HOW URBAN STRUCTURE CONSTRAINTS SUSTAINABLE MOBILITY CHOICES: COMPARISON OF COPENHAGEN AND OPORTO

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ABSTRACT

Urban passenger mobility has undergone significant changes over the past few decades with travel patterns becoming increasingly complex and difficult to predict and manage. From the variety of constraints and motivations influencing travel behaviour, land use and transport systems are believed to offer the baseline exogenous conditions steering travel patterns. Land use raises the need to move in order to participate in disperse urban activities, while the transport system provides the conditions to satisfy these mobility needs. There is an extensive discussion in the literature on the interaction of land use and transport and of their combined influence on mobility patterns. This vast but somehow disarticulated research field has been, so far, unable to built consensus. A number of authors have found inconclusive results while others have found statistically relevant influence within particular circumstances. Several authors have discussed methodological issues within this research field. There is clearly a need for further research in order to shed light on the intricate web of forces between urban structure and travel behaviour to encourage practical implementation of integrated land use and transport policies.

This paper discusses the influence of different metropolitan structures on the mobility choices available to their inhabitants. The Structural Accessibility Layer (SAL), developed at our research centre, analyses current land use and transport conditions of two distinct metropolitan areas – Greater Copenhagen and Greater Oporto. This analysis reveals the sustainability of mobility choices made available by each urban structure. Our results also provide evidence of the influence of land use and transport on mobility patterns. Furthermore they clearly reveal the influence of these two particular urban structures on sustainable travel behaviour, exposing their advantages and disadvantages.

Keywords: urban structure; mobility choices; diversity; density

INTRODUCTION

There is an extensive discussion in the literature on the influence of urban structure on mobility patterns; in other words, the influence of land use and transports on travel behaviour. The research is based on the theory of 'derived demand'. People are considered to travel to reach activities necessary to fulfil their needs. Within this context, travel constitutes a mean to achieve an end, participate in activities. Utility-based theories are frequently used to explain the choice to travel; travel will only be engaged when positive utility of the participation in the pursued activity exceeds the disutility of travelling (generally expressed in time and money spent). Within this theory, land use and transports have considerable influence since spatial structure affects both activity utility and travel disutility.
From the several research fields, concerning this topic, the study of the influence of land use on urban mobility is by far the most developed. Most publications present the results of case studies evaluating the influence of land use on travel behaviour. The majority of these case studies searched for the main land use factors influencing travel choice, with a considerable proportion also considering households characteristics and even some transport system characteristics (included as spatial structure variables) although, frequently, no analyses of the influence of the latter variables was included. Other publications present broad literature reviews complementing the results found in the case studies reviewed (Handy, 1996; Ewing & Cervero, 2001; Wee, 2002). 'The volume of literature on how land-use patterns and built environment influence urban travel demand has exploded over the past decade' (Cervero, 2002; pp. 265). Besides case studies and literature reviews, considerably less research was found on land use policy implications and recommendations.
It is fair to say that within this research field most authors believe that land use has influence on travel behaviour (e.g. Handy, 1996; Cervero & Kochelman, 1997; Ewing & Cervero, 2001; Wee, 2002) although many are sceptic of the identified factors mainly because of research methodologies, including conditions and constraints in which case studies are developed. Many case studies have not produced conclusive results (e.g. Cervero, 1995; Boarnet & Craine, 2001; Handy & Clifton, 2001) reinforcing the scepticism of the influence of land use on travel choice. Usually these studies evaluate a limited set of variables, which may, in fact, not be the most indicated for the intended purposes.
Even within those authors believing that land use characteristics influence travel behaviour there is considerable scepticism on the effect of land use policies and their contributions to sustainable urban mobility. The lack of research on the land use policy effect has encouraged these doubts. Several authors (e.g. Handy, 1996; Van & Senior, 2001; Wee, 2002) have argued that besides studying the potential land use factors influencing travel behaviour there is also a need for research on how this knowledge can be used to provide land use policies. It is important to evaluate the potential travel behaviour change due to land use characteristic changes (Van &Senior, 2001). '[…] finding a strong relationship between urban form and travel patterns is not the same as showing that a change in urban form will lead to change in travel behaviour, and finding a strong relationship is not the same as understanding that relationship' (Handy, 1996; pp. 162). Even if policy actions on land use characteristics could be understood. There is scepticism that when used in isolation of other measures, these could effectively contribute to sustainable mobility patterns in urban areas (Crane & Scweitzer, 2003). Wee (2002) argues that although acting on land use factors is a

necessary condition for travel behaviour change, it is not sufficient. Besides the fact that land use policies are generally a very slow-acting instrument, land use factors are interconnected and present mutual influence between each other and, more important, with factors of personal and transport characteristics (Kitamura *et al.*, 1997; Wen & Koppelman, 2000). Some authors believe that socio-economic characteristics have higher levels of influence on travel behaviour than land use factors (e.g. Handy, 1996; Stead *et al.*, 2000).

Within the analysed bibliography, relating travel behaviour and the available transport system, most studies evaluated attitudes towards and/or the effect of TDM (Travel Demand Management) measures or simply presented TDM measures and their categorization. Few studies were found considering the influence of household characteristics and/or land use, simultaneously with transport system, in travel behaviour. Excluding some scarce considerations of transport system characteristics as built environment characteristics in case studies evaluating the influence of land use on travel behaviour, no studies have been found evaluating the influence of the available transport system on travel behaviour, nor the main factors of transport system influencing travel choice. Knowing that the main research is based on the evaluation of TDM measures, it is reasonable to believe that the influence of the transport system is considered as a fact.

This vast but somehow disarticulated research field has been, so far, unable to built consensus. A number of authors have found inconclusive results while others have found statically relevant influence within particular circumstances. There is clearly a need for further research in order to shed light on the intricate web of forces between urban structure and travel behaviour to encourage practical implementation of integrated land use and transport policies. Although the influence of urban structure on travel is not made clear by current research it is clear that land use and transport systems offer the baseline exogenous conditions steering travel patterns. Land use raises the need to move in order to participate in disperse urban activities, while the transport system provides the conditions to satisfy these mobility needs. Other aspects, such as socio-economic and demographic characteristics, lifestyles, cultural backgrounds and energy issues further influence travel behaviour. Nevertheless, if the urban structure does not provide the necessary conditions to enable mobility to be sustainable then policy actions on other fields have only limited potential. Focussing on the ability of local planning to contribute to sustainable travel behaviour this research centres its attention on the land use and transport system. Indeed, the need for the integration of land use and transport policies has been recognized by several authors (e.g. Banister, 1994a,b; Cervero, 2003; Halden, 2002; ISIS, 1999; Stead, 2003; Wegner and Fürst, 1999). Integrated land use and transport policies can provide the necessary (albeit not sufficient) conditions for sustainable mobility patterns, without which complementary policy actions would have limited to no effect. Although recognising that land use and transport factors are certainly not the most important factors influencing travel behaviour, these can be more directly worked out by local planning instruments. More specifically, this research focuses on how the urban structure enables or disables travel choice, i.e. how urban structure constraints mobility into a range of potential mobility choices. *Potential mobility* (Silva and Pinho, 2010) is defined as mobility choices enabled by the land use and transport system. The research on how urban structure constraints travel behaviour into a range of potential mobility choices is an underdeveloped study topic in the context of a vast literature on the influence of land use and transport systems on travel behaviour. The research on how urban structure influences travel behaviour is focussed on how mobility choices are shaped by urban structure (for a review see, Ewing and Cervero, 2001; Handy, 1996; Silva, 2008; Stead *et al*., 2000; and Wee, 2002) while the research on how urban structure constraints travel behaviour aims to understand what mobility choices are made available by urban structure.

This paper uses the Structural Accessibility Layer (Silva, 2008; Silva and Pinho, 2010) to study how different urban structures constraint different mobility choices by comparing potential mobility provided by two metropolitan structures, namely Greater Copenhagen (Denmark) and Greater Oporto (Portugal). The Structural Accessibility Layer (SAL) uses the concept of *structural accessibility* (Silva and Pinho, 2010) to measure how urban structure constraints travel choices clustered into a range of potential mobility choices, with regard to mode choice. We argue that the comparison of mobility choices made available by these different urban structures (potential mobility) and the confrontation of these results with real mobility patterns in each case study, reveals new relevant insight on the role of urban structure in travel behaviour.

This paper discusses the relevance of urban structure and the role of urban planning in mobility management. The next sections provide a brief presentation of the SAL (for more detail see Silva, 2008) followed by its application to Greater Oporto and Greater Copenhagen. The following section presents the results of this application identifying the current accessibility conditions of each study area. These results are then compared to real mobility patterns of each study area. The paper ends with a brief discussion around the influence of particular urban structures on the sustainability of mobility choices.

STRUCTURAL ACCESSIBILITY LAYER

The Structural Accessibility Layer (SAL) provides a geographical representation of comparative accessibility levels by types of transport modes to different types of travel generating opportunities (Silva, 2008). This tool is based on the concept of Structural Accessibility (Silva and Pinho, 2010) assessing how urban structure constraints travel choices. By urban structure we refer to the land use and transport system. This tool uses activity-based accessibility concepts (for a review see Geurs and Eck, 2001), analysing the ability to reach the main travel generating activities from a given origin, i.e. analysing how the urban structure enables or disables people to fulfil every-day travel needs and what choices they have to fulfil those needs. Thus, structural accessibility reveals which travel choices are made available to inhabitants by the urban structure, in what could be referred to as potential travel behaviour.

More specifically, the SAL concerns the spatial distribution of opportunities as well as the availability and service level of different transport modes. The SAL includes two main accessibility-based measures: the diversity of activity index and the comparative accessibility measure (the accessibility cluster).

The diversity of activity index (DivAct) is an aggregate measure of accessibility to several activities. It measures the accessibility level by each transport mode (non-motorized, public transport and car), counting the number of activity types that one can reach from a given origin, within the number of activity types most relevant for travel demand generation. The results of the diversity of activity index range from 0 (no accessible activities) to 1 (all considered activities are accessible) for each transport mode. This index is measured and geographically represented at a high spatial disaggregation level, with the study area divided into several small sub-areas. A map is produced for each transport mode representing the diversity of activity index of each sub-area by a colour scale, according to accessibility levels available to an inhabitant of the sub-area. These geographical representations provide an overview of small scale variations of accessibility levels to the diversity of activities by each transport mode.

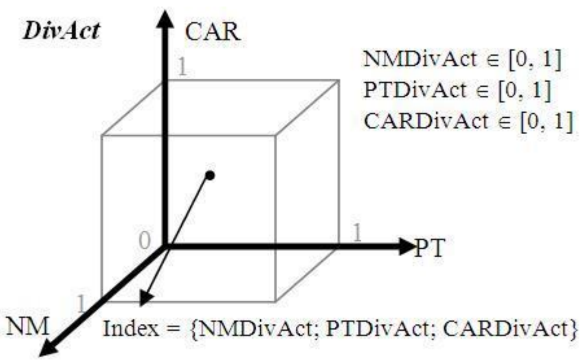

Figure 1: Potential combinations of accessibility values by three transport modes

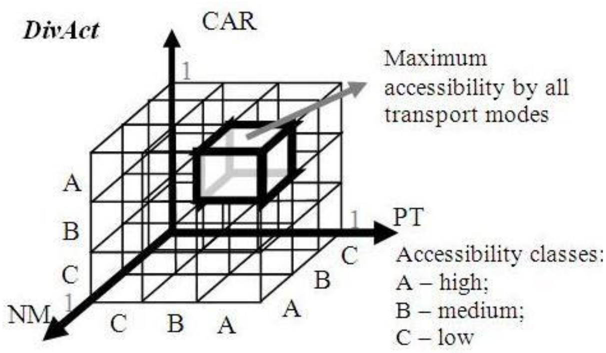

Figure 2: Benchmarking cube and accessibility classes by transport mode

The comparative accessibility measure uses the results of the previous index to develop the comparative analysis of accessibility by transport modes, identifying the mode choices made available to inhabitants by local land-use and transport conditions. This measure is made operational by the benchmarking cube, dividing the full range of accessibility levels by the three transport modes (Figure 1) into a limited number of categories and clusters (Figure 2). Accessibility categories result from the division of the range of accessibility levels by each transport mode into three accessibility classes: high accessibility level (class A); medium accessibility level (class B); and low accessibility level, (class C). The use of accessibility classes aims to simplify the analysis limiting the individual accessibility levels to 27 different categories, corresponding to the 27 possible combinations of accessibility classes by each transport mode. Accessibility class limits are defined, for each application, according to local perceptions of minimum accessibility requirements for each class.

The 27 accessibility categories are grouped into 9 accessibility clusters (see Figure 3)[1]. Each cluster aggregates land use and transport conditions favouring the use of the same transport mode (or modes). The use of a particular transport mode is considered to be favoured by land use and transport conditions when accessibility levels by that particular transport mode are perceived to be high (class A), i.e. when an acceptable range of activities can be reached making its use competitive in comparison to the other modes.

Land use and transport conditions unable to provide high accessibility levels by any transport mode are grouped into clusters VIII and IX according to the highest level of accessibility provided.

It is essential to point out that SAL is highly adaptable to local conditions and perceptions of accessibility. Therefore, to make SAL operational, several aspects have to be locally defined.

[1] The figure represents three slices of the same benchmarking cube to provide a clear view of all categories and clusters.

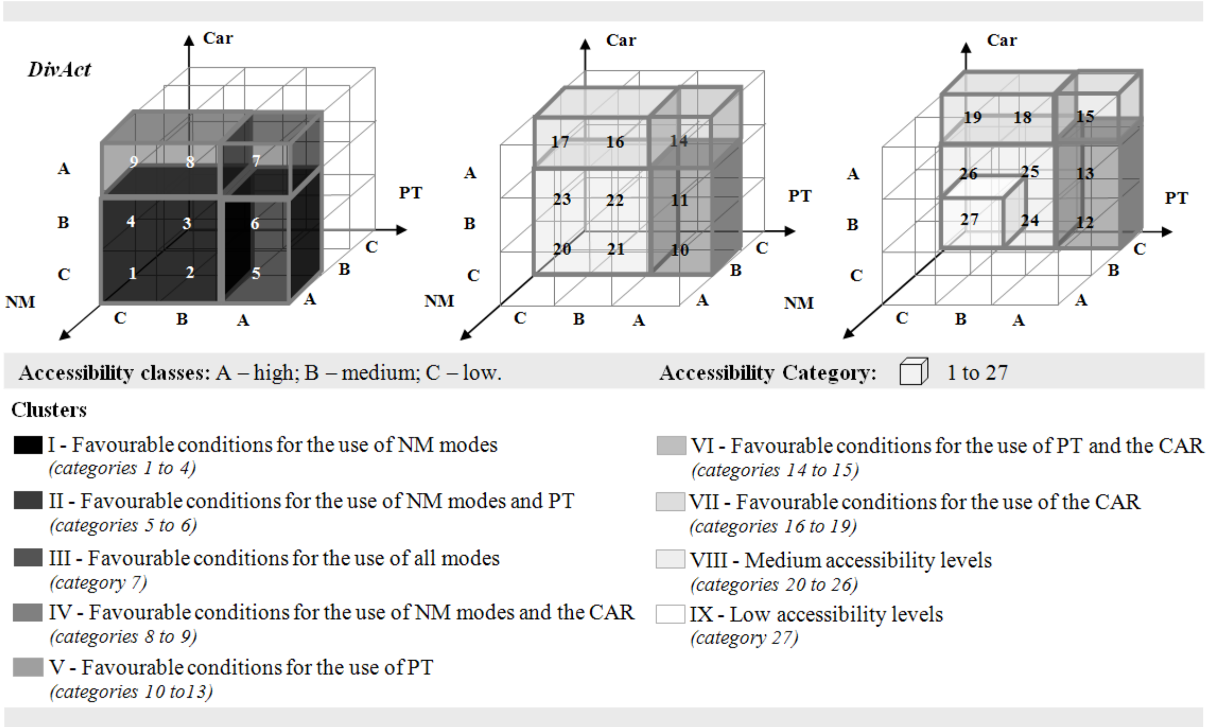

Figure 3: The benchmarking cube and accessibility clusters

CASE SPECIFIC APPLICATION

A number of choices are required for the application of the SAL to any case study. This section summarizes the main case-specific choices made for the application to Greater Copenhagen and to Greater Oporto.

Both case applications use a highly detailed spatial scale, with sub-areas of about 0.06km^2. This enables high detail of spatial variations in accessibility conditions provided by the land-use and transport system. For Greater Copenhagen, sub-areas where defined based on a 250x250m grid while Greater Oporto was disaggregated into census track sub-areas.

The application of SAL considered a broad list of travel generating activities, namely, employment, schools, leisure, shopping, healthcare and other activities. These activity types were disaggregated into a different number of activities in each case study – a total of 18 activities in Oporto and 15 activities in Copenhagen – due to constraints of statistical data in each country.

The transport modes considered for each transport mode type are walking and bicycle for non-motorized modes, public and private collective transport (including road and rail) for public transport modes and the private car for car transport modes. Among non-motorized modes, only walking was considered for Greater Oporto; bicycles were not considered since local data on road slope was not available and the use of this transport mode is to a far extent insignificant in Oporto. In these conditions, the bicycle was excluded from the analysis of non-motorized modes for this case study.

With regard to cut-off criteria, all three transport mode types use the criterion of total travel time, based on average travel time for each transport mode. Regarding the boundaries of accessibility by public transport, further detail was used, considering not only travel time, but

also walking time at entrance and exit of public transport system, the number of acceptable interchanges, the acceptable walking distance at interchange, the acceptable waiting time at interchange, and the total time from entrance to exit of the public transport system. The travel time cut-off values used for the definition of accessibility boundaries were, then, 20 minutes for non-motorized modes; 45 minutes for public transport and 30 minutes for the car.
Finally, accessibility classes were defined for the following values of diversity of activity index:

- class C (low accessibility): ranging from 0 to 0.5
- class B (medium accessibility): from 0.5 to 0.85 in Oporto and from 0.5 to 0.9 in Copenhagen
- class A (high accessibility): from 0.85 to 1 in Oporto and from 0.9 to 1 in Copenhagen.

The choice of the two values working as threshold of the three classes (0.5 and 0.85 in Oporto and 0.5 and 0.9 in Copenhagen) was based on the case-specific diversity of activity index (activity types chosen and the potential frequency of use of each activity type). Considering that the accessibility class A should be as narrow as possible, its lower limit was defined based on the cumulative value of the potential frequency of use of each activity type not considered to be necessary at local level. The value of diversity of activity index of 0.5 was found to be an acceptable upper limit for low accessibility levels in both the case studies.

POTENTIAL MOBILITY

Greater Copenhagen and Greater Oporto

Greater Oporto and Greater Copenhagen are considerably different. Despite being similar both in area and in population – Greater Oporto is 540 Km^2 wide and holds about 1.1 million inhabitants, while Greater Copenhagen has an area of 560 Km^2 and 1.2 million inhabitants (Table 1) – these two areas have quite different patterns of urbanization. The metropolitan structure of Copenhagen is clearly marked by land use and transport policies during the second half of the 20th century – notably the 'Finger Plan'[2] – resulting in a monocentric structure with high concentration of population and employment in the city core and a radial pattern of development along five 'fingers'. However, signs of a polycentric decentralization process can be seen today in Copenhagen, where several secondary centralities concentrating population, employment and activities can be found all across the metropolitan area, mainly around suburban railway stations. Greater Oporto, on the contrary, has historically a polycentric urban structure, related to the location of industrial activities. Today it shows a high concentration of jobs in the city centre, but is experiencing a process of population and employment decentralization towards the surrounding municipalities. Oporto has a more complex urban structure with a strong centre but a more sprawled urbanization

[2] The 'Finger Plan' is a land use plan for the metropolitan area of Copenhagen, whose first version dates back to 1947. It suggests an urban pattern with a form of a hand in which the 'palm of the hand' – central Copenhagen – should remain the principal regional centre, concentrating most of the jobs and services, while new urban development should be concentrated in the five 'fingers', along the existing radial commuter railway. Between these fingers, the land would remain undeveloped in favour of farmland and forest.

pattern – frequently emerging along the road network - and strong second order centres mainly due to administrative factors. The structure of centralities is not as evident as in Copenhagen when we look at the geographical distribution of population, employment or activities. The spatial distribution of population density in the two study areas (Figure 4) clearly illustrates the different urban patterns of Oporto and Copenhagen.

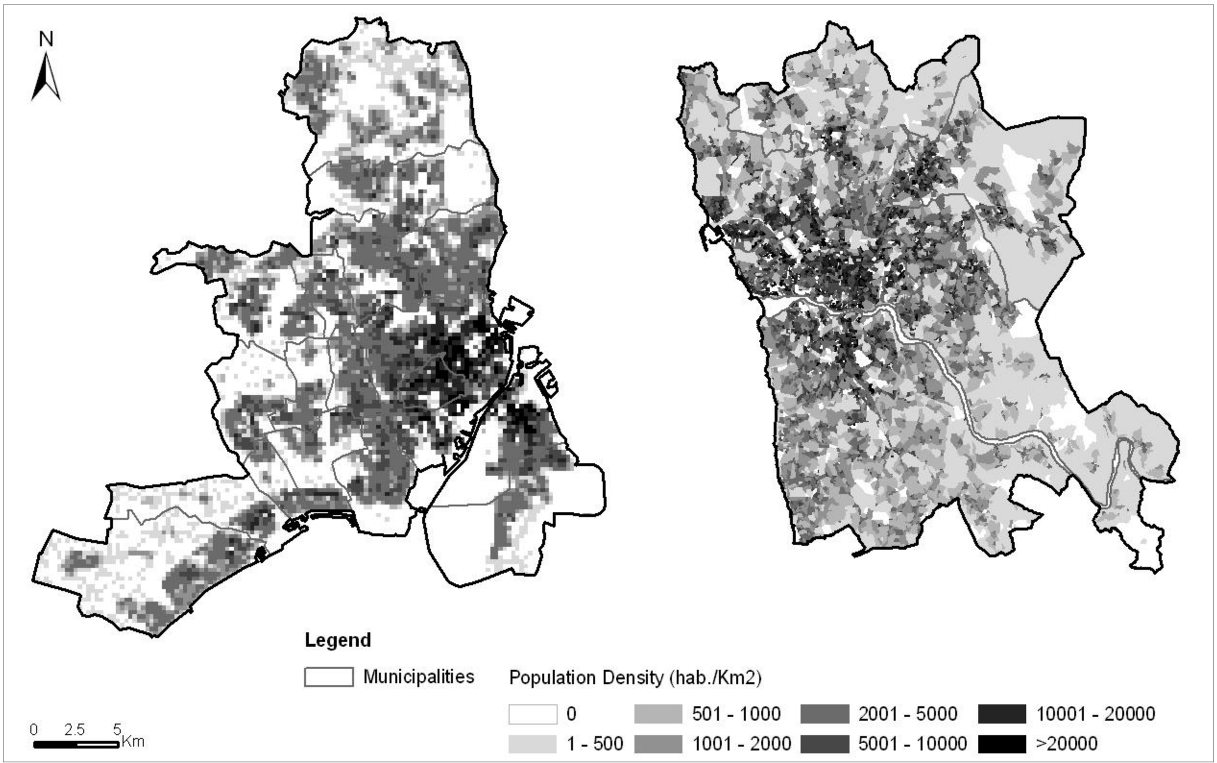

Figure 4 – Population density in Greater Copenhagen and Greater Oporto (1:450000)

In addition, lifestyles in these two cities are also very different and this fact has mobility implications, namely in the distribution of trips per purpose and in the modal split. The importance of trips related to leisure and shopping is higher in Copenhagen, whereas in Oporto there is a higher proportion of trips related to work and education. People in Oporto use the car more often, as well as public transport; while the proportion of trips by non-motorized modes is higher in Copenhagen, mainly the use of the bike - which is almost nonexistent in Oporto (see Table 1).

Moreover, the transport infrastructure is also different in the two study regions. Copenhagen's public transport network is mainly based on a radial railway system complemented by a wide bus network. There are also both radial and circular motorways. Oporto has a denser motorway network, with several radial and circular routes. Public transport is mainly based on bus. There is also a radial railway network including suburban train and the recently-built Metro system. This network is however mainly radial and, in Oporto municipality, limited to the city centre.

Table 1 - Some land use and transport characteristics of the two study regions

Greater Copenhagen		**Greater Oporto**
1.2 million	Population	1.1 million
542 Km2	Area	563 Km2
2215 hab/Km2	Average population density	1936 hab/Km2
Car: 42.9 Pub. Transport: 11.2 Walking: 21.4 Cycling: 23.2 Others: 1.3	Modal split (%)	Car: 47,6 Pub. Transport: 26,2 Walking: 20,2 Others: 6,1

SAL results

Figure 5 presents the spatial representation of the levels of accessibility by foot in Greater Copenhagen and Greater Oporto, while Table 2 provides an overview of the results of the SAL, by the levels of accessibility and by different transport modes.

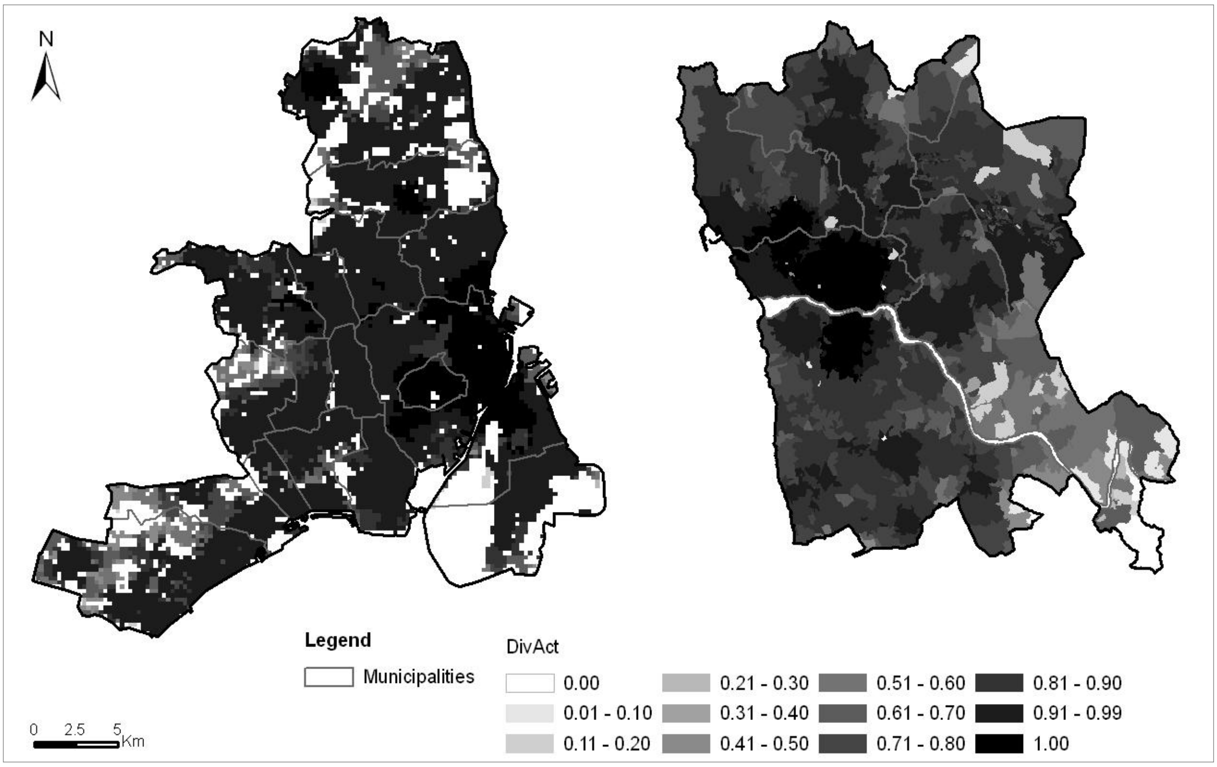

Figure 5 – Levels of accessibility by walking in Greater Copenhagen and in Greater Oporto (1:450000)

A first analysis of the map shows that most of Greater Copenhagen's territory presents high levels of pedestrian accessibility (class A). According to Table 2, these areas concentrate the great majority of the population: more than 93% of the inhabitants live in areas with high accessibility conditions, 38% of them live in areas with pedestrian accessibility to all activities

considered (DivAct=1). On the other hand, low accessibility areas (class C) have almost no population: only 0.2% of Copenhagen's inhabitants.
In Oporto, the map shows almost no area with low accessibility levels (class C) and a more or less even distribution of high and medium accessibility levels. However, the large majority of the Greater Oporto's inhabitants (78%) lives in good accessibility conditions by non-motorized modes, while less than 22% live in medium accessibility conditions (see Table 2).
Both Oporto and Copenhagen show the highest levels of accessibility by foot in their centres and, at the same time, there are in both cases several peripheral areas also with high accessibility levels. In Copenhagen, these areas correspond to a few peripheral centres, mainly to north and to west. In Oporto high accessibility conditions can be found along several corridors stretching north and east; and also to the south, with a more scattered pattern stretching south from Oporto municipality.

Table 2 – Accessibility levels in Greater Copenhagen and in Greater Oporto

	Greater Copenhagen (% of 1.201.390 inhabitants)				**Greater Oporto** (% of 1.089.118 inhabitants)		
Class	NM (walking)	NM (bicycle)	PT	CAR	NM (walking)	PT	CAR
A *DivAct=1*	93.3% *37,8%*	99.9% *80.4%*	94.6% *73,0%*	100.0% *100.0%*	77.6% *25.2%*	83.4% *71.2%*	100.0% *98.1%*
B	6.5%	0.0%	0.1%	0.0%	21.3%	1.7%	0.0%
C *DivAct=0*	0.2% *0,0%*	0.1% *0,0%*	5.4% *5.4%*	0.0% *0.0%*	1.1% *0.0%*	15.0% *15.0%*	0.0% *0.0%*
Average regional level[3]	0,97	1,00	0,95	1.00	0.91	0.84	0.99

The accessibility levels by walking provide a comprehensive picture of the structure of centralities in a metropolitan area. In Greater Copenhagen, sub-areas with high levels of accessibility to activities can generally be found either around the city centre or along the 'fingers'. The existence of these high accessibility areas located along railway lines reveals a rather good coordination between land use and transport policies (notably the 'Finger Plan'), following the principles of a transit-oriented development. In Greater Oporto, on the contrary, the outline of the main urban centres seems to be strongly related to traditional urban agglomerations along the main national road network (excluding motorways). While to the north these agglomerations are closer together forming urban corridors instead of centres, urban development has been more disperse to the south.
Moreover, the analysis of the spatial distribution of accessibility levels together with population density (Figure 4 and Figure 5) suggests a close relationship between density and pedestrian accessibility: areas with higher population density normally match the places with better accessibility conditions. Table 3 supports this observation, showing much higher

[3] The regional average diversity of activity is an average of diversity of activity of each sub-area weighted by population of each sub-area.

values of population density in areas with high accessibility by foot (class A), both in Oporto and in Copenhagen. This correlation between population density and accessibility to activities is indeed widely supported by both theoretical and empirical literature (Cervero and Kockleman, 1997; Kenworthy and Laube, 1999; Stead *et al*., 2000, among others).
Whereas the results both in Oporto and in Copenhagen hold for this positive correlation between population density and level of accessibility to activities, the exercise of comparing these two areas is not that linear. Despite having fairly similar population densities (slightly higher in Copenhagen) the average regional level of pedestrian accessibility is significantly higher in Greater Copenhagen (0,97), when compared to Greater Oporto (0,91). In Copenhagen there is also a higher share of population (93.3%) with high level of pedestrian accessibility to activities than in Oporto (77.6%). Furthermore, sub-areas with high accessibility conditions represent 64% of the Greater Copenhagen's surface, while in Oporto these areas are less than half of the territory. Even higher differences appear when we analyse the remaining accessibility classes. In Oporto, almost half of the territory has medium accessibility conditions while in Copenhagen the proportion of class B sub-areas is only 15% of the surface. Conversely, low accessibility areas are only 8% of Greater Oporto's territory, while in Copenhagen more than 20% of the region does not provide satisfactory accessibility conditions. This means that accessibility levels in Oporto are more homogeneous, while in Copenhagen there is a wider gap between high and low accessibility areas. The same happens when looking at the population distribution. In Oporto the proportion of inhabitants with medium levels of accessibility is higher than in Copenhagen (21.3% in Oporto against 6.5% in Copenhage, see Table 2).

Table 3 - Population density by classes of pedestrian accessibility

Greater Copenhagen	Accessibility by walking	**Greater Oporto**
Population density (hab./Km^2)		Population density (hab./Km^2)
3232	Class A	3461
940	Class B	849
180	Class C	261
2218	Average	1936

These effects reflect different patterns of urbanization in these two metropolitan areas, in part as a result of different planning traditions, and they suggest that, even though there is a link between higher population densities and higher levels of pedestrian accessibility, there are other structural factors influencing the accessibility conditions in a metropolitan area. In Oporto, for instance, population is more scattered throughout the urban area, making it more difficult to locate a wide variety of activities closer to a larger number of households. Activities in Oporto are also more scattered resulting in more homogeneous levels of accessibility. In Copenhagen, on the other hand, efficient land use and transport policies during the past decades provided for a more balanced location of population, jobs and activities, resulting in a pattern of 'concentrated decentralization' of the Copenhagen Metropolitan Area. This means that population is concentrated around several centralities all over the metropolitan region, making it possible for activities to locate closer to the places where people live and, therefore, providing better pedestrian accessibility conditions. Considering that most of these centralities are located in the vicinity of railway stations, the Copenhagen's urban pattern is not only capable of providing good conditions for walking, but it may also facilitate the use of public transport, promoting sustainable travel behaviour.

In the Copenhagen case study, levels of accessibility were also calculated considering the bicycle as the non-motorized transport mode. The results show that practically all residents (99,9%) live in sub-areas with high accessibility conditions, and 80% of the inhabitants have accessibility to all activity types considered (see Table 2). Moreover, Greater Copenhagen presents the maximum value (1.00) for the regional average level of accessibility by bicycle. Comparing these results with the levels of accessibility by walking, we can conclude that, although pedestrian accessibility is already quite high, the conditions of accessibility to activities by non-motorized modes in Greater Copenhagen improve significantly when the bicycle is considered. We may argue that the Greater Copenhagen has a great potential for its residents to use non-motorized transport modes in their daily mobility patterns. However, we must bear in mind that accessibility by bicycle does not substitute the importance of the analysis of pedestrian accessibility, mainly the accessibility to everyday needs, because not everyone has the ability (for reasons of health, age, etc) to use a bicycle.

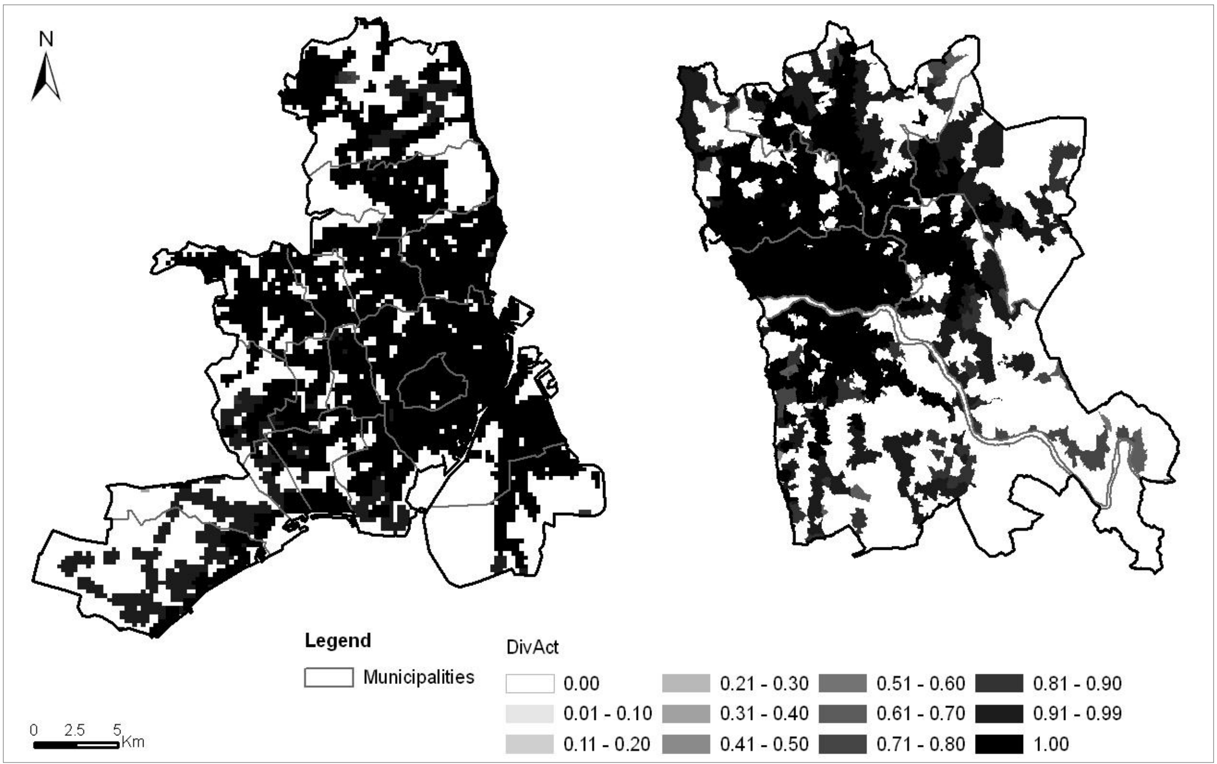

Figure 6 - Levels of accessibility by public transport in Greater Copenhagen and in Greater Oporto (1:450000)

With regard to accessibility by public transport, both study areas present fairly similar results. Both in Greater Copenhagen and Greater Oporto, the highest accessibility conditions can be found in the metropolitan centre and along the main public transport routes (see Figure 6). The geographical distribution of the accessibility levels by public transport clearly marks the spatial distribution of public transport availability. Although a large part of the surface of Greater Copenhagen and Greater Oporto has no access to public transport service, these territories only concentrate a small proportion of the overall population (5.4% in Copenhagen and 15% in Oporto). The great majority of the inhabitants - 95% in Copenhagen and 83% in Oporto live in areas with high accessibility conditions. The average value of accessibility levels by public transport is also higher in Copenhagen (0.95 against 0.85 in Greater Oporto). Accessibility levels by car are also similar in the two studied regions. Both in Oporto and in Copenhagen all the population live in areas with high accessibility conditions to all activities considered, and these territories represent almost the entire study areas (see Table 2 and Figure 7). Average accessibility levels by car of 1,00 in Greater Copenhagen and of 0.99 in Greater Oporto come, then, with no surprise.

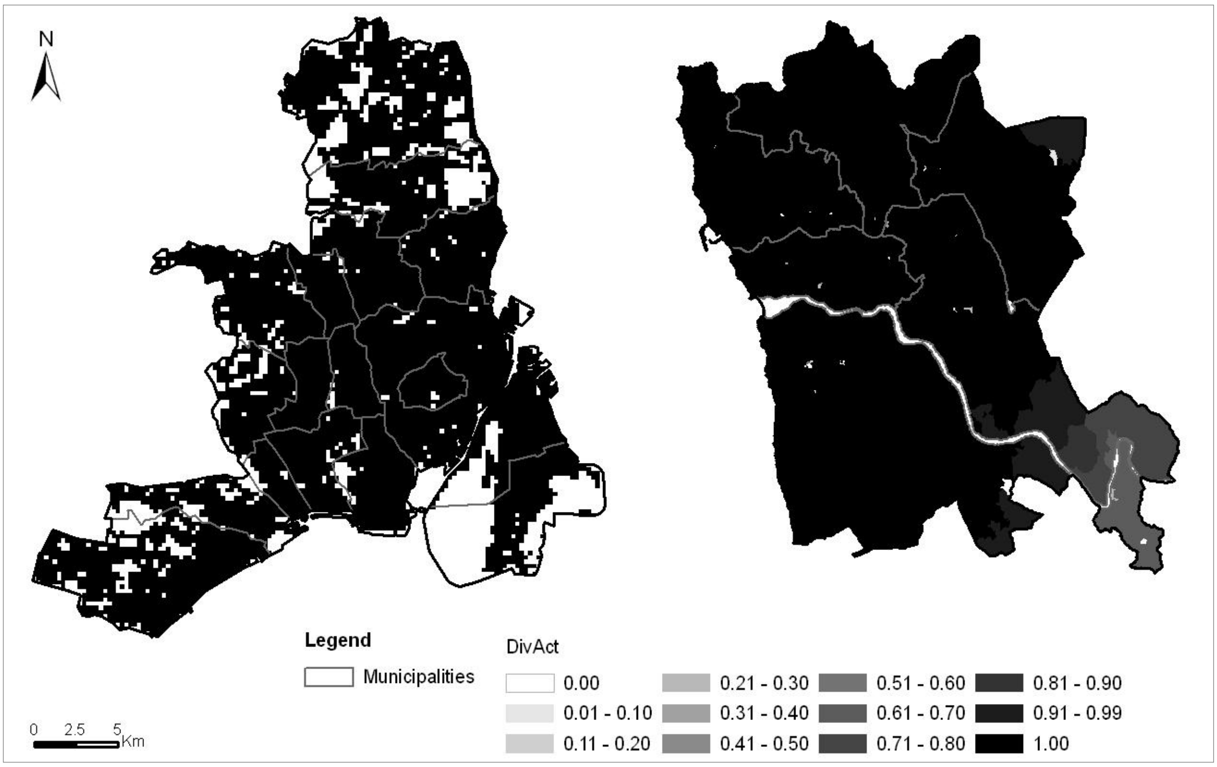

Figure 7 – Levels of accessibility by car in Greater Copenhagen and in Greater Oporto (1:450000)

The final part of this section concerns the comparative analysis of accessibility clusters for the two study regions. In both case studies, areas within cluster III (high accessibility by all transport modes) normally match the territories with high pedestrian accessibility. In Copenhagen these areas are generally located in the city centre as well as in the second order centres, along the ‘fingers’. Sub-areas with favourable conditions for car and PT use (cluster VI) are normally located in peripheral territories along the main public transport routes. Sub-areas with favourable conditions for walking and car use can usually be found in the vicinity of cluster III territories, corresponding to places further away from PT stops (see Figure 8).

In Oporto the picture is somewhat different, as sub-areas with favourable conditions for the use of all modes tend to be more centralized in Oporto municipality and its closest periphery. There is a first ring around this central area corresponding to sub-areas in cluster VI (mainly to the north and to the south) and cluster IV (mainly to the East). Territories that only favour car use are normally located in the more peripheral parts of Greater Oporto. There are however some exceptions to this tendency, notably in the North (with high accessibility by all

transport modes) and also some territories in the southern part of Greater Oporto, with more scattered sub-areas belonging to clusters III and IV (Figure 8).
Both in Oporto and in Copenhagen most of the population lives in sub-areas with favourable conditions for the use of all transport modes and the proportion of residents living with favourable conditions just for car use (cluster VII) is rather limited (see Table 4). However, conditions in Copenhagen are better, with almost 90% of its residents living in areas providing favourable conditions for the use of all modes (against 71% in Oporto), while less than 1% of Copenhagen's population lives with favourable conditions for car use only (in Oporto this share is 9.8%).
Regarding the proportion of territory, the results are similar: both cities present positive results but conditions in Copenhagen are better. Sub-areas in cluster III represent 54% of Greater Copenhagen and 32% of Greater Oporto's territory. On the other hand, 41% of the Greater Oporto corresponds to sub-areas in cluster VII (car favourable conditions), while in Copenhagen this territories are less than 30%.

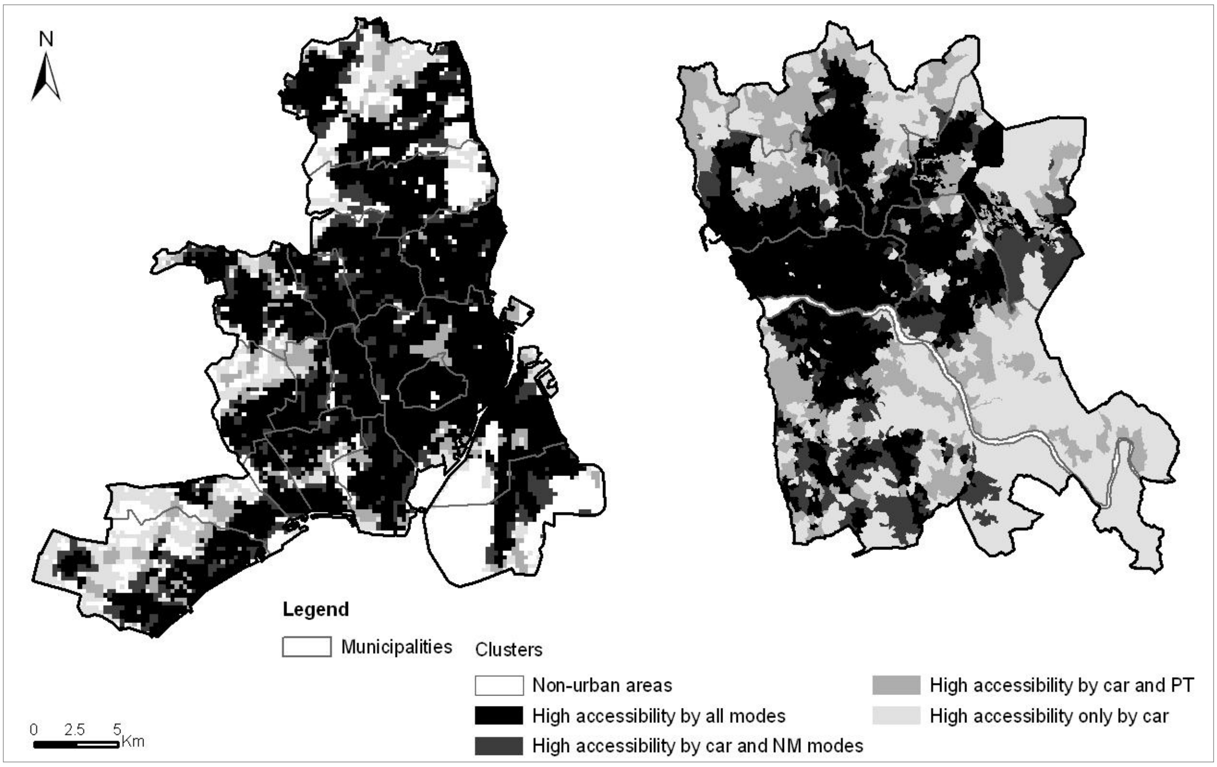

Figure 8 – Clusters of accessibility in Greater Copenhagen and in Greater Oporto (1:450000)

Similar to what happened with pedestrian accessibility, there is a positive correlation in both study areas between density and accessibility, with territories with high accessibility conditions by all transport modes clearly presenting the highest levels of population density, opposite to sub-areas with high accessibility only by car. However, as referred before, population density by itself does not explain the huge differences in accessibility conditions between the two case studies.
On average, Oporto falls into accessibility cluster IV, with high accessibility by car and non-motorized modes and medium accessibility by public transport modes, while Copenhagen has on average high accessibility conditions by all modes (cluster III, see Table 4) Therefore, we can argue that the two studied regions already provide good conditions for the use of

non-motorized modes, namely by walking and to a higher extent in Greater Copenhagen. Moreover, if we consider travelling by bicycle in Copenhagen, the level of non-motorized accessibility will be much higher (with a regional value of 1.00). On the other hand, Greater Oporto does not provide acceptable levels of accessibility by public transport yet, which offers a clear advantage for car use and therefore for non-sustainable travel behaviour.

Table 4 – Population and population density by accessibility clusters

	% Population		Population density (hab./Km^2)	
Clusters	Copenhagen	Oporto	Copenhagen	Oporto
III	88.5%	70.7%	3670	4263
IV	4.8%	6.8%	1006	1175
VI	6.0%	13.8%	1841	1435
VII	0.7%	8.7%	147	443
Regional average population density			2218	1936

REAL VS POTENTIAL MOBILITY

The Copenhagen's pattern of concentrated decentralization appears to provide accessibility conditions with potential to encourage more sustainable travel patterns, by promoting both non-motorized and public transport use. This idea is supported by the proportion of population with favourable accessibility conditions by sustainable modes, which is always higher in Copenhagen.

However, it is important to assess if this higher potential for sustainable mobility in Copenhagen actually corresponds to more sustainable travel behaviour of its residents. Table 5 compares two accessibility measures resulting from the SAL (proportion of population living in sub-areas with high accessibility conditions and average regional level of accessibility) with the real modal distribution of trips made by the residents of Greater Copenhagen and Greater Oporto.

In comparison to Oporto, the better conditions (in global terms) provided by Copenhagen's urban structure correspond to more sustainable travel behaviour in this study area, with a higher use of non-motorized modes and a slightly lower car use.

Whereas the better pedestrian accessibility conditions in Copenhagen are reflected in the higher share of travel by walking, the same relationship is not found when comparing mobility by public transport. Oporto residents tend to travel more often by public transport than their Danish counterparts, although accessibility conditions by this mode are considerably better in Copenhagen (see Table 5). Even though this might seem inconsistent, it is probably a reflex of the very different levels of bicycle use in these two cities. The much higher use of the bike in Copenhagen has two effects in travel behaviour that help to explain these results. On the one hand, if a new transport mode is available and if it has a high use (as it is the case of the bike in Copenhagen), modal shares of the other transport modes will automatically drop. On the other hand, literature shows that the bicycle, in particular, tends to compete with public transport. In any case, the car is by far the mostly used transport mode in both study areas, which is in accordance with the maximum levels of accessibility to activities by car found in both cities.

Table 5 - Comparison between accessibility conditions and real modal distribution

Greater Copenhagen			Transport mode	**Greater Oporto**		
Modal split[4]	Population with high accessibility	Average regional DivAct		Modal split[5]	Population with high accessibility	Average regional DivAct
24.1%	93.3%	0.97	NM (walking)	20.2%	77.5%	0.91
11.2%	94.6%	0.95	PT	26.2%	83.3%	0.84
42.9%	100%	1.00	CAR	47.6%	100%	0.99
23.2%	99.9%	1.00	NM (Bike)	-	-	-

For a more comprehensive picture of the relationships between potential mobility and actual travel behaviour across Oporto's and Copenhagen's urban areas, the remaining part of this section will focus on the comparison between results of the SAL and real mobility patterns, collected through a survey carried out in a set of 17 investigated areas in Greater Copenhagen and 11 investigated areas in Greater Oporto. These areas, distributed across the study areas, were chosen to represent diversified situations, such as different urban conditions, different metropolitan locations and contrasting public transport availability conditions, etc. (for more details see Pinho *et al*., 2010).

Table 6 summarizes minimum, maximum and average results of the weekday travel patterns, namely total travel distance, travel distance by car, by public transport, by non-motorized modes and mode shares for the car, for public transport and for non-motorized modes. According to this table, Danish respondents travel more kilometres from Monday to Friday than their Portuguese counterparts. However, Oporto residents travel, on average, a higher distance by car. Travel distances by non-motorized modes are much higher in Copenhagen, which is obviously a consequence of high use of bicycle in Copenhagen while in Oporto this mode is practically not used. The values regarding modal share are consistent with the data presented before for the whole study regions: car use is higher in Oporto, while in Copenhagen people tend to travel more often by non-motorized modes.

Furthermore, not only is mobility in Copenhagen higher than in Oporto (average travel distance is longer) but it is also more sustainable (distance by car is lower and there is a higher use on non-motorized modes). In other words, more sustainable travel patterns do not necessarily mean less mobility.

The analysis of the use of non-motorized modes in each investigated area of Greater Oporto and Greater Copenhagen produces, again, quite interesting results. In Oporto, the main city centre has by far the highest share of walking, representing almost half of the trips. The

[4] Number of trips by transport mode according to a travel survey carried out by DTU Transport (2006-2009). These data do not refer to Greater Copenhagen, but to a slightly different region corresponding to the municipalities of Copenhagen and Fredriksberg plus the former county of Copenhagen.

[5] Data concerning the number of trips per person by transport mode in Oporto in 2001, retrieved from INE. The values refer to the Metropolitan Area of Oporto.

proportion of trips by foot is also substantially high (between 13% and 20%) in areas located near second-order centres. All these areas provide high accessibility levels (class A). The remaining study areas have lower shares of NM modes which, in some cases, correspond to lower accessibility levels. Data concerning travel distance by NM modes are consistent with these results, with the area near the centre of Oporto presenting the highest travel length during weekdays (6.1Km). Respondents of study areas located near secondary centres also travel quite long distances, between 3.3 and 4.9 Km.
In Copenhagen, the highest use of NM modes can also be found in central areas, a couple of them having a proportion of trips by these modes over 50%. Along with this positive relationship between travelling by foot or bike and living close to the main metropolitan centre, some considerably high shares of NM modes use can also be found in outer parts of Greater Copenhagen, in study areas located near second order centres.

Table 6 - Travel behaviour in the AUM investigated areas (values referring to weekdays) and average levels of accessibility by walking (from SAL)

Greater Copenhagen				Greater Oporto		
Min.	Max.	Average[6]		Min.	Max.	Average[4]
84.1	221.8	142.4	Total travel distance (Km)	37.9	158.1	112.8
28.9	192.6	87.6	Travel distance by car (Km)	22.3	132.9	92.0
10.8	78.5	31.3	Travel distance by public transport (Km)	10.1	26.2	16.8
6.4	30.9	20.5	Travel distance by NM modes (Km)	1.5	6.1	3.7
22%	84%	49%	Car share	25%	77%	63%
6%	47%	20%	Public transport share	14%	32%	20%
6%	58%	30%	Share of non-motorized modes	4%	48%	15%
0.86	1.00	0.97	Average NM accessibility level (SAL)	0.33	1.00	0.95

The comparison between use of NM modes and diversity of activities is quite difficult, since, in Copenhagen, all the study areas are located in territories with high accessibility levels (DivAct higher than 0.9). However, study areas with higher shares of car use are located in zones with maximum pedestrian accessibility level (DivAct=1). Regarding travel distance, the results are consistent with the spatial distribution of NM modal share: respondents living in central areas travel on average longer distances on weekdays than those who live in more peripheral zones.
Summarizing, the comparison between the results of SAL and the actual amount of travel by NM modes in the two case studies suggests that there is a clear influence of urban structure

[6] Mean value weighted by the number of respondents in each investigated area.

on travel behaviour. In Greater Oporto, people living in the city centre and near the main second-order centres tend to travel more by foot. In Greater Copenhagen the levels of NM modes use are higher near the main metropolitan centre. Both the main centre and the second-order centres of Oporto and Copenhagen are generally located in areas with high levels of diversity of activities accessible by walking. In both case studies, investigated areas with the lowest proportion of car use are generally located near the main metropolitan centre. In Greater Oporto, a tendency to lower car use in the proximity of second-order centres is also observed, although to a lesser extent when compared to the influence of the main centre. All these study areas are located in territories with high levels of accessibility by foot, hence with accessibility to a high diversity of activities.
There are, however, some exceptions to this tendency: in both case studies there can be found specific investigated areas where car modal share does not seem to be related to any of the above mentioned structural characteristics. This finding stresses the idea that there are other non-urban structure related factors influencing travel behaviour to a similar or even higher extent. Concerning car use, income levels, socioeconomic condition and car ownership, are believed to be particularly relevant.
In conclusion, the comparison between the results of the SAL in these two metropolitan areas and the actual travel behaviour of their residents found considerable evidences of influence of accessible diversity of activities on travel distance and mode choice. In general, there is a tendency for people who live in areas with high activity diversity to travel more and more often by non-motorized modes and also to use the private car less. It is true that several other factors influence travel behaviour and that, in some cases, it is possible to find low use of walking and cycling or a high car use in areas where accessibility conditions are favourable. But we do not find high use of the more sustainable transport modes in areas where walking accessibility conditions are low. Providing favourable conditions for the use of these modes is therefore a necessary but not sufficient condition to achieve more sustainable travel patterns.
Moreover, the analysis carried out in this section also confirms the importance of other urban structure factors, namely the proximity to the main central places. Comparing areas with similar SAL accessibility conditions, the research found considerable differences associated to the location of those areas in relation to the metropolitan structure of central places. In Oporto, proximity to the main centre and to secondary centres is a rather important factor to achieve sustainable mobility; while in Copenhagen a central location relative to the whole urban area seems to be more relevant. This highlights the differences between these two cities, confirming our initial idea that Copenhagen has a more monocentric performance when compared to Oporto, which still is more polycentric.

CONCLUSION

Conceptually, SAL enables the study of the relationships between urban structure and travel behaviour. More specifically, the method provides a geographical representation of how urban structure, namely the spatial distribution of activities and transports, constraints travel choices and, specifically, mode choice. Therefore this method is able to study the influence of the location and diversity of activities (opportunities) on the model choice of residents. This application of SAL reached overall consistent and meaningful results for both case studies, confirming the usefulness of this method for the current analysis.

Results show that Copenhagen's urban structure provides more sustainable mode choice conditions than Oporto (both in proportion of area and served population). Development based on transit oriented development brought about by the famous *fingerplan* in Greater Copenhagen produced urban structures able to provide more sustainable mode choices to inhabitants, then dispersed developments in Greater Oporto that, although scattered around a traditional polycentric structure (the initial spatial matrix of Greater Oporto), seem to show inefficient and inconsistent planning controls, bound to serve private investment interests in detriment of a global and more sustainable territorial organization.

In addition, it is important to point out that results from both case studies corroborate a clear connection between local accessibility and local density. Areas with higher accessibility levels (diversity of activities) correspond to higher local densities (population).

Furthermore, it must be highlighted that, for similar areas and population, Copenhagen is able to offer larger areas of higher accessibility levels by slower modes than Oporto. While differences in served population can be explained by better organisation of the urban structure, differences in area result from higher concentration (density) of activities and a better geographical distribution. There are important differences between these two study areas. First, it is important to point out that Copenhagen is the capital of Denmark and that therefore there are some good reasons why, in the same territory and for the same population, more areas can be found with high accessibility levels then Oporto. Being a capital city, many more activities are likely to be concentrated there. Greater Oporto cannot expect to have the same amount of activities with high accessibility, in such a wide area, with less population. Also connected to this is the slight difference in terms of the respective mobility catchment areas. In Oporto, around 94% of trips are made within the study area, while in Copenhagen this proportion decreases to around 81%. Although in both cases the study area has an acceptable size for the analysis by SAL, this difference must be taking into consideration in the comparison of results.

Results from the application reveal that urban structure not only (passively) influences, but also (actively) constraints travel choices, enabling or limiting particular travel choices, and corresponding sustainability levels. For instance, people living closer to urban centralities tend to travel less while using more soft modes (non-motorized) in comparison to residents living far from these urban centralities. On the one hand, the behaviour of the former group is influenced by the presence of a variety of activities, within walking distance. On the other hand, the absence of these conditions prevents residents of the latter group from having a similar behaviour. It is important to point out that the presence of a variety of activities at walking distance is not sufficient to constraint resident's travel choices to non-motorized modes but it clearly has an influence on more sustainable choices. Concluding, it can then be said that the presence of favourable urban structure conditions for sustainable travel has an influence on behaviour towards more sustainable travel, and that the absence of such conditions restraints people from making sustainable mobility choices. Clearly, the absence of these conditions has a stronger effect on behaviour than the presence, although both effects co-exist.

It is important to go into more detail on the practical consequences of this finding for planning practice on two perspectives. First, when accessibility levels are high by all modes (and therefore all mode choices are available) the constraint role of urban structures is weak (unless there is political will to use it to limit the use of the car). In this case, the effect of other variables on travel behaviour is more independent of the effect of diversity. Second, the constraint to use sustainable modes by urban structure acting simply on increasing the accessibility by non-motorized modes is limited but, nonetheless, a first requirement. Differences between Copenhagen and Oporto show that Copenhagen offers more travel choices to people, with consequently, people travelling more but with increased mobility brought upon mainly by sustainable modes (as discussed before). Oporto has still to provide these conditions while Copenhagen is at a point where urban structure is about to fulfil its potential as a "carrot" for sustainable behaviour.

In summary, the SAL revealed, first, the importance of concentrating population around main centralities where high levels of diversity of activities are available and therefore accessible by several transport modes, including slow modes; and second, the importance of car restriction measures ("stick" measures) and of other non-urban structural measures when large proportion of the population already live within high accessibility levels by all modes. In addition it is important to highlight that the comparison of these case studies suggests that there is an effective relationship between potential mobility (mobility choices enables by urban structure) and real mobility. These results reveal the existence of a role for urban structure in sustainable mobility and therefore of urban planning in mobility management.

In conclusion, it is clear that urban planning has a role in mobility management. The role revealed by this research is the ability to constraint and influence travel choice. Whether consciously, or not, urban planning has this power over travel behaviour.

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