Journal of Traffic and Transportation Engineering 12 (2024) 151-161
doi: 10.17265/2328-2142/2024.03.005

Sustainable Urban Mobility: (A)Synchrony between Subway Systems

Ana Paula Borba Gonçalves Barros
University of Brasilia, Brasilia 70910-900, Brazil

Abstract: The present study analyses the differences between the subways systems of two cities, Lisbon (Portugal) and Brasília (Brazil), verifying the extent to which their subway systems are spatially integrated with the respective urban fabric—which would promote a better synchrony in terms of economy and sustainability. For interpreting the data, the methodology and tools of the Theory of the Social Logic of Space were used, by means of axial maps, researching the relationship between the constructed and empty (public spaces) areas of the urban structures. Based on the findings, meaningful differences between the subway systems and the configuration of urban spaces were observed, as a product of specific design matrixes. In Lisbon, the mobility associated to the subway seems to be encouraged by the integration of the system with the potential for movement provided by the urban tissue (making the secondary centralities articulated with the subway stations more dynamic). In Brasilia, however, there are several difficulties for such mobility, due to the predominant role of the empty spaces in the city which weakens the gathering potential of such areas, despite the fact that such articulation with secondary centralities is also present there.

Key words: Urban mobility, spatial configuration, space syntax, subway system.

1. Introduction

The present article aims to explore and analyse the articulation process between spatial and functional aspects of the subway network in urban systems. The premise here is that the subway mobility, in order to contribute to a sustainable urban mobility, must be associated with the urban centers, both making the existing centers more dynamic and creating new ones. It is understood that in order to debate these issues, strategies for identifying the active urban centers must be sought, and these centers must be confronted with the transportation systems available. As a means to materialize the study, the particular cases of Lisbon (Portugal) and Brasília (Brazil) are investigated once they hold antagonistic spatial structures and distinct mobility scenarios.

Lisbon, the largest Portuguese urban settlement, fits perfectly in the paradigm of "traditional city", in which the clearly defined streets and the blocks promote the urban ethos (where the constructed space predominates). The result is a continuous urban fabric, heterogeneous in terms of use and occupation. Brasília, the fourth largest city in Brazil, is a product of a design concept based on empty spaces: the limits of the block are tenuous and the modernist zoning clear. There are great open spaces between the cities that integrate the urban system, which gives an impression of fragmentation and discontinuity.

From the contrasts of the two cities, two questions emerge, which give rise to this research: (1) from a global perspective, how do the features of the urban tissue articulate to their respective subway network? and (2) from a local standpoint, how do the subway stations relate to the secondary urban centralities, a crucial factor for making the city's sections more dynamic?

2. Methodology and Theory

2.1 Urban Form and Mobility

Studies prove that the urban fabric pattern presents a

Corresponding author: Ana Paula Borba Gonçalves Barros, research fields: urban mobility.

vast possibility, with extremes of regularity or irregularity, according to Medeiros [1]. The standards are varied, and go from the traditional urban tissue or a chessboard layout to extreme irregularity as seen in settlements which follow the topography, as so many Portuguese colonial cities in Brazil.

It is well know that the composition and the arrangement of the urban street plan are responsible for defining the concentration and dispersal of uses or activities in the space. Although the socio-economic aspect is a strong structuring element of the city, as Ojima [2] states, it cannot be considered the only factor, for there are other elements that influence the process of urban mobility. For instance, Nigriello [3] states that it is common to find the large active urban centers where the concentration of streets is higher, due to the fostering of more numerous possibilities of routes and accesses. This means that certain places are more accessible to the urban settlement as a whole. It is the social logic of space in itself, subordinate to the spatial configuration, as explained by Hillier and Hanson [4], Hillier [5] and Holanda [6].

It is thus assumed that the urban form influences the way people come and go, and their choices of ways [7]. If the urban form influences the way people come and go, it will surely influence the displacements inside the city, directly affecting mobility.

2.2 Social Logic of Space

The Theory of the Social Logic of Space or Space Syntax establishes the relation between the configuration of spaces (either in buildings or in cities) and different degrees of vitality (movement). It is believed, as Hillier and Hanson [4], Hillier [5], Holanda [6] and Medeiros [1] argue, that the spatial structure is able to engineer the social relations and interfere in the displacement processes, which contributes to the different manners places are appropriated.

From the strategies of representation recommended by the Space Syntax, the axial map was chosen for this study (Figs. 2 and 4), which corresponds to the simplification of the urban fabric displacement system into a mesh of interconnected lines representing all possible trajectories in the urban system. When the relations between the axes are processed mathematically, based on a topological principle [1], integration values are obtained. Integration values represent the potential for topological accessibility of each axis in relation to all others in the system. The most integrated axes are those more easily reachable from any other axis in the system.

Several studies have proven the straight correlation between the integration values and the real levels of vehicular and pedestrian movement identified in the city (cf. Synthesis in Barros [8]). This fact is articulated to what Hillier [9] calls “natural movement”, once it assumes that the configurational characteristics of the urban tissue are, in itself, able to engineer movement due to the human displacement strategies.

The axial maps usually present the integration values converted to a chromatic scale from red to blue, in which the hotter the colors are, the higher the potential for integration. Likewise, the colder the color, the lower the integration potential. The chromatic scale conversion makes the reading easier and allows for a rapid visual understanding of the areas and axes that present a higher potential for movement. The set of most integrated axes in the system, for example, are named “integration core” (or morphological center) which tend to coincide with the active urban centers, those to where all flows and different uses converge, in both quantity and diversity.

2.3 Research Methodology

In light of concepts presented in the items above, the research is based on the comparative investigation of the urban realities associated to the subway networks from the cities of Lisbon and Brasília. Structured in an exploratory manner, the study seeks to identify aspects which may be revealing the spatial organization of the networks and its corresponding implications for their performance, by means of the established procedures.

The choice of the samples, the comparative study of the capitals of Brazil and Portugal, reflects the search for apparently antagonistic physical locations: while in the Portuguese context the interference of the topography is paramount to the irregular arrangement of the settlement, the Brazilian scenario expresses the intention of globally organising the space in a remarkably flat location, which theoretically would favor infrastructure.

In order to reach the results, the data of the subway systems from the two cities (dimension; number, characteristics and extent of subway lines and stations; etc.) and the spatial configuration along the axes of movement (axial maps) are confronted. For the final analysis the Spatial Syntax techniques [4, 5] are adopted, for they provide the values of potential movement on the streets, which has a strong correlation with the real flow [8] and the functional implications in the city [1, 6], as the literature proves.

3. Analysis and Results

3.1 General Overview

The subway systems of Lisbon and Brasília present metro lines that cover, respectively, 39.6 km and 46.5 km. Despite the similar of values, the networks serve very distinct urban realities: while in the capital of Brazil the political area reaches 5,787.78 km^2 (encompassing the FD (Federal District)), in Lisbon it is of approximately 84 km^2. The population officially served, also according to the official political limits, is of 564,657 people in Portugal and of 2,579,160 in Brazil. However, it is important to clarify that the Region of Lisbon (Greater Lisbon and Setúbal Peninsula), according to data from the Instituto Nacional de Estatística (National Institute of Statistics) for the 2011 Census, reaches 2,815,851 inhabitants. Such value is very similar to the one from RIDE—Região Metropolitana de Desenvolvimento Integrado (Metropolitan Region of Integrated Development) of Brasília, with 3,717,728 people, which makes the data about the relative population served by the subway system relative (Table 1).

Table 1 General overview of the subway system in Brasilia and Lisbon.

Data*	Lisbon	Brasilia
Number of inhabitants	564,657	2,570,160
Number of inhabitants (Metropolis)	2,815,851	3,717,728
Area (km^2)	83.84	5,787.78
Population density (hab/km^2)	6,734.94	444.07
Size of the subway system (km)	39.6	46.5
Density of lines (km of lines/km^2)	0.47	0.01
Number of subway stations in operation	46	27
Number of subway stations under construction	4	5
Density of stations (number/km^2)	0.549	0.005
Average distance between stations	0.861	1.722

* The data about the subway system were obtained in the official websites of the corresponding managing departments (Companhia do Metropolitano do Distrito Federal-Metrô DF: http://www.metro.df.gov.br > and Carris< www.carris.pt). Census information was taken from the webpages of IBGE (InstitutoBrasileiro de Geografia e Estatística—Brazilian Institute of Geography and Statistics: www.ibge.gov.br) and INE (InstitutoNacional de Estatística/Portugal: www.ine.pt) and refers to the 2011 Census.

** For the case of Lisbon, the public company that has exclusivity for the public transportation in the city is called Carris, and it is responsible for the bus lines, cable cars, lifts and elevators (www.carris.pt). The other companies (Transtejo, Vimeca and Lisboa Transportes) act in the Greater Lisbon with ancillary services to and from the city: boarding is allowed only in three multimode stations in the city: Gare do Oriente, Campo Grande and Roma-Areeiro.

The official urban limits reveal a density of 0.47 km of lines per km^2 on the subway system of Lisbon while in Brasilia the values decrease to 0.01, as a result of the spreading of the modernist urban structure, as opposed to the density of a diachronic consolidated settlement, such as Lisbon. A similar relation can be observed for the number of stations (46 in Lisbon and 27 in Brasília): there is a density of 0.549 stations per km^2 in the Portuguese context and of 0.005 for Brasília, which is not very expressive. The last data is also associated to the long average distances in the FD and to the fact that the urban street plan is concentrated only in a certain patch of the urban territory, as we will discuss further ahead.

From the relation between the length of the network and the number of stations, it is possible to notice that the average distance between stations in Brasilia (1.722 km) is significantly higher than in Lisbon (0.861 km). The scenario is a product of both a system that presents several stations that were designed but not built (especially in the South Wing of the Pilot Plan of Brasilia) and an urban design in which the empty spaces are predominant, which results in a low population density (fifteen times lower than in Lisbon).

3.2 The Global Perspective

The subway systems of Lisbon and Brasília have different spatial configurations, resulting from opposite processes of territorial occupation. In the Portuguese context, the settlement results from a local dynamic of growth of the urban fabric, which fosters additions and a gradual modification of the existing urban tissue. On the other hand, Brasilia was created with the intention of establishing a new capital ex-nihilo, which implies a lack of flexibility in the design, once the city was created as whole, based on the concepts of a modernist urbanism that was characteristic of the mid-20th century.

In Lisbon, the urban ethos is based on the centuries-old relation of the city with the Tejo River. The urban core opens itself in a focus point of strong symbolism, whose peak is the “Praça do Comércio” (Patio of the Palace), an icon of the Portuguese urban savoir faire. If historically the urban matrix is structured along the river, adapting itself to the surrounding hills, it is natural that the subway system clearly expresses the relation between the center (river side) and the outskirts of the city, articulating itself to the active urban core (Fig. 1). The scenario justifies the intersection of the Green and Blue subway lines in Baixa Pombalina, converging, respectively, to the stations of Cais do Sodré and Santa Apolónia, resulting from the arrival of the railway to the consolidated urban core until the late 19th century [10].

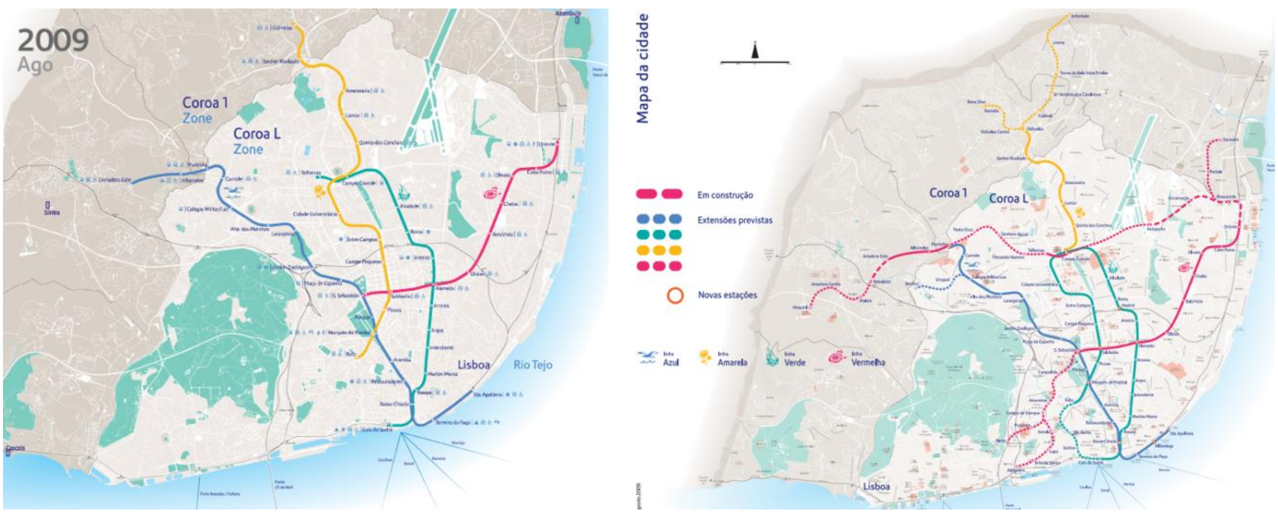

Fig. 1 Map of the subway network of the city of Lisbon. Source: Martínez [11].

The city grew from the river towards the valleys that later became the avenues Almirante Reis and Liberdade, establishing the two axes of articulation that distribute the flow to the north. Thus, it is not surprising that these avenues coincide with the Green and Blue Lines, the oldest ones from the existing system: "in the initial project, the subway network was built according to the parameters defined in the Urban Planning of the city, creating a set of radial urban sprawl axes" [10].

According to Gomes [10], the exploration started on January 29th, 1959, with a network of 6.5 km and 11 stations. On the first stage, the project of the Subway network had two lines, with 19.5 km, whose construction was supposed to be done in a period of three years. The construction of this network aimed to replace other means of public transportation, specially the electric cable cars. The construction of the priority network had some delays, which resulted in the fact that only one of the lines (12 km) was finished by 1972.

The consolidation of the future Yellow and Red Lines corresponds to the progressive migration to areas more integrated to the urban system, originally from Baixa Pombalina to the region of Saldanha, along the axis of Republica Avenue. The active core of Lisbon has shifted towards the North with the expansion of the urban fabric throughout the 20th century.

Currently, the resulting network is inserted within the political limits of Lisbon and it is similar to the radial structure converging to the old urban core, the river side. If on the one hand the shores of Tejo have become the convergence point, on the other the Red Line acts as a radius that transversely crosses the streets that converge to Praça do Comércio. The region of Parque Monsanto, however, acts as a spatial barrier to the continuity of the urban system and, given its dimension, it implies a significant reduction of the construction and populational density of that area. The characteristic and the process of occupation from Alcantara to Oeiras somehow foster the reduction in the offer of public transportation, and there is not a plan for a subway line expansion in that direction.

On the other hand, geographical and topographical issues also seem to interfere, specially due to the crest of the hills of Alfama-Castelo de São Jorge towards Graça and Penha de França: the configuration of the system also does not encompass these areas because the terrain tends to present reduced densities, once accessibility is restricted.

It is important to notice that the region which currently concentrates the highest number of integrated lines in the axial map of the city—urban integration core—also corresponds to the settlement site that presents a smother terrain, exactly in the regions of Saldanha and Campo Pequeno, which tends towards regularity, like a chessboard layout (Fig. 2). It is well known that flat terrains usually receive grid-based patterns [1] and the resulting regularity coincides with a system of higher connectivity, that is, higher number of connections (crossroads), which in turn, associated to the position of the streets in the system, implies a higher potential of use, in relation to the possible trajectories in a city (the very concept of integration).

Therefore, it is possible to notice the existing subway network of Lisbon is not only compatible with the movement potential identified in the urban system by the axial map—higher concentration of lines happens in the integration core—but also its consolidation process apparently follows the displacement of the active urban core, from the shores of the Tejo River, articulating the historical center to the contemporary morphological center. In addition to that, radio centric urban fabric favors better coverage of the urban territory, although certain characteristics of the site imply a reduction of density, difficulties in implementing the subway system and, consequently, an increased need for lines.

Brasilia derives from a peculiar urbanistic thinking and results from a global concept (the city was thought of as a whole), following the concepts of a modernistic urbanism, developed in the first half of the 20th century,

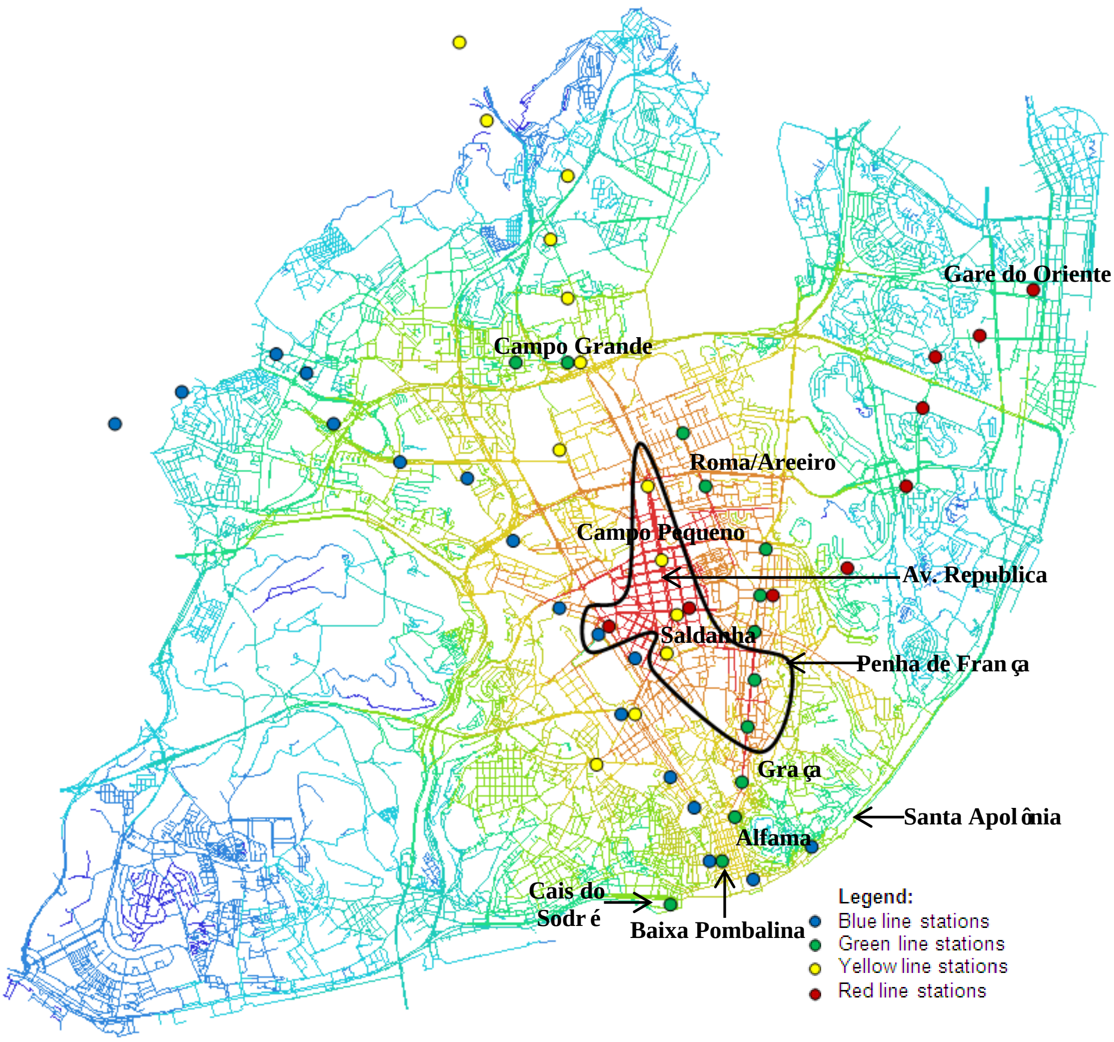

Fig. 2 Axial map of Lisbon with the location of each subway station.

with its logics tied to the "Era of Machines". Inaugurated on April 21st, 1960, the Brazilian Capital is a testament to the interpretation of a city according to the Charter of Athens, in which the urban quality is based in aspects such as zoning, regularity and great green corridors surrounding the human occupations. If on the one hand the modernistic design is the answer to the effects of the Industrial Revolution over the city—the exaggerated density, poverty and pollution, for example—on the other hand the result is an urban design that fragments the spatial relations by making the empty spaces the predominant feature of the city.

Historically, the cities are characterised by the density of the constructed space in opposition to the empty spaces of streets, squares and other public spaces. Bras ília has inverted the premise and has turned into the maximal expression of the notion of park cities, garden cities and green belts, for it was the result of a series of previous experiments. As a result of such principles, the Pilot Plan and the adjacent cities symbolize spatial solutions separated by immense empty spaces, not articulated to one another and with a significant distance between them (although the word "city" is used to name the settlements surrounding the Pilot Plan, the settlements and the Pilot Plan together work as one single city).

If the speech underlying the contemporary land issues is that of preserving the green belt around the

Pilot Plan, the empty spaces between the urban core spread through all the FD, maximising the average distance, increasing the cost of land and creating an urban system composed of unarticulated fragments—despite the flat terrain which would theoretically foster a continuous urban tissue. It is truth, however, that the growth of Bras ília (the city is now the fourth largest in Brazil, behind S ão Paulo, Rio de Janeiro and Salvador) throughout the last two decades has fostered the filling of the voids, progressively altering the discontinuity seen before.

The result of these characteristics is a flawed public transportation system, which cannot supply the population's displacement demand. Such system is frequently subject to criticism on the part of the entrepreneurs who have hold the rights of exploring this system, once the IPK (rate of passenger per kilometer) is relatively low compared to other Brazilian cities (a product of the excessive distances and the empty spaces which result in low population density)[1]. In the case of the subway system, whose implementation costs are remarkably high, the conflict for the context of Bras ília is exactly in the cost/benefit relation for maintenance, because the equation "long distances" versus "low density" compromises the financial balance.

From the form standpoint, the system of Bras ília is linear, with two lines that go from the Pilot Plan towards the cities that present the highest population density in the FD—Ceilandia, Samambaia and Taguatinga. In Aguas Claras, where currently there is the greatest percentage of constructions in the FD, the two lines converge[2] and, from then on, they continue together until the Pilot Plan Bus Station, which is the urban core of the spatial structure of the Capital of Brazil (Central Area of Bras ília). The train runs through the South Wing, alternating stations between the Superblocks (some are working, other are not).

Analysing this phenomenon from a global perspective, despite the implications of the urban design, the subway system of Bras ília tries to reach those areas of highest population density, although it must cross great voids to do it (Figs. 3 and 4). The result is the fact that the integration core and the predominance of stations in that area do not coincide—which, somehow, reinforces the difficulties of such global systems to adapt to the economical logics of urban spaces, thus becoming more sustainable. It must be considered, however, that there are stations in nodal points of the dynamics of the capital, such as the Shopping Mall station, which allows access to the great commercial and service providing enterprises, scattered along the EPIA, the line of greater integration in the system.

Nevertheless, the way the settlement is organised results in the existence of several cities not served by the subway system, especially when the aspect of spatial fragmentation is considered, both in the North and South directions. In this case, the cause is not the physical characteristics of the site, but the low densities and the great distances that need to be crossed to serve places like and Planaltina, revealing that alternative solutions must be added to the subway system in order to achieve a better urban mobility performance in the Brazilian capital.

3.3 The Local Perspective

The location of the subway stations tends to function as a powerful element for making the urban areas more dynamic. Therefore, if the location of the stations converges with the places of potential accessibility from the urban system, a scenario of synergy of efforts would be reached, in which the potential of the street network articulated to the subway network would be compatible with the distribution of uses and activities of the city. This is the greater economical stage and the optimal sustainability performance, as Hillier [12] argues.

[1] It is important to highlight that at peak time the passenger density per kilometer is very high in Brasilia, but it drops exponentially between the peaks.

[2] It must be highlighted that in peak times, all the trains (in both lines) arrive at Aguas Claras with their maximum capacities, which provokes long waits.

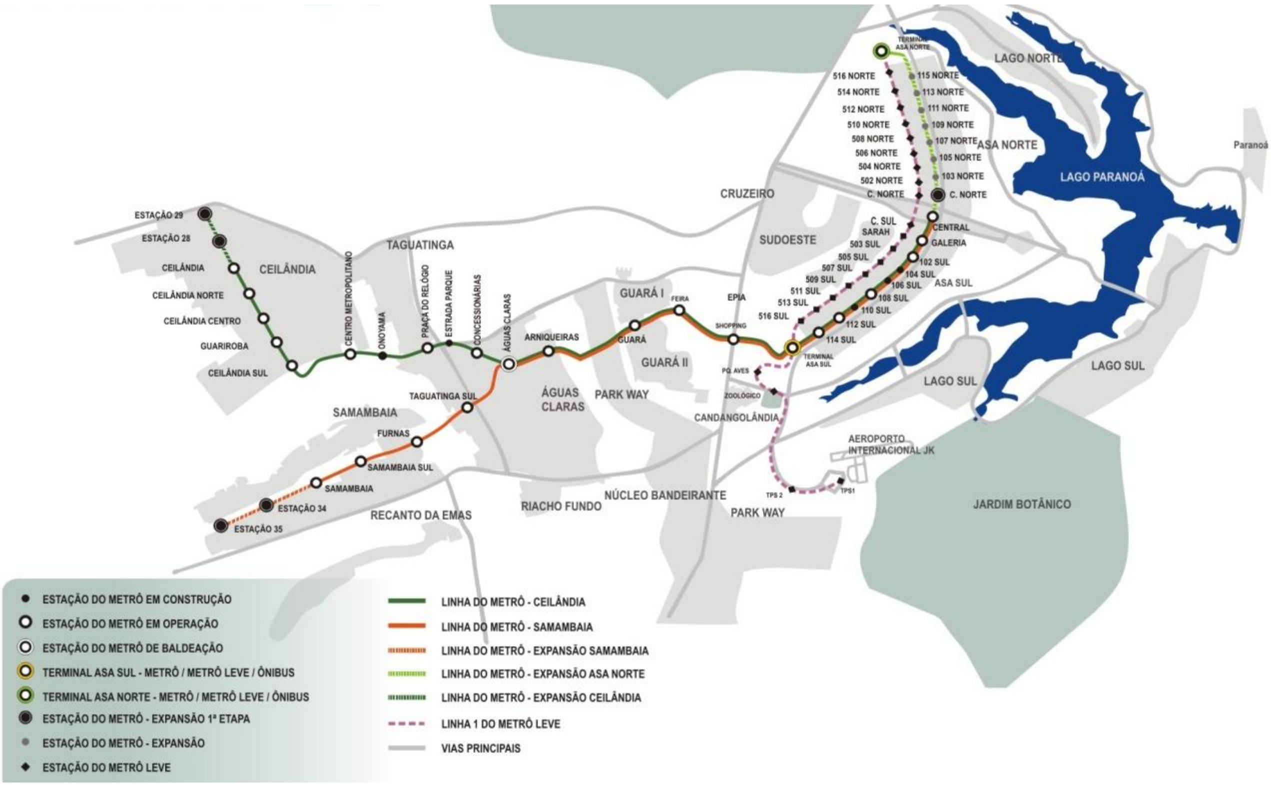

Fig. 3 Subway network of Brasilia. Source: http://www.metro.df.gov.br/.

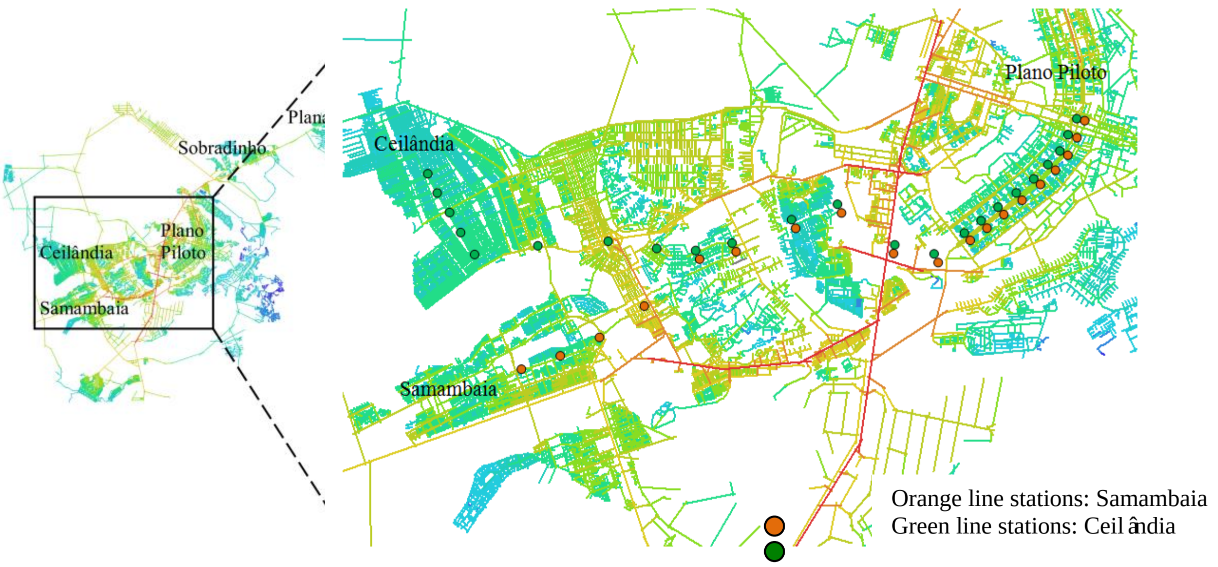

Fig. 4 Axial map Rn of Brasília (left), with the location of the subway stations (right). Source: DIMPU (2009). (scale not indicated).

In order to carry out the procedures, the scale of integration obtained in the axial maps of Lisbon and Brasilia was converted to a numeric one, from 0 to 100, as suggested by Medeiros [1, 13]. Afterwards, the measure of integration of each street immediately adjacent to the entrance of the stations was selected, which allows the creation of Figs. 5 and 6. The stations served by two or more lines were replicated in the graph,

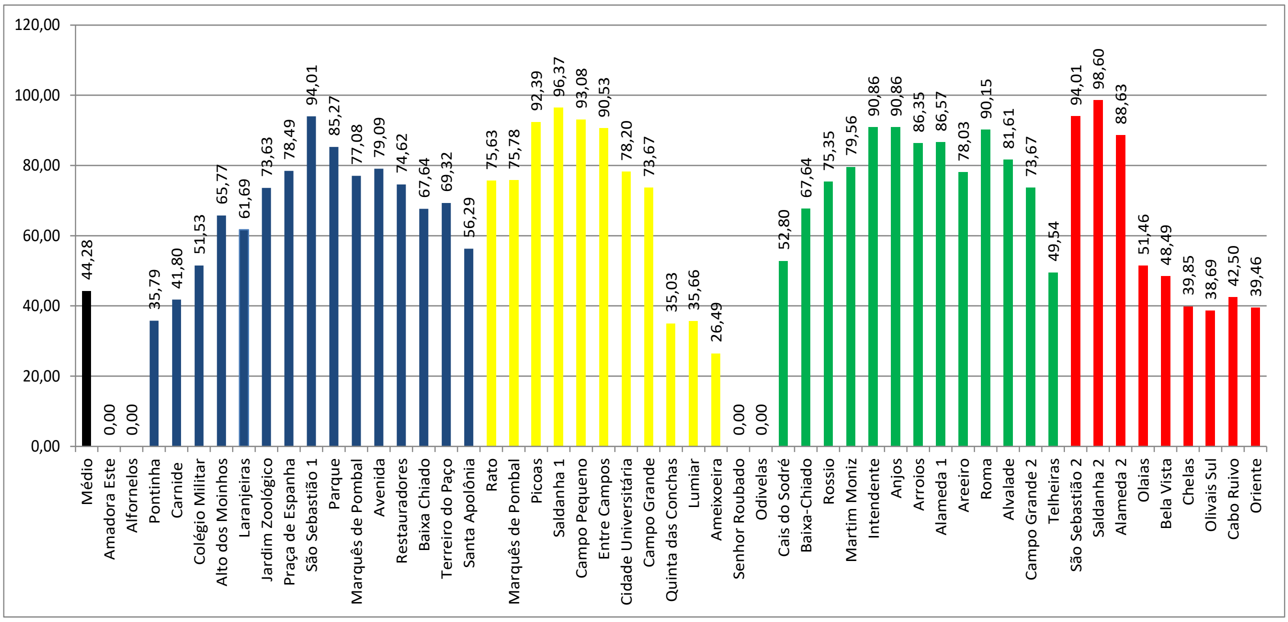

Fig. 5 Distribution of the integration values (base 100) for the subway stations in Lisbon, according to the colors of the lines.

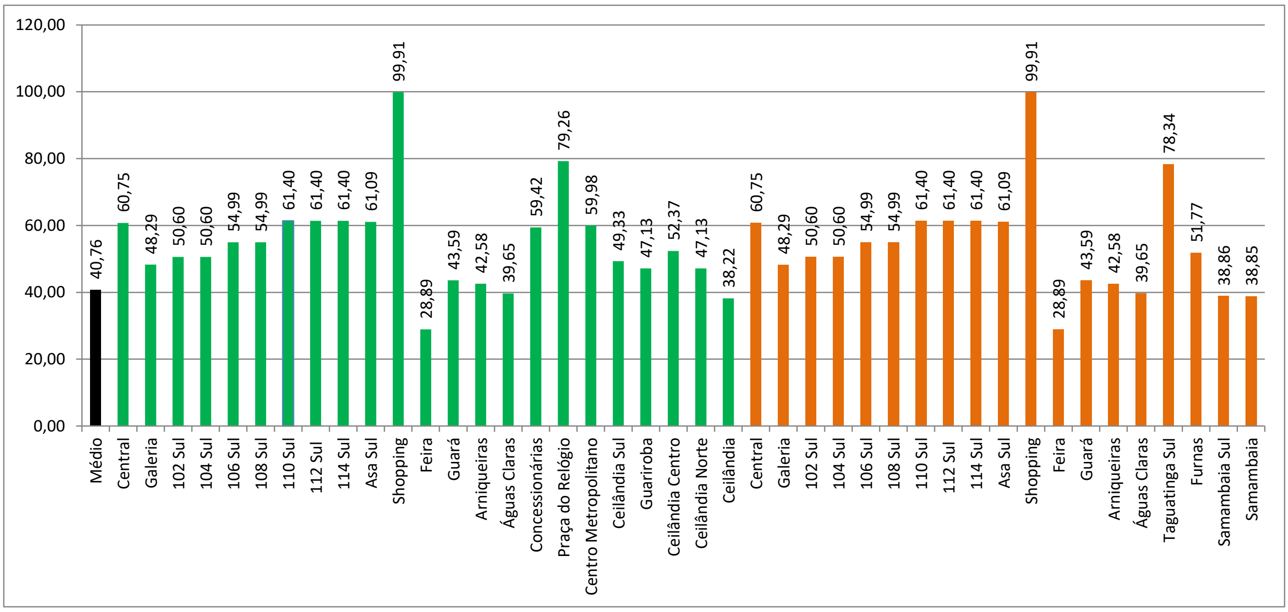

Fig. 6 Distribution of the integration values (base 100) for the subway stations in Bras ília, according to the colors of the lines.

so that they would be present in each corresponding line: the colors of the bars derive from the colors of the lines for both cities. The values “0.0” for some stations in Lisbon indicate that these are outside the official city limits.

For both scenarios, the findings reveal an inherent nature to the subway system: the relation between center and outskirts. According to the charts, identified according to the color of each subway line, the behavior is similar to that of an arch: the beginning of the line presents lower values, the center presents the higher values (including the top) and the end the lowest measures. The behavior for Lisbon shows progressive increase in the integration potential towards the center, later followed by a gradual decline of the values.

The Portuguese scenario also exposes the discussion of the movement process towards the active core in relation to the old city center. The stations that established the access to the river currently have a secondary position in the system from an integration standpoint, although it keeps functioning as an important magnet: the train stations Santa Apolonia and Cais do Sodré, from where the ferry boats to cross the river leave, as well as the suburban train lines.

The values for Brasília, however, show a conflict: despite the fact this trend can be verified for both lines, there is an apparent rupture in the scale. The Shopping Mall station presents an extremely elevated value, close to 100, while the following stations have an abrupt decline in integration. This means that the system crosses the morphological center of the FD, but later it goes through areas which are thinly connected from the topological standpoint—a product of the land occupation process that led to the predominance of low densities and a labyrinth like configuration of some areas in the FD. The arch is disrupted and only starts following the trend again after the station of Praça do Relógio, in Taguatinga, from where the measures gradually decline.

Based on the derivation of the results, it is possible to notice that the average integration values of all the stations (69.37) is significantly higher than the average of the city (44.28 or 57%) in Lisbon, which reveals a subway system which coincides with the highest potential for integration in the urban fabric. In Brasília, the situation does not present such a meaningful correlation: while the average of the system is 40.76 (lower than Lisbon), the one of the stations reached 54.31 (33% higher).

4. Final Considerations

From the findings, it was possible to verify significant differences between the two cases. The majority of the stations in the system of Lisbon present an strategic location, once they are placed either in the areas with the highest potential movement or very close to it, in areas notorious for their centrality; on the other hand, in Brasília, the stations are placed quite distant from the axes with the highest potential for movement, not corresponding to the urban centralities (with some exceptions). It is possible to infer that the users of the subway system of Lisbon have their mobility encouraged by the integration with the city's urban fabric and by the shorter distances between the stations and the corresponding centralities. In turn, Brasília presents a certain displacement difficulty, due to the great voids in the urban tissue and the absence of dynamic centralities that could benefit from the movement created.

The potential of the urban street plan is considered to effectively correspond to the standards of land use, according to the synchrony scenario, being thus more sustainable [12]. As a consequence the average displacements would be reduced, because the uses which most attract movement (placed in the urban centralities) would lie on the more easily accessible streets. These streets are more accessible from any given point to the whole urban system (potential for movement), thus being more appropriate to concentrate the axes of public transportation. In a "traditional" city, convergence is recurrent (Lisbon). On the contrary, in experiences of rigid regulation (Brasília), the non-refined correspondence among land use, urban densities, configuration and the subway stations creates diachronic scenarios: in addition to a higher cost, it encourages a transportation that does not foster the aggregating potential of the street network.

Acknowledgements

The lead author would like to thank CAPES for the financial support during the Doctorate internship carried out at IST-UTL (Lisbon/Portugal).

References

[1] Medeiros, V. 2006. "Urbis Brasiliae." Ph.D. thesis, Universidade de Brasília. (in Portuguese)

[2] Ojima, R. 2006. "A Produção e o Consumo do Espaço nas Aglomerações Urbanas Brasileiras." Accessed November 19, 2008. http://www.nepo.unicamp.br/vulnerabilidade/?navega=producões&codigo=63. (in Portuguese)

[3] Nigriello, A. 2006. "Planejamento de Transporte como

Instrumento de Organização do Espaço Urbano." Accessed November 20, 2008. http://www.cbtu.gov.br/eventos/encontro/encontro9/texto.htm. (in Portuguese)

[4] Hillier, B., and Hanson, J. 1984. *The Social Logic of Space*. Londres: CUP.

[5] Hillier, B. 1996. *Space Is the Machine*. Londres: CUP.

[6] Holanda, F. 2002. *O Espaço de Exceção*. Brasília: Editora UnB. (in Portuguese)

[7] Hammer, M. 1999. "Well Connected." *Journal New Scientist*. Accessed January 20, 2012. http://www.newscientist.com/article/mg16422124.700-well-connected.html.

[8] Barros, A. P. 2006. "Estudo Exploratório da Sintaxe Espacial como Ferramenta de Alocação de Tráfego." M.Sc. thesis, FT/UnB. (in Portuguese)

[9] Hillier, B. 2001. "A Theory of the City as Object. Or, How Spatial Laws Mediate the Social Construction of Urban Space." In *Proceedings of the 3rd International Space Syntax Symposium*, Atlanta, Georgia, USA.

[10] Gomes, G. 2001. *Transportes Públicos Urbanos em Portugal*. Lisboa: CTT. (in Portuguese)

[11] Martínez, L. M. G. 2010. *Financing Public Transport Infrastructure Using the Value Capture Concept*. Lisboa: DECivil, UTL.

[12] Hillier, B. 2009. "Spatial Sustainability in Cities." In *Proceedings of the 7th International Space Syntax Symposium*. Stockholm: KTH.

[13] Medeiros, V. 2002. "Da Praça-forte Seiscentista aos Grandes Eixos." https://app.bczm.ufrn.br/home/#/item/115698. (in Portuguese)