great Lisbon, that killed about 700 people (Malheiros et al., 2018).

Composed by 15 isolated blocks with three storeys (figure 3) and a total of 160 dwellings (about 600 inhabitants), the Gulbenkian estate combines modernity with human scale. In fact, following the practice of the urban planning in Lisbon during the 1960s, namely, the experience of Olivais Sul (Salgado and Lourenço, 2006: 144), the estate is structured by a small square (*Praceta Grão Vasco*) and its street network is hierarchical and separates car traffic from pedestrians (figure 4).

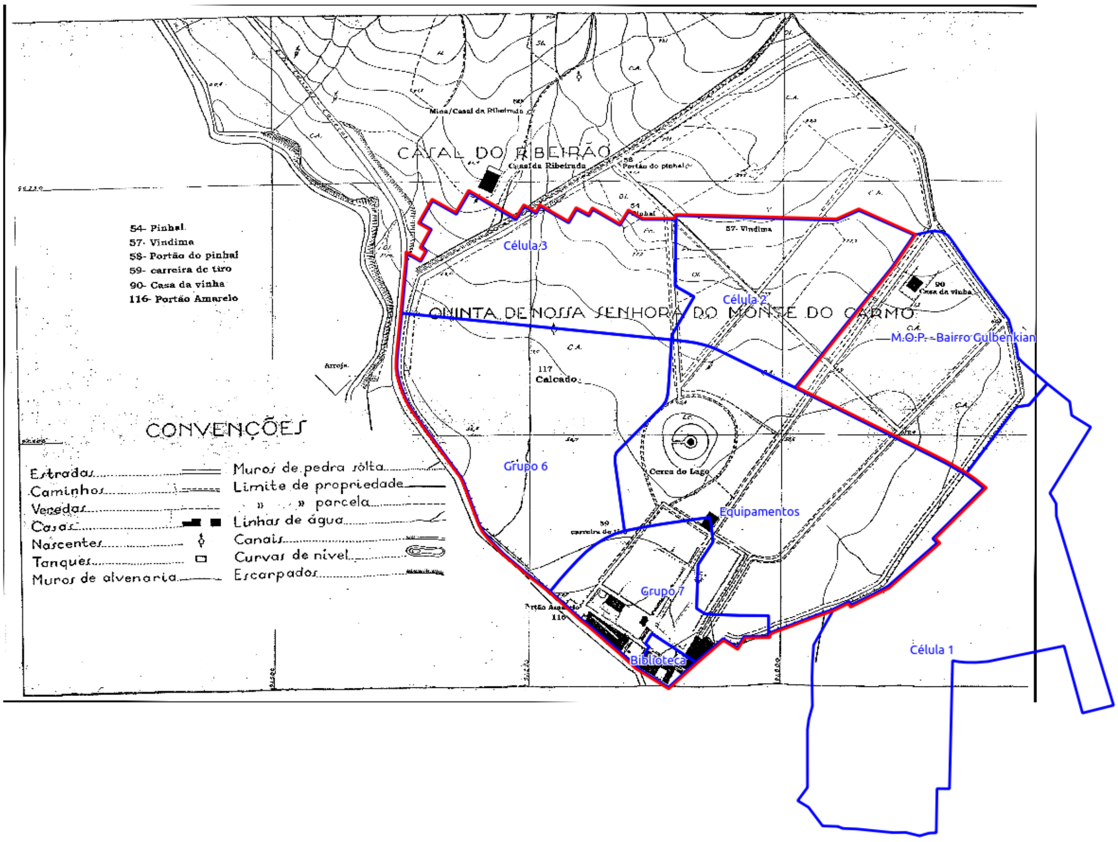

Figure 2: Scheme of the zoning of Quinta do Mendes, Odivelas.
The Gulbenkian estate is located at northeast.

Figure 3: Example of an isolated block, Gulbenkian estate.

Besides, the Gulbenkian estate was equipped with an amenity that combines a sports hall with several common services, namely, a nursery and an elderly centre, in order to improve the overall liability of the neighbourhood and its articulation with the city of Odivelas.

Figure 4: Detailed plan of the Gulbenkian estate (1968-1970) in Malheiros et al. (2018: 384) with its axial map (dashed red line: outside).

The settlement is not easy to access. In fact, several stairs and ramps deal with a sloping terrain, especially in the interfaces with the (outside) streets that delimit it. We introduce this feature of Bairro Gulbenkian directly in a Prolog program, available online at https://swish.swi-prolog.org/p/gulbenkian_ntc.pl. For example, the two stairs near Hotelcar building and Girassol mall were declared in the following fashion:

```
connected(outside, hotelcar, 3).
connected(cc_girassol, pcta_jose_regio, 3).
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Similarly, the sloping pattern of *Praceta José Régio* was declared with the term:

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connected(outside, pcta_jose_regio, 2).
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FINDINGS

One interesting feature of Bairro Gulbenkian is that the most integrated spaces are closer to the outside, rather than deep inside or at the middle of the neighbourhood. In fact, the axial lines of *Rua Bordalo Pinheiro*, *Praceta José Régio*, *Pavilhão* and *Rua Helena Aragão* – the 25% integration core – are directly connected with the estate's perimeter, that is, they are one-step away from outside (figures 4 and 5).

Axial lines	Classic measures (with topological costs)						Measures with non-topological costs			
	AC	E	DfO	MD	RA	IHH	DfO	MD	RA	IHH
rua_bordalo_pinheiro_S	7	1.41	1	1.68	0.08	2.96	2	2.79	0.20	1.13
rua_bordalo_pinheiro_E	6	1.70	1	1.74	0.08	2.75	2	2.84	0.21	1.10
pcta_jose_regio	6	1.53	1	1.68	0.08	2.96	2	2.95	0.22	1.04
pavilhao	6	1.19	1	1.74	0.08	2.75	1	2.95	0.22	1.04
rua_helena_aragao_E	4	1.24	1	1.95	0.11	2.14	1	3.00	0.22	1.01
casinha	6	1.43	2	1.95	0.11	2.14	3	3.05	0.23	0.99
confraria	4	0.80	1	1.95	0.11	2.14	1	3.11	0.23	0.96
rua_helena_aragao_S	2	0.33	1	2.21	0.14	1.67	1	3.16	0.24	0.94
pcta_grao_vasco	5	0.92	2	2.00	0.11	2.03	3	3.16	0.24	0.94
cc_girassol	3	0.41	1	1.95	0.11	2.14	1	3.21	0.25	0.92
Average	**4**	**0.89**	**1.3**	**2.00**	**0.11**	**2.12**	**2.4**	**3.40**	**0.27**	**0.88**
outside	13	3.56	0	1.32	0.04	6.42	0	2.32	0.15	1.54
rho (*)	**0.62**	**0.56**	**-0.12**	**-0.57**	**-0.57**	**0.57**	**-0.33**	**-0.55**	**-0.55**	**0.61**

(*) Linear correlation between the number of moving pedestrians and each syntactic measure.

AC - Axial Connectivity; E - Control; DfO - Depth from Outside; MD - Mean Depth; RA - Relative Asymmetry; IHH - Integration Hillier and Hanson.

Figure 5: Syntactic measures for the integration core (50%) of the Gulbenkian estate.

Thus, the small square that intentionally structures the estate (*Praceta Grão Vasco*) is only the ninth most integrated space. This result explains itself why Bairro Gulbenkian is so introvert. In addition, we found that the existence of stairs and ramps, namely, in the interface between the estate and its perimeter, increases dramatically the overall mean depth (MD) from 2.00 to 3.40, that is, +70%. Besides, relative asymmetry (RA) becomes 0.27 from 0.11 and integration (IHH), the inverse of real relative asymmetry, reduces from 2.12 to only 0.88 on average.

Finally, we found a greater correlation (rho coefficient, ρ) between pedestrian counts and IHH when we introduce non-topological costs, from 0.57 to 0.61 (figure 4).

DISCUSSION AND CONCLUSION

The method proposed in this paper to deal with non-topological costs has similarities with the weighted graph of segments (Turner, 2007), but it is simpler to implement and understand, due to the declarative nature of logic programming. Additionally, it can be applied to either axial or convex maps, rather than segment maps, and may produce better syntactic measures in the sense that they are more correlated with pedestrian counts. In summary, it may be a relevant tool to describe the (introvert) nature of a public housing estate like Bairro Gulbenkian.

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