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URBAN STRUCTURES AND MOBILITY
A Case-study in Copenhagen

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ABSTRACT

During the last decades, European and North American cities have experienced population and employment decentralization. With this process, more and more trips have been transferred both from public transport and non-motorized modes to the private car, which has become the most used transport mode, leading urban mobility away from sustainability. This process, allied to the more recent concerns about environmental problems, such as the consumption of fossil fuels and the emission of greenhouse gases, have motivated the current debate about the sustainability of mobility patterns, notably the questions of energy efficiency in transport. In this context, achieving a less transport-demanding urban structure may be an important step to ensure a more sustainable urban development. This dissertation relies on the notion that urban structure influences daily mobility of individuals, considering that urban structure characteristics determine the accessibility of a destination. In this context, a question may arise: which type of urban structure enables a more sustainable mobility?

This question is extremely complex and it is currently at the centre of the debate, dividing the scientific community. The answers are not clear or consensual and there can be found several studies reaching contradictory conclusions. The main goal of this dissertation is to explore the relationship between urban structure and mobility patterns, with the purpose of contributing to the present debate on this issue. This dissertation encompasses a theoretical part concerning a literature review - which aims to enable a better understanding of the complex relationship between urban structure and travel behavior - and also the development of two case studies, in the metropolitan areas of Porto and Copenhagen. This research used an accessibility-based tool – the Structural Accessibility Layer – to assess the levels of pedestrian accessibility to activities in the Copenhagen Metropolitan Area. These results were crossed with the ones already available for Greater Porto, enabling a comparative analysis between these two metropolis, which have very different urban structures.

This dissertation found that, in both case studies, there is an important relationship between urban density and pedestrian accessibility. The results of this study support the idea that denser patterns of urbanization tend to promote higher levels of accessibility by foot, hence providing the conditions for more sustainable travel behaviour in daily trips. Moreover, the results reached in Copenhagen proved that, with efficient land use-transport policies, it is possible to have high levels of pedestrian accessibility even in a region with low average population density, with a pattern of concentrated decentralization.

KEYWORDS: Urban Structure, Sustainable Mobility, Accessibility, Polycentrism

RESUMO

Nas últimas décadas, as cidades, tanto na Europa como na América do Norte, têm vindo a experimentar processos de descentralização de população e emprego. Com este fenómeno, o automóvel tornou-se o meio de transporte mais utilizado, em detrimento de modos de transporte mais sustentáveis, como o transporte público ou modos não motorizados. Aliado a este processo, as mais recentes preocupações relativamente a problemas ambientais, como o consumo de combustíveis fósseis ou a emissão de gases com efeito de estufa, tem motivado o debate sobre a sustentabilidade dos padrões de mobilidade urbana, como por exemplo questões relacionadas com eficiência energética no transporte. Neste quadro, conceber uma estrutura urbana menos exigente do ponto de vista dos transportes poderá ser um factor importante para assegurar um desenvolvimento urbano mais sustentável. Esta dissertação parte do pressuposto de que a estrutura urbana de uma cidade influencia os padrões de mobilidade dos seus habitantes, já que as características da estrutura urbana condicionam a acessibilidade aos diversos destinos. Assim sendo, poder-se-á colocar a questão de que tipo de estrutura urbana permite uma mobilidade mais sustentável.

Esta questão é extremamente complexa e está actualmente no centro do debate. Não tem respostas claras nem consensuais e existe uma série estudos com conclusões contraditórias que dividem a comunidade científica. O principal objectivo deste trabalho é explorar a relação entre estrutura urbana e mobilidade, de forma a contribuir para o debate actual. Esta dissertação é composta por uma parte teórica – que procura, através de uma revisão bibliográfica, compreender melhor a complexa relação entre estrutura urbana e padrões de viagem – e pelo desenvolvimento de dois casos de estudo, nas áreas metropolitanas do Porto e de Copenhaga. Neste estudo foi usada uma metodologia baseada no conceito de acessibilidade – o *Structural Accessibility Layer* – que permitiu determinar os níveis de acessibilidade pedonal na Área Metropolitana de Copenhaga. Estes resultados foram posteriormente cruzados com os já existentes para o Grande Porto, permitindo uma análise comparativa destas duas metrópoles, cujas estruturas urbanas são bastante diferentes.

O estudo concluiu que, em ambos os casos, existe uma forte relação entre densidade urbana e acessibilidade pedonal, sendo que padrões de urbanização mais densos tendem a permitir maiores níveis de acessibilidade, criando, desse modo, condições para a promoção de comportamentos mais sustentáveis nos padrões diários de deslocação. Concluiu-se ainda, a partir dos resultados obtidos em Copenhaga, que é possível atingir níveis elevados de acessibilidade a pé, mesmo em regiões com baixa densidade populacional, desde que haja uma conjugação de políticas eficazes de uso do solo e transportes, no sentido de promover um padrão urbano de ‘concentração descentralizada’.

PALAVRAS-CHAVE: Estrutura Urbana, Mobilidade Sustentável, Acessibilidade, Policentrismo

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1.
INTRODUCTION

1.1. URBAN STRUCTURE, MOBILITY PATTERNS AND SUSTAINABILITY

The UN World Commission on Environment and Development believes that reducing the consumption of fossil fuels is a key issue in the efforts to promote a sustainable development. The combustion of fossil fuels causes air pollution and it also contributes indirectly to soil and water pollution through acid rain, affecting the natural environment both in a local and in an international scale. More recently, the focus has increasingly been set on the accumulation in the atmosphere of greenhouse gases, notably carbon dioxide (CO_2), caused by fossil fuels' combustion. According to the United Nations panel on climate change, there has been a clear human influence on the global climate due to emissions of greenhouse gases. Unless the consumption of fossil fuels is reduced, the concentrations of greenhouse gases in the atmosphere will double or triple within the next 100 years.

The transport sector is probably one of the areas where the reduction of greenhouse gas emissions will be most demanding and less consensual. Urban mobility has undergone significant changes during the past decades. The number of trips as well as travel distances have increased in most European and North American cities, and the private car has become the most used transport mode, leading urban mobility away from sustainability (Silva, 2008).

Greenhouse gases emission is not the only negative consequence of urban transportation. There are other negative environmental and social impacts, such as local air pollution, noise, traffic accidents, congestion, loss of recreational areas and public space and degradation of landscape quality, which may compromise the quality of life and competitiveness of urban areas.

In this context, achieving a less transport-demanding urban structure may be an important step to ensure a more sustainable urban development. The mutual influence between land use and transport system and the need to integrate land use and transport policies are widely recognised. According to Cervero and Kockelman (1997), three main transportation objectives can be numbered: to reduce the number of trips; to increase the share of non-motorized trips (i.e. by foot or bicycle); and to reduce travel distances and increase vehicle occupancy levels.

Besides the environmental relevance, these goals have also an important welfare dimension. An urban structure with large needs for transport requires its inhabitants to spend a lot of time and/or money on travel. The disparities will grow between socioeconomic groups that have the means to pay for a high mobility (namely the private car) and the ones that do not have a car at their disposal. The latter group includes households that cannot buy and keep a car, it includes people who cannot use the household's car because it is being used by another household member and all the people that are unable to drive (children, elderly, handicapped, etc). These people will either need to spend a long time on daily travel or restrict their options for job opportunities and service facilities to a limited part of the urban area (Næss, 2006).

This dissertation relies on the notion that urban structure influences daily mobility of individuals. The concept of urban structure is not always clear. Some authors define urban structure as the land use characteristics of an urban area, i.e. the spatial distribution of population, employment and other facilities and equipments. Others include in this concept some transport characteristics, such as mobility patterns, or road or public transport infrastructure, sometimes using the designation of 'built environment'.

Throughout this dissertation the concept of urban structure will refer mainly to land use characteristics, such as population and job densities and the city's specific patterns of development. However, since land use characteristics and transport infrastructure are closely inter-linked (see section 2.2), the analysis of a city structure must also take into consideration some transport characteristics.

The concepts of sustainability and sustainable mobility are also not always clear. The notion of sustainability has been widely used in the past few years in very different contexts - such as the environment, economy and welfare – what might have lead to a trivialization and ambiguity of the concept. The most well-known definition for sustainable development is the one suggested by Bundtland, who describes it as the capability 'of meeting today's needs without compromising the ability of future generations to meet their needs'. Sustainable mobility may be defined as a 'transport system and transport patterns that can provide the means and opportunities to meet economic, environmental and social needs efficiently and equitably, while minimising avoidable or unnecessary adverse impacts and their associated costs, over relevant space and time scales' (EC, 2001 cited in Silva, 2008; 13).

Considering the hypothesis that urban structure characteristics determine the accessibility of a destination and thus have an influence on individual travel behaviour, a question may arise: *which urban structure enables a more sustainable mobility?*

The literature on urban structure normally considers two types of urban patterns: monocentric and polycentric. The monocentric urban structure refers to the traditional European city, where population and employment are highly concentrated in a relatively dense city core, opposite to the low density and mostly residential suburbs. However, the growing process of cities during the last decades led them towards a more polycentric form, in which the traditional duality between centre and suburb is replaced by a multi-centred urban area, shaped by several employment and population concentration sub-centres (Anas *et al.*, 1998; Van der Laan, 1998).

There can also be considered a third type of urban pattern - the dispersed or sprawled city – which sometimes is muddled with polycentrism. Authors like Ewing (1997) and Martens (2006) emphasize the distinction between a polycentric structure - with medium density and some concentration of jobs and housing around several nodes - and a sprawled low density pattern, where the dispersion of residences, jobs and activities makes it difficult to walk or bike or to implement an efficient public transport network.

If it is apparently obvious that urban sprawl leads to more unsustainable mobility patterns, the answer to the question addressed, on the contrary, is not that clear when comparing the monocentric and polycentric structures. On the one hand, one may argue that monocentric urban areas with strong concentrations of jobs and activities in the inner-city provide the conditions for a good public transport system and for higher shares of walking and cycling, hence using less energy on transport than cities where jobs are dispersed. On the other hand, however, when a city grows to a certain dimension, the monocentric structure may lead to congestion and functional segregation. Therefore, encouraging outward movement of employment closer to the places where most of the people live may reduce commuting lengths.

This question is extremely complex and it is currently at the centre of the debate, dividing the scientific community. The answers are not clear or consensual and there can be found several empirical and theoretical studies using different methods and reaching contradictory conclusions.

1.2. THESIS CONTEXT AND OBJECTIVES

The work developed here is integrated in a wider research project, the *MOPUS – Mobility Patterns and Urban Structures*, currently being developed at CITTA, the Research Centre for Territory, Transports and Environment of the Faculty of Engineering of the University of Porto. The MOPUS project encompass two different research methodologies – The Structural Accessibility Layer (SAL) and the Aalborg University Methodology (AUM) - and two study regions – the metropolitan areas of Porto (Portugal) and Copenhagen (Denmark).

The SAL is a methodology developed by Silva (2008), which was designed to assess the potential of land use and transport systems to provide the necessary conditions (although not necessarily sufficient) for sustainable mobility (for more on the SAL see section 3). This methodology only concerns structural factors and has been applied to the Metropolitan Area of Porto (Silva, 2008). The Aalborg University Methodology aims to identify the overall relationships and the more detailed mechanisms through which the location of residence influences travel behaviour. This methodology, already put in practice in the Copenhagen metropolitan area (Næss, 2005; Næss, 2006), investigates the complex relationship between land use and travel, focusing on the comprehensive analysis of socioeconomic and attitudinal characteristics of travellers.

Considering that these two methodologies are complementary, the MOPUS intends to combine them, providing an analysis of both the structural and behaviour aspects of mobility patterns for the two study regions. This process will involve the application of the SAL to the Copenhagen metropolitan area and the application of the AUM to the Porto metropolitan area, crossing the results with the work already carried out in both sides. In addition, the MOPUS aims to assess the influence of alternative urban structures on sustainable mobility, since Copenhagen is a typical monocentric metropolis whereas Porto's metropolitan area shows a more polycentric urban form (Pinho *et al.*, 2009).

The main goal of this dissertation is to explore the relationship between urban structure and mobility patterns, with the purpose of contributing to the present debate on this issue. In order to pursue this purpose, the current dissertation has three main objectives:

1. To explore the literature on land use and mobility and provide for a better understanding of the complex relationship between urban structure and travel behaviour.
2. Applying the SAL methodology to the Copenhagen metropolitan area. On account of time constraints, this study will not use the complete SAL methodology. Only the analytical part concerning pedestrian transportation will be considered, since accessibility by foot provides the most interesting map regarding the structure of urban centralities.

3. To carry out a comparative analysis between two types of urban structures and, therefore, the assessment of the influence of urban structure on mobility patterns. This will be possible crossing the results of the application of the SAL to Copenhagen with the results achieved by Silva (2008) in Porto.

1.3. Structure of the Thesis

The three objectives mentioned above are addressed in this dissertation throughout six chapters. After this introductory chapter, Chapter 2 presents a literature review on urban structure and mobility, structured into three parts. The first part intends to understand the relationship between land use characteristics, transport system characteristics and travel behaviour. The second part discusses the main concepts regarding urban structure – such as polycentrism, monocentrism or urban sprawl - and makes a presentation and characterization of different types of urban structures. The third part provides a comprehensive understanding of the influence of the urban structure on mobility patterns, focusing mainly on the analysis of empirical studies.

The following chapters – 3 and 4 – present the methodology. Chapter 3 presents the general concepts and components of the methodology used in this study: the Structural Accessibility Layer (SAL), whereas Chapter 4 focuses on the specific factors and choices for the application of the SAL to the Copenhagen metropolitan area, after presenting the main characteristics of this region.

Chapter 5 holds the results of the case-study, being divided into three parts. Firstly, the results of the application of the SAL to the Copenhagen metropolitan area will be presented. The second part makes a brief characterization of the Porto metropolitan area and presents the results from the application of the SAL to this region. The chapter ends with a discussion about the comparison of these two metropolitan areas. Considering the main urban structure characteristics and the results achieved with the SAL on both regions, we will try to understand how different urban structures influence the pedestrian mobility patterns. The analysis of the urban structure constraints on the possibility to reach an activity by foot enables the assessment of the conditions provided by urban structure for a more sustainable mobility. Chapter 6 presents the main conclusions of the dissertation.

2. URBAN STRUCTURES AND MOBILITY

2.1. INTRODUCTION

The literature on the influence of urban structure on travel patterns has been growing during the last years, encompassing a wide, diverse, and sometimes contradictory range of studies. Environmental concerns, as fossil fuels consumption or air pollution, foster the discussion about urban forms that allow for more sustainable travel patterns.

The purpose of this chapter is to review the main issues found on the literature about urban structure and the way it affects mobility patterns. The chapter is divided into four parts. Section 2.2 will make a general review of the main theories behind the relationship between land use characteristics and transport and the extent to which land use and transport factors affect people's travel behaviour. Section 2.3 will address questions of urban structure. Some of the models for urban form presented during the last decades will be briefly reviewed, and an attempt will be made to clarify some of the main concepts related to urban structure, namely the concepts of 'polycentrism', 'monocentrism', and 'urban sprawl'.

In section 2.4, a literature review on the influence of urban structure on travel behaviour will be done, focusing on empirical research developed during the last years, both in Europe and North America. This section will aim at understanding the extent to which urban structure factors are able to influence travel patterns, as travel distances and times or the modal choices, both for work trips and other purposes. Finally, in section 2.5, some concluding remarks will be made about the issues discussed on the previous sections, trying to understand the role of the urban structure factors for more sustainable mobility patterns.

2.2. LAND USE, TRANSPORT AND MOBILITY

2.2.1. LAND USE AND TRANSPORT INTERACTION

Most of the planners and the general public agree on the idea that land use and transport are closely inter-linked (Wegener and Fürst, 1999). On the one hand, the spatial separation of human activities creates the need for travel and transport of goods. This explains the connection between cities suburbanization and the increasing spatial division of labour and the increasing mobility. On the other hand, it is also recognized – although less studied – the impact of transport on land use: evolution from the traditional compact city, where walking was used for most of the daily trips, to the vast modern metropolitan areas with high volumes of metropolitan commuting would not be possible without the development of the railway, at first, and then the private car (Wegener and Fürst, 1999). However, the exact way in which transport system influences the location choices of landlords, investors, firms and households is still not clearly understood by many urban planners (Wegener and Fürst, 1999).

This reciprocal relationship between land use and transport and the recognition that trip and location decisions determine each other and hence that land use and transport planning must be coordinated, is illustrated by the 'land use transport feedback cycle' (see figure 1) (Wegener and Fürst, 1999). According to these authors, the set of relationships implied by the land use transport feedback cycle can be summarised as follows:

- 'The distribution of land uses, such as residential, industrial or commercial, over the urban area determines the locations of human activities such as living, working, shopping, education or leisure.
- The distribution of human activities in space requires spatial interactions or trips in the transport system to overcome the distance between the locations of activities.
- The distribution of infrastructure in the transport system creates opportunities for spatial interactions and can be measured as accessibility.
- The distribution of accessibility in space co-determines location decisions and so results in changes of the land-use system' (Wegener and Fürst, 1999; 5).

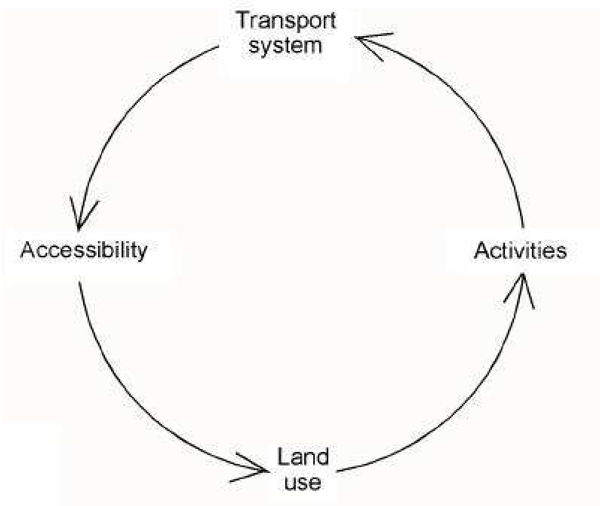

Figure 1 – Land use transport feedback cycle (source: Wegener and Fürst, 1999)

The empirical discussion on the influence of transport on land use is mostly focused on the increasing of land prices fostered by motorway construction; empirical studies analysing the influence of public transport provision and improvement on land use development have been limited and with mixed results (Silva, 2008). Several authors argue that the influence of transport on land use has been decreasing during the last decades. Some of them suggest that the influence of transport on land use is now weaker, while others argue for a change in geographical scale of that influence with the maturation of the transport system (Silva, 2008).

Cervero and Landis (1995) argue that although investments in new transportation systems no longer shape urban form by themselves, they still have a strong influence on land use patterns, urban densities, and housing prices (Cervero and Landis, 1995). In a study on the BART (Bay Area Rapid Transit System), these authors concluded that proximity to BART stations increases the likelihood of the redevelopment on residential sites into commercial or industrial centres (Cervero and Landis, 1995). Moreover, they state that BART has undoubtedly helped to create and strengthen the San Francisco Bay Area's multi-centred form (Cervero and Landis, 1995).

2.2.2. LAND USE AND TRANSPORT INFLUENCING TRAVEL BEHAVIOUR

The relationship of land use and travel behaviour has been a matter of considerable amount of research during the past two decades. Most of this research lie on utility-based theories of urban travel demand (Cervero and Kockleman, 1997). These theories suggest that travel demand is a 'derived' demand because trips are made and distributed according to the desire of reaching places, such as office buildings, parks or shopping centres (Cervero and Kockleman, 1997). In other words, people travel to reach activities necessary to fulfil their needs: travel will only take place when positive utility of the participation in the pursued activity exceeds the disutility of travelling (normally expressed in time and money spent).

According to the utility-based travel demand theories, land use has a considerable influence on travel behaviour since spatial structure affects both activity utility and travel disutility (Cervero and Kockleman, 1997; Silva, 2008). Taking, for instance, the dimension of density, one may argue that compact neighbourhoods can reduce vehicle trips and encourage non-motorized travel. On the one hand, in a high density neighbourhood, origins and destinations are closer to each other, and that fact gives the opportunity to walk or cycle to reach a destination, instead of using the car. On the other hand, compact neighbourhoods tend to have less parking, better quality public transport services, wider mixes of land uses, and larger shares of low-income households, all factors that reduce car usage (Cervero and Kockleman, 1997).

According to Stead et al. (2000), population density may be linked to travel patterns for several reasons. First, higher population densities allow for a wider range of opportunities for the development of contacts and activities without having to use motorised travel. Second, higher densities widen the range of services that can be supported in the local area, reducing the need to travel long distances. Third, compact patterns of development tend to reduce average distances between homes, services and employment. And fourth, urban density influences modal choice, because higher densities allow for a more efficient public transport operation and are less amenable for car ownership and use (Stead *et al.*, 2000).

Moreover, density is by far the most studied land use factor, considering the literature on the influence of land use on mobility. In a study on car dependence in cities all over the world, Kenworthy and Laube (1999) conclude that higher urban density is associated with lower levels of car ownership and car use, higher levels of transit use, and lower operating costs of public transportation systems. They advocate for policies that increase urban density, associated with activity diversity, as a mean of reducing car dependence in cities and developing a more transit-oriented urban pattern (Kenworthy and Laube, 1999). They also suggest that economic development and wealth are not necessarily synonymous of increasing car dependence in cities: they point Zurich as an example of a very wealthy city that has also one of the highest transit uses per capita. The authors argue for the role of public policy in avoiding car dependent urban structures (Kenworthy and Laube, 1999; Silva, 2008).

In another study, Cervero and Kockleman (1997) studied the influence of land use density, diversity and design – 'the 3D's of the built environment' – on travel frequency and modal choice for non-work trip purposes in the San Francisco Bay Area. Their aim was to test the hypothesis that high density compact neighbourhoods, richly mixed land uses, and pedestrian-friendly designs reduce vehicle trips and encourage residents to walk, bike, or use public transport as substitutes for car travel (Cervero and Kockleman, 1997).

The results of this study suggest that effects of the built environment on travel demand in the San Francisco Bay Area are modest. Nevertheless, density has the strongest effect on business trips, and diversity, although generally having a modest impact, shows a more significant influence than density in the case of residential neighbourhoods spatially accessible to commercial activities (Cervero and Kockleman, 1997). The authors suggest, however, that more appreciable impacts may be produced by the synergy of the 3D's in combination.

The influence of land use diversity on travel behaviour was analyzed in studies by Van and Senior (2000[1]) and Handy and Clifton (2001[1]). In the former study, results were sceptical about the influence of diversity on travel frequency and modal choice (Silva, 2008). The latter evaluated the influence of local shopping on modal choice, travel time and distance and concluded that this strategy is not particularly effective. Not only there was no proof that travel distances, travel times and car dependency would be reduced; but also evidence show that local shopping may even induce extra travel (Silva, 2008).

In short, most of the case studies found on the literature reached mixed results and conclusions, either on the way in which land use factors influence travel behaviour, or even questioning the existence of that influence (Silva, 2008). According to this author, this situation can be explained by several reasons. On the one hand, the different results found may be due to the lack of systematic methodological approaches related, for instance, with the variable choices, levels of aggregation, geographical scales, or specificities of local conditions. On the other hand, misleading results may be explained by the evaluation of land use variables without the consideration of other factors - such as transport system and socioeconomic characteristics - since this factors are believed to be mutually correlated (Silva, 2008).

Authors like Stead *et al.* (2000) argue for the role of socioeconomic factors – such as household size and income, car ownership, employment status, gender and age - on the relationship between land use and travel patterns (Stead *et al.*, 2000; Stead, 2001). A literature review developed by Stead at al. (2000) shows that the relationship between land use and travel behaviour is complicated by the fact that socioeconomic characteristics also affect travel patterns and, in addition, that different land use characteristics are often associated with different socioeconomic factors. For instance, evidence suggests that higher densities are associated with less travel, but this may be a consequence of the variation of income with density, rather than the effect of land use per se (Stead, 2001). Furthermore,

[1] Referred to in Silva (2008)

these authors conclude that, although land use characteristics have a considerable effect on travel patterns, socioeconomic factors explain even more the variations in travel patterns than land use characteristics. They argue that socioeconomic characteristics typically explain half of the variation in travel distance per person, whereas land use characteristics normally only explain one third of the variation (Stead *et al.*, 2000; Stead, 2001).

Despite the fact that most of the authors believe that land use characteristics influence travel behaviour, there has been considerable scepticism about the effect of land use policies and their contribution to sustainable urban mobility (Silva, 2008). Moreover, the amount of literature studying land use policy effects on travel behaviour is scarce and publications suggesting policy recommendations are even scarcer (Silva, 2008).

Some studies, however, can be found in the literature about the effect of land use policies on travel behaviour. In a study on the influence of self-containment policies on modal choice for commuting trips, Cervero (1995) reached inconclusive results. This author studied several planned communities both in Europe and the U.S. and concluded that more balanced or self-contained communities – where a wider range of activities can be reached without having to travel outside – are not necessarily less car dependent (Cervero, 1995). Car use reduction and shorter average commutes in European cities may rather be achieved by the provision of integrated transport infrastructure. As to America, the evidence on the link between planned communities and commuting is quite limited (Cervero, 1995).

Other studies can be found addressing the effect of land use policies based on urban design schools, such as New Urbanism, Transit-Oriented Development and Neotraditional planning (Silva, 2008). These schools believe in the influence of land use planning on travel behaviour and propose land use policy measures, such as creating compact, socially and functionally mixed neighbourhoods that are pedestrian friendly and that offer a good public transport service (Crane 1996; Crane and Scweitziger 2003, both referred to by Silva 2008). Compact development, characterized by high densities and mixed land uses, is believed to enable higher accessibility to activities and employment, favour economic viability of public transport systems and improve public security by reducing segregation. The research on this issue is, however, quite sceptical: there is no credible empirical or theoretical evidence supporting the idea that these policies lead to a more sustainable urban mobility (Crane and Scweitziger 2003, referred to by Silva 2008).

A paper by Schwanen *et al.* (2004) studied the effect of several physical planning policies adopted since the 1970s in The Netherlands on travel distance, travel time and modal choice. This policies include the ‘concentrated decentralization’, during the 1970s and the 1980s; a policy of compact urban growth, formulated in the 1980s and put in practice during the 1990s; and the A-B-C location policy (Schwanen *et al.*, 2004).

The policy of concentrated decentralization consisted in accommodating new urban growth into ‘growth centres’ and prohibiting the growth of rural settlements. Growth centres should be high density sites located outside the existing cities and well served by public transport (Schwanen *et al.*, 2004). The policy of compact urban growth relies in large investments on the renewal of inner-city housing stock and in strict regulation of the location of retail facilities, prohibiting the development of large out-of-town shopping malls. This policy included the redevelopment of brownfield sites and conducting urban growth towards sites directly adjacent to the built-up areas of the larger cities (Schwanen *et al.*, 2004). The A-B-C policy for location of firms had the goal of discourage the use of the private car and promote the use of public transport together with cycling and walking. *A* locations were centrally located places, often situated near rail stations and hence with high accessibility by public transport, while *B* locations were reasonably well served by public transport but readily accessible by car, normally located in development nodes outside the main centre. C locations had very good motorway access. The objective of the A-B-C policy was to guide new development as much as possible towards A and B locations (Schwanen *et al.*, 2004).

The evaluation of the effects of the implementation of these policies on travel behaviour showed mixed results. With regard to modal choice, the policies of compact urban growth, such as the redevelopment of brownfield sites, urban renewal and upgrading the inner-city housing stock, in addition with policies for retail planning have been the most successful in increasing walking, cycling and public transport use for commuting trips (Schwanen *et al.*, 2004). As to the concentrated decentralization, this policy showed more mixed results. On the one hand, the inhabitants of growth centres were less dependent on the private car for commuting, because these sites were normally directly connected by train to the main employment centres. On the other hand, however, the level of bicycle use is lower in the growth centres, what shows a qualitative mismatch between residents and employment in many new towns (Schwanen *et al.*, 2004). The A-B-C policy should have increased public transport use, but this policy's impact on travel behaviour seems to have been slight (Schwanen *et al.*, 2004). As to travel distance and time, the authors conclude that the spatial policies presented only made a modest contribution to increase travel efficiency (Schwanen *et al.*, 2004).

In short, the empirical research on the relationship between land use and travel behaviour does not enable the generalization of the land use factors most influencing travel patterns, in part because of methodological limitations found in the case studies (Silva, 2008). However, and although there is no general consensus on the exact way in which land use factors influence travel behaviour, three of these factors assume special focus on the literature. The 3D's - density, diversity and design - are believed to have influence at least on some travel characteristics, showing a relatively wide support by the literature on land use and travel interaction.

As to the influence of transport on travel behaviour, the empirical research on this issue is less developed, perhaps because this influence is already taken for granted and so the current discussion concentrates on policy measures (Silva, 2008). Although the focus of this dissertation is set mostly on land use characteristics, some transport factors are relevant for the understanding of the urban structure and mobility interaction. The transport-related variables more often presented as being capable of influencing mobility patterns are car ownership rates, public transport supply, road infrastructure availability, oil prices, public transport prices, and congestion (Martens, 2006).

Moreover, some literature can be found on the combined influence of transport and land use on travel behaviour. Authors like Cervero and Kockelman (1997) or Stead (2001) consider in their studies some transport factors, although not making a clear distinction between transport and land use variables. Other authors, like Kenworthy and Laube (1999), argue for policies that combine land use and transport factors – like increase urban density around railway stations – to achieve a more sustainable, less car-dependent and more transit-oriented city. Similar principles can be found in other policies referred on the literature, like the Dutch A-B-C location policy (Schwanen et al., 2004).

2.3. URBAN STRUCTURE: MONOCENTRIC AND POLYCENTRIC URBAN SYSTEMS

2.3.1. WHAT IS POLYCENTRISM

The literature on urban structure is fairly consensual as to the idea that cities - both in Europe and in North America - have evolved during the past decades into a different urban form. Despite the fact that cities have been spreading out for centuries, it would appear that recently this growing process is experiencing qualitative changes towards a more polycentric form (Anas *et al.*, 1998), in which the traditional duality between centre and suburb is replaced by a multi-centred urban area, shaped by several employment and population concentration sub-centres (Anas *et al.*, 1998; Van der Laan, 1998).

Furthermore, the concept of polycentricism has been gaining in the last years widespread currency amongst urban planners and policy makers (Davoudi, 2003) being referred to, for instance, in documents like ESDP[2]. However, the notion of polycentrism is not supported by a clear definition; on the contrary, it is an ambiguous concept liable to multiple interpretations (Davoudi, 2003) depending, for instance, on the area of knowledge.

Moreover, and according to Davoudi (2003), polycentricity means different things when applied to different scales. This author argues that there are essentially three concepts/scales of polycentrism: the ‘intra-urban scale’, the ‘inter-urban scale’ and the ‘inter-regional scale’. As an attempt to clarify the notion of polycentrism the remaining part of this section will make a brief description of these tree concepts.

The ‘intra-urban scale’ refers to the more traditional concept of polycentrism applied to the level of the individual city and aims at conceptualizing new forms of urban development that are no longer compatible with the traditional monocentric spatial structure model. This concept will be developed further in the following sections.

The ‘inter-urban scale’ of polycentrism is a more recent concept usually applied to the existence of multiple centres (cities) in one region (Davoudi, 2003). As Davoudi states, ‘The main distinction between conceptualizing polycentricity at this level as compared with the intra-urban scale is that the latter refers to a polycentric city characterized by the development of multiple sub-centres within one built up area (Gordon et al., 1986), whilst the former refers to a polycentric urban region characterized by separate and distinct cities or smaller settlements which interact with each other to a significant extent’ (Davoudi, 2003; 984).

The last concept of polycentrism – the ‘inter-regional scale’ – has been associated with several conceptualizations of urban form proposed by numerous commentators during the past decades; for instance, the concept of megalopolis (Gottman 1957[3]), referring to the group of contiguous metropolitan areas in the east coast of the US (between Boston and Washington); or the Beijing-Seoul-Tokyo urban corridor (Choe 1998[3]), encompassing five mega-cities with a total population of 98 million inhabitants.

In Europe, the concept of polycentrism associated with an inter-regional scale has had a particular interest in the spatial planning context after the publication of the ESDP (1999). This document added to the concept of polycentrism not only a new pan-European spatial scale but also a normative dimension. ESDP advocates the promotion of polycentricity as a policy option with the aims of

[2] *European Spatial Development Perspective*, Commission of European Community, 1999

[3] Referred to in Davoudi (2003)

enhancing Europe's economic competitiveness in the global market and achieving a more balanced and cohesive development across Europe (ESDP, 1999; Davoudi, 2003). The extent to which these two goals can be compatible remains questionable.

In short, the concept of polycentrism has different meanings when applied in different contexts or spatial scales, and its definition is not always clear or consensual. In the current work, the focus will be set on the 'intra-urban scale' concept of polycentrism.

2.3.2. The Monocentric and Polycentric models

The continuous growth and spread of cities during the past century has preoccupied researchers who have tried to conceptualize the development of urban form. Amongst the numerous models that have been produced by researchers from different disciplinary backgrounds to allow for the analyses of the internal structure of cities, it is possible to distinguish between two general categories: models that conceptualize cities as a monocentric spatial structure and models that attempt to explain the polycentric pattern of urban change (Davoudi, 2003).

The development of the motorized transport fostered a range of fundamental changes in the land use system of cities, based until then on pedestrian mobility and animal power. Cities were, therefore, limited in size (Martens, 2006). One of the most relevant changes on urban spatial form due to motorised transport was the emergence of the suburb (Martens, 2006).

Car ownership and the development of the road network made it possible for workers to disconnect to some extent the place of work and the place of residence. This freedom allowed for a high amount of households to move away from the crowded cities, to other settlements that were too small and low dense to be considered urban but, at the same time, too large and well structured to be called rural (Martens, 2006). This process of outward urban expansion gave origin to the monocentric model of urban development, that assumes that regional functions - like jobs, services, etc – are concentrated in the inner-city, while residential areas are clustered around this centre (Martens, 2006)

Until the 1970s, the conceptualization of cities was based on monocentric city models (Davoudi, 2003). One of the most significant approaches was the ecological analysis developed by the Chicago School of Sociology, pioneered in the study of Chicago's Urban Structure by Ernest Burges (1925[4]). It introduced a famous diagram of concentric circles dividing the city into five zones (Davoudi, 2003). This model gained further support during the 1960s with the dawn of economic theories of urban land rent (Davoudi, 2003) which envisaged the city as a circular residential area surrounding a central business district (CBD) in which all jobs are located (Anas *et al.*, 1998).

During the 1960s, other models emerged conceptualizing the city in different ways, mostly along with the monocentric structure principle. One of the most notable is a study by Kevin Lynch (1961) which predicted several patterns of city's future growth (Davoudi, 2003) and analyzed them using criteria of grain (degree of 'intimacy' with which the different elements – as stores and residences – are related) , focal organization (interrelation between the nodes of concentration and in contrast with the general background) and accessibility, evaluating, for example, the suitability of each proposed urban pattern for public transport (Lynch, 1961).

In this work, Lynch idealized five ideal urban forms - the 'dispersed sheet', the 'urban galaxy', the 'core city', the 'urban star' and the 'urban ring' (Lynch, 1961) (Figure 2). These types include

[4] Referred to in Davoudi (2003)

three different patterns of monocentric structure: the 'core city', with a high density and intensity of activities in the city centre, allowing for a high accessibility by public transport and pedestrian movement; the 'urban star', also with a strong core but introducing radial lines of dense development, suitable for an efficient public transport system of high capacity; and 'the ring', characterized by a very low density centre with high densities and special activities surrounding it (Lynch, 1961).

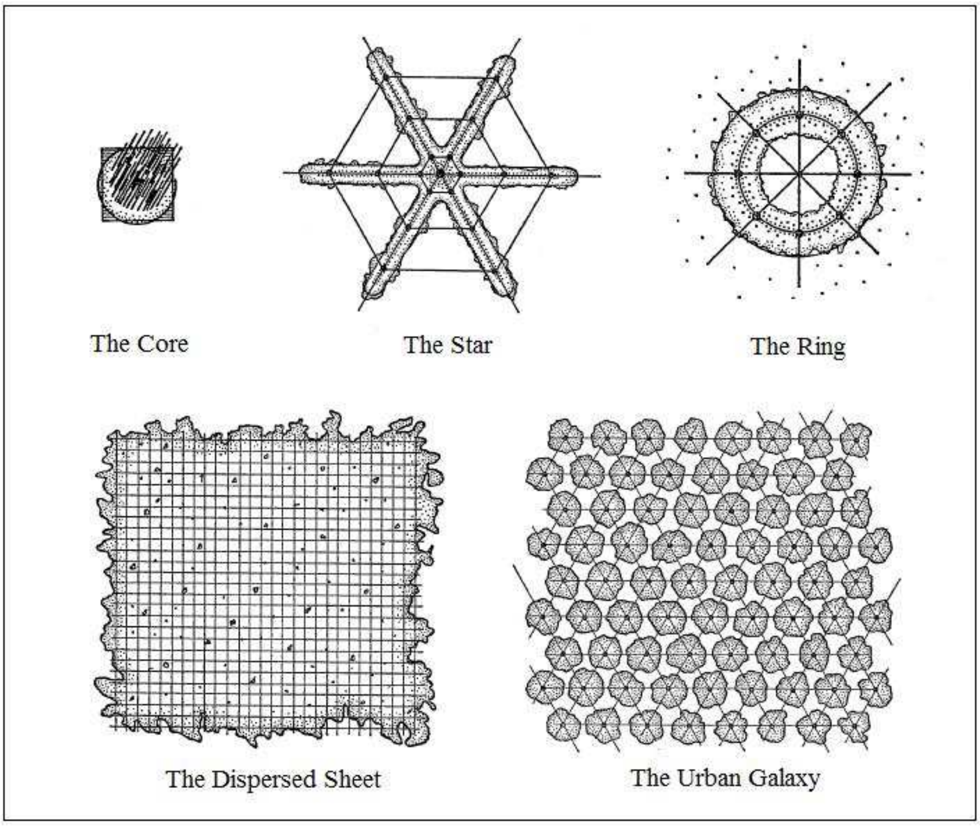

Figure 2 – Five types of urban patterns (source: adapted from Lynch, 1961)

The 'dispersed sheet' pattern, on the other hand, consists of a sprawled low density city with substantial interstices of open land kept in reserve. The activities are dispersed throughout the region and the individual vehicle would be the main transport mode (Lynch, 1961). Perhaps the most interesting of these urban forms proposed by Lynch is the 'urban galaxy', which can be interpreted as one of the first conceptions of polycentrism. Here the city is formed by a group of small and relatively dense units separated from each other by a zone of low or zero structural density (Lynch, 1961). Activities would be concentrated within each urban cluster forming an over-all system of centres relatively equal in importance. The individual vehicle would be the main transport mode, yet it would be complemented by a public transport system (Lynch, 1961).

The monocentric city model, however, remained the most widespread representation of urban structure until at least two decades after World War II, as it enabled a good understanding of the broad population decentralization that had occurred in numerous cities around the world (Davoudi, 2003).

Nevertheless, during the 1970s, it started to become clear that cities would develop towards a more polynucleous structure, due to a number of factors such as the decentralization of economic activities; the increased mobility due to new transport technologies; changes in household structure and lifestyle; and the existence of complex cross-commuting (Davoudi, 2003). According to Anas *et al.* (1998), the process of decentralization 'has taken a more polycentric form, with a number of concentrated employment centres making their mark on both employment and population distributions' (Anas *et al.*, 1998; 1). They state that these sub-centres can be older towns that progressively became integrated into an expanded but coherent urban area; or new urban centres built up next to nodes of a transportation network often distant from the urban core, the so called 'edge cities' (Anas *et al.*, 1998). The 'edge cities' are characterized by large concentrations of office and retail activities often in conjunction with residential and other types of development (Davoudi, 2003).

Van Der Laan (1998) goes further with regards to this idea and states that the hierarchical structure between core and periphery is changing into a horizontal one, where the nodal model becomes less attractive and the spatial process is no longer mainly controlled by the central core. In consequence, 'the traditional duality between centre and suburb disappears and a multi-centred urban area emerges with each part having a function of its own' (Van der Laan, 1998; 235).

Similar to the monocentric model, the polycentric model has its foundations in theory of agglomeration economies. Agglomeration economies create a centripetal trend in cities that leads the agents to cluster into large or small groups, as a way of facilitating interaction and saving costs (Anas *et al.*, 1998; Martens, 2006). Anas *et al.* (1998) use simulation models to prove that these tendencies logically result in sub-centre formation and, if cities grow, may lead to an evolution from a monocentric towards a polycentric urban structure.

The growth of a monocentric city increases the demand – and consequently the costs – of locations in the inner-city influence the location decisions of businesses. Businesses that are land extensive and businesses that do not need frequent interaction with others (back office functions) are the first to move to the urban fringe, followed later by other businesses that try to escape high rent prices and accessibility costs in the inner-city (Martens, 2006). There are also centripetal tendencies in the urban fringe that make businesses to cluster forming peripheral sub-centres (Martens, 2006).

Arguing that this growth pattern has some theoretical assumptions (like assuming that the peripheral areas are empty and that sub-centre formation starts from zero), Champion (2001[5]) suggests two other alternative paths that explain the formation of polycentric urban areas. The first path assumes that there can be smaller villages in the vicinity of a city that attract some of the regional functions that used to locate in the inner-city. These villages are incorporated in the urban area and develop into sub-centres. A second alternative path emerges when the cities in the vicinity are not smaller, but have similar size. In this case, the growth process is made by fusion and results in an urban region formed by two or more functionally diverse cores. This pattern is particularly suitable to explain development processes of higher scale (regional scale), as the Randstad in the Netherlands or the Ruhr-area in Germany (Martens, 2006).

2.3.3. MEASURING URBAN STRUCTURE

Whilst the literature is fairly consensual as to the idea that cities are evolving to a more polycentric urban form, several methodological variations can be found when trying to determine the extent to which a metropolitan area is more or less polycentric or monocentric. This issue assumes great importance when comparing different studies about urban structure, including naturally the

[5] Referred to in Martens (2006)

studies analyzing the relationship between urban structure and travel behaviour, which constitute the main focus of this dissertation.

When trying to determine the degree of monocentrism/polycentrism of an urban system, most of the authors use indicators like population density, proportion of population in the inner areas, number of jobs or proportion of employment in the centre (Gordon *et al.*, 1989; Newman and Kenworthy, 1989; Schwanen, 2002) or employment size and density in the centre and the sub-centres (Cervero and Wu, 1998).

References to mobility – for instance, whether the sub-centres constitute privileged spaces of attraction for commuters – are scarcer, although often appropriate in the context of the research (Aguilera and Mignot, 2004).

Notably, Van der Laan (1998), in a work on Dutch cities, proposed a method to classify urban stucture based on the direction of commuter trips inside the urban area and reflecting the degree in which suburban commuters travel to the central city. This classification – adopted by other authors such as Schwanen *et al.* (2001) or Schwanen *et al.* (2004) – considers four types of urban structures: one monocentric – ‘centralized’ – and three different types of polycentric urban areas – ‘decentralized’, ‘cross-commuting’ and ‘exchange commuting’.

Therefore, in the ‘centralized’ pattern all commuter traffic is directed to the city centre, and the suburbs barely attract commuters. This is the traditional monocentric form where workers living in suburban areas commute to the centre in the morning and return to their dormitory towns in the evening, while employees who live in the central city usually work there too (Van der Laan, 1998). In the ‘decentralized’ pattern, suburbs attract commuters both from other suburbs and from the city centre. In this case, the suburbs are complementary to the centre and are important in job supply (Van der Laan, 1998).

The ‘exchange commuting’ pattern is the case in which a high number of inner city residents work in the suburbs, while many inhabitants of suburban areas have their jobs in the city centre. There is a spatial job mismatch that may be caused by a qualitative mismatch between demand and supply – for instance, the suburbs offer low quality jobs but its residents are highly qualified, whilst the inner city needs qualified labour but has poorly educated residents (Van der Laan, 1998).

Finally, in the cross-commuting pattern many suburban residents work in the suburbs and, at the same time, many inner city dwellers are locally employed. There is a dual spatial labour market without much relationship between the core city and the suburbs (Van der Laan, 1998). This archetypal polycentric area emerge when workers seek to minimize travel expenditure (Schwanen *et al.*, 2004). These four types of urban structures are schematically represented in Figure 3.

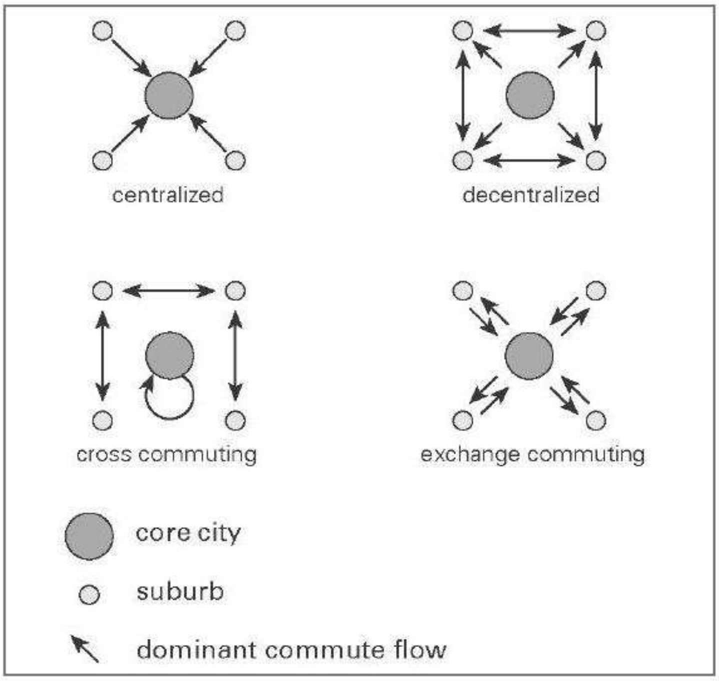

Figure 3 – Types of urban systems (source: adapted from Schwanen et al., 2004)

However, and according to Aguilera and Mignot (2004), this research methodology does not consider several important factors, contrarily to the methodology used by Gordon and Richardson (1996). On the one hand, these authors state that sub-centres should not be defined only according to their number of jobs, but it is also important to take into account the nature of these jobs, since different activity centres with the same number of jobs may generate clearly different levels of traffic (Gordon and Richardson, 1996; Aguilera and Mignot, 2004). They point out that 'if metropolitan spatial structure is largely the result of the interaction between transportation and land use, a sub-centre anchored on a suburban mall may have more significance than one based on an industrial park, even if the latter generates more jobs' (Gordon and Richardson, 1996; 290). On the other hand, they argue that the same methodology does not distinguish in any concrete way the sub-centres located in the periphery from the ones located in the vicinity of the city centre (Aguilera and Mignot, 2004).

In a study developed in France, Aguilera and Mignot (2004) define the sub-centres based on attraction of intra-urban commutes: first, they identify the municipalities most attractive to non-local workers and then they define the sub-centres maximizing internal commutes. These authors also consider two types of sub-centres: 'suburban sub-centres', larger and located near the city centre, and 'outlying sub-centres', smaller and located further from the centre, but still well situated on main transport axes (Aguilera and Mignot, 2004).

This distinction between sub-centres located inside the central city and the ones to be found in the urban periphery is also highlighted by Martens (2006). After studying several West-European cities, Martens found out that in European context there are roughly three relevant types of polycentric urban structures, besides the traditional monocentric structure (see Figure 4).

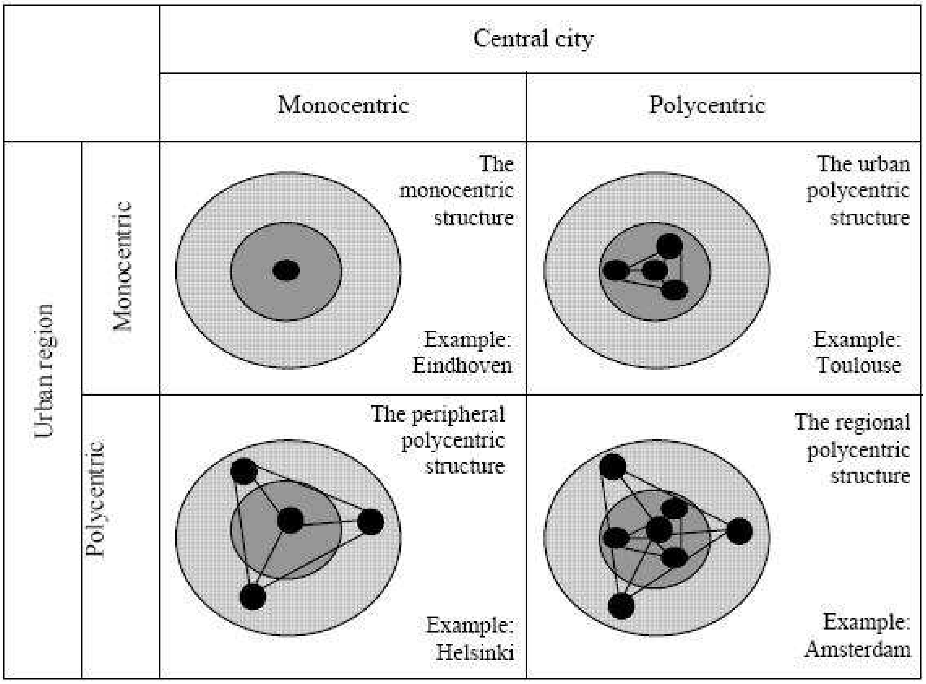

Figure 4 – Types of urban structures (source: Martens, 2006)

The peripheral polycentric structure is the classical polycentric urban model where Edge cities emerge outside the central city, usually competing with the inner-city (Martens, 2006). According to the author, this model is common on American cities but has only limited relevance in Europe. A second model is the urban-polycentric structure, where sub-centres develop inside the central city, instead of at the urban periphery. In this model, often seen in Europe, the sub-centres may be adjacent to the inner-city or located in the edge of the central city (Martens, 2006). He states that the urban-polycentric structure emerges when there is a lack of space for development in an inner city that still is attractive for that development or as a result of urban planning policies. The last model is the regional-polycentric structure. According to the author, this model combines peripheral sub-centre formation with central city sub-centre formation and is also commonly seen in Europe (Martens, 2006).

2.3.4. Polycentricity vs. Urban Sprawl

Even if nowadays it is widely recognized that the contemporary urban systems present a complex and multi-nodal structure, the exact nature of this polycentric system has been subject to multiple interpretations (Davoudi, 2003). According to this author, research has remained inconclusive regarding the distinction between a polycentric city and a dispersed one. In other words, many commentators distinguish between an organized system of sub-centres (the former) and an apparently unorganized urban sprawl (the latter), depending on factors like the definition of sub-centres (as job locations only or as activity centres) and the significance given to the employment densities compared with the level of interaction between the centres and sub-centres, measured in trip-generation rates (Davoudi, 2003).

Authors like Peter Gordon and Harry Richardson make almost no distinction between a dispersed and a polycentric spatial pattern (Gordon and Richardson, 1997), stating that the accelerating growth and dispersion of population and economic activities, fostered by the revolution in information processing and telecommunications, may lead to a point where geography is irrelevant (Gordon and Richardson, 1997). “Geography” in this context is interpreted as “centres of any type” (Ewing, 1997).

On the other side, scholars like Reid Ewing see polycentrism as a type of compact development rather than sprawl (Ewing, 1997). According to this author, compact development requires some concentration of employment, some clustering of housing and some mixing of land uses (but neither high density nor monocentric development). He argues for a multicentered urban pattern (see Figure 5) with moderate average densities and primarily continuous, except for permanent open spaces (like public parks) or vacant lands to be developed within the standard planning time frame (Ewing, 1997).

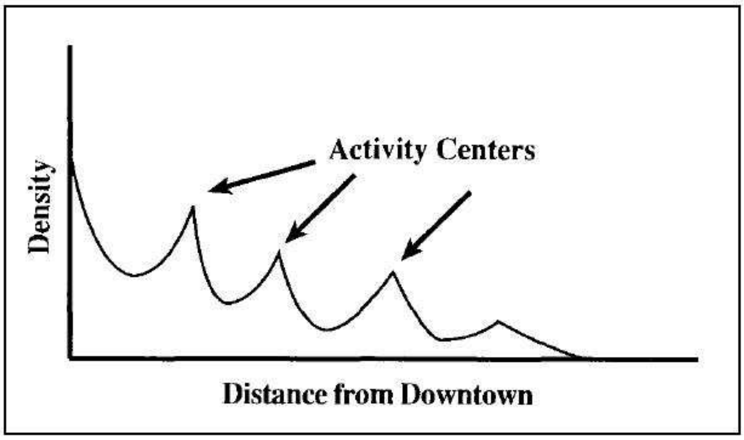

Figure 5 – Polycentric compact development, in terms of urban density (source: adapted from Ewing, 1997)

In this paper, Ewing seeks to clarify the concept of urban sprawl, suggesting a definition of sprawl based on two quantifiable indicators: *poor accessibility* and *lack of functional open space*.

The former indicator refers to the fact that residences may be far from out-of-home activities, and that these activities may be located far from each other (Ewing, 1997). Therefore, a sprawled urban structure with poor accessibility leads to less efficient household travel patterns, because in a scattered development residents must pass vacant land on their way from one developed use to another; in a strip development the consumer must pass other commercial uses on the way between stores; and ‘in a low-density, single use development, everything is far apart as the result of large private land holdings and segregation of land uses’ (Ewing, 1997; 109).

As to the latter indicator, Ewing states that in a suburban low density area there is abundance of open spaces (mainly private yards), but not permanent open spaces with a useful public function (‘functional open space’), because it is impossible to preserve large open spaces in reasonable proximity to people when they are spread out in uniform low densities (Schneider 1970, referred to in Ewing 1997). Ewing (1997) also enhances the environmental and social significance of this type of open spaces for the surrounding neighbourhoods.

Martens (2006) also highlights the distinction between a polycentric structure and a dispersed one. He conceptualizes the dispersed urban structure as a complete different model for urban development, to be considered together with the monocentric and the polycentric models. Furthermore, Martens argues that these three urban models can be distinguished by the analysis of two dimensions: the number of urban centres and the level of concentration (Figure 6).

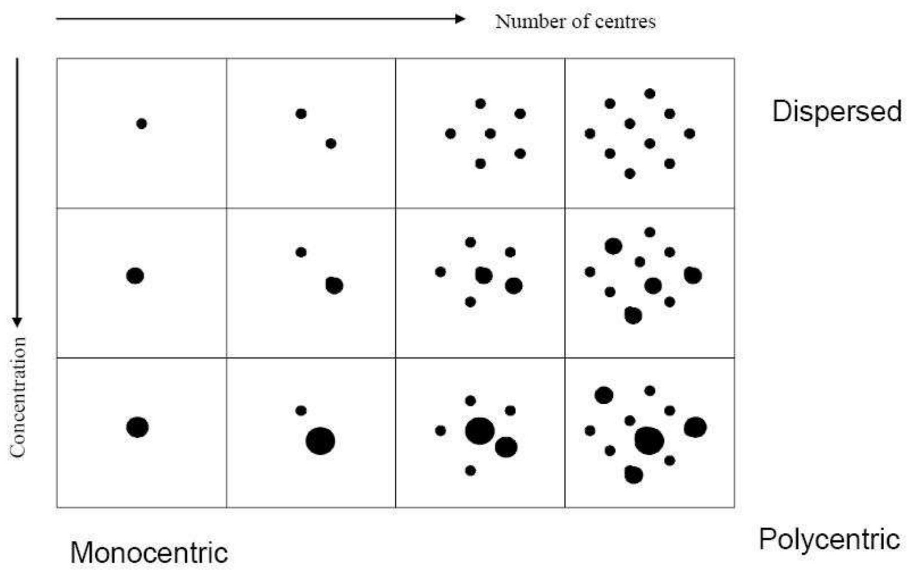

Figure 6 – Classification of urban structures (source: Martens, 2006)

Thus, the number of urban centres allows for the distinction between polycentric and monocentric structures, while the level of concentration distinguishes the monocentric and polycentric structures from the dispersed structure (Martens, 2006).

In conclusion, when studying the relationship between urban structure and travel behaviour (section 2.4), this issue assumes special relevance, since the distinction between polycentrism and urban sprawl has accessibility and mobility implications. For instance, while a system of medium density and relatively autonomous sub-centres may be suitable for non motorized modes (as walking and cycling) and may allow for an efficient public transport system a sprawled or dispersed pattern will probably foster an increase in car use.

2.4. URBAN STRUCTURE INFLUENCING TRAVEL BEHAVIOUR

It begins to be clear that some human objectives are intimately connected with the physical pattern of a city, while others are very little affected by it. For example, there has been little discussion of the healthfulness of the environment or its safety.

Kevin Lynch, 1961

Opposite to what happened during the early 1960s, today the concern with the environment – and in particular with the environmental consequences of urban transport - is on the agenda. Supported by it, a growing number of research literature has recently been found addressing the relationship between the spatial pattern of cities and the inhabitants' travel behaviour (Næss, 2005).

The efficiency of urban forms (particularly the monocentric-polycentric issue) in terms of commuting distances and times as well as the influence of urban structure on modal choice is at the heart of the debate (Schwanen *et al.*, 2001; Schwanen, 2002; Schwanen *et al.*, 2004).

However, the literature on how monocentric and polycentric metropolitan structures affect travel behaviour is far from being consensual (Schwanen *et al.*, 2001). Some authors, often adhering to the 'co-location' hypothesis, advocate that a de-concentrated urban structure tends to reduce commuting distances and times; while other scholars refute this positive view on the effect of polycentricity on travel behaviour, stating the opposite (Cervero and Wu, 1998; Schwanen *et al.*, 2001).

Furthermore, most of the research literature focuses on spatial and temporal aspects (like travel distances and times, respectively) and to a lesser extent on the question of how decentralization affects mode choice and average vehicle occupancies (Cervero and Wu, 1998). These questions of resource efficiency are as important as the former to the concerns over environmental quality and excessive auto mobility (Cervero and Wu, 1998). Moreover, the spatially diffuse commute patterns in decentralized urban areas make it more difficult for public transport providers to guarantee a quality of the service that might be capable of competing with the private car (Schwanen *et al.*, 2004).

This discussion is mainly based on the analysis of American data sources (Schwanen *et al.*, 2001; Schwanen, 2002) – evidence from European context is scarcer (Schwanen *et al.*, 2004). Moreover, it is not clear whether conclusions based on US data may be valid in Europe. Schwanen (2002) argues that transport contexts in Europe and in the US differ in four fundamental ways: first, European cities tend to be smaller, older and denser; second, urban planning policies in Europe have been more efficient on preventing urban sprawl when compared to what has been done in the USA; third, there are different domestic economic contexts; and finally the culturally defined norms and values in many European countries may affect individual travel behaviour. This factors result in less car ownership, car use and car dependence in Europe as well as in a more widespread use of public transit and other transport modes (Schwanen, 2002).

Thus, the remain part of this section will attempt to review the most important theories on the influence of urban structure on travel distances, travel times and mode choice and present some of the empirical studies found on the literature.

2.4.1. THEORETICAL EVIDENCE

An interesting theory developed in the 1980s that illustrates the relationship between urban spatial structure and mobility is the ‘Brotchie Triangle’. According to this theory, any city can lie between the three extreme points (A, B and C) of the Brotchie Triangle (Silva, 2008) (see Figure 7).

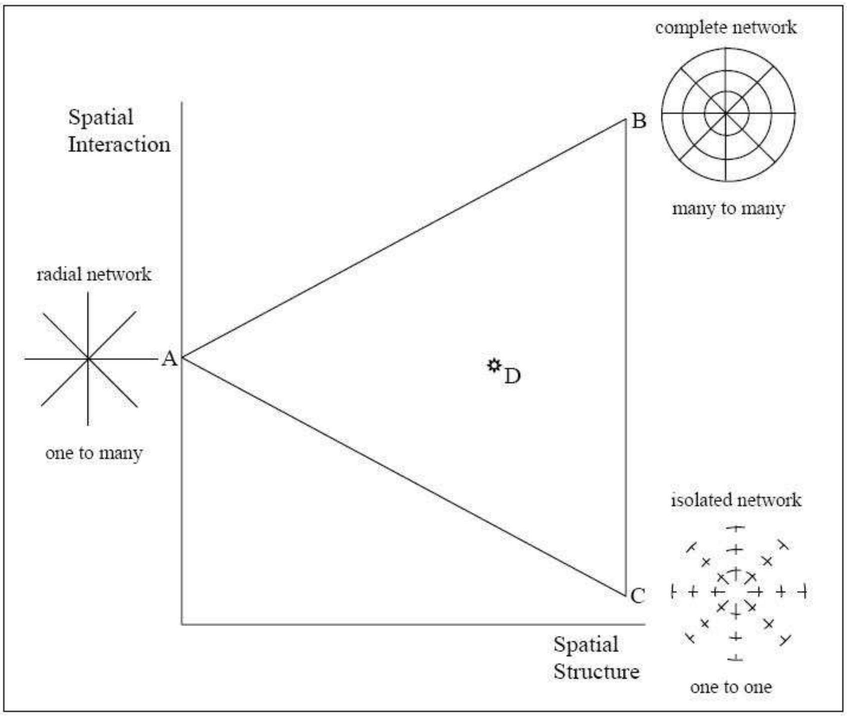

Figure 7 – The 'Brotchie Triangle' (source: Silva, 2008)

Spatial structure is represented in the horizontal axis as the dispersion of working places from the centre (e.g. mean travel distance of employment from the centre of the region). The vertical axis represents dispersion patterns of travel, as mean travel distance to work. Point A represents the ultimate model of the monocentric city, with total concentration of jobs in the core and radial commuting patterns. The line BC corresponds to the complete employment dispersal: point B represents the city with decentralized employment and dispersed commuting (workers maximize travel) and point C represents the city with decentralized employment but where workers choose to reside near to the places of work. Point D represents a given city (Wegener and Fürst, 1999; Silva, 2008).

The line AC represents the minimum need to travel in a city (as if every worker would choose to minimize the distance between his job and residence locations; while line AB represents the longest average trip length (Wegener and Fürst, 1999). Therefore, the Brotchie Triangle shows that decentralization of jobs does not necessarily lead to shorter travel distances, these distances can even increase if spatial interaction increases (Silva, 2008). On the other hand, spatial structure is not the only factor influencing travel patterns: for instance, transport policies promoting slow transport modes may shift spatial interaction in a city across line BC towards point C (Silva, 2008).

Increased commuting distances as well as lower transit use and lower average vehicle occupancy reflect costs carried by society, since these phenomena are responsible for rises on air pollution and energy consumption (Cervero and Wu, 1998). According to Cervero and Wu (1998), one of the most robust and strong measures correlated to social costs and transport externalities is 'vehicle miles travelled' (VMT). VMT per employee can be estimated combining data on commuting distances, modal split and vehicle occupancy levels[6]. According to Ewing (1995), VMT per employee is a good indicator of transport system performance, 'intimately related to such worthy social objectives as accessibility, sustainability and livability' (Ewing, 1995; quoted by Cervero and Wu, 1998). Nowadays trends in VMT per capita have particular policy relevance, considering the current debate around air quality and environmental consequences of transport.

Another element assuming a central position in the literature on the impact of metropolitan structure on commuting is the 'co-location hypothesis'. Authors like Peter Gordon argue that individual households periodically change their place of residence or work as a way of avoiding the increased travel times caused by the extensive congestion in monocentric urban areas (Gordon *et al.*, 1989; Schwanen *et al.*, 2004). Suburbanization is, thus, seen as a successful mechanism for mitigating congestion, as jobs and housing mutually co-locate allowing for different travel modes and high travel speeds that maintain the average commuting time quite constant (Gordon *et al.*, 1989; Kim, 2008).

Firms also try to avoid some of the disadvantages of high density locations (as traffic congestion, poor accessibility to suburban labour force, higher land prices and limited potential for spatial extensions) choosing new locations in less congested places of the metropolitan area (Schwanen *et al.*, 2004) or locations where potential employees reside (Cervero and Wu, 1998). These trends foster the development of polycentric urban areas with higher dispersal of activities across urban space and lower average commute times and distances. As workers are assumed to minimize travel distances and times, the 'co-location hypothesis' advocates expect these factors to be lower in polycentric than in monocentric urban structures (Schwanen *et al.*, 2004).

2.4.2. Empirical evidence

Several empirical studies support the co-location theory. A study conducted by Gordon *et al.* (1987) on 19 urbanized areas in the US based on 1980 Census data states that low-density metropolitan areas with their decentralized employment centres facilitate short work trips (Gordon *et al.*, 1989).

According to these authors, the *a priori* relationship between residential densities and mean travel time is not clear. On the one hand, the impact of residential density on the length of work trips is ambiguous since while in a monocentric city high densities lead to shorter trips, in a polycentric city low densities may mean either shorter or longer trips, depending on the workers place of residence (whether they choose homes around employment sub-centres) and on the importance of cross-commuting across the metropolitan area. On the other hand, high densities may lead to higher mean travel times because of the effects of congestion (Gordon *et al.*, 1989).

The results presented in the study lead us to conclude that residential densities and commuting times are positively correlated (Gordon *et al.*, 1989). The results also show that commute times are higher in monocentric urban structures, suggesting that 'polycentric or dispersed spatial structures

[6] Cervero and Wu (1998) suggest the following expression to calculate VMT:

$$\text{VMT/employee}_j = [\sum_i \sum_k (T^k_{ij} / O_k) D^k_{ij}] / E_j$$

where, T = total person work trips; D = network distance; E = employment; O = average occupancy level; i = residential census tract index; j = employment centre index; k = commute mode index reduce rather than lengthen commuting times' (Gordon *et al.*, 1998; 148). It is, however, important to note that the concept of polycentrism is used here as 'urban sprawl' - a low-density and dispersed city (see section 2.3.4).

Levinson and Kumar (1994) reached similar conclusions in a study developed in the Washington D.C. metropolitan region, using data from person travel surveys for 1968 and 1987 (Levinson and Kumar, 1994). They found that average trip times have remained stable or declined during this 20 year period for all trip purposes and all transport modes. However, the analysis shows that decentralization leads to the increasing of travel distances, but higher travel speeds allow for lower travel times (Levinson and Kumar, 1994).

Other authors refute the 'co-location' hypothesis' positive view of the effect of polycentrism on travel behaviour (Schwanen *et al.*, 2001). These scholars argue that several phenomena may be responsible for longer commute distances and times in polycentric areas. The assumption of travel minimization may be challenged by constraints on residential choice behaviour (Schwanen *et al.*, 2004). For instance, there may be several workers in a household (Clark et al. 2002; Giuliano and Small 1993, both referred to in Schwanen, Dieleman *et al*. 2004), or a lag in housing development near employment centres (Cervero and Wu, 1998) or policy measures creating greenbelts around urban nodes (Jun and Bae 2000, referred to by Schwanen *et al.* 2004). Moreover, people may be reluctant to change job and particularly to change the place of residence, because of the substantial costs involved in this process, not only for the worker but also for his/her family (Schwanen *et al.*, 2004).

Several empirical studies can be found in the literature showing results that contradict the 'co-location' hypotheses. A study developed by Cervero and Wu (1998) in the San Francisco Bay Area showed that commute distances and times increased with the decentralization of employment during the 1980s. Crossing census data and journey-to-work statistics from 1980 and 1990 this study analyzed 22 'employment centres' (EC) – defined based on size and density criteria (for detailed explanation see Cervero and Wu 1998, pp 1060) – and examined five output measures of commuting impact: average durations, average distances, modal splits, average vehicle occupancy levels and VMT per employee (Cervero and Wu, 1998).

This study concluded that, among all 22 EC, average commute distances increased 12% and average durations increased by 5% during the 1980s, suggesting that the 'co-location' hypotheses did not hold for the San Francisco Bay area during this decade of continuing job decentralization (Cervero and Wu, 1998).

As to modal split, the same study showed that the share of commutes by drive-alone car rose during the 1880s (from 55,7% of commutes in 1980 up to 61,3% in 1990). The results also show that modal shares by carpool fell from 17,0% to 13,8% during this period of time, while public transit dropped even more – from 19,3% to 15,4% of EC workers commutes. This shifts in modal split caused a decline in average commute occupancies from 1,3 to 1,25 persons per vehicle (Cervero and Wu, 1998). However, the authors note that the declining of transit shares may have been consequence not only of spatial trends but also of other factors, like demographic characteristics and declining expenditures with fuel and toll charges (Cervero and Wu, 1998).

Cervero and Wu (1998) also concluded that VMT per employee in the 22 EC in the San Francisco Bay Area increased 23% during the 1980's. According to them, 'this is a direct product of average commute distances and drive-alone shares having increased and average vehicle occupancy levels and transit/ridesharing shares having fallen during the 1980's' (Cervero and Wu, 1998; 1071). The results also suggested that rising commute lengths was the biggest contribution for the growth in commute VMT per worker.

In 1989, in a study comparing gasoline consumption per capita in ten large US cities, Peter Newman and Jeffrey Kenworthy concluded that the urban structure within a city is fundamental to its gasoline consumption (Newman and Kenworthy, 1989).

This study found that gasoline use has a significant negative correlation with the proportion of population living in the inner city. However, and unlike what could be expected, the overall metropolitan journey-to-work trip length does not relate significantly with gasoline use. This suggests that, in this sample of relatively large cities, city size is less important than other physical planning parameters, like the intensity of land use, defined by population and job densities (Newman and Kenworthy, 1989).

The same study also concludes that the strength of the city centre affects transportation patterns, particularly the share of transit use. The results show significant (negative) correlations between gasoline use and both the number and proportion of jobs in the city centre.

Comparing these American cities with other cities around the world (including European cities) Newman and Kenworthy (1989) reached similar conclusions suggesting, however, that the overall population and jobs density is more important for travelling characteristics than the centralization factor. They also state that evaluating the role and importance of strong sub-centres within the urban area could be a valuable exercise, as sub-centres could be the means for more intensive outer area land use.

In short, these authors advocate for a low transportation energy city characterized by a dense form, a strong centre and intensively utilized suburbs in the inner area that allow for a better transit system and more walking and biking. They recommend a variety of policy measures that include increasing urban density, strengthening the city centre, extending the proportion of city that has inner-area land use; providing a good transit option and restraining the provision of road infrastructure.

Most of the European literature on this matter also contradicts the point of view argued by the ‘co-location’ hypothesis. Schwanen (2002), based on data collected by Kenworthy *et al.* (1999[7]) for 11 European cities[8], argues that the relocation of employment and residences may not occur to the same extent in European countries as in the US which might be due to the more comprehensive regulation on housing and land markets in Europe (Schwanen, 2002). As a result, this author states that commuting times in Europe do rise with increasing urban size.

The analysis developed in this study shows that concentration of employment in the CBD results in smaller travel distances, although this is partially offset by the positive effect on commuting distance by the concentration of the population in the inner areas (Schwanen, 2002). As to commuting times, the results reveal that they are shorter in the inner-city area, though with a less significant impact, probably as a result of congestion (Schwanen, 2002). Therefore, commuting distances and times tend to be shorter in monocentric cities with a concentration of both population and employment in the urban core. Concerning modal split, the same study reveals that concentration of employment

[7] KENWORTHY, J.R., F.B. LAUBE, P.W.G. NEWMAN, P.A. BARTER, T. RAAD, C. POBOON & B. GUIA (Jr.) (1999), An International Sourcebook of Automobile Dependence in Cities 1960–1990. Boulder, CO: University Press of Colorado.

[8] Amsterdam, Brussels, Copenhagen, Frankfurt, Hamburg, London, Munich, Paris, Stockholm, Vienna and Zurich

within the CBD has virtually no effect on the modal split in the 11 European cities examined (Schwanen, 2002).

Another important conclusion of this study is the significant negative correlation between population density and commuting distance and time: as population density increases, commuting distance and time decrease. These results are in complete contrast to the findings of Gordon *et al*. (1989) for American cities. On the other hand, population density seems to positively correlate with the share of commuters using public transport, presumably because higher densities create larger potentials for public transport networks (Schwanen, 2002). However, this beneficial effect of higher densities on public transport use has often been reached at the cost of less use of environmentally friendly transport modes, like cycling and walking (Schwanen, 2002).

Another study developed by Schwanen, Dieleman and Dijst (2004) in the Netherlands also reached important conclusions regarding the influence of urban structure on modal choice and travel distances and times as a car driver (Schwanen *et al.*, 2004). The types of urban structure used for this study were based on the classification developed by Van der Laan (1998) that distinguishes four types of urban systems: one monocentric – 'centralized' – and three different types of polycentric urban areas – 'decentralized', 'self-contained[9]' and 'exchange commuting' (see section 2.3.3).

This study found that the influence of a monocentric or polycentric urban structure on mode choice is rather limited, though in high-density environments and core cities the probability of driving a car to work seems to be lower (Schwanen *et al.*, 2004). Thus, polycentrism does not result necessarily in higher shares of car use for commuting, especially if well-developed transit networks serve urban areas (Schwanen *et al.*, 2004).

Concerning commute distance and time for car drivers, evidence show that both are significantly longer in the majority of polycentric areas than in monocentric centralized urban structures (Schwanen *et al.*, 2004). Only in one type of polycentric area – the 'self-contained' region consisting of relatively independent nodes - are commuting distances and times equivalent to the values found in monocentric systems.

This study also concludes, however, that other non-planning related variables – as socioeconomic status, gender, household structure or employment indicators – are important explanatory factors on commute behavior. On the other hand, the extent to which circumstances in the Netherlands can be replicated elsewhere is unclear, since population densities have always been high and transport networks well developed in the Netherlands (Schwanen *et al.*, 2004).

Another study developed in France by Aguilera and Mignot (2004) suggests that the effects of polycentrism on travel behaviour depend on the nature of the employment sub-centre, its location (distance to the city centre or positioning in terms of the transport axes), its size and its density (Aguilera and Mignot, 2004). The study consisted in comparing data from the 1990 and the 1999 Census in several French urban areas[10] with different sizes and also different structures in terms of level of employment suburbanization (Aguilera and Mignot, 2004).

The analysis considered four types of places in the urban area: 'centre', 'suburban sub-centres', outlying sub-centres and 'rest of the urban area'. The suburban sub-centres are large, locate near the city centre and, together with the city centre, they constitute a greater centre where proximity between

[9] The 'self-contained' urban system corresponds to Van Der Laan's 'cross-commuting' system.
[10] Paris, Lyon, Marseille-Aix, Bordeaux, Grenoble, Dijon and Saint-Etienne.

housing and jobs is quite high. The ‘outlying sub-centres’locate outside this centre and are both further and smaller but well situated on main transport axes (Aguilera and Mignot, 2004).

The study results show that average commuting distances are shorter in the sub-centres than in the rest of the urban area. Furthermore, the city centre and the suburban sub-centres form a greater centre where commuting distances are reduced. As to the outlying sub-centres, they do not employ a sufficient proportion of their own residents – many work in suburban sub-centres – and attract only a weak proportion of the workers from the rest of the urban area (Aguilera and Mignot, 2004).

The analysis of the data from 1990 and 1999 reveals that while most jobs continue to concentrate in the centre and suburban sub-centres, people live more and more in outlying sub-centres and in the rest of the urban area. This phenomenon led to an average lengthening of commuting distances between 1990 and 1999, since the number of locally employed people has fallen and the non-locally employed workers live further and further from their place of work (Aguilera and Mignot, 2004).

A study developed by Petter Næss (2006) on the Copenhagen Metropolitan Region shows that residential location in the urban structure clearly affects travel behaviour, even when taking into consideration socio-economic differences. This study was based on a questionnaire survey among inhabitants of 29 selected residential areas in the Copenhagen Region, completed with qualitative interviews and detailed travel surveys. The results show that higher density areas located closer to Copenhagen city centre contribute to less travel, lower shares of car driving and more trips by non-motorized modes; while the peripheral parts of the metropolitan area show a higher amount of transport and a lower share of non-motorized modes (Næss, 2006).

According to these results, the urban structure factor exerting the strongest influence on the length and travel mode of commuting trips is the distance from the residence to central Copenhagen. However, other factors like urban density and the distances from residence to the closest second-order centre or to railway stations also influence travel patterns to a relatively high extent (Næss, 2006).

Finally, in this same book, Næss refers to other research studies both in Copenhagen and in other Scandinavian cities. Authors like Hartoft-Nielsen (2001), Nielsen (2002), Næss et al. (1995) or Røe (1999) (all referred to by Næss, 2006) reached similar results in cities like Oslo, Copenhagen, Arhus, Aalborg and other Danish towns: the trip length and the use of motorized modes tend to increase with increasing distances between residences and the city centre. However, several studies indicate that the amount of travel may be lower in areas distant enough from large urban centres (Næss, 2006). This phenomenon was observed in the Copenhagen Metropolitan Area (Hartoft-Nielsen, 2001, referred to by Næss, 2006; Næss 2006) and in other Danish provinces (Næss and Johannsen, 2003, referred to by Næss, 2006) and corresponds to the effect of the distance from residence to the closest second-order urban centre.

In summary, the empirical literature on the influence of urban structure on travel behaviour is quite contradictory and sometimes inconclusive. While several authors state that a higher urban density and a strong city centre lead to shorter trip lengths and higher use of public transport and non-motorized modes, others argue for lower densities advocating that housing and jobs mutually co-locate allowing for shorter commuting times and distances.

On the other hand, several methodological differences can be found in the numerous studies analysed, like the level of aggregation of the data used, the variables choice, whether or nor not leisure trips are also considered and, mainly, whether or not socio-economic factors are taken into consideration.

Moreover, some differences can also be found when comparing North American and European literature. In this matter, there is a reasonable degree of consensus in European literature around the idea that a high density, centralized city with a strong transport system may contribute to lower car use and shorter commuting and leisure trips. However, some results indicate that more polycentric regions with several high density centres and an efficient public transport service can also show lower car use and high shares of public transport and non-motorized modes.

2.5. CONCLUSION

The literature on urban structure and mobility is wide and multi-disciplinary, encompassing a large range of studies with very different results, depending on the Region (for instance Europe or North America), the academic background, the subject on focus (urban planning, transport or the environment, for example) and, related to the last two, the methodology used. Thus, it would be impossible in this dissertation to go through all the topics currently in discussion regarding urban structure and mobility. However, the previous sections provided for an overview of the most important theories regarding both urban structure and mobility matters developed during the last decades and attempted to address the main issues currently in discussion.

In this last section, the main conclusions of the literature review will be summarized. The section is divided into three parts. First, the main conclusions regarding urban structure will be presented. The second part will address the subjects concerning mobility and the relationship between urban structure and travel patterns. This chapter ends with a discussion focusing on the role of the urban structure for a more sustainable mobility.

2.5.1. URBAN STRUCTURE

The review of literature on section 2.3 showed that there is some consensus around the idea that cities are developing from a monocentric urban structure to a more polycentric or decentralized one. However, the exact process of city growth, the nature of this new polycentric form and even the concept of polycentrism still remain somewhat unclear in the literature.

The ambiguity around the concept of polycentrism normally emerges related to two dimensions: the spatial scale of polycentrism (Davoudi, 2003) and the distinction between polycentrism and sprawl (Ewing, 1997; Martens, 2006). The three scales of polycentrism suggested by Davoudi (2003) (see section 2.3.1) help to clarify the distinction between the ‘urban polycentrism’ - that refers to several centres of employment and housing concentration inside the city boundaries or in its vicinity – and the ‘regional scale polycentrism’ – characterizing a region with two or more separated cities of similar dimension with a certain degree of interaction.

A considerable amount of studies on the influence of land use on mobility are based on the conceptualization of only two types of urban forms – the monocentric (centralized) city and the decentralized one - not making a clear distinction between different types of decentralization. This dissertation supports the idea that deconcentration does not imply a loss of centralization (Martens, 2006). Therefore, and for this specific purpose, a classification of urban structure only based on urban density or level of concentration in a high scale is not enough: the specific pattern of decentralization assumes major relevance.

In this context, a clear distinction must be made between a polycentric structure and a dispersed or sprawled one. As section 2.3.4 showed, a polycentric structure with medium density and some concentration of jobs and housing around several nodes may be suitable for the use of non motorized transport modes (like walking and cycling) and public transport, contrarily to a sprawled low density pattern where the dispersion of residences, jobs and activities practically forces the use of the car.

Another conclusion taken from the literature review is that the difference between urban structures in the United States and Europe is high (Martens, 2006). American cities have a much lower density and their urban structure is much less determined by historic roots than cities in Europe (Schwanen, 2002; Martens, 2006). Planning traditions in Europe (like the compact city concept) have prevented, at least to some extent, the decline of the inner-city. Moreover, the polycentric development in Europe appears to be different from the edge city development in the United States, since in Europe many sub-centres are located inside the central city. According to Martens (2006), new urban centres in Europe develop more often in the proximity of the inner-city so as to utilising its amenities.

2.5.2. URBAN STRUCTURE AND MOBILITY PATTERNS

The first conclusion taken from the literature review regarding urban structure and mobility is that most of the authors believe that urban structure has an important influence on mobility patterns. The literature is also fairly consensual about the principle that urban structure (either including or not transport factors) is not the only characteristic influencing people’s travel behaviour: socioeconomic factors (like average wage, car ownership, etc) also affect mobility patterns in a similar or even higher degree.

Despite the relatively large consensus around these two principles, the same does not happen when the question about how urban structure influences travel patterns is addressed. In this subject, and according to Schwanen *et al.* (2001), there are two camps: on one side are *the liberals*, who believe in the efficiency of market mechanisms and adhere to the co-location hypothesis (see section 2.4.1); on the other are the *regulators*, who recognize in urban planning the answer for environmental and congestion problems caused by travel behaviour, essentially by the extensive use of the car.

Moreover, the empirical literature on this issue remains inconclusive and even contradictory, showing a wide range of different results. While some authors state that a higher urban density and a strong city centre leads to shorter trip lengths and higher use of public transport and non-motorized modes, others argue for lower densities advocating that housing and jobs mutually co-locate allowing for shorter commuting times and distances. Both these theories are supported by several empirical studies.

These differences on the results can be explained by three fundamental reasons: 1) unclear definition of the urban structure characteristics (especially the concept of polycentrism); 2) methodological differences between the studies; 3) structural regional differences (namely between Europe and the United States).

The first aspect was already addressed before in this section. The concept of polycentric urban structure is sometimes not clear and is often used to describe other types of urban pattern - as the urban sprawl - or to characterize low density settlements. When studying the influence of urban structure on travel behaviour the distinction between different patterns of deconcentration, as it was said before, has relevant implications, for instance, on mode choice. On the other hand, as section 2.2.3 shows, different methodologies can be used to measure urban structure, i.e. to determine the degree of monocentrism or polycentrism of a city. Some authors classify cities based mainly on land use data (Newman and Kenworthy, 1989; Gordon and Richardson, 1996; Cervero and Wu, 1998), while others include mobility factors as well (Van der Laan, 1998; Schwanen *et al.*, 2001; Schwanen, 2002; Aguilera and Mignot, 2004) and others still take into consideration the location of sub-centres in relation to the inner-city (Aguilera and Mignot, 2004; Martens, 2006).

As to the second aspect, several authors argue that the lack of systematic methodological approaches may explain the differences in the results (Silva, 2008) and limit the comparison between different studies. The most important methodological differences found on the literature review are related to the following topics:

a. The choice of boundaries for the study region, the level of disaggregation of the data and the choice of variables for the analysis.

b. Whether the analysis is based only on commuting travel or if it also considers trips for leisure and other purposes.

c. Whether or not socio-economic characteristics and other specific local conditions are taken into consideration.

The choice of the study area and level of disaggregation are important factors that can highly affect the study results. However these choices are often constrained by the availability of the data. On the one hand, data may only be available on an aggregation level that is not the ideal for the study purpose. On the other hand, the data may refer to administrative boundaries that often do not correspond to the present patterns of urbanization of a city anymore. The availability of data mostly on a national level may also pose problems to the elaboration of cross-national comparative studies (Martens, 2006).

The consideration or not of non-commuting trips may also have an important influence on the results. Most of the empirical literature analysed in this chapter focus on the study of commuting travel. However, there is a current tendency, at least in European countries, for the increasing of non-commuting trips share. In Copenhagen, for instance, ‘leisure & entertainment’ represented about 35% of the daily trips in 2006, a value higher than the 27% observed for commuting trips (DTU-Transport, 2006). Thus, studies that consider other trip purposes besides commuting may provide a more realistic representation of the actual travel patterns in a region.

Finally, Stead *et al.* (2000) and Stead (2001) argue that considering socio-economic factors is necessary for the understanding of the cause-effect relationship between land use characteristics and travel patterns (see section 2.2.2). Næss (2006) also supports this point of view, stating that socio-economic characteristics and the travellers’ attitudes and lifestyles (as income levels, household characteristics, or leisure interests) may be different in different zones of the metropolitan area.

The third factor suggested for the inconsistency of the results found relates to the variation between different regions in the World. This discussion will focus on differences between Europe and the United States, since these are the most studied cases. Besides the differences in urban structure, addressed in the previous section, there are other differences between Europe and the U.S. that exert some influence on people’s travel behaviour. For instance, American cities are much more dependent on the automobile when compared to their European counterparts. European cities have lower levels of car ownership and car use and a much higher share of travel by public transport and non-motorized modes (Schwanen, 2002; Martens, 2006).

2.5.3. DISCUSSION: URBAN STRUCTURE AND SUSTAINABILITY OF THE MOBILITY

During the last decades, European cities have experienced both population and employment decentralization (Hall, 1995; Ewing, 1997; Anas et al., 1998; Davoudi, 2003; Aguilera and Mignot, 2004; Martens, 2006). With this process, more and more journeys have transferred from public transport to the private car, causing a mass car ownership in Europe (Hall, 1995). This context, allied to the more recent concerns about environmental problems, such as the consumption of fossil fuels and the emission on greenhouse gases, mainly carbon dioxide (Næss, 2006), have motivated the current debate about the sustainability of the mobility patterns, notably the questions of energy efficiency in transport.

This literature review reached the conclusion that changes in urban structure have an impact on the daily mobility of individuals, since land use and transport characteristics determine the degree of accessibility of a destination (Martens, 2006). Therefore, a question for discussion arises: what type of urban structure allows for a more sustainable mobility?

As the literature review showed, the answer for this question is complex and far from being consensual. Several authors argue that cities with strong concentrations of jobs in the inner core (the monocentric structure) provide the conditions for a good public transport system and thus have lower energy use for transport than the cities where jobs are dispersed (Hall, 1995; Kenworthy and Laube, 1999).

However, when a city grows to a certain dimension, the monocentric structure may be less efficient because of the effect of congestion or functional segregation. According to Hall (1995), Gordon and Richardson may also be right in arguing that encouraging outward movement of employment closer to the places where most of the people live may reduce commuting lengths. Other authors (Cervero and Wu, 1998; Stead, 2001; Schwanen *et al.*, 2004; Næss, 2006) add even more complexity to this problem, arguing that other factors - like household structure, costs of moving, individual preferences and lifestyles and other socioeconomic characteristics – may influence the individuals residential location choices more than the distance to work.

At least in European literature, most of the authors seem to reach an agreement regarding the idea that higher urban densities provide for a more sustainable mobility, since dense settlements allow for shorter travel distances, higher use of cycling and walking and a better provision of public transport. However, density does not imply a monocentric structure. Authors like Ewing (1997), Schwanen *et al.* (2004) and Martens (2006), argue that a polycentric structure with several medium/high density sub-centres may also be transport efficient and environmentally sustainable, depending of the specific pattern of polycentrism. Some empirical evidence supports this idea, showing the highest rates of public transport use in urban areas with a polycentric pattern.

Summarizing, the questions of how urban structure affects mobility patterns, and what kind of structure provides for a more sustainable mobility are currently in the centre of the debate and do not have neither clear nor consensual answers. This dissertation, by presenting two empirical case-studies - Copenhagen and Porto - will aim to make a contribution to the present debate on this issue.

3.

METHODOLOGY:

THE STRUCTURAL ACCESSIBILITY LAYER

3.1. INTRODUCTION

According to several authors, as Bertolini et. al. (2005), if adequately defined, the concept of accessibility can be directly related to both the land use and the transport system qualities. In particular, a focus on accessibility factors may enable a better understanding of how more sustainable travel options (as non-motorized modes and public transport use or making shorter trips), in certain land use conditions, may provide a degree of accessibility capable of competing with less sustainable options (Bertolini et al., 2005).

According to Geurs and Wee (2004), accessibility is defined in several different ways, by different authors and for different purposes. Considering a study that intends to use accessibility measures as indicators for the impact of land-use and transport on mobility - as it is the case of this dissertation – these authors suggest the definition of accessibility for passenger transport as the extent to which land use and transport systems enable individuals to reach different types of activities or destinations (Geurs and Wee, 2004). This definition of accessibility reflects the spatial distribution of opportunities and, as well, the availability and service level of different transport modes (Silva, 2008).

In this context, an accessibility-based tool – The Structural Accessibility Layer (SAL) – will be used in this dissertation (applied to a practical study on the Copenhagen Metropolitan Region) to analyze the influence of urban structure on mobility patterns. The results will, then, be compared to the results reached by Silva (2008) in the application of the SAL to the metropolitan area of Porto.

The presentation of this tool and the discussion of its concepts will be addressed in the following sections of this third chapter.

3.2. THE STRUCTURAL ACCESSIBILITY LAYER – CONCEPTS

This section will present the conceptual framework of the accessibility-based support tool used in this research – the Structural Accessibility Layer (SAL), developed by Silva (2008). This tool was built upon the assumption that urban structure and mobility are interrelated but, contrarily to the majority of the research on this subject, regards the urban structure and mobility interaction from the perspective of a constraint factor instead an influence factor (Silva, 2008).

The author argues that ‘the assessment of land use and transport constraints on urban mobility provides a far more objective and realistic approach for mobility management than the traditional influence-based approach’ (Silva, 2008; 68). In fact, the traditional research on urban structure and mobility interaction, centred on the influence land use and transport have on travel behaviour, has been mostly unable to understand the cause-effect of urban structure on travel behaviour, often showing ambiguous and inconclusive results (see section 2.4). According to Silva (2008), although the influence of urban structure on travel behaviour is uncertain, it is clear how urban structure constraints (enables or disables) certain mobility choices, affecting, thus, the sustainability of that mobility.

The author suggests that the SAL has two main purposes: analysis and design support (Figure 8). It enables the analysis of urban structure constraints on the sustainability of potential mobility patterns, and supports the identification of policy strategies that enhance conditions for a more sustainable mobility.

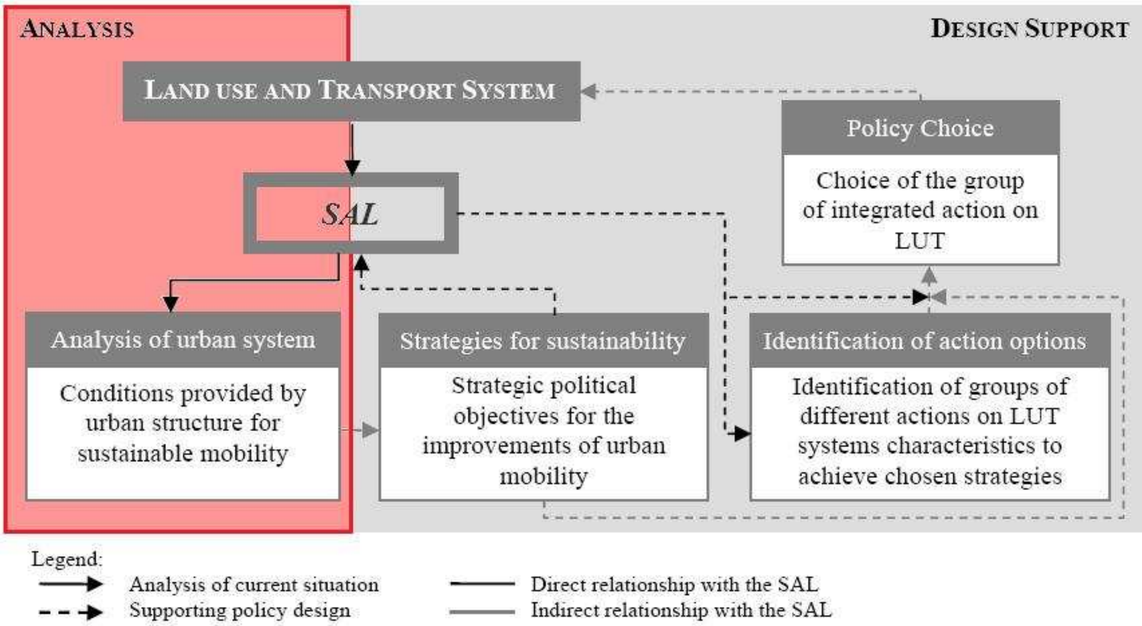

Figure 8 – SAL’s framework (source: adapted from Silva, 2008)

The SAL resorts to accessibility measures, namely accessibility levels by transport mode, based on the principle that comparing accessibility by mode, in certain land use and transport conditions (i.e. urban structures), provide a measure of (potential) mode choice, and therefore enables an evaluation of the urban structure constraints for sustainable mobility (Silva, 2008).

The object of analysis of the SAL is not, then, ‘real’ travel behaviour, but the travel behaviour enabled by the urban structure (i.e. potential mobility). As the author states, ‘the SAL does not measure mobility itself, neither its sustainability, it rather measures the extent to which the urban systems provide the necessary conditions to enable sustainable mobility patterns’ (Silva 2008; 69).

Considering the purposes of this dissertation, the current work will focus only on the SAL as an analysis tool (the red part of Figure 8).

3.3. SAL MEASURES

According to Silva (2008), the SAL is a geographical representation of comparative accessibility levels by transport mode to different types of travel generating opportunities, characterized by three fundamental aspects:

- The production of geographically represented (GIS based) results.
- The use of accessibility measures.
- The comparison of accessibility values by transport mode (defining the sustainability measure).

To determine the conditions that land use and transport systems provide for mobility, the SAL uses accessibility-based measures. The concept of accessibility is defined here as 'the extent to which the land use and transport system enable individuals to reach different types of opportunities' (Silva, 2008; 71).

These measures are represented by two different indexes: the diversity of activity index (the accessibility measure) and the comparative accessibility index (the sustainability measure). While the former measures the level of accessibility by each transport mode, the latter develop a comparative analysis of accessibilities by transport modes - using the results of the first index – and tries to measure the level of sustainability of the potential patterns of mobility enabled by the land use and transport conditions (Silva, 2008). These two measures will be presented in the remaining part of this section.

3.3.1. THE ACCESSIBILITY MEASURE

The level of accessibility by transport mode is measured using the diversity of activity index. This index counts 'the number of types of activities which can be reached within a defined number of activity types found to be the most relevant for travel demand generation' (Silva, 2008; 71, 72). The diversity of activity index (DivAct) can be defined by the following expression:

$$DivAct = \frac{\sum_y (Act_y * f_y)}{\sum_y f_y}$$

where y is the activity type; Acty represents the existence or not ($Act_y \in \{0; 1\}$) of the activity type inside accessibility boundaries; and fy is the potential frequency of use of the activity type.

The index is calculated for central points (potential travel origins) of the spatial units that result from a high spatial disaggregation of the study region. For each location, the index is calculated for each transport mode type considered - non-motorized transport (NM), public transport (PT) and the private car (CAR) – representing an aggregate measure of accessibility to several activity types. This measure encloses a simplification when considering the closest destination among the same activity type (regardless of quality, price and other personal preferences).

In addition to the accessibility to each activity, this index also considers the potential frequency of use (fy), which represents the potential use of an activity type when compared to others (for instance, the percentage of trips by activity type). Therefore, the diversity of activity index calculates an average of the number of accessible activity types, weighted by the potential frequency of use (Silva, 2008; Silva and Pinho, 2009). The results of this index range from 0 (no accessible activities) to 1 (all activity types are accessible).

After the complete definition of the accessibility measure, the SAL uses a GIS-based technology to identify accessibility areas for each sub-regional origin. This process requires the calibration of the local transport system for each type of transport mode. Figure 9 provides a schematization of this procedure.

The SAL's accessibility measure concludes with the production of three accessibility maps for the study region, one for each transport mode: NMDicAct, PTDivAct and CARDivAct.

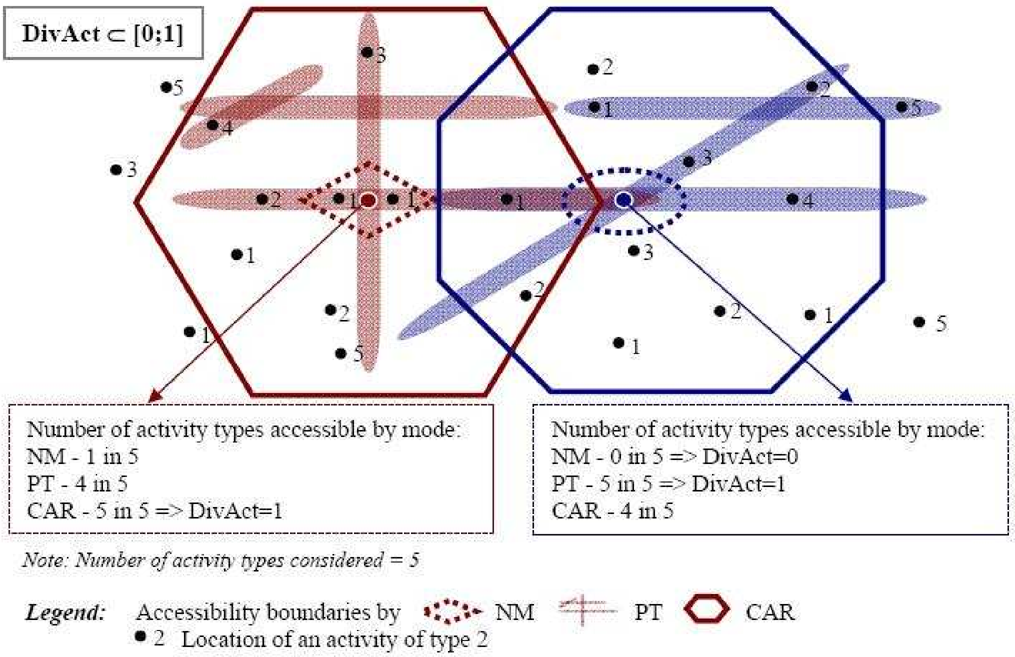

Figure 9 – Accessibility boundaries by transport mode - example of 2 origin points (source: Silva, 2008)

3.3.2. THE SUSTAINABILITY MEASURE

By calculating the accessibility measure disaggregated by transport mode type, the SAL enables the comparison of accessibility levels between the different types of transport modes – NM, PT and CAR. This comparison provides a measure of both the potential mode choice and the potential travel distance, allowing, therefore, for an evaluation of the sustainability of potential travel patterns constrained by land use and transport conditions.

The sustainability of potential mobility is measured by the comparative accessibility index, which consists in grouping different combinations of accessibility levels (DivAct) by each transport mode. This index, therefore, produces an aggregated value of comparative accessibility for all transport mode types.

The accessibility levels of each transport mode will be divided into three classes: A (high accessibility level), B (medium accessibility level), and C (low accessibility level). The use of these classes reduces the number of possible combinations of accessibility values to 27, forming the benchmarking cube presented in Figure 10.

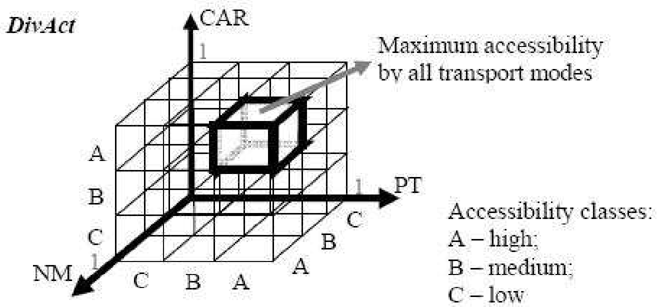

Figure 10 – Benchmarking cube and accessibility classes by transport mode (source: Silva, 2008)

Each one of these 27 combinations of accessibility values (named accessibility categories) represents different conditions enabled by urban structure factors for travel behaviour, concerning the potential choice of transport mode and the potential travel distance. For a better comprehension, the 27 categories were grouped into 9 accessibility clusters that define different levels of sustainability of potential mobility.

Figure 11 represents these clusters, providing a better understanding of their meanings. In this figure, accessibility categories are numbered from 1 to 27, while the nine clusters are numbered from I to IX and defined by the nine colours used in the benchmarking cube.

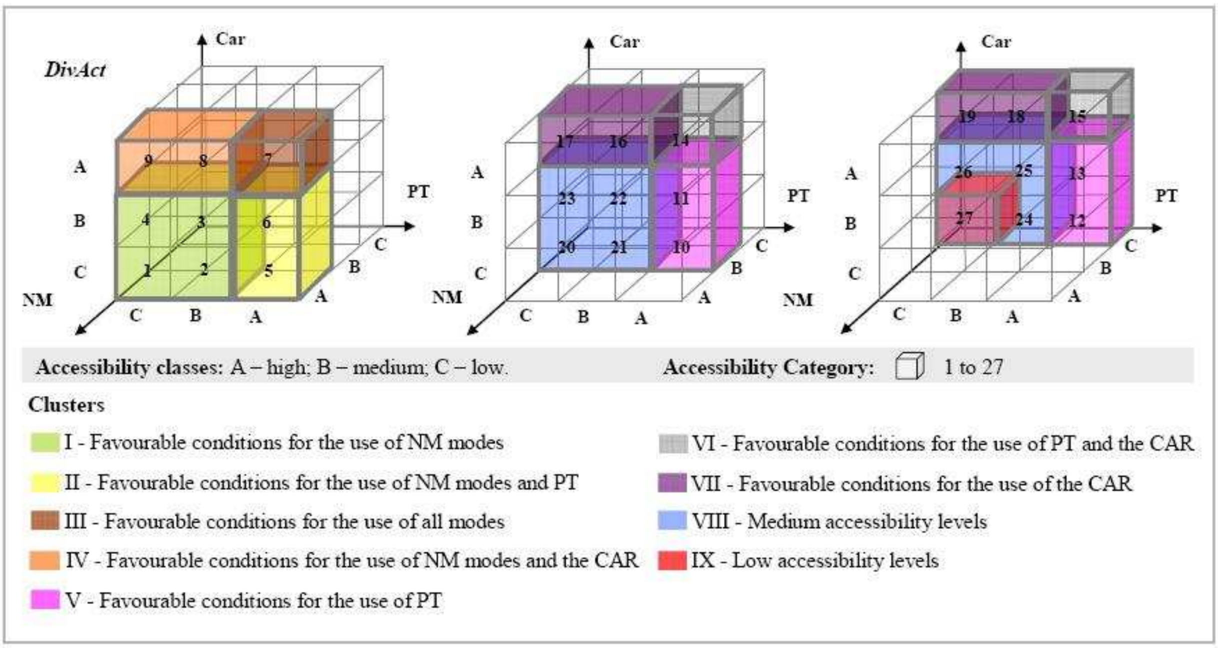

Figure 11 – Benchmarking cube and accessibility clusters (source: adapted from Silva, 2008)

The benchmarking cube, including the accessibility categories and clusters, is the central element of the SAL for the analysis purpose. The clusters can be geographically represented in a single aggregate map, synthesizing the urban structure constraints on potential mobility. This map allows for an overview of small scale variations of sustainability levels and can be analyzed in addition to the accessibility level maps for each transport mode, providing a thorough understanding of the urban structure conditions for mobility.

3.4. Local choices for the application of the SAL

According to Silva (2008), the SAL is responsive to local conditions and perceptions of accessibility and, therefore, several aspects have to be defined regarding the local context. Table 1 summarises these case-specific choices of the SAL for the analysis purpose. The current section will discuss some aspects to be taken into consideration, regarding the case-specific choices.

Table 1 – Case-specific choices (source: adapted from Silva and Pinho, 2009)

Case-specific choices	Definition of boundaries of the study region
	Level of spatial disaggregation
	Level of disaggregation by activities
	Potential use frequency (fy)
	Cut-off criteria and values
	Division of accessibility classes

The diversity of activity index provides a location based measure of accessibility – i.e. the accessibility measure evaluates accessibility of places, rather than accessibility of people or activities. Thus, the choices of the study region and the level of spatial disaggregation are particularly relevant.

The study region must be wide enough to cover the main potential mobility patterns of an urban agglomeration and must focus primarily on internal travel patterns, since the object of the SAL is travel behaviour enabled by the urban structure, and not the real travel patterns (Silva, 2008). As to the level of spatial disaggregation, the region must be divided into small enough sub-regions (high disaggregation), to provide the identification of small-scale variations of accessibility levels and improve the soundness of the measure. However, the spatial disaggregation is conditioned by the level of disaggregation of the statistical data available.

The activity type level of disaggregation is another case-specific choice in the development of the SAL. The choice of activities must be done taking into account the local travel demand (regarding statistical data, for instance) and the level of detail desired (more activity types and higher disaggregation of the same activity types provide higher detail for the land use conditions). The activity types must at least include the basic activities normally considered to have the most influence on travel behaviour, namely work, school, leisure, shopping, healthcare and other services (Silva, 2008).

The application of the SAL requires the definition of potential use frequency. The choice of the fy values must be based on the knowledge of local travel behaviour, for example the percentage of trips per trip purpose.

In order to identify the activity types which are reachable from a given origin, accessibility boundaries must be defined. The limit of the accessibility area is determined by the choice of the cut-off criteria – time and cost are the cut-off elements normally used for contour measures - and their values. This choice of the criteria for each transport mode, as well as the maximum value of the criteria is a very important issue. This choice should be based on the knowledge of local travel behaviour in order to provide a realistic assessment of the aspects dictating accessibility boundaries (Silva, 2008).

Finally, the division of accessibility classes should also be locally defined. As Silva and Pinho (2009) argue, 'the limits of these classes should make the meaning of the accessibility classes operational, translating the local understanding and perception of high, medium and low accessibility levels' (Silva and Pinho, 2009; 23). The definition of class limits can be done in accordance to the dispersion of spatial units' accessibility in the cube.

The case-specific choices for the SAL's application to the Copenhagen Metropolitan Region will be discussed later on chapter 4.4, after a brief presentation of this region.

4.
THE METROPOLITAN AREA OF COPENHAGEN

This fourth chapter presents the study region: the Copenhagen metropolitan area. The chapter has two main purposes: (1) to make a general presentation and characterization of the Copenhagen metropolitan area; (2) to present and explain the choices for the case-specific factors for the application of the SAL to this region.

The first purpose will be addressed in the first three sections. Section 4.1 will address Copenhagen, pointing some of the city's main geographical, demographic and economic characteristics. Section 4.2 will present the region of study and frame it into the Denmark's administrative boundaries. This has particular relevance due to the recent changes in the Danish local administrative structure. Section 4.3 will analyze Copenhagen's urban structure, considering the transport system, land use characteristics and the main land use plan that shaped the metropolitan region during the last decades – the 'Finger Plan'.

The second purpose will be addressed in section 4.4. In that section, the choices surrounding every case-specific factor used in SAL will be explained and justified.

4.1. THE CITY OF COPENHAGEN

With an urban area of approximately 2 million people, Copenhagen is the largest city in Denmark, a small and sparsely populated country (with roughly 5.5 million people) comprised of the mainland – Jutland - and several islands, including Fyn and Zealand. Copenhagen is located in the North-East of Zealand, at the margin of Europe but at the centre of the Øresund Region, a transnational region that includes the Danish islands of Zealand, Lolland, Falster, Møn and Bornholm and the Swedish region of Skåne (see Figure 12). With the construction of the Øresund Bridge, Zealand is now connected to the Scandinavian Peninsula by train and road and Copenhagen is just a few minutes away from Malmö, the third largest city in Sweden.

Copenhagen has a diversified, open and service-based economy, with relatively high import and export shares. Copenhagen's economy is diversified in several sectors, mainly business and services (encompassing 17% of regional employment), retail (15,8%) and several public services, as social institutions (13,2%), education (8,5%) and public administration (8,2%). Amongst cities in Europe, Copenhagen has the largest employment share in the services sector (86%) and the lowest share (13%) in manufacturing. [OECD, 2009]

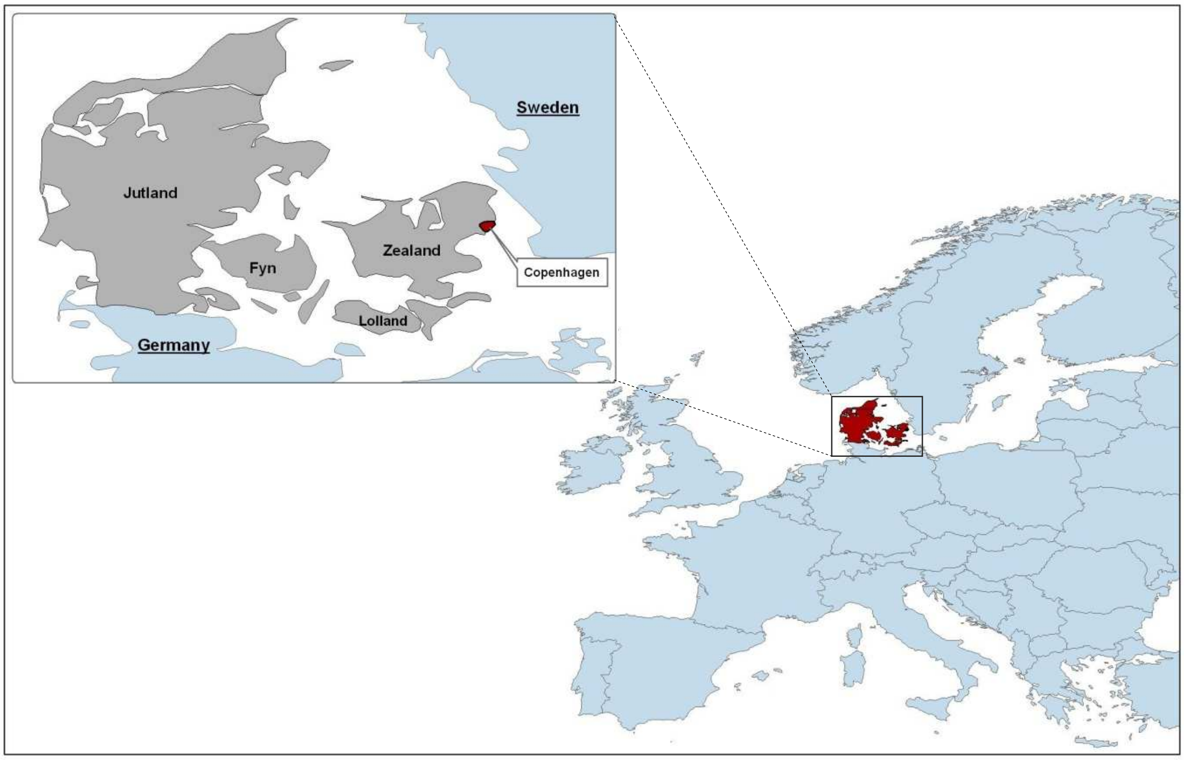

Figure 12 – Europe and Denmark

The same OECD report states that, unlike many other OECD metropolitan areas, Copenhagen's economic performance has not resulted in economic disparities, but, on the contrary, shows low unemployment rate, high participation rate and limited social segregation. Moreover, Denmark benefits from unusually low unemployment and remarkably little income disparity between regions, and it has one of the most equal income distributions in the world (OECD, 2009).

Copenhagen is also well-known worldwide for its environmental performance. Several environmental and energy policies during the last decades allowed for the reduction of CO_2 emissions by 25% since 1990. Recently, the City of Copenhagen has also agreed on a strategy to reduce these emissions by 20% in 2015 (OECD, 2009). Copenhagen aspires to become the 'greenest' capital in Europe and will host the UN Climate Change Conference in December 2009.

The environmental performance of Denmark and, in particular, of the city of Copenhagen is the result of several policies, notably the wind energy production (in 2006, 9% of Copenhagen's electricity came from this source and in Denmark this rate rises up to 18%), energy savings and the district heating system, one of the most sophisticated and environmentally friendly heating systems in the world, whose implementation in 2005 allowed for the reduction of 950040 tons of CO_2 emissions (OECD, 2009).

4.2. ADMINISTRATIVE STRUCTURE AND THE REGION OF STUDY

As in most European metropolitan areas, administrative boundaries in Copenhagen do not correspond to functional areas. According to Julià Sort (2006), the extension of a metropolitan city may be defined by the zone that constitutes a single labour market, *i.e*. a territory that embraces the living and work places of the mass of its population. Functional areas are, then, the areas in which people live and work on a daily basis; these are the areas relevant for public policy but they are dynamic over time and they have different sizes for different functions (Julià Sort, 2006; OECD, 2009).

Furthermore, the administrative structure of Denmark has been recently altered by the Danish Local Government Reform. In 2007, a reform of the public administration came into force creating a new map of Denmark. This reform abolished 13 counties, created 5 regions and reduced the number of municipalities from 271 to 98. The city of Copenhagen is now part of a region called *Hovedstaden* ('Capital Region'), with a population of 1.64 million inhabitants, and which includes the city of Copenhagen, 28 neighbouring municipalities and the island of Bornholm (OECD, 2009).

According to the 'OECD Methodology', the Copenhagen metropolitan region does not correspond to the Capital Region. It is composed of the municipalities of Copenhagen and Fredriksberg and the five former counties surrounding them – Copenhagen, Fredriksborg, Roskilde, Vestsjaelland and Stostrøms – with a population of 2.39 million inhabitants. This methodology takes into account population size (a minimum threshold of 1.5 million inhabitants), population density (more than 150 inhabitants per square kilometre) and commuting flows as indicators of whether urban areas represent a contained labour market (OECD, 2009).

The region considered in this study is a functional area that does not correspond to any administrative boundary. It is not the same as the region defined by the OECD either, because the latter is considered too wide and not representative of the most frequent commuting patterns. The Study Region is an area larger than the Capital Region but smaller than the boundaries considered by the OECD. It includes the municipalities of Copenhagen and Fredriksberg as well as the former counties of Copenhagen, Fredriksborg and Roskilde. According to the new local government reform, this region is composed of 34 municipalities and has a population of about 1.8 million inhabitants (see Figure 13 and Table 2).

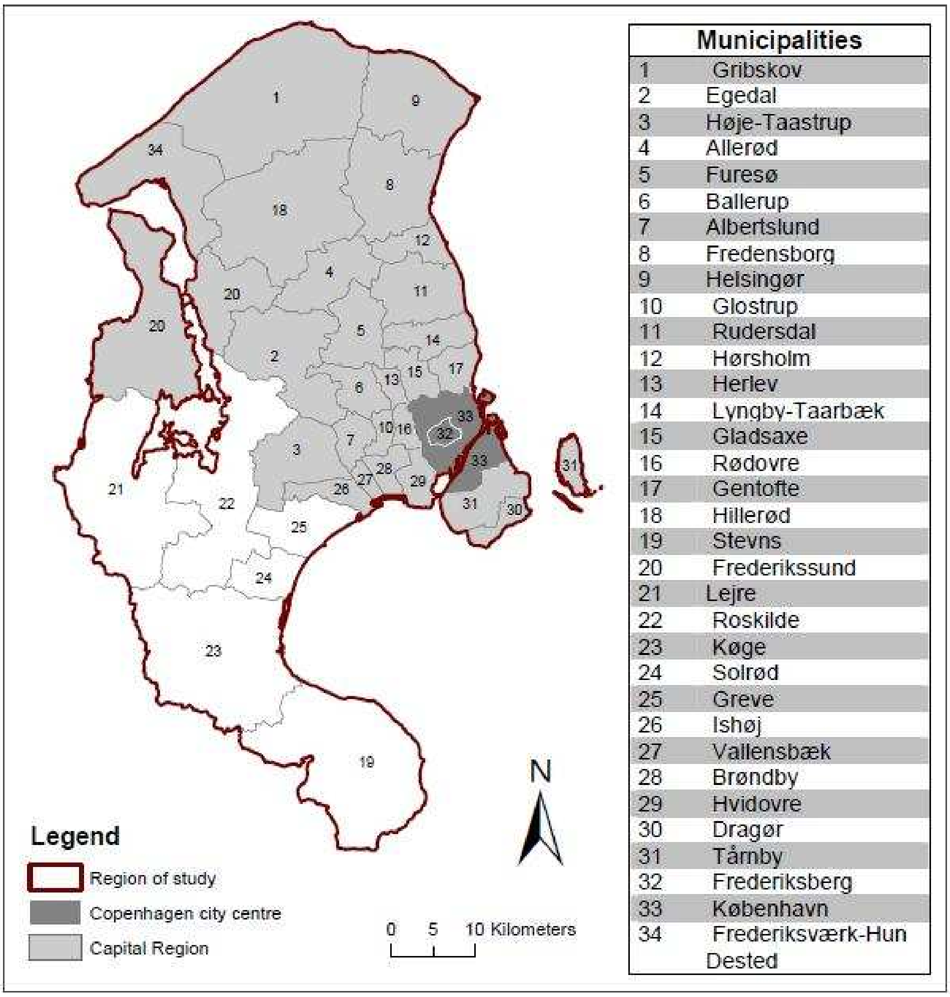

Figure 13 – Region of Study

Table 2 – Approximated area and population shares in Copenhagen

Region	Population	Area (Km²)
Municipalities of Copenhagen and Fredriksberg (Copenhagen city centre)	593 000	98
Capital Region	1 640 000	1977[1]
Copenhagen Metropolitan Area (Region of Study)	**1 800 000**	**3037**
Copenhagen metropolitan area (OECD)	2 390 000	9419

[1] This area does not include the island of Bornholm; the total area of the Capital Region is 2561 Km²

Data sources: OECD, 2009; Næss, 2006; DTU Transport

This region is considered to be the most appropriate area for the purpose of this study, because it corresponds to a conurbation that works largely as one single functional city, with a continuous job and housing market (Næss, 2006). It corresponds also to the area defined by the 'Finger Plan', a series of planning documents that have been shaping the Copenhagen's urban form since 1947 (see section 4.3.1).

Julià Sort (2006) states that there is a strict relationship between the outreach of the suburban railway network and the extension of the metropolis. This argument also supports the choice for the boundaries of the Study Region, because it encompasses most of the commuting trips and the transport infrastructure, notably the S-train lines (see section 4.3.2). From now on, the designation of Copenhagen Metropolitan Area (CMA) will be used in this dissertation referring to the region of study.

4.3. COPENHAGEN METROPOLITAN AREA: LAND USE AND TRANSPORT CHARACTERIZATION

4.3.1. LAND USE CHARACTERISTICS AND THE 'FINGER PLAN'

The history of the spatial development of the Copenhagen Metropolitan Area is strongly connected to the history of land use planning in Denmark, notably the 'Finger Plan'. This plan (see Figure 14), whose first version dates back to 1947, suggests an urban pattern with a form of a hand: 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 (S-train) lines (Hermansson, 1999). Between these fingers, the land would remain undeveloped in favour of 'green wedges' of farmland and forest, ensuring that the inhabitants of the urban areas of Copenhagen would not be far away from rural and natural environments (Næss, 2006). The plan further recommended that urban growth in the suburbs should develop into small independent communities connected to the city core by the S-train lines (Hermansson, 1999).

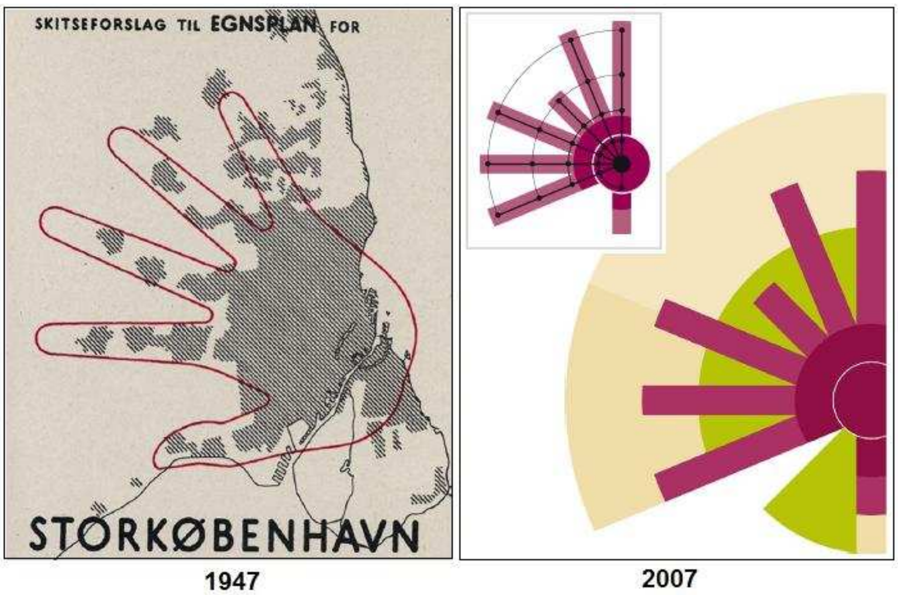

Figure 14 – Scheme of the Copenhagen's Finger Plan: the first version (1947) and the current plan

Since the first Finger Plan, spatial plans of Copenhagen have always promoted a clear demarcation of urban and rural land. Several authors (Hermansson, 1999; Næss, 2006; OECD, 2009) agree that the Finger Plan's principles have been, in general, successfully achieved: most of the urban development since the plan's implementation has been in accordance with its main ideas, especially regarding the protection of green spaces. However, the Plan has not been completely effective on preventing urban sprawl. According to the OECD (2009), with the population growth and the outward development of economic activity, the fingers have become much longer and larger than it was originally intended. The 2007 Finger Plan shows an effort to accommodate the urban expansion in the fingers by requiring municipal plans to provide for phased development of new urban areas and reviving the principle of proximity to railway stations, introduced in the 1989 Regional Plan (OECD, 2009).

The following maps (Figure 15 and Figure 16) show the spatial distribution of population and employment in the Copenhagen Metropolitan Region in 2009.

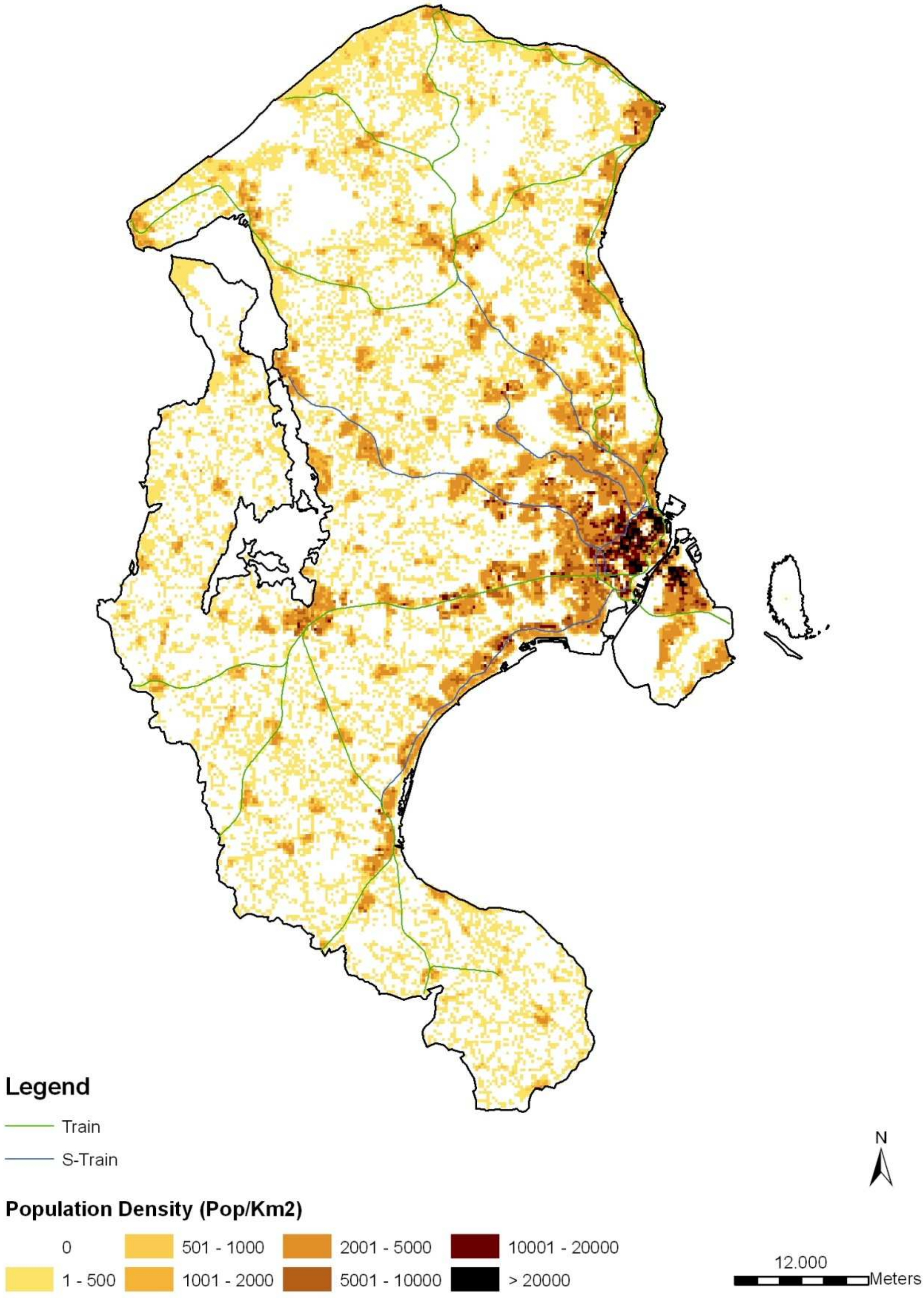

Figure 15 – Population density in the CMA (Source: DST, 2009)

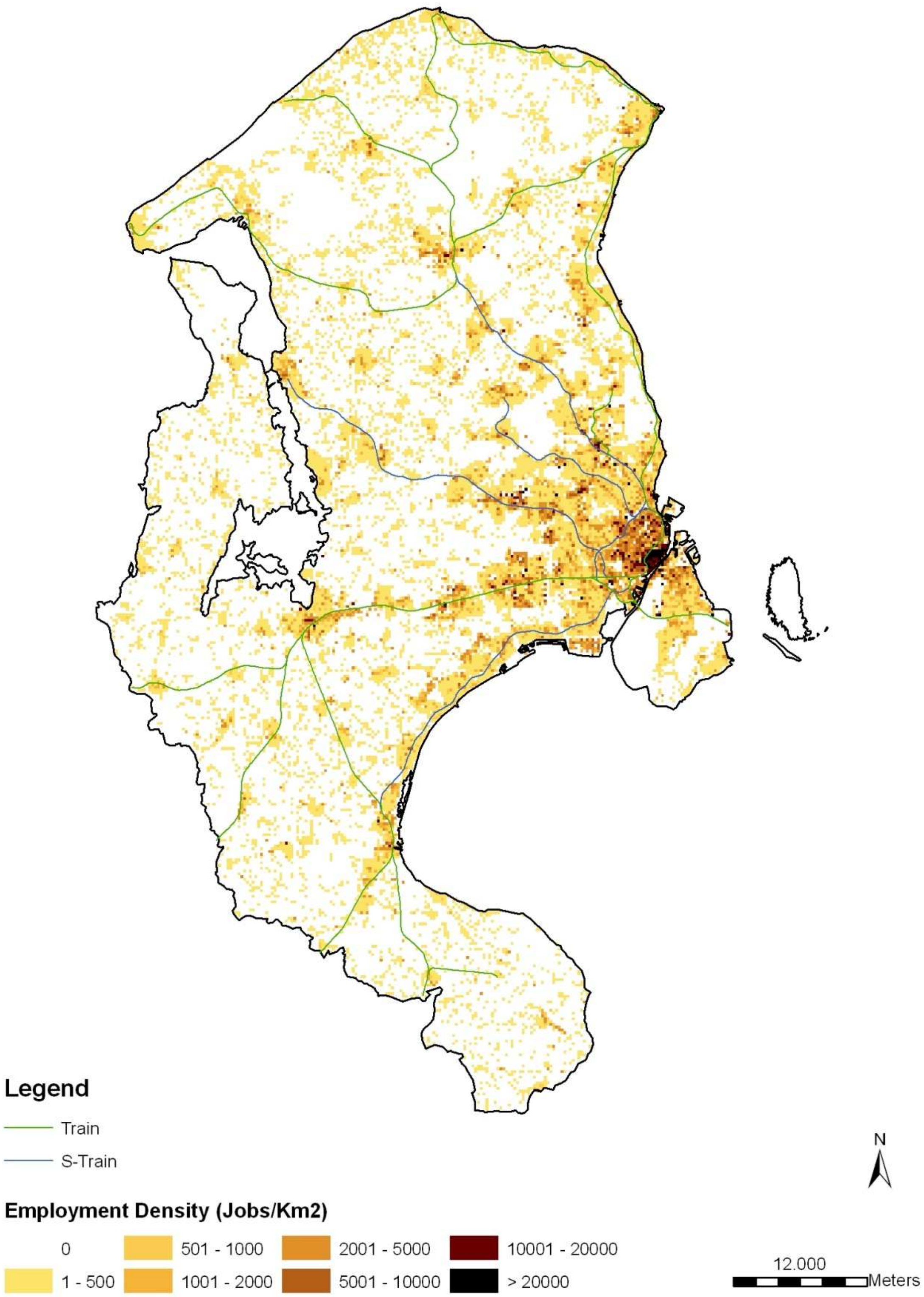

Figure 16 – Employment Density in the CMA (Source: DST, 2009)

Observing the maps, the influence of the Finger Plan on Copenhagen's urban pattern becomes clear. In fact, there is a clear concentration of jobs and most of all, of population along the five fingers defined by the Finger Plan. However, the maps also support the OECD's argument that it has not prevented urban sprawl.

Moreover, the maps show a high concentration of population and jobs (especially the latter) in Copenhagen's city centre. As has been discussed in chapter 2 of this dissertation, most of the American and also several European metropolitan areas have experienced population and job decentralization during the last decades. The historical urban core has lost most of its dominance and the urban pattern shall now be understood more as a polycentric or net-shaped city, rather than as a hierarchic central structure. However, and according to Næss (2006), this does not appear to be the case in Copenhagen, where the urban core is still the dominating centre of the metropolitan region.

The maps presented here support this argument. The CMA shows not only a high concentration of population and jobs in the centre, but also different degrees of concentration for population and employment. In fact, while there are some clusters of relatively high population density along the fingers (some decentralization of housing in second-order centres), employment is still rather concentrated in the 'palm of the hand'[11]. As Næss (2006) argues, the CMA can be characterized as hierarchic, with the city centre of Copenhagen as the main centre; a number of 'second-order' centres – among others the towns of Roskilde, Køge, Hillerød and Helsigør - that concentrate some regional-oriented retail activities and services; and also some more local centres that have emerged in the vicinity of railway stations.

Therefore, it can be argued that Copenhagen has quite a monocentric urban structure, with a strong inner-city centre and predominantly residential suburbs. However, these are not completely scattered suburbs; on the contrary, they have an interesting pattern with higher urban density along radial lines (sometimes clustering in second-order centres), as a result of the land and transport policies put in practice during the last decades, notably the Finger Plan and the commuter railway (S-train).

4.3.2. TRANSPORT STRUCTURE

As referred to before, the Finger Plan would not have been so effective in shaping the CMA's urban pattern without the help of the railways, mainly the S-train lines built along the fingers. In fact, land use and transport planning have always been connected in Copenhagen. According to Hermansson (1999), a finger like pattern already existed along the radial S-train lines (which came into use in the 1930s) and the Finger Plan's objective was to reinforce and regulate development trends that were born with the S-trains.

However, the transport infrastructure in the CMA is more than just the S-train. Copenhagen has a good transport infrastructure, with a high railway capacity and an average highway capacity, when compared to other European cities. It has also a large bus network, with different types of buses providing different services and at different times of day and night and a recently built underground system – the Metro. Figure 17 summarizes the transport infrastructure in the Copenhagen Metropolitan Area.

[11] With the two exceptions of Roskilde and Hillerød, which have also some concentration of employment

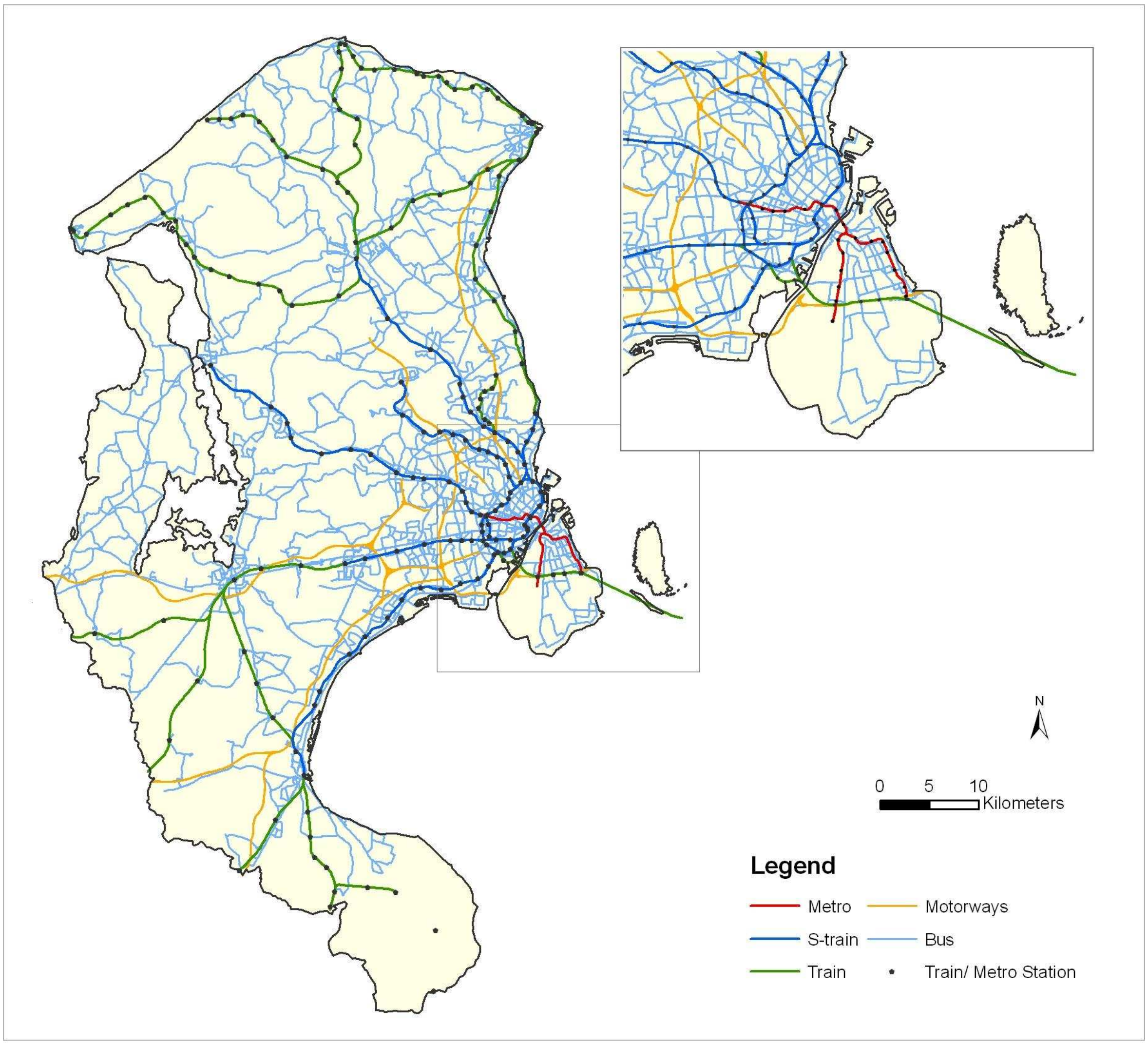

Figure 17 – Transport infrastructure in the CMA

The Metro has currently two lines: a common path crosses the city centre of Copenhagen in the N-S direction and then divides in two different lines serving the southern suburbs of Copenhagen and connecting to the Airport. These lines complete the S-train network, since there is no S-train line in the South of Copenhagen. Plans for the expansion of the Metro system are currently in elaboration, namely a circle line in the Copenhagen city centre.

The transport system in the CMA has suffered a major change after 2000, with the opening of the Øresund Bridge, which connects the city by railway and road to Sweden. This connection provides not only the link between Copenhagen and Malmö – the third largest city in Sweden, with roughly 300.000 inhabitants – but also the connection between the South of Sweden and the Copenhagen Airport. The southern suburbs of Copenhagen, in the island of Amager, have also recently been target to a large urban development, fostered by the Øresund link, the new Metro lines and the proximity to the Airport. Moreover, the most recent version of the Finger Plan (2007) includes an extra finger corresponding to this area.

Copenhagen is also known as a ‘City of Cyclists’, due to its large number of cycling tracks (a network of over 300Km) and high cycling rates (OECD, 2009). Copenhagen has also a considerable percentage of trips made by walking, although relatively low when compared to the benchmarking cities (OECD, 2009). Moreover, exclusively walking streets are common in the CMA, especially in the city centre where there are several retail-oriented streets without traffic.

Figure 18 shows the modal split in Copenhagen between 2006 and 2009, according to a travel survey developed by DTU Transport[12] (DTU-Transport, 2009).

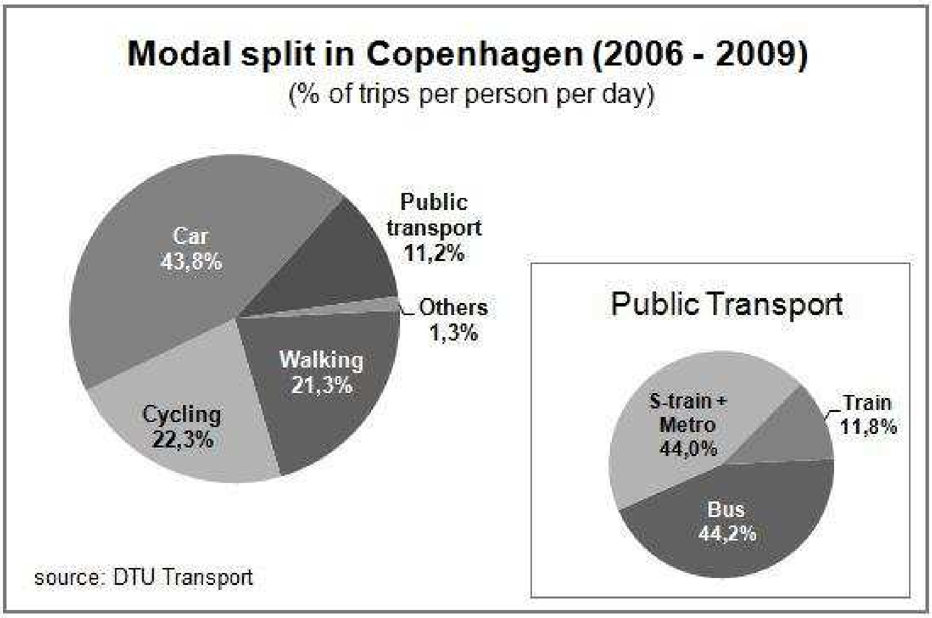

Figure 18 – Modal split in Copenhagen

These data confirm the high shares of cycling and walking in Copenhagen. This may also be the reason why the percentage of public transport users is not as high as in other European cities, because for short distances people may walk or bike rather than use the bus. The private car is, however, the most used transport mode, with a share of almost 44% of the daily trips.

In short, the CMA has a good and complete transport infrastructure. The public transport system consists mainly of a radial railway system that converges in the city centre, complemented by a wide bus network. According to the OECD (2009), this radial system is putting pressure on the railway capacity in the inner-city. The current plans for the expansion of the Metro (in the inner-city) and some studies recently developed suggesting the implementation of a ring light rail system connecting the fingers (in the suburbs) may bring a solution for the railway congestion. However, and according to the OECD (2009), these projects, as well as the ring road infrastructure, may lead to further development between the fingers and enhance urban sprawl, conflicting with the principles of the Finger Plan, which called for a clear demarcation of urban and rural land.

Summarizing, despite being traditionally pictured in the literature as a clear example of a monocentric metropolis – mainly because of its markedly hierarchic land use and transport structures

[12] The values presented in Figure 18 do not refer to the Study Region, but to a slightly smaller area that does not encompass some of the municipalities further away from the city centre.

that converge towards the city centre - Copenhagen shows some degree of decentralization – or even polycentrism – according to the spatial distribution of population and employment. Analysing the previous maps (Figure 15 and Figure 15 – Population density in the CMA (Source: DST, 2009)) we can find relatively high population densities concentrated in areas outside the urban core, mainly along the ‘fingers’, as well as some secondary centres of population and employment concentration, notably Roskilde and Hillerød.

4.4. SAL: CASE-SPECIFIC CHOICES FOR THE COPENHAGEN METROPOLITAN REGION

In this study, the SAL will be used in the CMA to assess the level of accessibility by foot, measured by the diversity of accessibility index (see chapter 3). According to Silva (2008), the SAL is responsive to local conditions and perceptions of accessibility and, therefore, several aspects have to be defined regarding the local context. Therefore, the following five aspects must be defined before using the SAL in the Copenhagen metropolitan area:

- the study region;
- the spatial disaggregation level;
- the disaggregation of activities;
- the potential frequency of activities – f_y;
- the cut-off criteria and values.

These choices were made according to two main principles: (1) being as much as possible representative of the Copenhagen’s local conditions, characteristics, lifestyles, etc; (2) enabling the comparison of these results with the ones reached in the application of the SAL to Porto.

The choice of the study region has already been justified in the previous sections. The present study considers the Copenhagen Metropolitan Area as it was defined in Figure 13, because it is believed to be the most appropriate representation of a functional metropolis, encompassing the most important commuting travel patterns.

With regard to the spatial disaggregation, this study used one of the levels provided by DST (the Danish Institute for Statistics) – a grid of 250x250 meters. This level is believed to be the most appropriate because it allows for a high spatial disaggregation but, at the same time, not so high that it would compromise the technical capacity to run the SAL. In addition, this level defines sections with an area of 0,0625 Km^2, very similar to the average area of the sections used in Porto (0,06 Km^2) (Silva, 2008).

Concerning the disaggregation of activities, 15 types of activities were considered to have the most relevant influence on travel generation. These activity types - presented in Table 3 – encompass work and school activities, as well as leisure, shopping and other activities including main public and private services. These choices were based on the activity types used in the Porto’s case study and adapted to Copenhagen taking into consideration the opinion of a Danish expert – Professor Petter Næss – and the data regarding the distribution of trips by purpose from the Danish Travel Survey (DTU-Transport, 2006). For each activity type, Table 3 also shows the associated NACE/DB03 codes for the statistical classification of economic activities (see appendix A).

Table 3 – List of activities considered and the values of f_y

	Activities	**NACE/ DB03**	**Activity Type (y)**	**% of trips**	**a)**	**f_y**
Schools	Infant School	801000	**1**	7%	18%	**1**
	High school	802000	**2**		66%	**5**
	University	803000	**3**		16%	**1**
Leisure & Entertainment	Parks, public gardens, squares	-	**4**	35%	12	**18**
	Restaurants	553009	**5**		3	**5**
	Cinema, theatre,sport, museum,etc	920000	**6**		8	**12**
Shopping	Food	158120 521100 522000	**7**	26%	12	**21**
	Others	522909 524109 524409	**8**		3	**5**
Healthcare	Pharmacies	523000	**9**	2%	1	**1**
	Hospitals and Clinics	851100 851209	**10**		1	**1**
Other activities	Administration offices	751100 751209 752000	**11**	3%	1	**0,5**
	Postal Office	640000	**12**		1	**0,5**
	Banks	651000 652000	**13**		2	**1,5**
	Others	660000 741100 742009	**14**		1	**0,5**
Employment	Employment	-	**15**	27%	-	**27**

a) **for schools:** Percentage of students enrolled in each school level;
for the remaining activities: estimation of the average frequency of use per person (in one month)

This table also presents the potential frequency of activities – f_y – taken into consideration in the calculation of the diversity of activity index. This correction factor was based on real travel behaviour, namely the distribution of trips by purpose provided by the Danish Travel Survey (see Table 6, in section 5.3) (DTU-Transport, 2006).

These data were only available disaggregated into six types of activities: Employment, Schools, Leisure & Entertainment, Shopping, Healthcare, and Other activities. Therefore, to be able to disaggregate them into the 15 activity types required, other factors needed to be used in order to choose the values for f_y. Concerning schools, the values for the three levels of education were calculated distributing the percentage of trips to school by the proportion of the number of students enrolled in the different school levels in Denmark, according to data from Eurostat (Mejer and Gere, 2008). As to the remaining activities, the percentage for each one of the five original activity types was distributed considering an estimation of the average number of trips each person makes per month (see Table 3).

Total travel time was used as the cut-off criteria in this study. The value used for the admissible travel time to reach an activity by foot was 20 min. This value, assumed to be higher than real travel time, is similar to the one considered in Porto and it was corroborated by two Danish experts: Professor Petter Næss and Professor Otto Nielsen.

The definition of boundaries of the accessibility measure also requires the calibration of the transport network. For walking, road infrastructure was considered (excluding roads without pedestrian access, such as motorways) as well as pedestrian streets. In the absence of detailed walking conditions, accessibility was calibrated for an average walking speed of 5 Km/h, a value often used in this kind of studies (EC, 2000).

5.
RESULTS OF THE CASE-STUDY

This chapter will present and discuss the results of the application of the SAL to the Copenhagen Metropolitan Area and the Greater Porto. This research used one of the main indexes of the SAL, namely the diversity of activity index (DivAct). As referred to before, this index measures, for each territory section, the types of activities reachable within a walking distance of 20 minutes.

This chapter is divided into three parts. Section 5.1 regards the results of the application of the SAL to Copenhagen, presenting the spatial distribution of the diversity of activity index in this region. Since one of the purposes of this dissertation is to compare two urban areas, section 5.2 aims to make a general characterization of the other region of study - the Greater Porto. This section also summarizes the findings of Silva (2008), regarding the calculation of the DivAct for pedestrian transport in Porto. Finally, section 5.3, presents a comparative analysis of the two case-studies.

5.1. RESULTS OF THE SAL IN THE COPENHAGEN METROPOLITAN AREA

The following map (Figure 19) presents the spatial representation of the diversity of activity index (DivAct) in the Copenhagen Metropolitan Area.

Observing the map, we can see that it is in accordance with the spatial distribution of the population and employment densities (Figure 15 and Figure 16, in chapter 4). In fact, it was to be expected that the level of activities would match the spatial distribution of employment, for two main reasons: firstly, because accessibility by foot is mostly conditioned by proximity and some of the activities considered are important job generators (such as hospitals, schools, public administration offices, etc) and secondly, because the SAL also considers 'Employment' as an activity (activity 15), and this activity has a relatively high weighing factor (f_y=27%). The relationship between level of accessibility by foot and population density is more interesting because there is no direct influence of population in the calculation of the DivAct. The high correlation between these two factors in the Copenhagen region hold the theory - supported by a large number of authors (see section 2) – that high density urban patterns lead to higher levels of accessibility by sustainable modes.

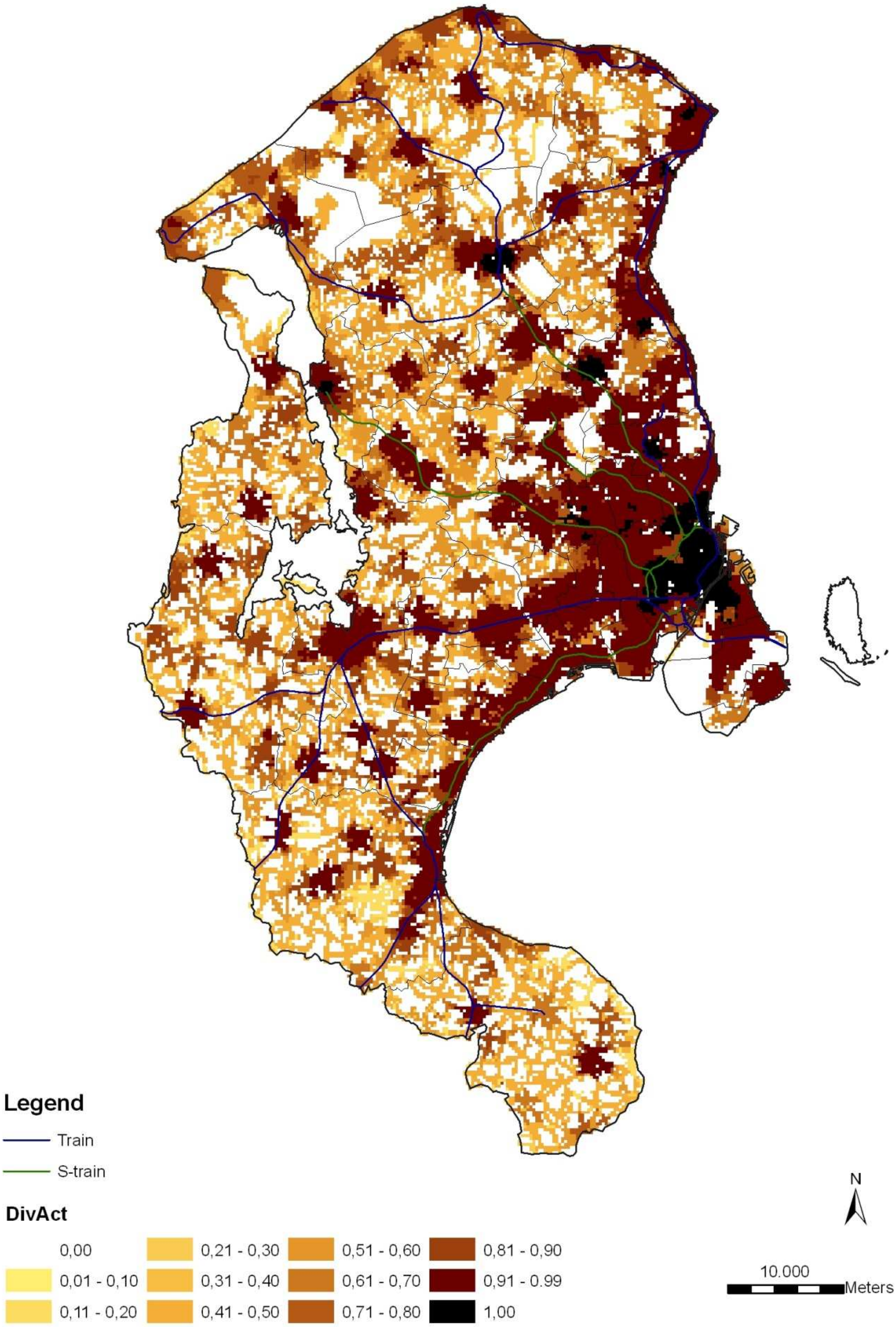

Figure 19 – Diversity of activity index in the CMA

The uppermost levels of accessibility (DivAct=1) can be found in the centre of Copenhagen (municipality of Frederiksberg and the inner parts of the municipality of Copenhagen) as well as in a few peripheral centres, such as Lyngby, Birkerød, Hillerød, Frederikssund and Helsingør (see Figure 44, in appendix C). The main reason why the area with maximum accessibility is so limited is that most of the CMA does not have accessibility to activity 3 (Universities), as we can see in Figure 31 (in appendix B).

This is the case with Roskilde. Judging by population and job densities, Roskilde is the main secondary centre in the CMA, and so it would be expected to have the maximum level of accessibility to activities. However, that is not the case, mainly because most of Roskilde's area (notably the town centre) does not have accessibility to any university. There is accessibility to universities in the east part of Roskilde, but there is also no maximum accessibility due to lack of accessibility to activities 7 (Shopping – food), 9 (Pharmacies) and 10 (Hospitals) (see Figure 35, Figure 37 and Figure 38, in appendix B).

Nonetheless, the impossibility of reaching a university in a 20-minute walk is considered acceptable, thus there are several areas in the CMA with high levels of accessibility to activities despite not reaching the maximum value of DivAct. These areas - with DivAct > 0,9 – are shown in Figure 45 (in appendix B) and encompass three types of territories:

- The central area of the metropolitan region, which includes the municipalities of Copenhagen and Frederiksberg as well as the municipalities in their vicinity, namely Tårnby, Dragør, Hvidovre, Brøndby, Vallensbæk, Glostrup, Rødovre, Ballerup, Herlev, Gladsaxe, Gentofte and Lyngby-Taarbæk. The suburbs in the south of Copenhagen also show some deficiencies regarding the accessibility to activities 2 (High schools) and 11 (Public administration offices).
- The second-order centres identified before, including Roskilde.
- A number of smaller centralities to be found along the railway lines, such as Køge, Ishøj, Stenløse, etc. The existence of these sub-centres, small in dimension but with high levels of accessibility by foot, located in the vicinity of railway stations, reveals a rather good coordination between land use and transport policies, following the principles of a transport-oriented development.

Concerning the remaining territory, the levels of accessibility by foot are significantly lower. This effect is probably a result of low accessibility to activities 2 (High schools), 6 (Theatre, cinema, sport, etc) and 7 (Shopping – food), since these are more concentrated around a small number of centres (see Figure 30, Figure 34 and Figure 35, in appendix B) and, at the same time, they have higher values of f_y (frequency of use index). One can also find areas with no accessibility to activities (DivAct=0). These areas refer to land sections without residents[13] or with no activities accessible in a 20-minute walking distance, due to a highly sparse urban pattern or a scarce road infrastructure.

Analyzing the levels of accessibility by population, we find out that the great majority of the residents in this region live in areas with high accessibility conditions. 87,9% of the inhabitants live in areas with DivAct higher than 0,85 (26,2% with DivAct=1), while only 1,8% of the residents live in areas with DivAct lower than 0,5 (see Table 4). This is a positive indicator for Copenhagen, because

[13] Only 33379 of the initial grid of 50109 cells of 250x250m^2 were used for the calculation of the DivAct. We excluded the cells that verified both the following conditions: areas with no access to road infrastructure (corresponding to cells whose centroid is more than 200m away from any road) and cells with no population.

it means that population is concentrated in areas where they can reach most of the activities by foot, without having the need to use less sustainable transport modes.

Table 4 – Analysis of the DivAct by population

	Population (% of 1.860.260 inhabitants)
DivAct < 0,50	**1,8%**
DivAct=o	*0,0%*
DivAct between 0,50 and 0,85	**10,3%**
DivAct > 0,85	**87,9%**
DivAct=1	*26,2%*

Finally, there are a few zones within the centre of Copenhagen that present lower levels of accessibility (DivAct between 0,7 and 0,8) than the surrounding areas (see Figure 46, in appendix C). If we look at Figure 32 (in appendix B) we can conclude that this situation is the result of shortage of accessibility to activity 4 (Parks, public gardens and squares). This information is interesting and ought to be considered by the local authorities, since this problem could be easily solved by the provision for public space.

5.2. RESULTS FROM THE APPLICATION OF SAL TO GREATER PORTO

This section will present the results and the main conclusions of the first application of the SAL to Porto's metropolitan area, by Silva (2008). The section starts with a brief presentation of this region, including the characterization of the land use structure and the transport system. The results of the SAL and the region characteristics will later be used for the comparison with the Copenhagen Metropolitan Area. Therefore, regarding the SAL, this section will only present the results for the pedestrian mode (or the "non-motorized (NM), as it was called, since no other non-motorized transport mode was used in that study). Results from the application of the complete SAL methodology to the Porto metropolitan area can be found in Silva (2008).

5.2.1. STUDY REGION CHARACTERIZATION

With a metropolitan area of about 1.2 million inhabitants, Porto is the second biggest city in Portugal and the greater metropolis on the north-west of the Iberian Peninsula. The region chosen for the study developed by Silva (2008) comprises the municipality of Porto and its five surrounding municipalities: Matosinhos, Maia, Valongo, Gondomar and Vila Nova de Gaia (see Figure 20). Similarly to what happened in Copenhagen, this region – normally called Greater Porto (GP) - does not correspond to any administrative boundary. It is the central part of the Metropolitan Area of Porto (AMP), comprising 70% of its area and 90% of its population (Silva, 2008).

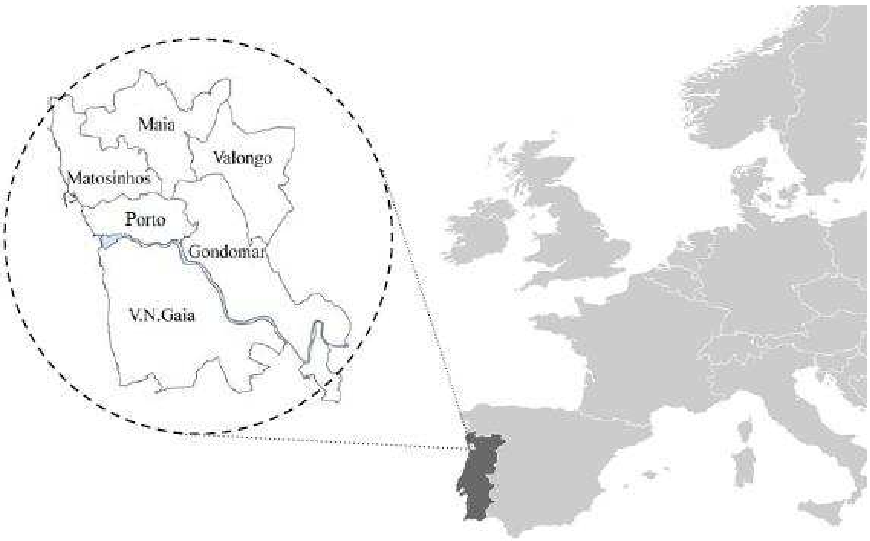

Figure 20 – Region of Study (Source: adapted from Silva, 2008)

The following maps (Figure 21 and Figure 22) show the spatial distribution of population and employment in the Greater Porto.

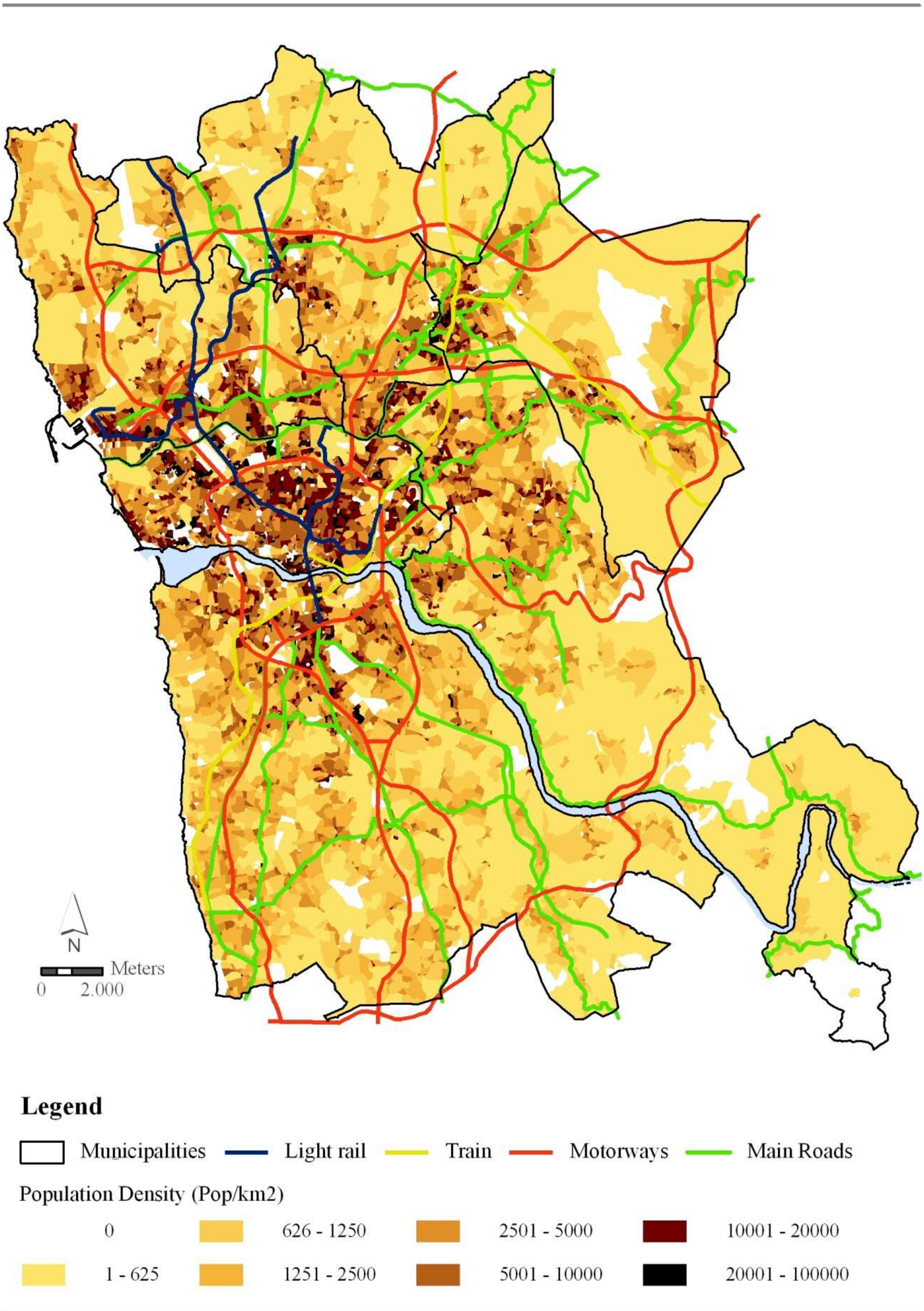

Figure 21 – Population density in the Greater Porto (source: Silva, 2008)

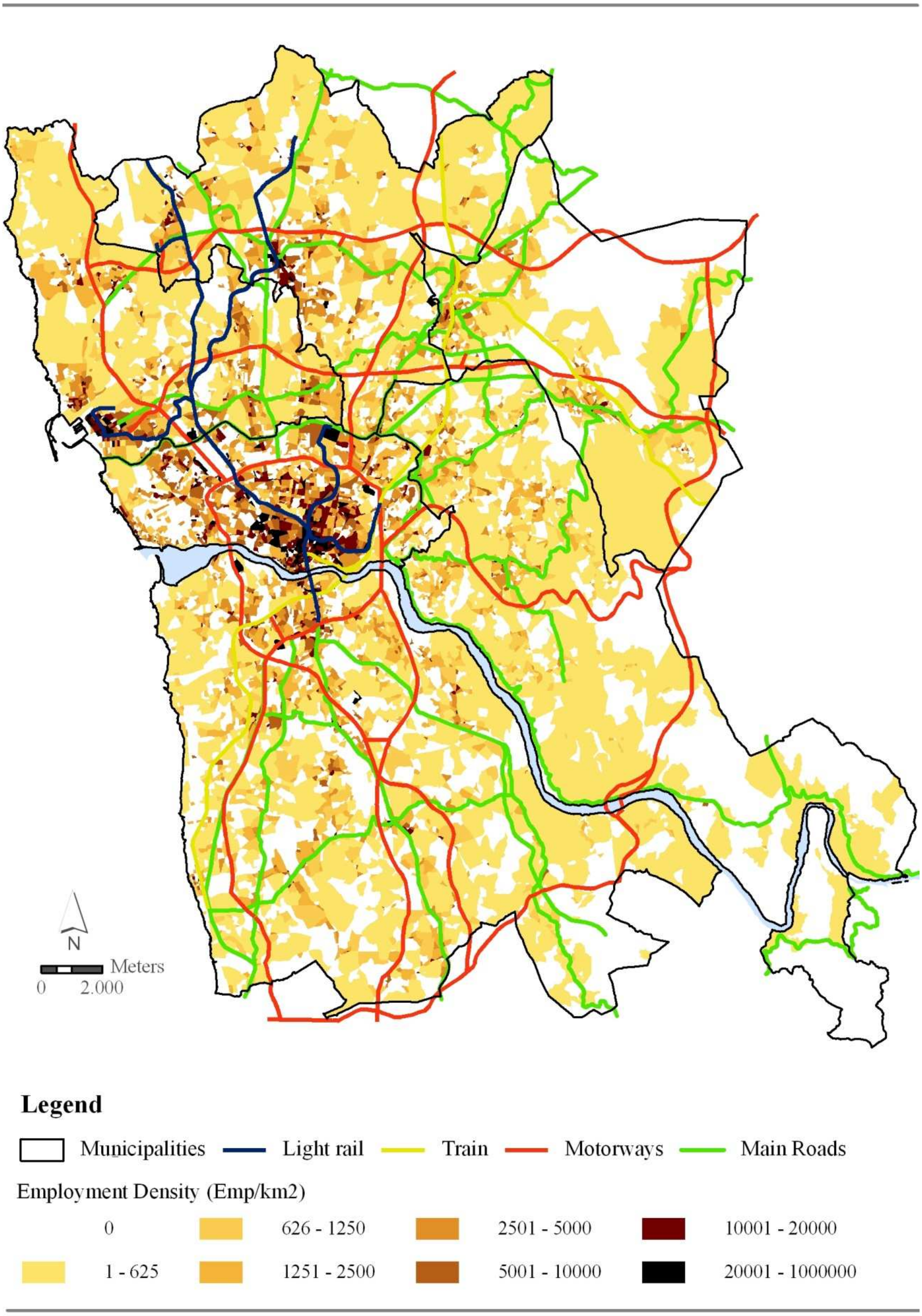

Figure 22 – Employment density in the Greater Porto (source: Silva, 2008

The first aspect revealed by the previous maps is the high population and employment densities in this region. Although the Porto's city centre shows the highest levels of population concentration, population density is also high in the first land strip surrounding it, notably in the municipalities of Matosinhos and V.N. Gaia. In addition, other population agglomerations can be found further away from the city centre, mainly in Maia, Ermesinde (Valongo) and Gondomar. Besides these main clusters of population concentration, population density is still relatively high in the remaining territory. This dispersion of population throughout the whole territory clearly distinguishes the Greater Porto from the Copenhagen Metropolitan Area.

Employment on the GP is visibly more centralized in the city centre than population. Despites the clear dominance of the Porto municipality as the main job centre, some important concentrations of employment can also be found in Matosinhos, Maia and V. N. Gaia. In addition, several other areas with relatively high employment densities can be found scattered across the study region.

Regarding the transport system (see Figure 24) , the GP has a high road density, intensifying towards the centre, including several circular and radial motorways, built mainly during the last two decades (Silva, 2008). The car is, indeed, the most used mode of convenience by far (see Figure 23), with a share of around 48% of the modal split in 2001 (more than twice its share in 1991) (INE, 1991; INE, 2001).

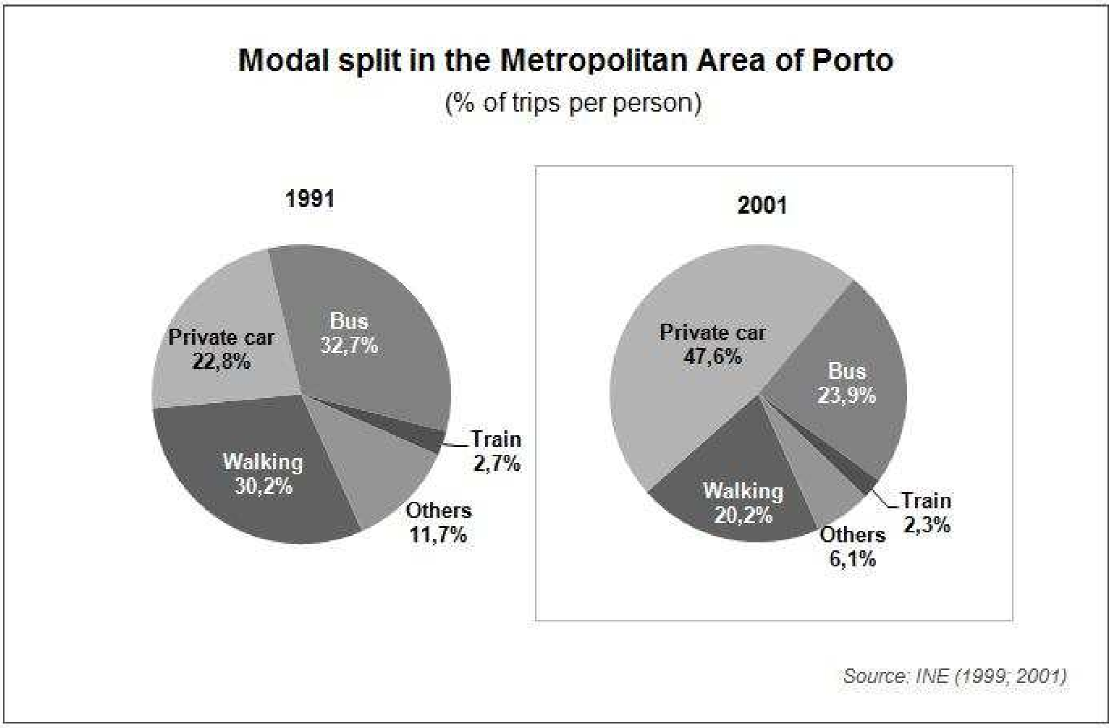

Figure 23 – Modal split in the Porto Metropolitan Area[14] in 1991 and 2001

[14] The data in this chart do not refer to the study region (the Greater Porto), but to the Metropolitan Area of Porto. Since the GP encompass around 90% of the population of the Metropolitan Area, these results are believed to be a good estimation of the shares in the study region.

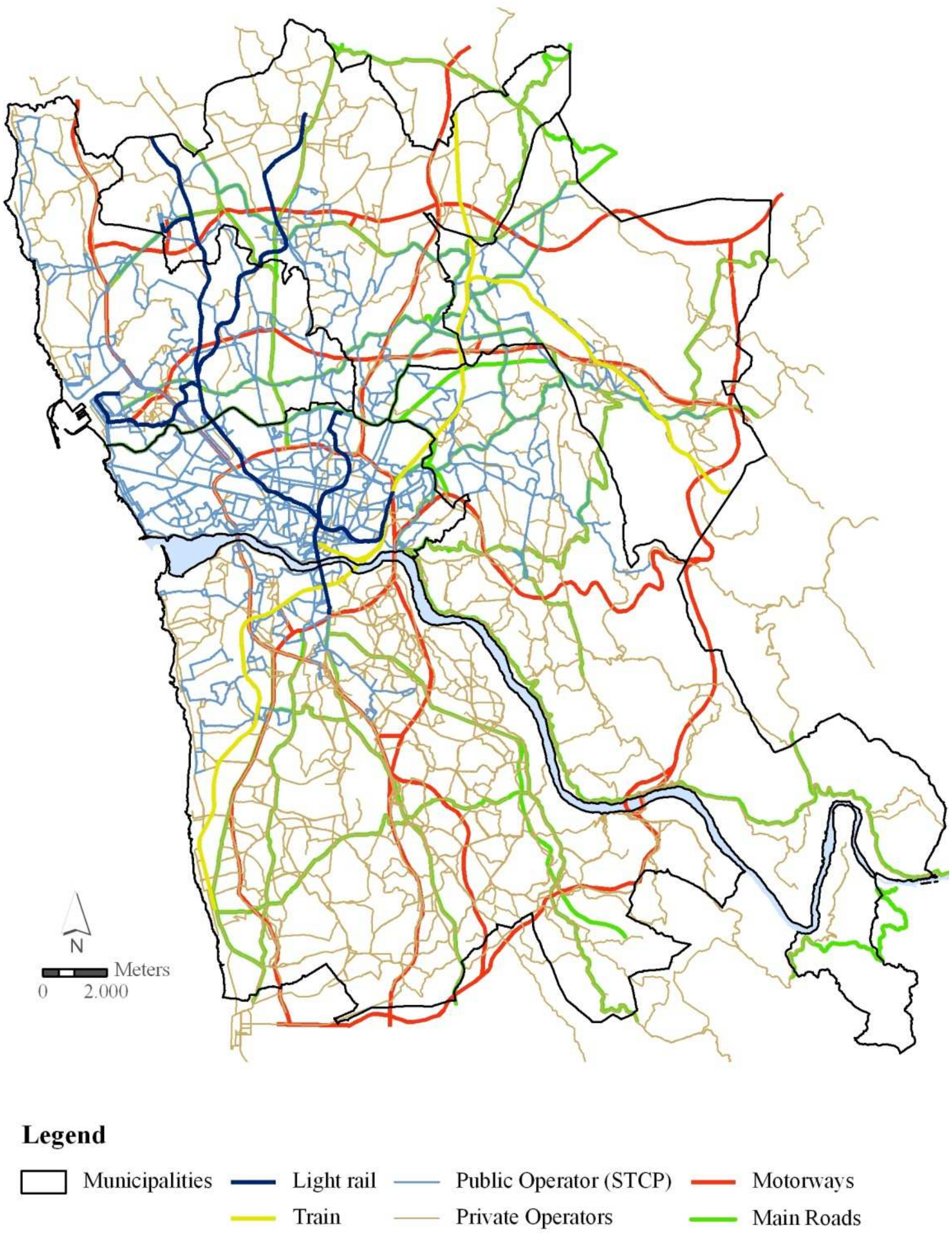

Figure 24 – Transport infrastructure in the GP (source: Silva, 2008)

The transport service has suffered several changes in the last few years with the introduction, in 2002, of the light rail system – the Metro. The Metro network is characterized by several radial corridors connecting the city centre to some of the peripheral municipalities. The commuter train network has a similar pattern, limited to the central area of Porto municipality and a few radial corridors. Besides the rail network, there is a wide bus network, composed of the public operator (STCP) mainly in the central areas of the GP and completed by several private operators, mainly serving the outward municipalities. As Figure 23 shows, public transport has a very important share in the Porto Metropolitan Area (around 25% of the modal split in 2001), mainly the bus. However, these data must be interpreted carefully, because they refer to a period of time prior to the introduction of the Metro.

Moreover, comparing the modal split in 2001 with the data from 1991, it is clear that car use is largely replacing walking and travelling by public transport. According to Silva (2008), the car based development of the GP in the last decades is associated with an increase not only in travel distances and times but also in the complexity of mobility patterns. These changes in mobility patterns are related to the changing land use patterns of the Greater Porto, namely the decentralization of population during the last few decades in a much higher rate than of employment.

Figure 25 provides a comprehensive picture of the changes in travel patterns between 1991 and 2001. Although Porto is still concentrating most of the trip destinations to work and school purposes, other different mobility patterns are becoming significant, both in the opposite direction (from Porto to the surrounding municipalities) and between these surrounding municipalities, notably between Matosinhos and Maia.

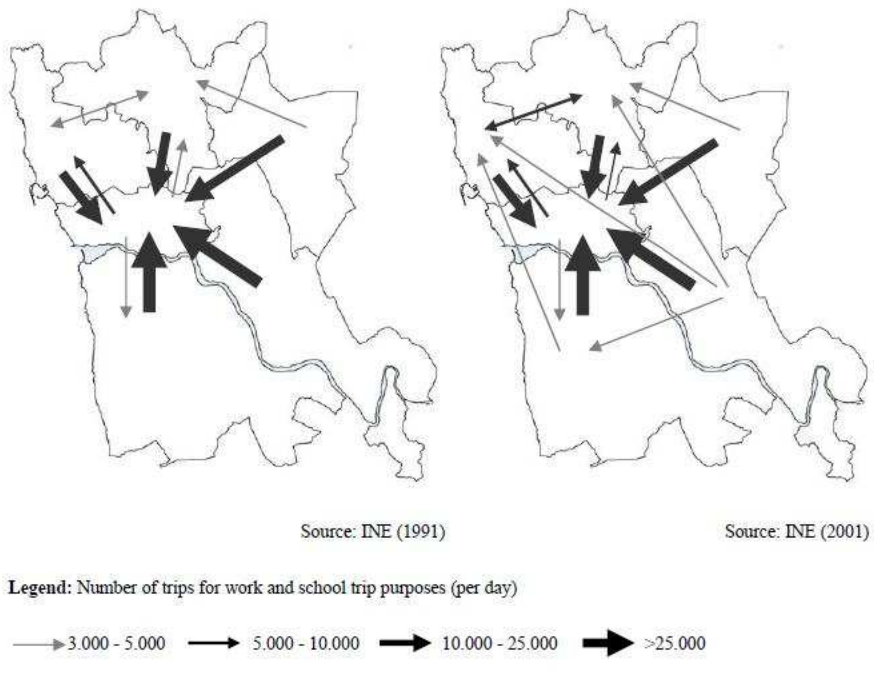

Figure 25 – Mobility patterns in the GP (source: Silva, 2008)

Commentary note: is Porto polycentric?

The Greater Porto is commonly recognized in the literature as an example of a polycentric metropolis. However, the population distribution and, above all, the employment distribution (Figure 21 and Figure 22) appear to indicate the contrary: a high concentration of employment in the urban centre, typically a characteristic of monocentric cities. In addition, the mobility patterns are also quite centralized in the Porto municipality, with a clear predominance of the radial trips between the centre and the peripheral municipalities (see Figure 25). Therefore, it is fair to question if Porto can really be considered a polycentric urban area.

The polycentric roots of this region date back to the second half of the 19^{th} century, with the relatively decentralized location of the industry in some peripheral areas of the Greater Porto. The concentration of employment in these areas, associated with the lower housing costs - due to the extensive provision of inexpensive land and the absence of land use regulation - fostered the household settlement in these areas (Breda-Vásquez, 1992). However, the development of a service-based economy during the second half of the 20^{th} century promoted the prominence of the Porto urban core as the main employment and population centre, leading to a more monocentric behaviour illustrated in Figure 21, Figure 22 and Figure 25.

During the last decades, though, Porto is experiencing a decentralization process, characterized by the migration of population and tertiary employment towards the peripheral municipalities. This process of suburbanization, however, is leading to an expansion of the central area to its vicinities, assuming the shape of an 'urban ring', rather than creating a polycentric pattern (see Figure 47, in appendix D). The growing importance of the circular commuting patterns between the peripheral municipalities from 1991 to 2001 (see Figure 25) is a result of this process.

In conclusion, Porto is currently not a polycentric metropolis, at least in the traditional conceptualization of polycentrism. However, Porto is not a monocentric urban area either. We could argue that Porto has some type of polycentricity in a smaller spatial scale, in which several centralities can be found within a metropolitan core of relatively high density. These centralities encompass the inner city centre (currently losing power), the surrounding municipalities that are presently experiencing a population and job increase, creating a ring of developing areas surrounding Porto's municipality, and a few more peripheral centres with relative importance in population and employment, such as Maia and Valongo.

5.2.2. RESULTS OF THE SAL IN THE GREATER PORTO

This section will present the results reached by Silva (2008) in the Greater Porto. Since these results will be used for comparison with Copenhagen's, the presentation and discussion of the results will be limited to the ones concerning pedestrian transportation. Table 5 summarizes the case-specific choices for the SAL, used in the Greater Porto.

Table 5 – SAL: case specific choices for Porto (source: Silva, 2008)

Region of study:	Greater Porto
Level of spatial disaggregation:	Census track level (sub-regions with an average area of 0,06 Km^2)
Level of disaggregation by activities:	18 activities (see appendix D)
Potential use frequency:	See appendix D (Table 9)
Cut-off values:	Maximum total travel time of 20 min.

The following map (Figure 26) shows the geographical representation of the accessibility levels - the diversity of activity index (DivAct) – in the Greater Porto, calculated for walking. According to Silva (2008), this indicator provides a clear picture of the urban structure, highlighting the urban centres of different levels.

While analysing the map, it becomes clear that the higher levels of accessibility by foot are located in the central parts of the Greater Porto. In fact, the maximum level of accessibility (DivAct=1) can only be found in the central part of Porto municipality and in zones located in its vicinity, namely in the south part of Matosinhos and in the north part of V.N. Gaia. According to Silva (2008), around one quarter of the population of the study region lives in this privileged area, where all activity types are accessible by foot.

The author also argues that most of the sub-regions with diversity of activity index between 0,9 and 1 are lacking activity types 3, 6 and 7, concerning universities, cinemas and theatres. Other activity types, such as parks and public gardens, postal offices or sport facilities are also missing in some cases. These locations with high but not maximum level of accessibility also give good conditions for the use of non-motorized modes for most daily activities, although forcing their inhabitants to choose other less sustainable means of convenience to reach other activities.

These places of high accessibility are generally located in the first urban ring outside the Porto city centre (in the closest vicinity of the areas with maximum diversity of accessibility index) or in more peripheral locations, normally along the main roads.

Areas with diversity of activities lower than 0,5 are rare and normally located in the more peripheral zones of the municipalities of Valongo and Gondomar. According to Silva (2008), only 1% of the population lives in these conditions, in an area representing 8% of the study region.

Comparing the spatial distribution of the diversity of activity index with the population density (Figure 21), we can see that they normally match, with the exception of the south areas of the GP, in the municipality of V.N. Gaia, where the scattered pattern of household location does not correspond to lower levels of accessibility by foot. This general correspondence between population density and accessibility is a positive element, since it indicates that people can reach most of the daily activities by foot from their homes. This also supports the argument that land use patterns with higher population densities promote better accessibility conditions, notable by sustainable modes.

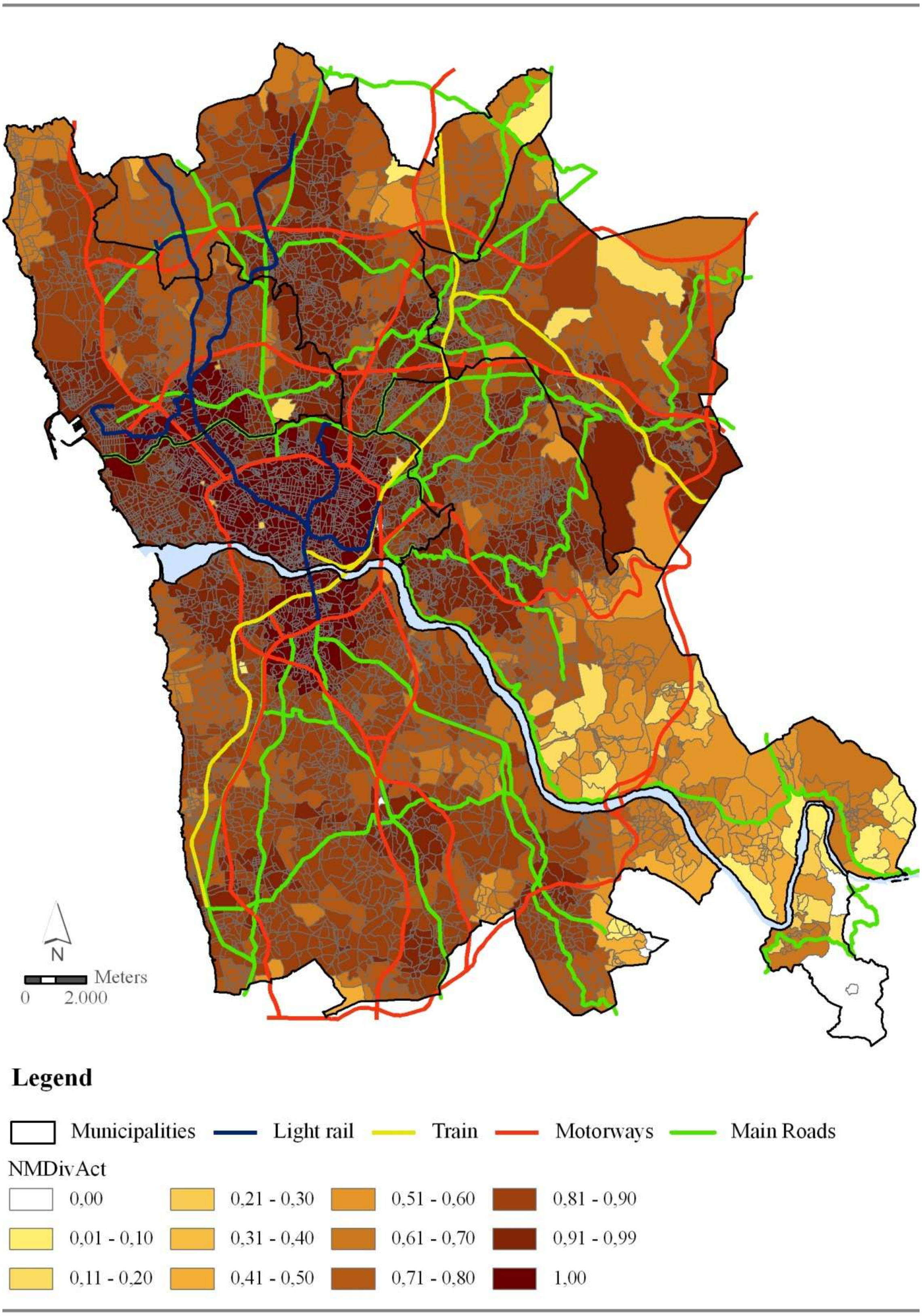

Figure 26 – Diversity of activity index in the GP (source: Silva, 2008)

5.3. Discussion

This section aims to carry out a comparative analysis of the results of the SAL in the two regions of study: the Greater Porto and the Copenhagen Metropolitan Area. As we could observe throughout the previous chapters, Porto and Copenhagen are very different metropolises. Despite having a relatively similar number of inhabitants – the CMA with 1.8 million people has around 1.5 times more population than the GP, which has 1.1 million - the area of the CMA is more than 5 times larger (see Table 6). Therefore, Porto has a markedly higher population density, which results in very different patterns of urbanization in these two metropolitan areas.

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, as well as the use of the bike, which is almost nonexistent in Porto. Moreover, the transport infrastructure is also different in the two study regions, as well as the urban structure, as we could observe in the previous sections. Table 6 summarizes some of the main characteristics of the two study regions.

Table 6 – Characteristics of the two study regions

Copenhagen Metropolitan Area		**Greater Porto**
1.800.000	**Population**	1.100.000
3037 Km^2	**Area**	560 Km^2
593 Inhab./Km^2	**Mean population density**	1964 Inhab./Km^2
Car: 43,8 Pub. Transport: 11,2 Walking: 21,3 Cycling: 22,3 Others: 1,3	**Modal split (%)**	Car: 47,6 Pub. Transport: 26,2 Walking: 20,2 Others: 6,1
Work: 27,1 School: 6,8 Leisure: 35,5 Shopping: 25,9 Others: 4,6	**Trips per purpose (%)**	Work: 40,8 School: 11,6 Leisure: 21,7 Shopping: 10,4 Others: 15,6
Complete public transport network based on a radial railway system complemented by a wide bus network. Radial and circular motorways with a medium capacity.	**Transport infrastructure**	High density radial and circular motorway network. Public transport mainly based on bus. Railway network (Metro and train) is radial and, in Porto municipality, limited to the city centre.
Traditionally monocentric structure with high concentration of population and employment in the city core and a radial pattern of development along the 'fingers'. Today shows some signs of polycentricity due to an efficient transport system and restrictive land use policies since the 50's.	**Urban Structure**	Historically polycentric structure related to the location of industrial activities. Today shows a high concentration of jobs in the city centre, but is experiencing a process of population and employment decentralization towards the surrounding municipalities.

The following map (Figure 27) shows the spatial distribution of the diversity of activity index in the two study regions. The CMA and the GP are represented in the same spatial scale, to enable a better comparison between the levels of accessibility and provide for a more comprehensive picture of the urban structures. Figure 28 represents, in a similar way, the population density in the two study regions.

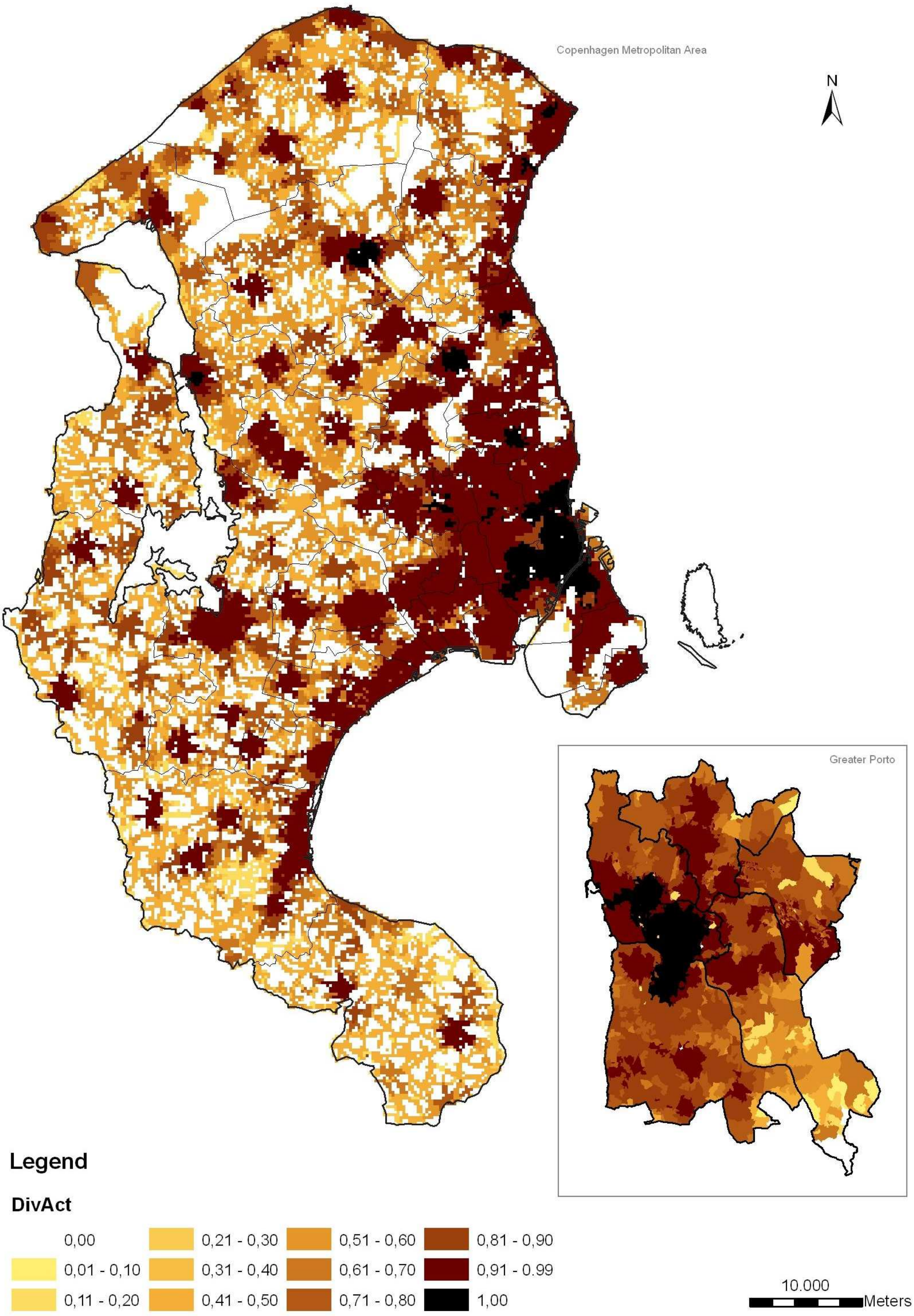

Figure 27 – Diversity of activity index in the two regions of study

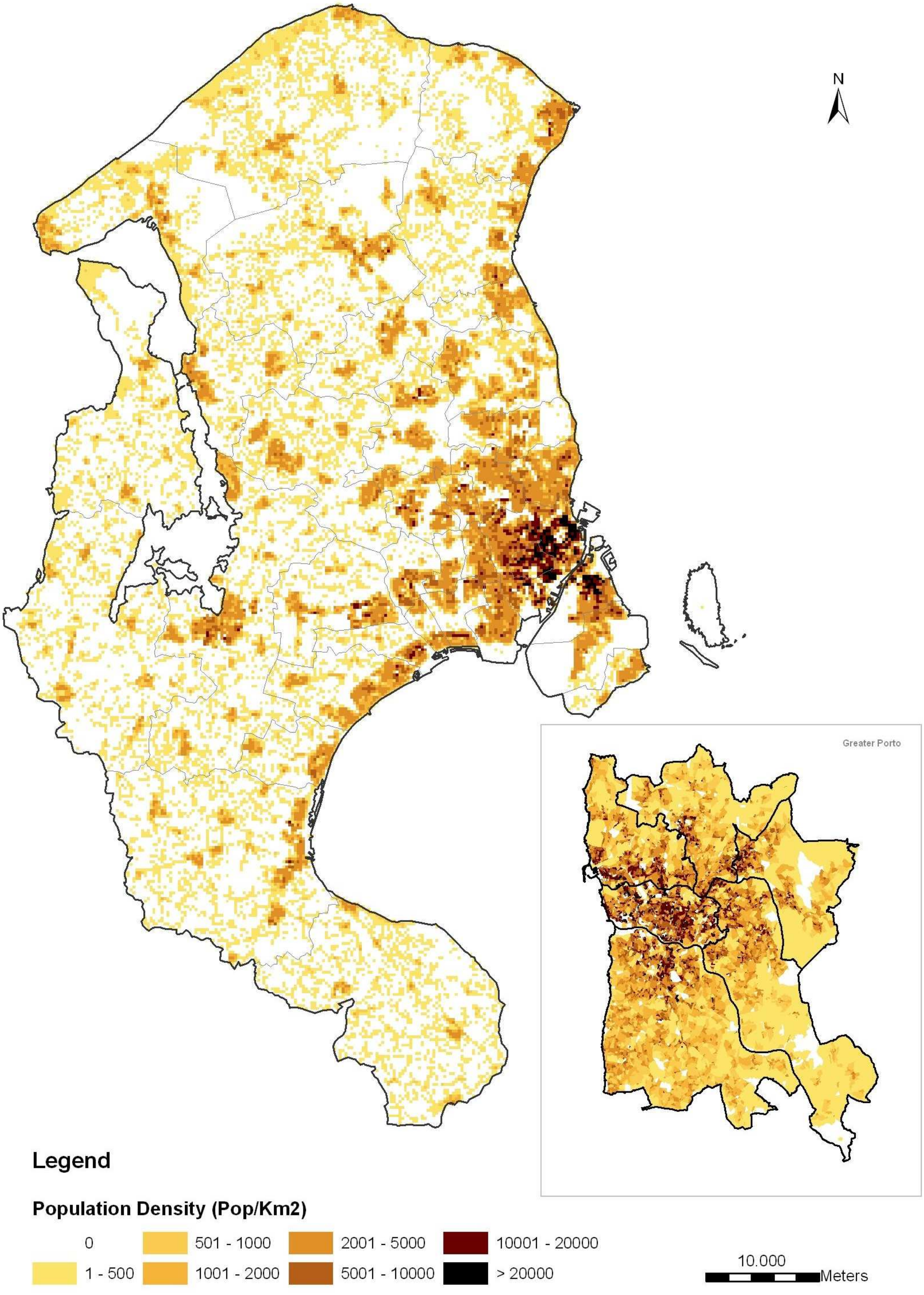

Figure 28 – Population density in the two regions of study

The first conclusion taken from the analysis of the first map regards what these two metropolitan regions have in common. Both Porto and Copenhagen show the highest levels of accessibility by foot in their centres but, at the same time, there are in both cases several peripheral centralities that have also high accessibility levels.

In fact, the main differences between the GP and the CMA become visible outside the centralities. While Porto is more homogeneous, with almost all the metropolitan area showing relatively high levels of accessibility, Copenhagen has higher contrasts between the main centralities and the remaining territory, which normally has a much lower level of accessibility (sometimes even 0). We may argue that this fact challenges the initial idea that Porto is a polycentric metropolis and Copenhagen is a monocentric one.

Moreover, the analysis of the two maps together proves once more the close relationship between density and pedestrian accessibility: the areas with higher population density normally match the places with better accessibility conditions. In addition, Porto, whose overall density is substantially higher when compared to Copenhagen, appears, observing the map, to have also a higher average level of accessibility by foot (considering the peripheral territories in Copenhagen which have very low diversity of accessibility index).

However, an important factor to consider is the difference in the spatial scales between the two regions. Despite being similar when it comes to population, the Copenhagen Metropolitan Area is more than five times bigger than the Greater Porto, which may limit the comparative analysis. This does not mean that we should compare the GP just with the central part of the CMA, because this region corresponds to a single functional city, with a common job market and mostly internal trips (Næss, 2006). On the contrary, enlarging the Porto study region to a larger area - for instance the Metropolitan Area of Porto, which has around 1.7 million inhabitants and a surface of 1885 Km^2 (INE, 2008) - could be an interesting idea to allow for a better comparison between the two cities.

The huge disparity in size between these two regions may also be a result of the very different time-space relationships in Porto and Copenhagen, primarily due to the transport structure. The transport system in Copenhagen is faster and heavier than in Porto, because it is mainly based on rail (while in Porto the bus is more significant) and also because the levels of car congestion are lower. This enables longer distances in the commuting trips, and hence a more extensive pattern of urbanisation. This phenomenon also explains the lower levels of accessibility in the more peripheral areas of Copenhagen. In these zones, the longer distances between activities and also the lack of road infrastructure may limit the level of pedestrian accessibility.

However, it is remarkable the number of zones with maximum or very high levels of accessibility throughout all the Copenhagen Metropolitan Area. Despite having a lower population density, Copenhagen has not only more centralities with very high values of DivAct, but these areas are also distributed more evenly throughout the whole metropolitan region, when compared to Porto, where the maximum levels of accessibility are more centralized. The analysis of the levels of accessibility by population (see Table 7) confirms this idea. In Copenhagen there is a higher share of population (87,9%) with very high level of pedestrian accessibility to activities than in Porto (77,6%).

This phenomenon does not happen without a reason, it is a result of notable land use and transport policies during the past decades which provided for a more balanced location of population, jobs and activities, resulting in a pattern of ‘concentrated decentralization’ of the Copenhagen Metropolitan Region. This means that even though there is a lower overall population density – for instance when compared to Porto - population in Copenhagen is more concentrated around several centralities, resulting in clusters of high population density in a smaller scale. This concentrated polycentric pattern makes it possible for activities to locate closer to the places where people live and, therefore, to provide for better pedestrian accessibility conditions.

Considering that most of these centralities are located in the vicinity of railway stations (see section 5.1), the Copenhagen's urban pattern of concentrated decentralization is not only capable to provide good conditions for walking, but it may also facilitate the use of public transport, promoting a sustainable travel behaviour.

Table 7 – Analysis of the DicAct by population in the two study regions

Copenhagen M.A. (% of 1.860.260 inhabitants)	**Analysis by Population**	**Greater Porto** (% of 1.089.118 inhabitants)
1,8%	DivAct < 0,50	1,1%
10,3%	DivAct between 0,50 and 0,85	21,3%
87,9%	DivAct > 0,85	77,6%

In Porto, on the other hand, despite the higher overall density, population is more scattered throughout the urban area, and this fact makes it more difficult to locate a wide variety of activities closer to a larger number of households. Activities in Porto are also more scattered resulting in more homogeneous levels of accessibility. This is the reason why in Porto the share of inhabitants with very low levels of accessibility is lower (1,1%) and the percentage of population with medium accessibility conditions is higher (21,3% against 10,3% in Copenhagen).

The results of the application of the SAL to these two metropolitan areas appear to point out that density is an extremely relevant factor influencing accessibility, at least concerning accessibility by foot. However, it is difficult to take conclusions concerning the role of a monocentric or polycentric urban structure, since high density settlements with high accessibility appear to be possible in both these types of structures.

In fact, we can argue that, nowadays, there are no completely polycentric or monocentric cities but, as Martens (2006) suggests, all metropolitan regions have some levels of 'monocentrism', 'polycentrism' and 'dispersion' (see Figure 6, in section 2.3), so they can be classified considering the relative importance of these three dimensions. In fact, the monocentric and polycentric models – in their traditional conceptualization – do not appear to suit any of the metropolitan areas in study.

Porto, which is historically a polycentric region where the peripheral centres have assumed, since the 19th century, an important role in employment generation (notably related to industrial activities), experienced during the second half of the 20th century a 'suburbanization' of the periphery, showing today a high concentration of jobs in the city centre. Furthermore, the more recent decentralization of some economical activities and the population decay of the inner city resulted in an expansion of the centre outwards the boundaries of the Porto municipality (creating a kind of 'central ring'), rather than developing or consolidating a polycentric urban pattern.

Copenhagen on the other hand - traditionally seen as a highly centralized and hierarchical urban structure - has experienced a decentralization process which is more extensive in area (due to the transport system characteristics) and, simultaneously, more concentrated around secondary centres (as a consequence of restrictive land use polices), leading this metropolis towards a more polycentric urban form.

Moreover, we can conclude that the overall density of a region highly influences the classification of the urban structure. We chose to compare two cities with a similar number of inhabitants but which are very different in population density (and, related to it, different in size too), which may challenge, for instance, the concept/scale of polycentrism. In Copenhagen, the clear contrast between the centres and the remaining territory regarding both population density and accessibility level highlights the polycentric form, while in Porto the higher average accessibility (that matches the higher average population density) hides a more local polycentrism that exists inside the central area. Using the classification suggested by Martens (2006), we could argue that Porto is more like an 'urban polycentric structure' while Copenhagen is developing towards a 'peripheral polycentric' form (see Figure 4 in section 2.3).

6. CONCLUSION AND FURTHER RESEARCH

This dissertation studied the complex relationship between urban structure and mobility, with the purpose of understanding which type of urban structure provides the better conditions for more sustainable mobility patterns, namely the pedestrian modal choice. In order to accomplish this purpose, two urban areas were studied. They are similar in population but very different in size, density, lifestyles and urban structure – while Porto was considered a polycentric urban area, Copenhagen has traditionally been seen as a monocentric metropolis.

The empirical literature regarding the influence of urban structure on mobility is somehow inconclusive and contradictory, showing a wide range of different results. While some authors state that a higher urban density and a strong city centre lead to shorter trip lengths and higher use of public transport and non-motorized modes, others argue for lower densities, advocating that housing and jobs may mutually co-locate allowing for shorter commuting times and distances. Both these theories are supported by several empirical studies.

Concerning urban structure, although the literature normally considers two types of structures – monocentric and polycentric – and despite the wide consensus around the idea that cities are developing from a monocentric urban structure to a more polycentric or decentralized one, the exact process of city growth, the nature of this new polycentric form and even the concept of polycentrism still remain somewhat unclear.

The literature suggests that decentralization does not imply a loss of importance of the main centrality, and, therefore, that a clear distinction must be made between a polycentric structure – with medium density and some concentration of jobs and housing around several nodes – and a dispersed or sprawled one. Moreover, we may argue that, nowadays, the traditional conceptualization of the monocentric and polycentric models does not suit most of the urban areas. The measurement of urban structure today is very complex because many metropolitan regions show, at the same time, some levels of ‘monocentrism’, ‘polycentrism’ and ‘dispersion’.

This is the case with the two regions studied in this dissertation that, contrary to the initial assumption, appear to have very complex urban structures that do not suit any of the two theoretical models of monocentrism or polycentrism. Copenhagen, despite having a high concentration of jobs in the urban core and an essentially radial transport network, shows several peripheral centralities with high levels of pedestrian accessibility to activities, i.e., high diversity of activity index. This indicates that Copenhagen might be developing a polycentric urban pattern, though the analysis of data regarding the commuting patterns would be important to support this hypothesis. Porto, on the other hand, does not have a typical polycentric urban structure – with clear distinct centres interacting with each other and with the main centre – but a number of centralities with higher levels of pedestrian accessibility, located within a greater central area with a dense pattern of urbanization.

Considering the results of the case-study, we can conclude that in both case studies there is an important relationship between urban density and pedestrian accessibility. The results of this study support the idea that denser patterns of urbanization tend to promote higher accessibility levels by foot, hence enabling more sustainable travel behaviour for daily trips.

The significance of density is, indeed, one of the main conclusions of this dissertation. Nevertheless, it is essential to analyse not only the overall density of a region, but also the population density in a smaller scale, i.e. the capacity of a region to concentrate the population into a number of centralities. This is the case with Copenhagen, where the concentration of households and activities around several centralities provide evidence that it is possible to have high levels of accessibility even in a region with low average population density. Several authors, such as Ewing (1997), consider that this pattern of 'concentrated decentralization' is a type of polycentric structure capable of promoting the use of sustainable transport modes.

These results also highlight the importance of land use and transport policies. This urban pattern of 'concentrated decentralization', which results in better accessibility conditions in Copenhagen, was only possible because of very efficient and restrict land use policies which have been put into practice since the 1950s, with the *Fingerplan*. Moreover, in the Copenhagen Metropolitan Area, these clusters of high pedestrian accessibility are normally located in the vicinity of railway stations, which is a sign of good coordination between land use and transport policies. In Porto, the decentralization process resulted in a more scattered location of households and activities that appears to be driven essentially by market processes rather than by efficient planning policies and which led to lower levels of pedestrian accessibility when compared to Copenhagen.

Considering the results of this study, it is not possible to compare the monocentric and the polycentric models in order to determine which type of urban structure provides better conditions for pedestrian accessibility, because none of the regions in study appears to be a typical example of a monocentric or polycentric structure. However, this study suggests that a polycentric urban pattern does not imply loss of centralization and may even provide better conditions of accessibility by foot. The level of pedestrian accessibility to activities seems to be strongly connected to population density, not referring exclusively to the density of the whole region, but to the density of the centralities of an urban area. Therefore, the location of population, job and activities in a concentrated decentralized pattern, shaped by a number of centralities with medium to high density along transit corridors, seems to provide the conditions for higher levels of pedestrian accessibility.

In the Copenhagen Metropolitan Area, these clusters of high pedestrian accessibility are normally located in the vicinity of railway stations, so it would be interesting to calculate the diversity of accessibility index for public transport in Copenhagen. In fact, we can suggest for future research the application of the complete SAL methodology to the Copenhagen Metropolitan Area. The calculation of the diversity of accessibility index for other transport modes – namely bicycle, public transport and car - would not only enable the assessment of the sustainability measure for Copenhagen, but also the comparison with the results already reached in Porto.

Another suggestion for further research could be to extend the application of the SAL in Porto to a larger region, allowing for a better comparison with the Copenhagen Metropolitan Area. We could use the Metropolitan Area of Porto, which has, both in population and surface, a more comparable dimension to the CMA than the Greater Porto, or an even larger region surrounding this metropolis.

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APPENDIX A

NACE/DB03 CLASSIFICATION

NACE - Nomenclature generale des Activitiés économique dans les Communautes Européennes – is a classification of economic activities prepared by the EU in 1970. In 1990, it was decided to make it obligatory for all EU Member States as from 1 January 1993 to introduce a new four-digit statistical classification of economic activities in the European Communities - *NACE rev. 1* - a revised version of *NACE* from 1970. *DB03*, the *Danish Industrial Classification 2*003, is based on *NACE rev. 1.1*. The first four digits correspond to *NACE rev. 1.1*, whereas the 2 last digits are Danish sub-groupings. A complete list of *DB03* is given in the publication *Dansk Branchekode 2003*, published by Statistics Denmark 2002.

DB03 comprises 825 industries, intended to reflect the Danish industrial structure in the best possible way. The DB03 for the economic activities considered in this study are presented in the following table.

Table 8 – Danish Industrial Classification

NACE/DB03	Economic activity
158120	Baker's shops
521100	Retail sale of food in non-specialized stores
522000	Retail sale of food in specialized stores
522909	Department stores
523000	Retail sale of pharmacy goods and cosmetic art
524109	Retail sale of clothing and footwear
524409	Retail sale of furniture and household appliances
553009	Restaurants
640000	Post and telecommunications
651000	Financial institutions
652000	Mortgage credit institutions
660000	Insurance
741200	Accounting, book-keeping and auditing
742009	Consulting engineers and architects
751100	General public service activities
751209	Administration of public sectors
752000	Defense, police and administration of justice
801000	Primary education
802000	Secondary education
803000	Higher education
851100	Hospital activities
851209	Medical, dental and veterinary activities
920000	Recreational, cultural and sporting activities

APPENDIX B

MAPS OF ACCESSIBILITY TO ACTIVITIES

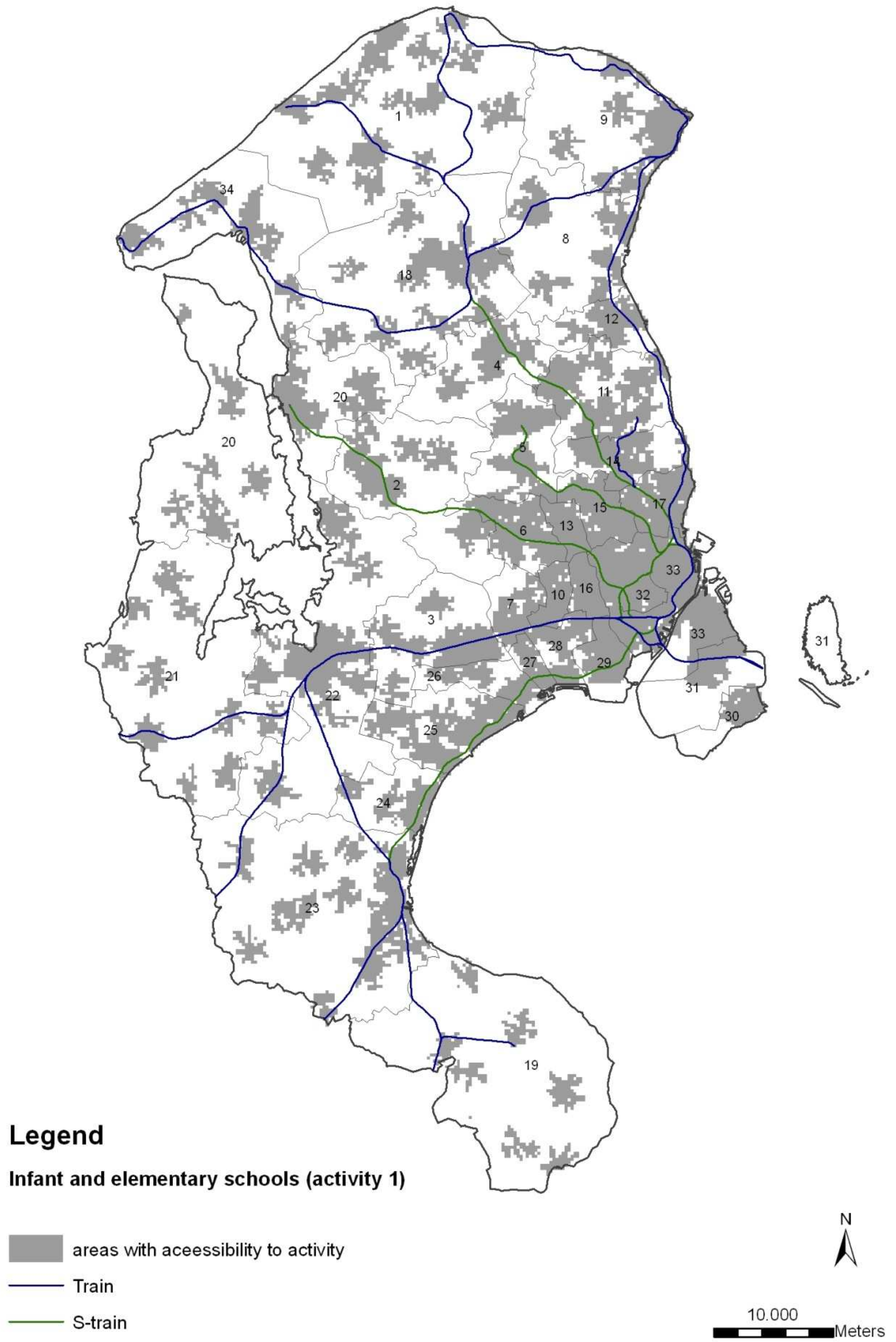

Figure 29 – Areas with accessibility to activity 1

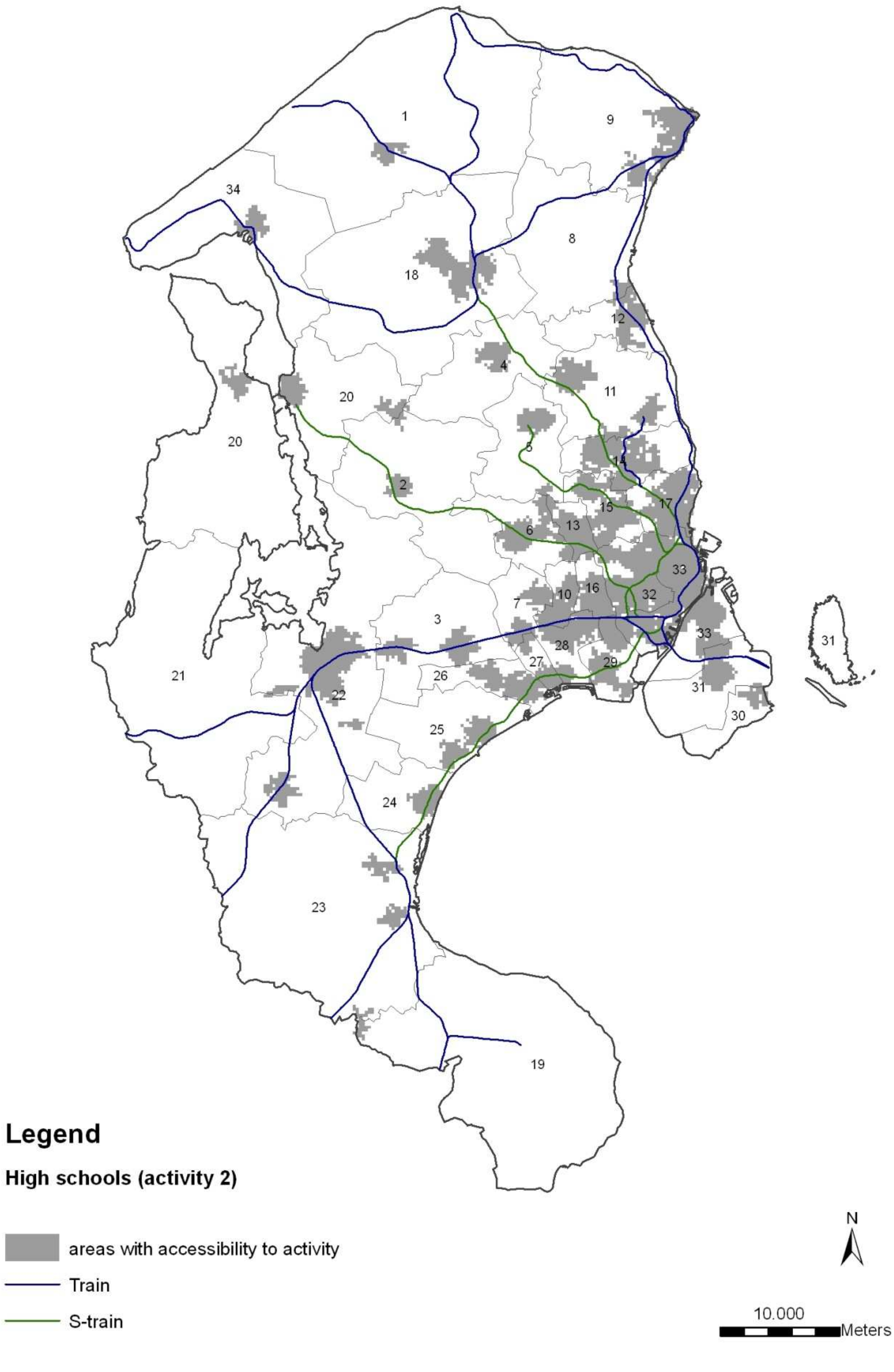

Figure 30 – Areas with accessibility to activity 2

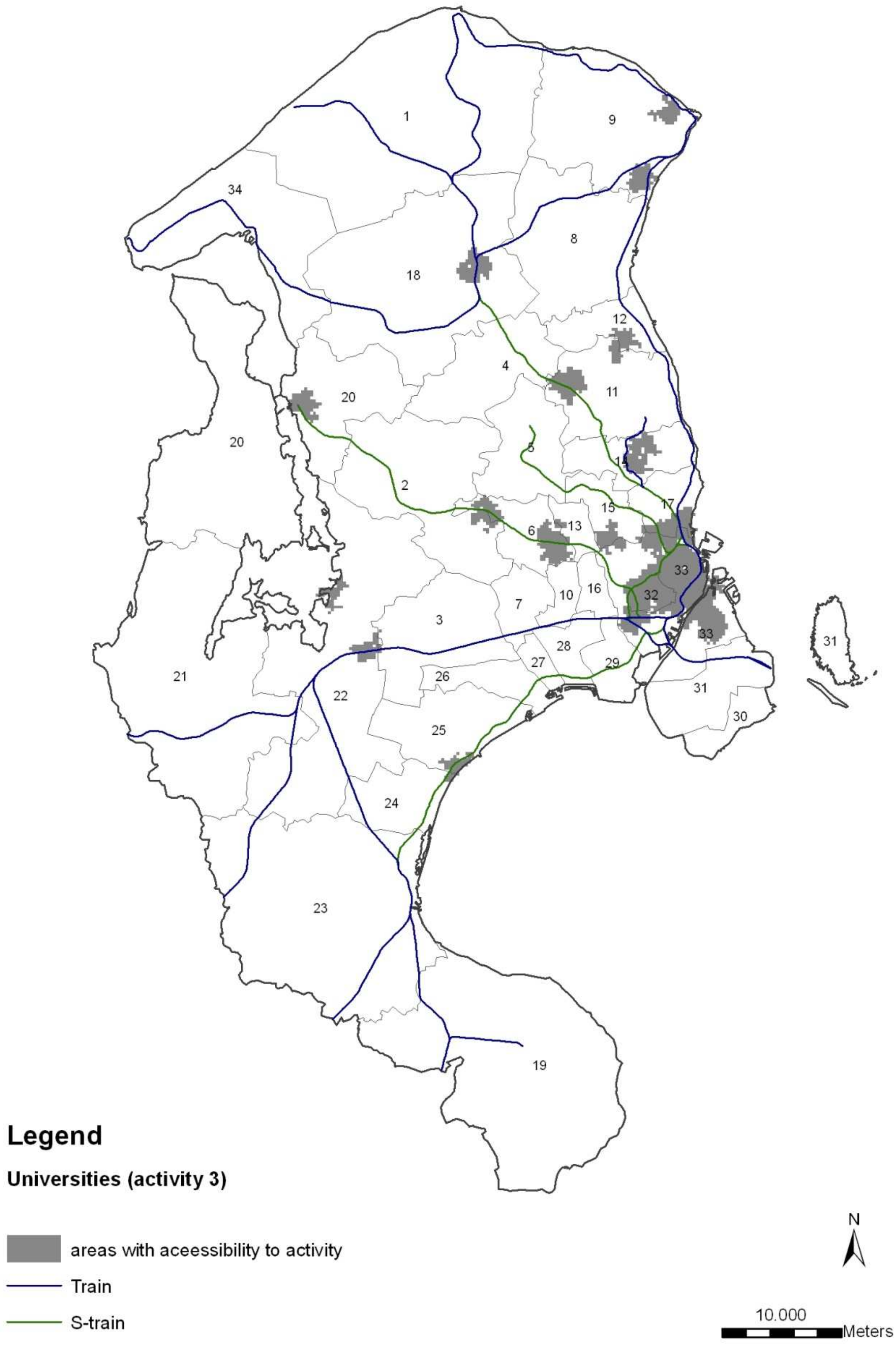

Figure 31 – Areas with accessibility to activity 3

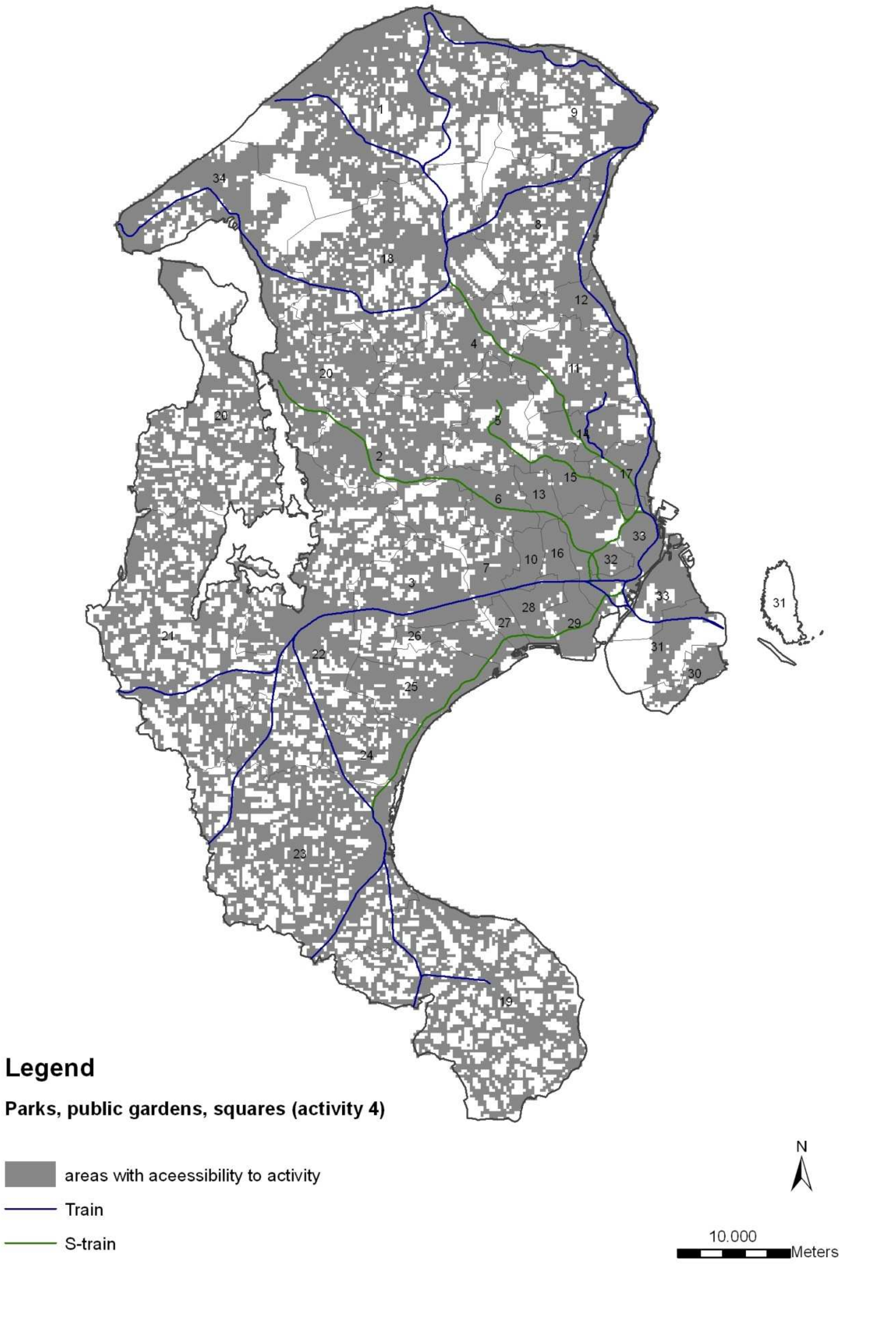

Figure 32 – Areas with accessibility to activity 4

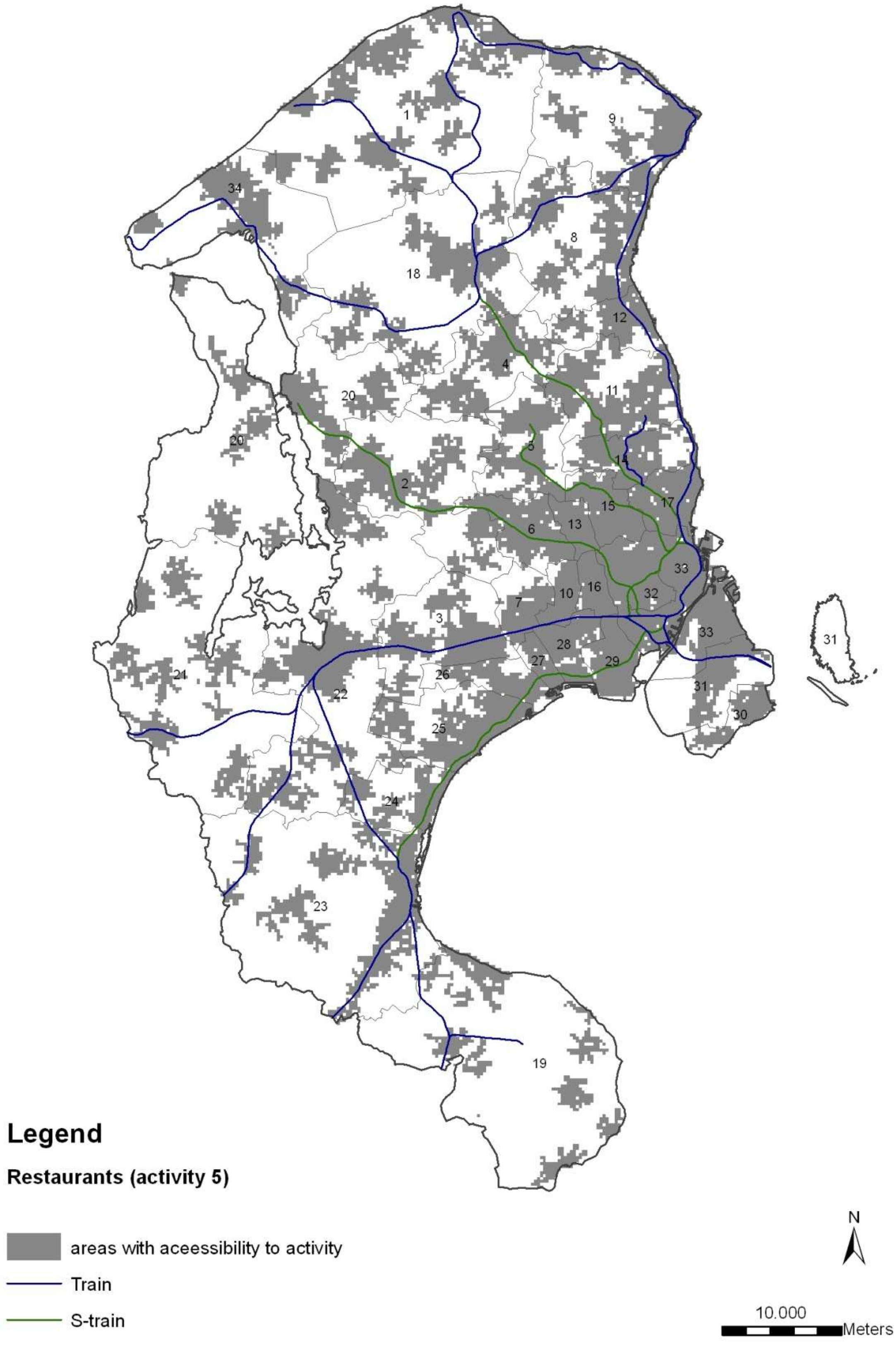

Figure 33 – Areas with accessibility to activity 5

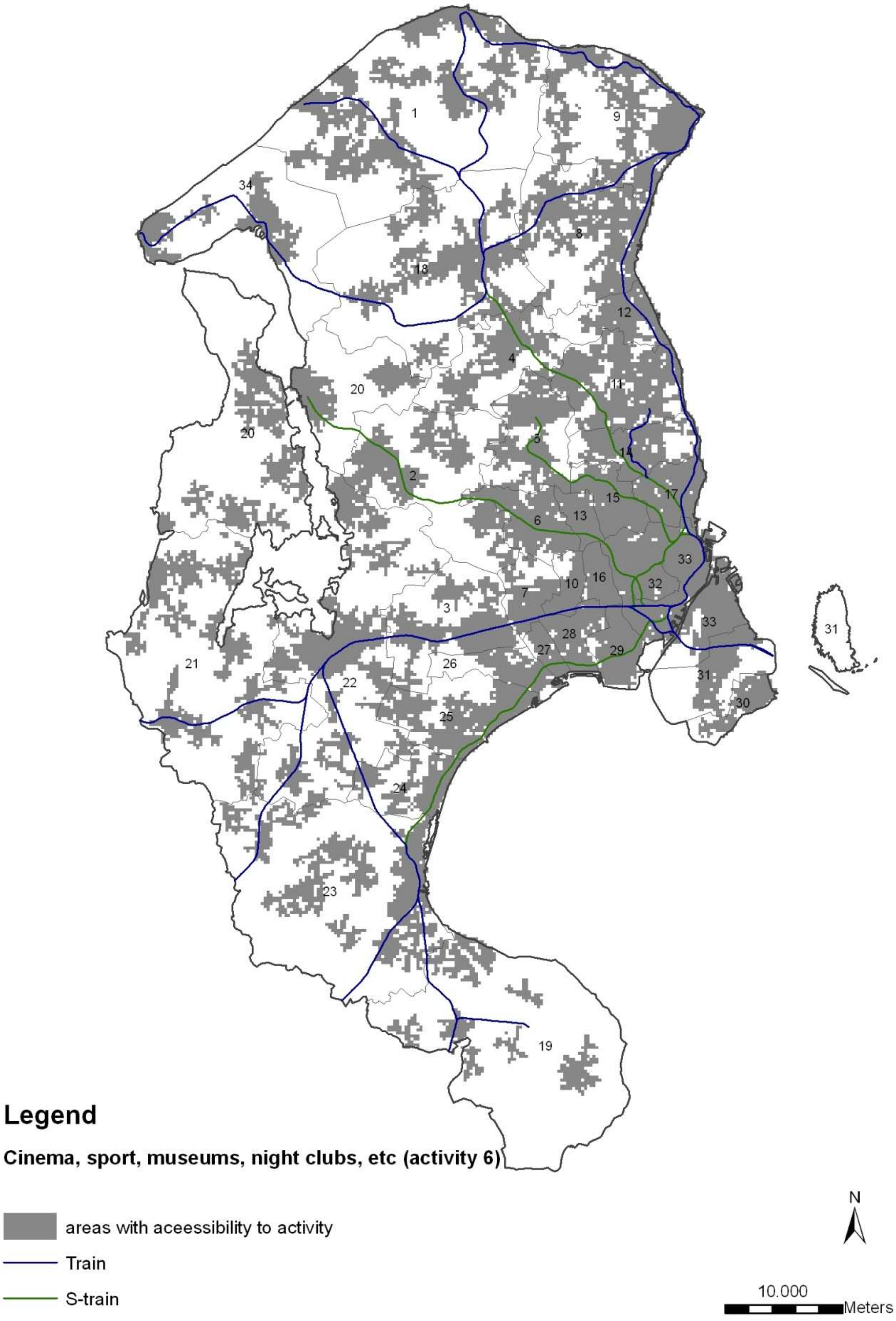

Figure 34 – Areas with accessibility to activity 6

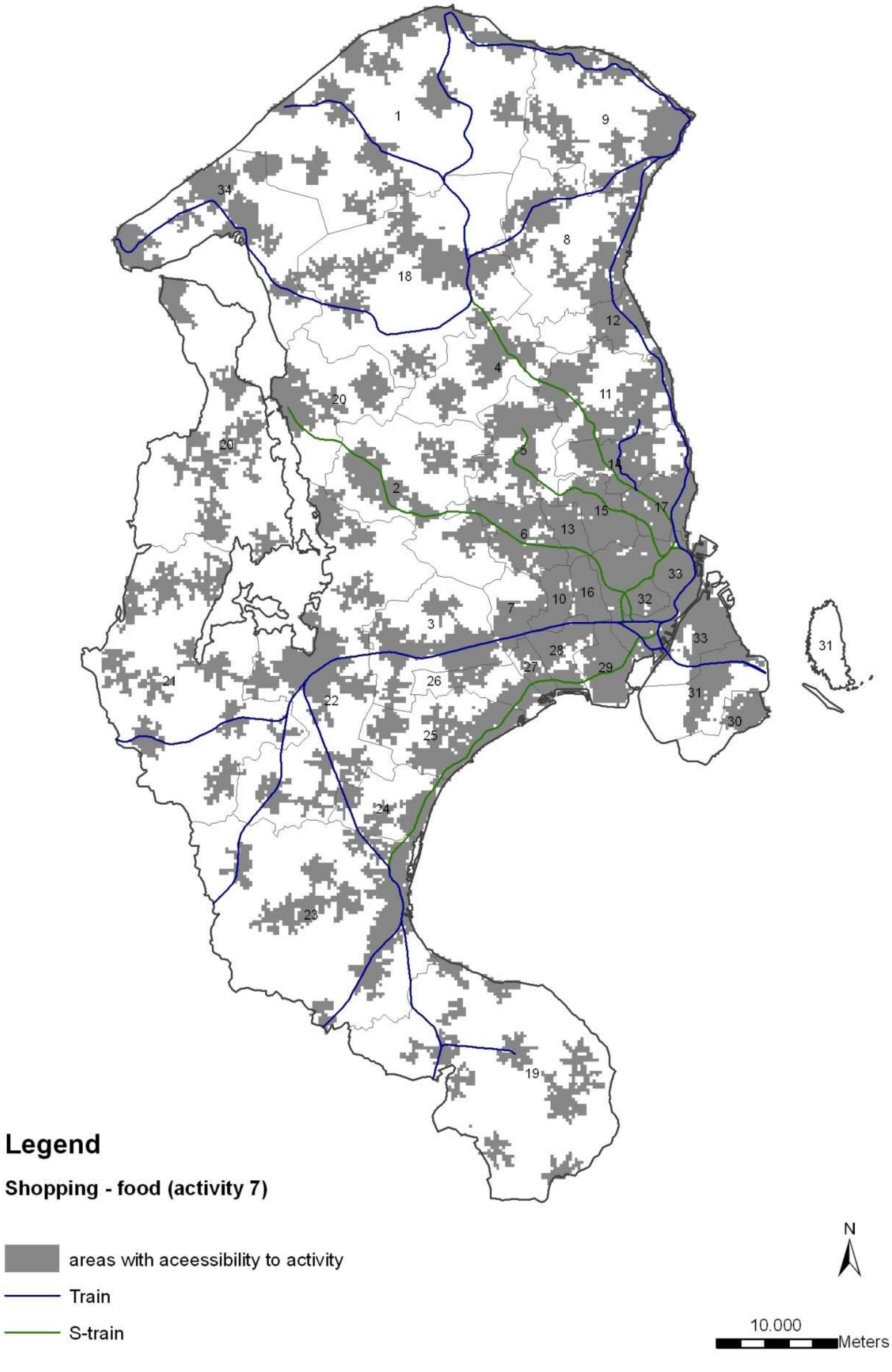

Figure 35 – Areas with accessibility to activity 7

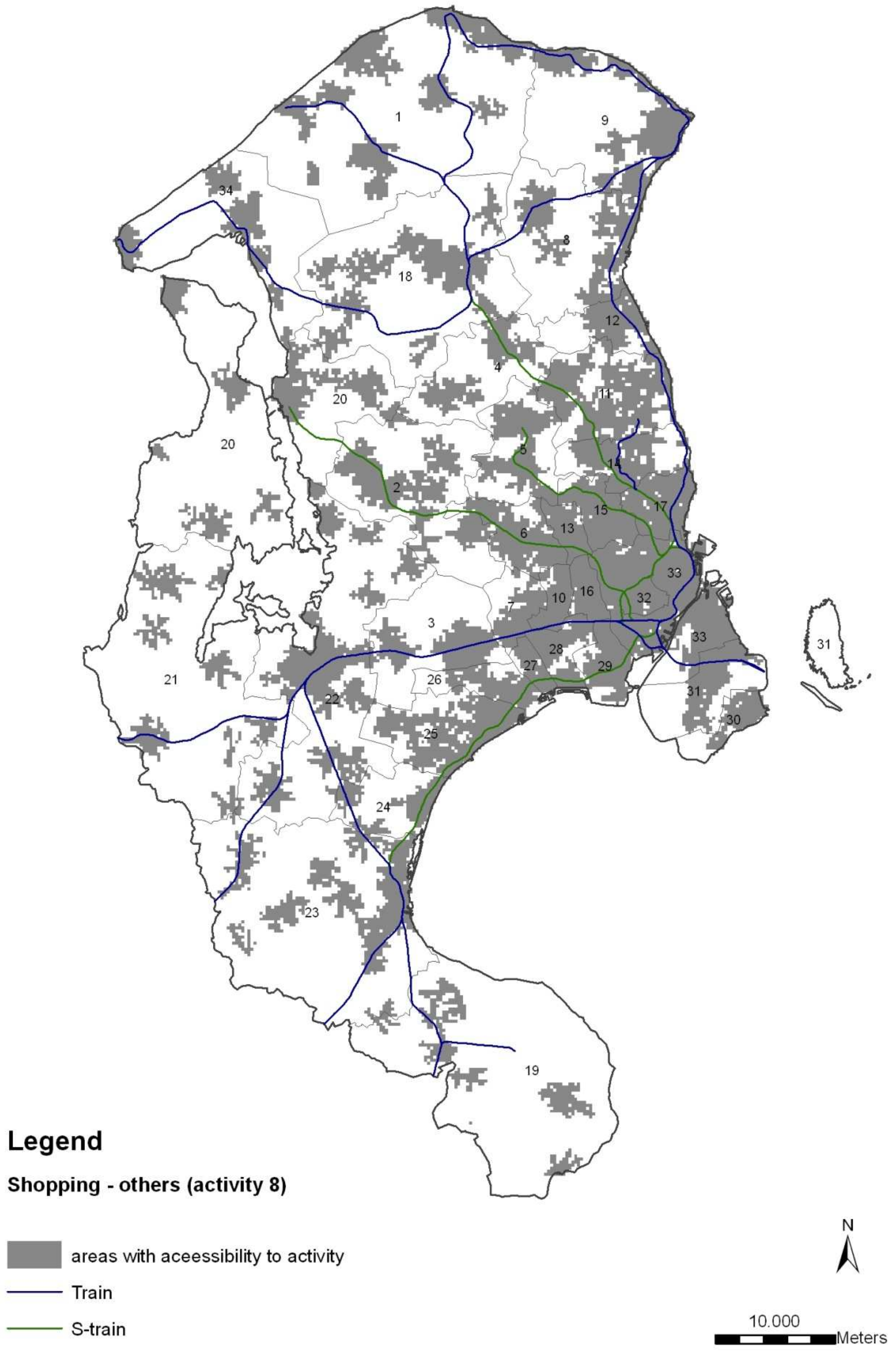

Figure 36 – Areas with accessibility to activity 8

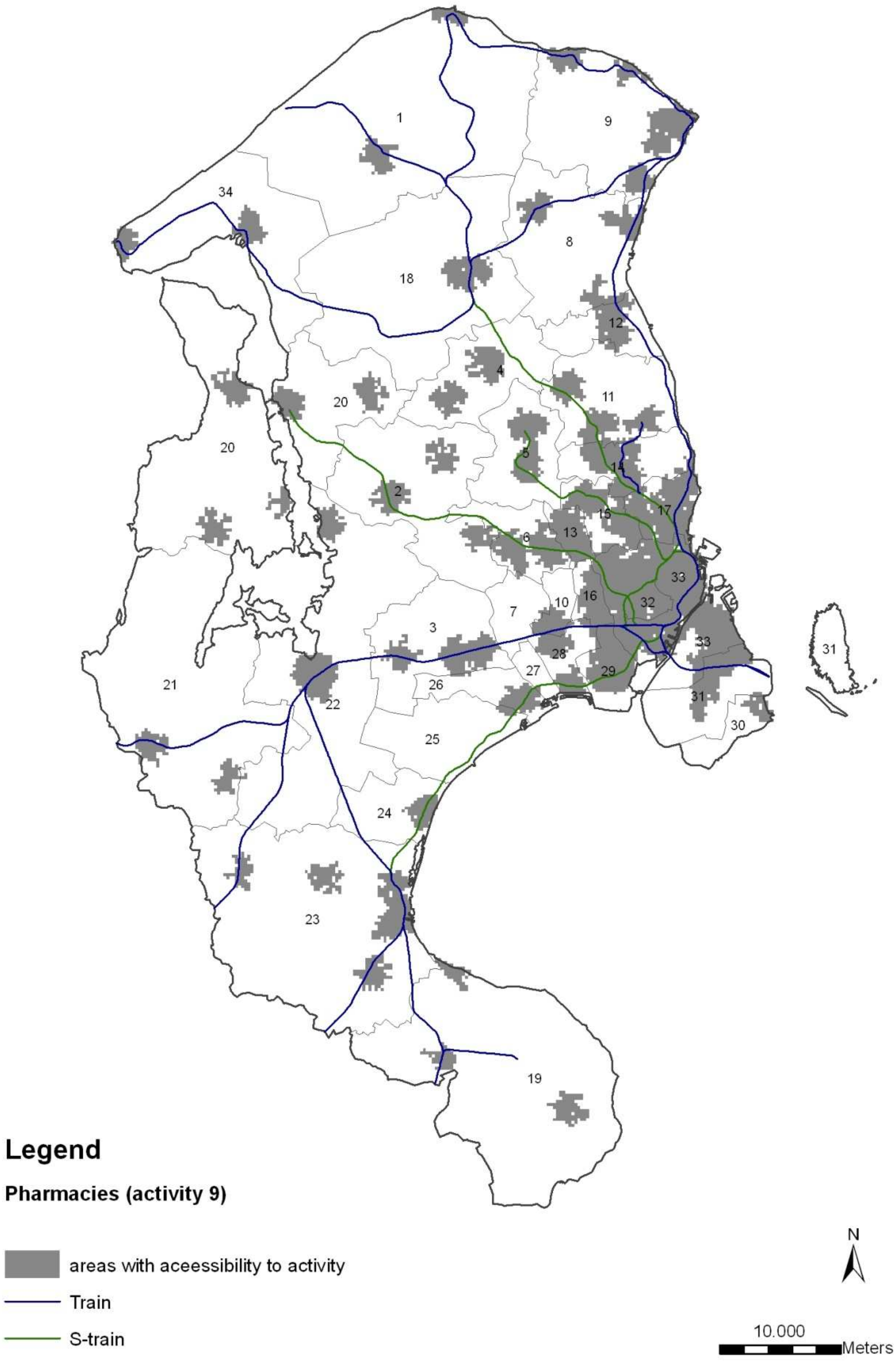

Figure 37 – Areas with accessibility to activity 9

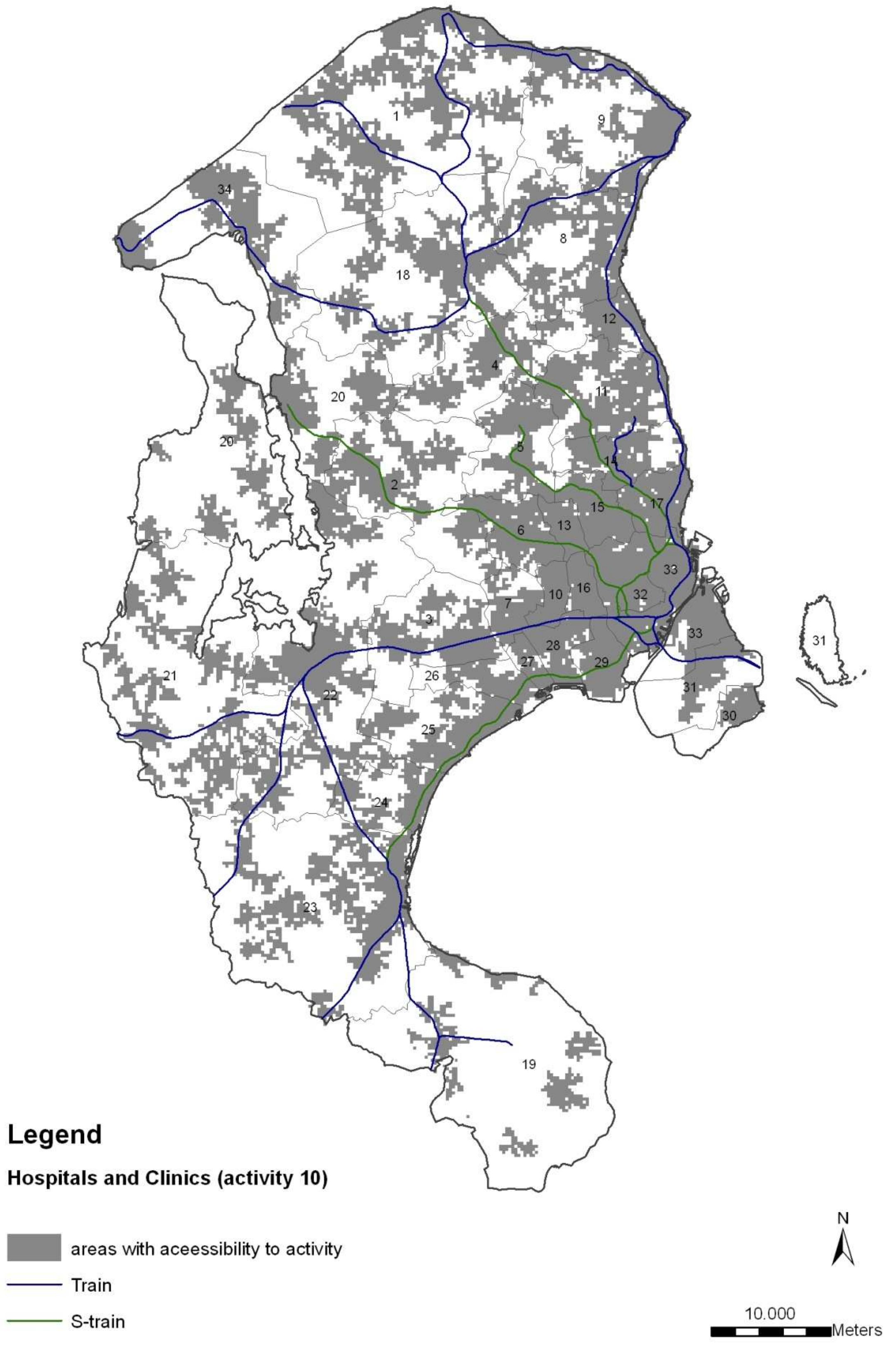

Figure 38 – Areas with accessibility to activity 10

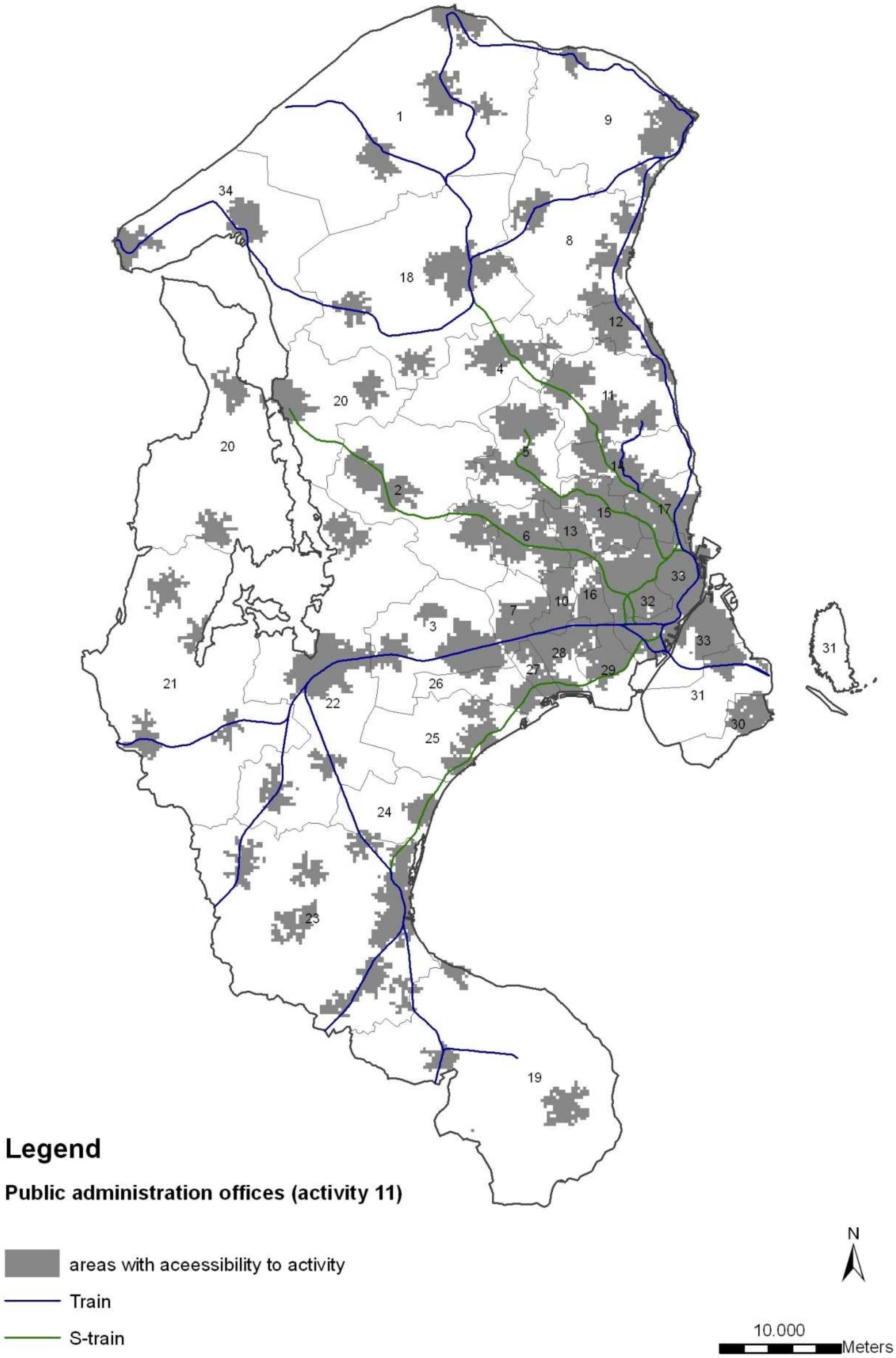

Figure 39 – Areas with accessibility to activity 11

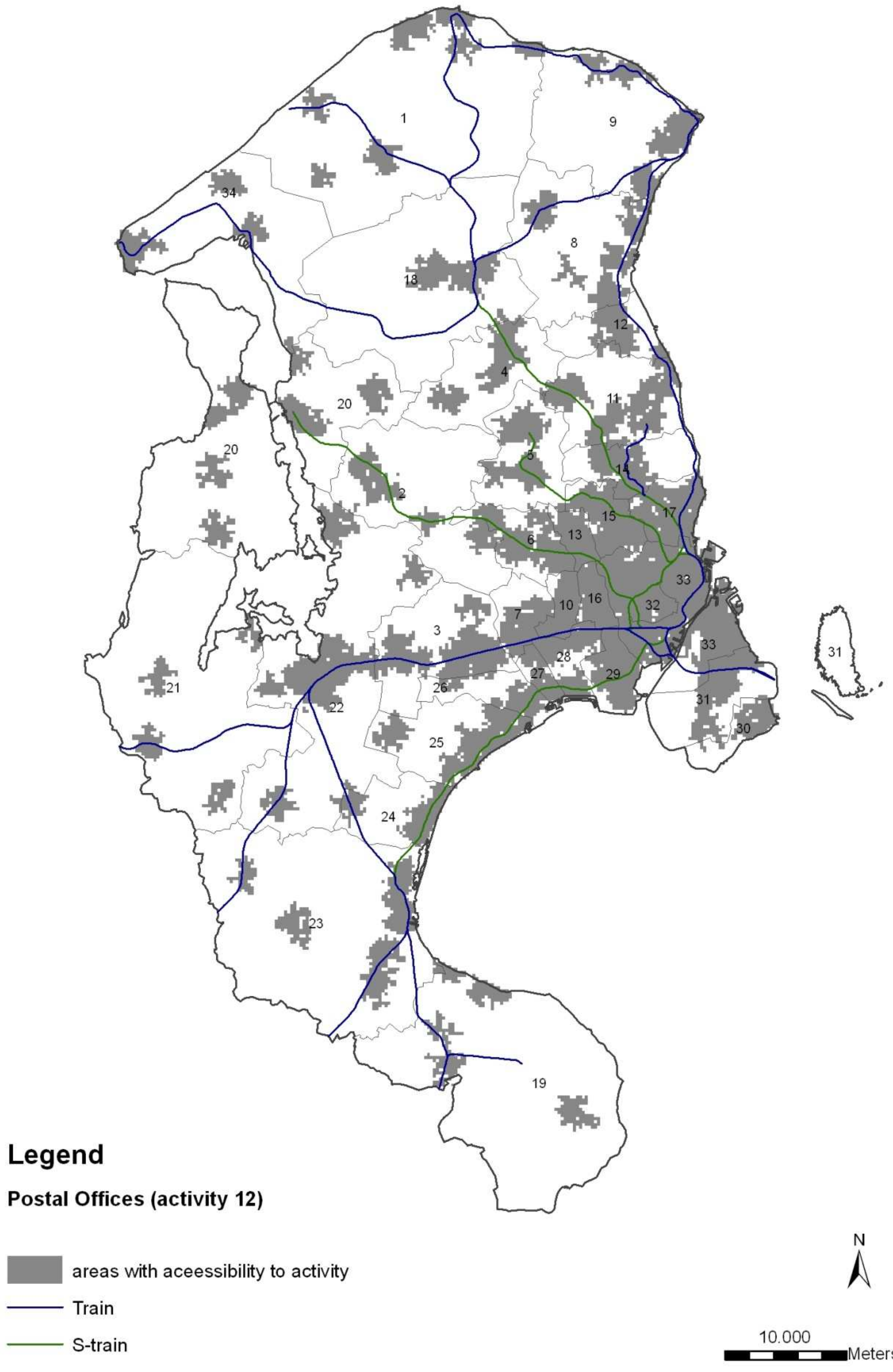

Figure 40 – Areas with accessibility to activity 12

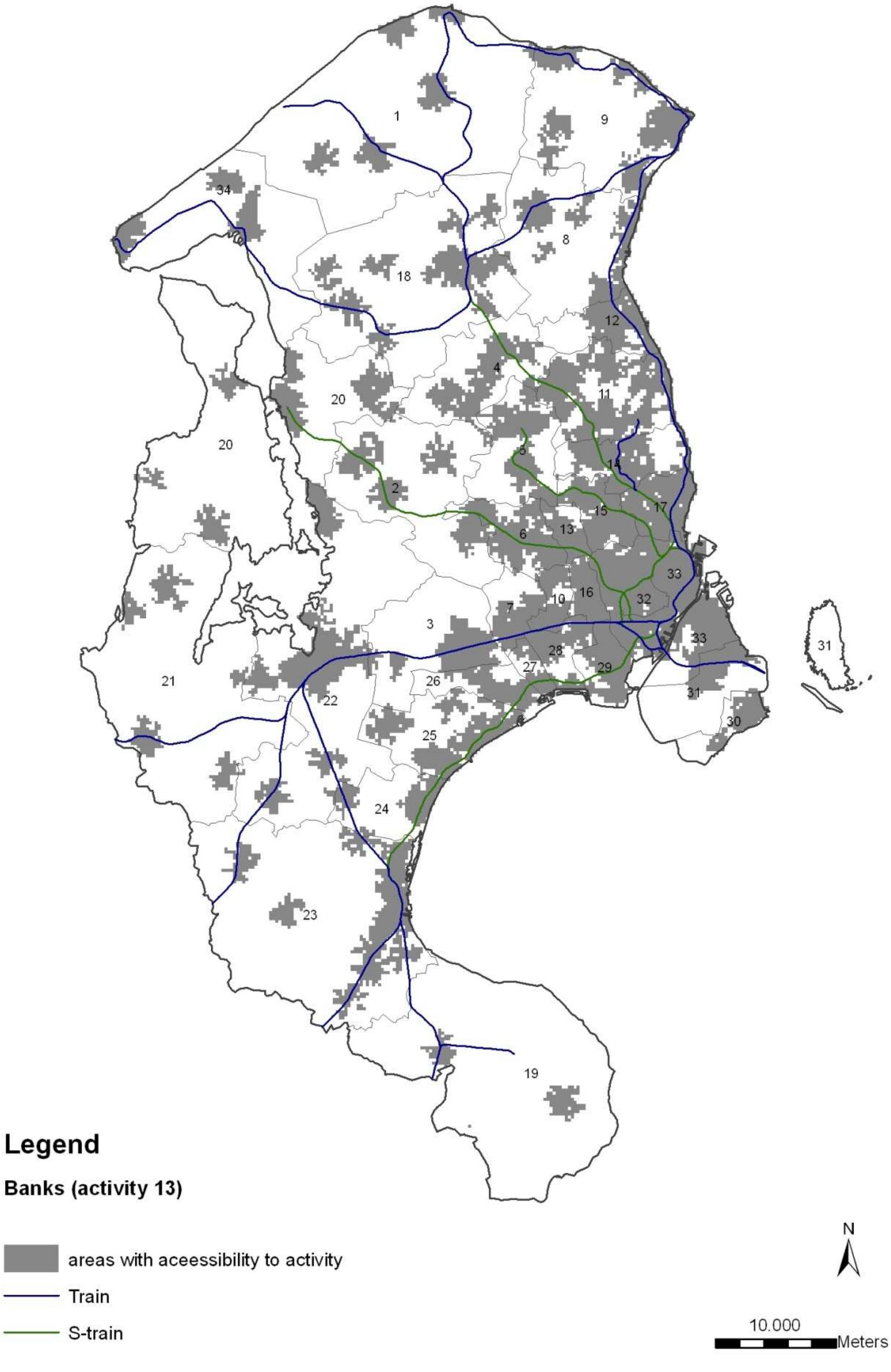

Figure 41 – Areas with accessibility to activity 13

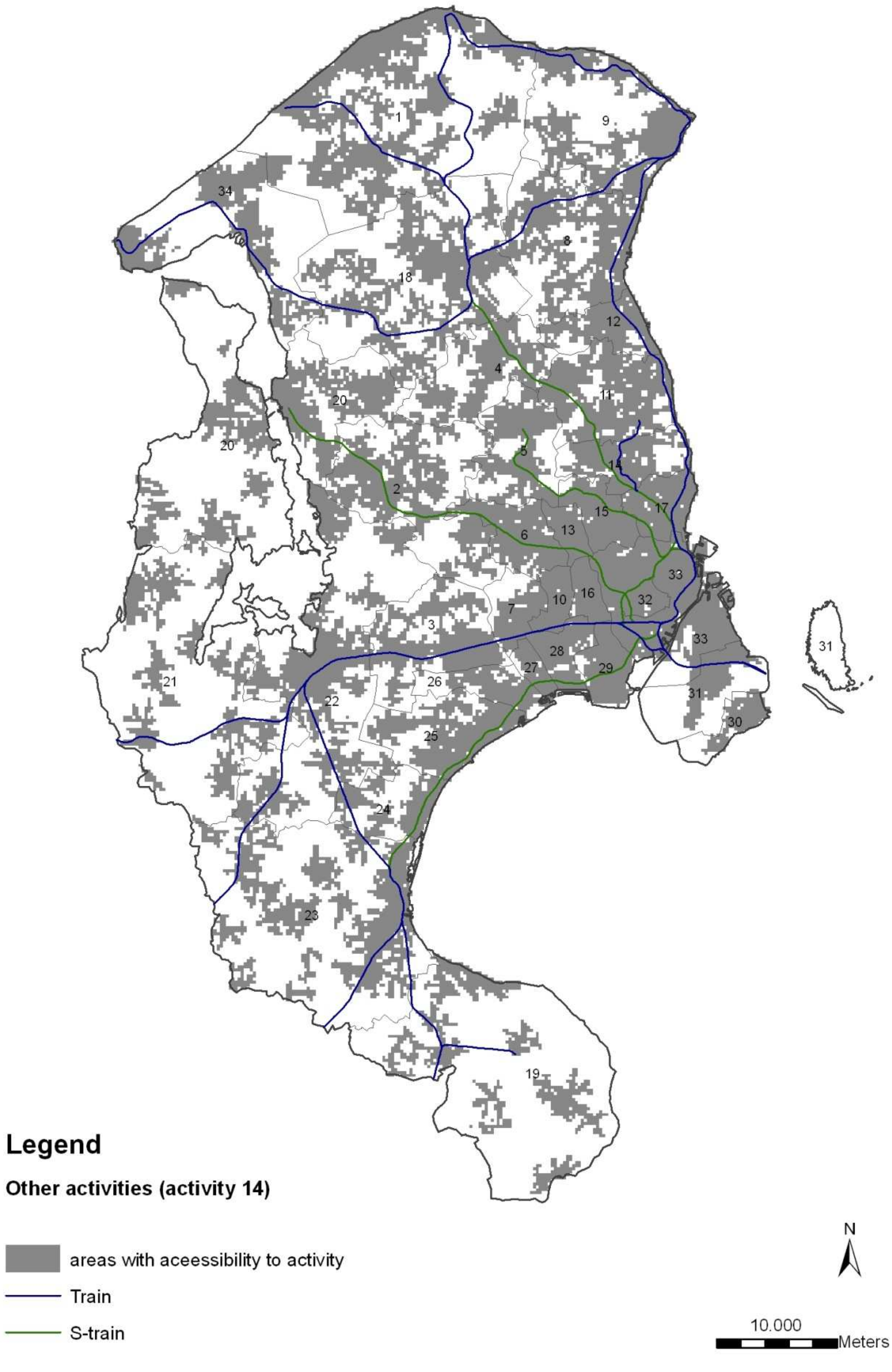

Figure 42 – Areas with accessibility to activity 14

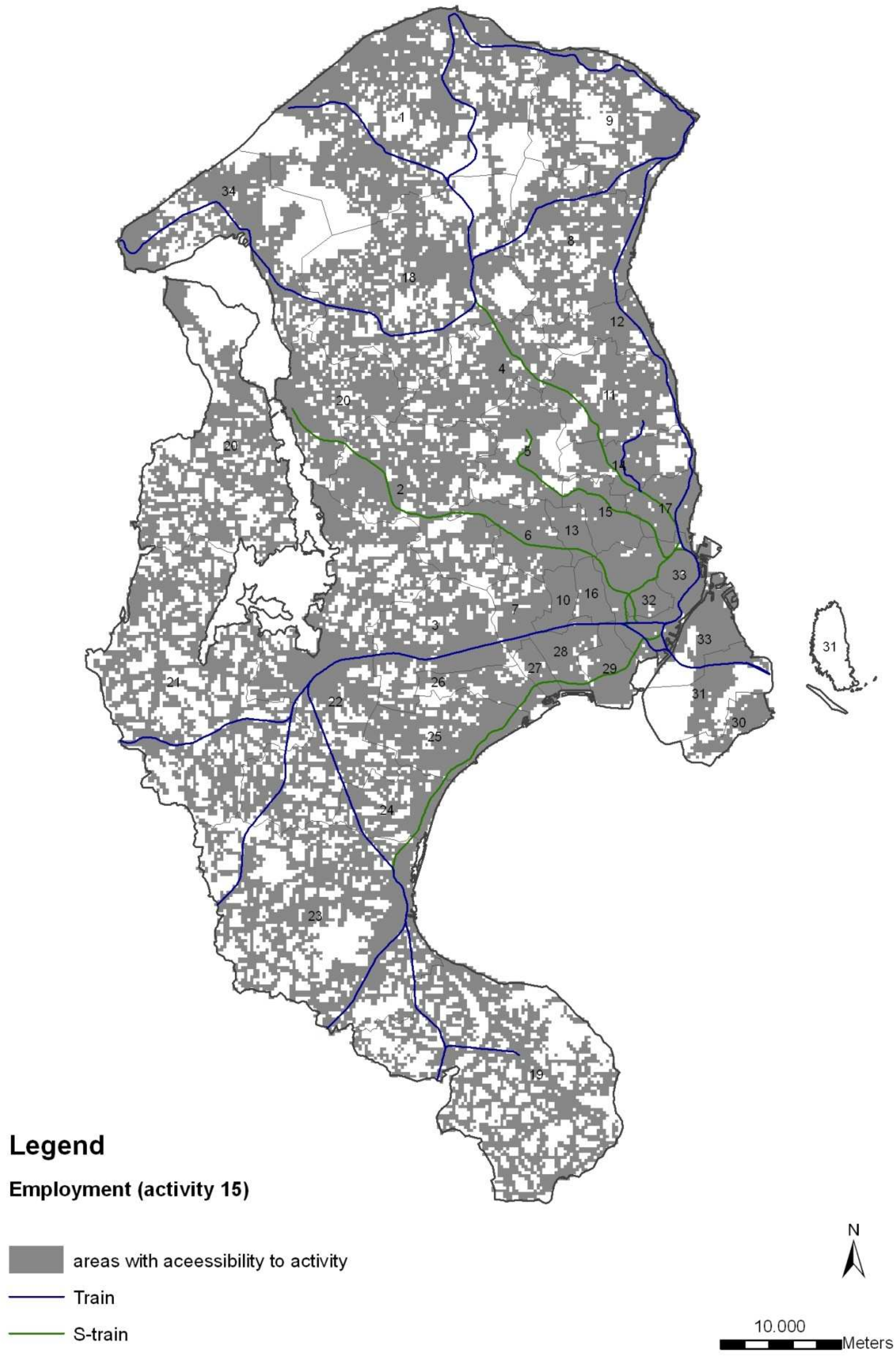

Figure 43 – Areas with accessibility to activity 15

APPENDIX C

MAPS REPRESENTING THE DIVERSITY OF ACCESSIBILITY INDEX IN THE CMA

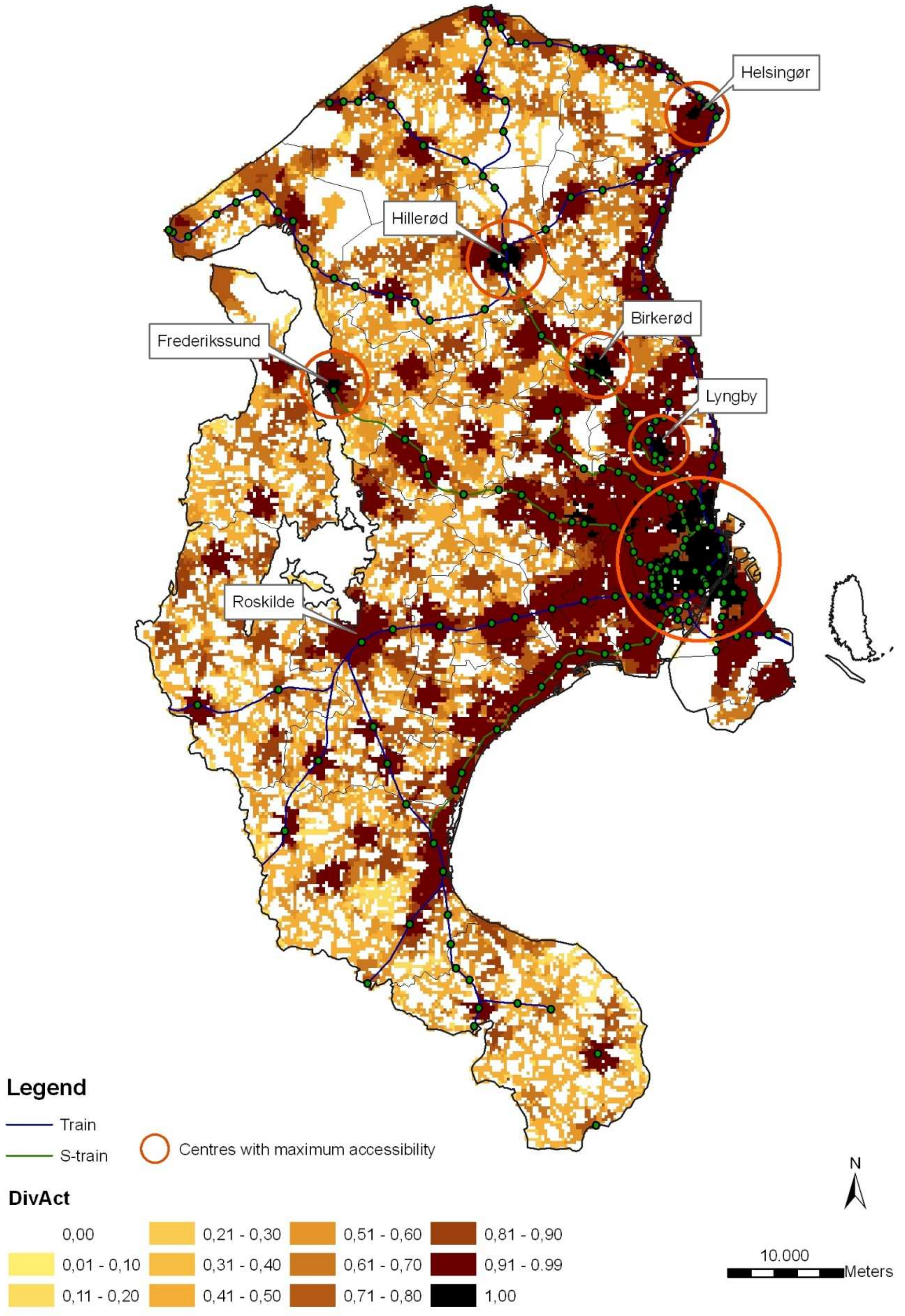

Figure 44 – Centralities with maximum accessibility conditions (DivAct=1)

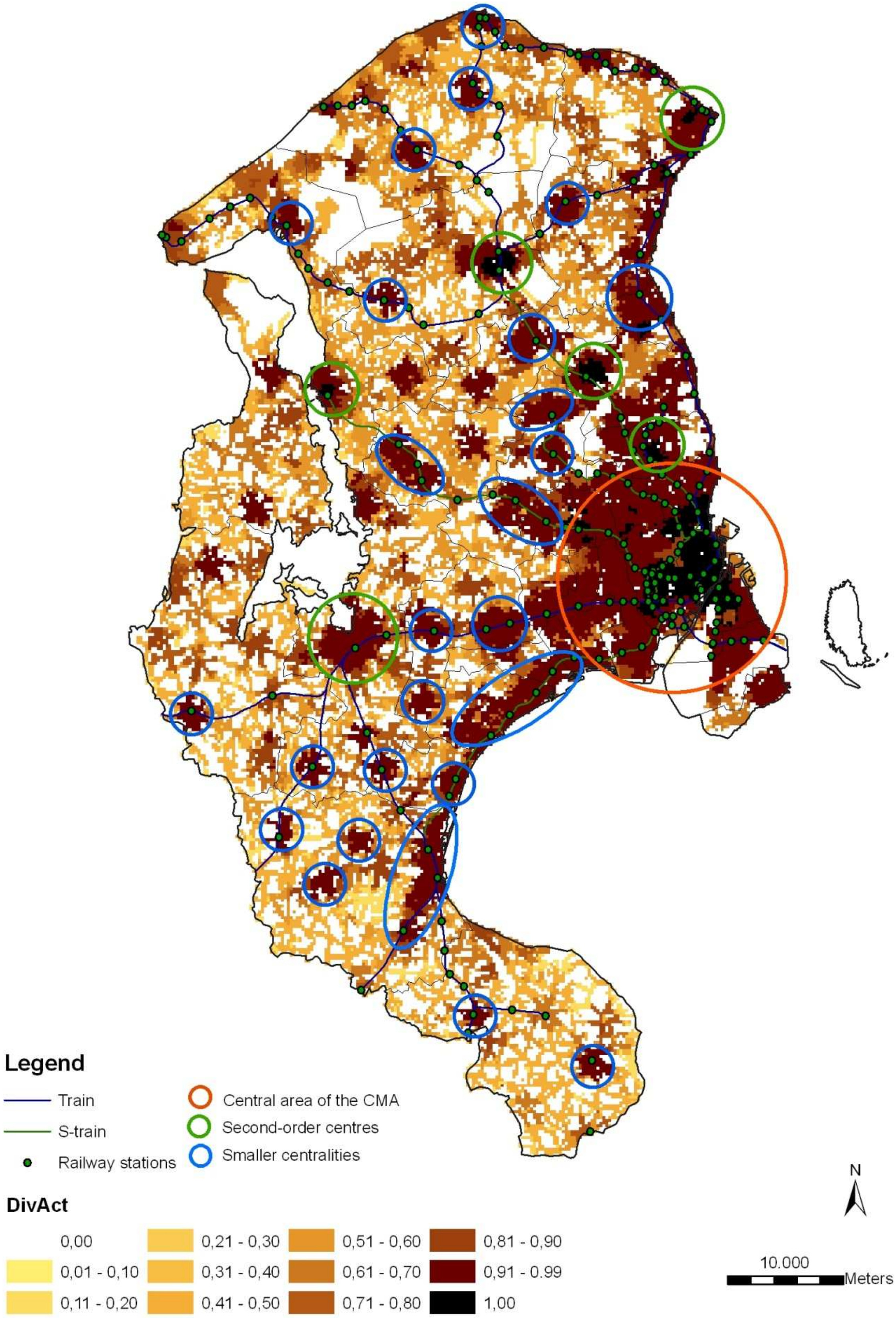

Figure 45 – Areas with high levels of accessibility

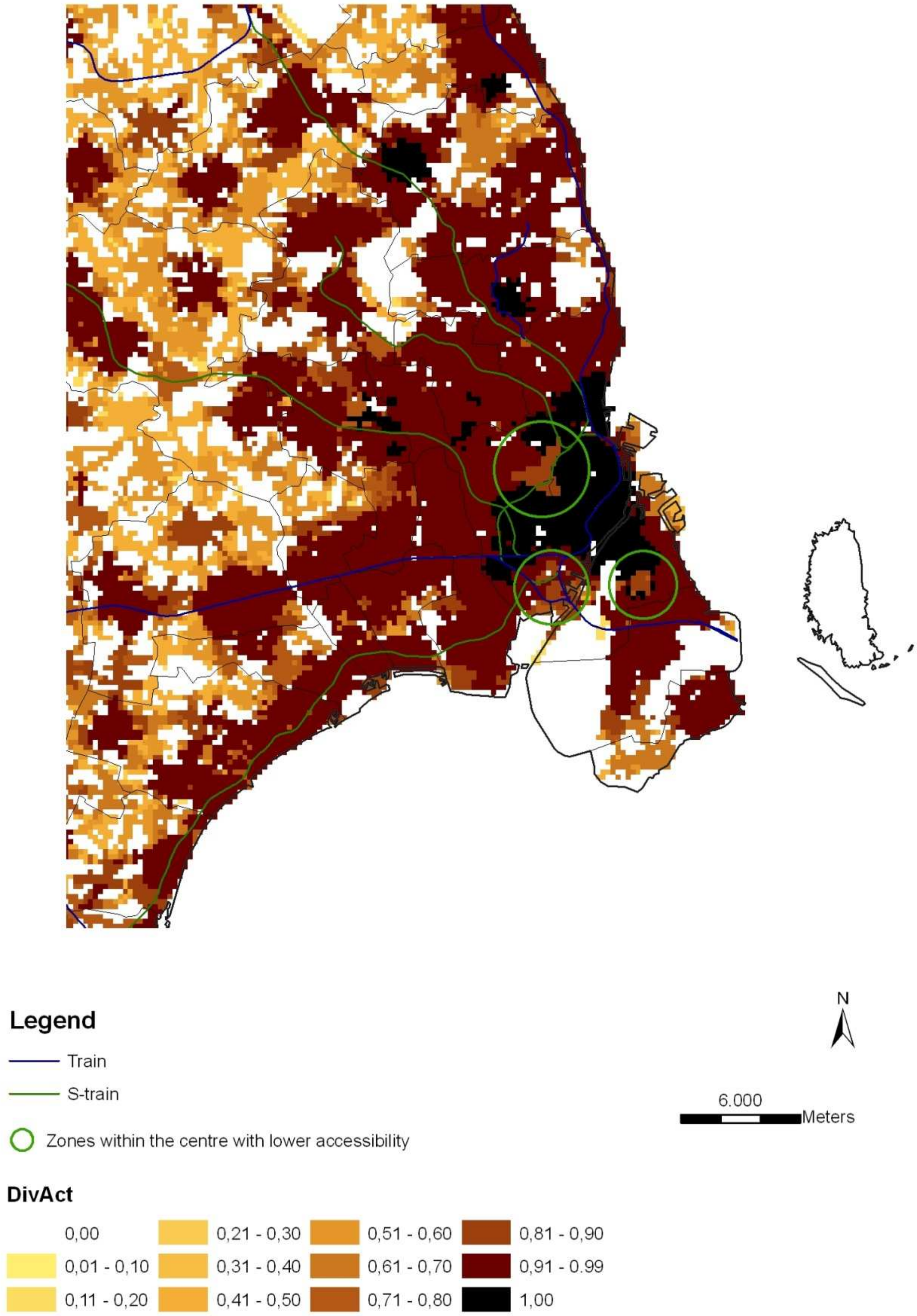

Figure 46 – Zones within the inner city with lower accessibility conditions

APPENDIX D

DATA CONCERNING THE GREATER PORTO

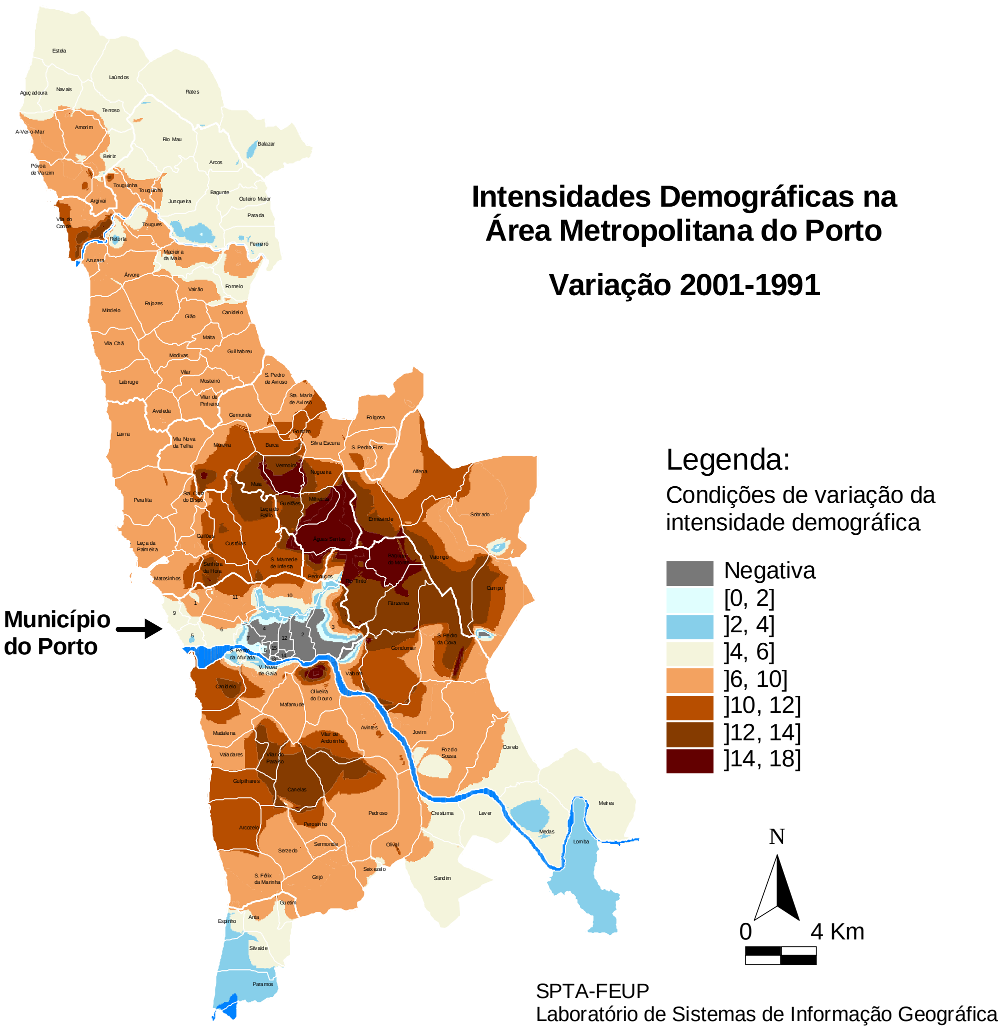

Figure 47 – Demographic variation between 1991 and 2001 in the Metropolitan Area of Porto[15]

[15] Source: Breda-Vásquez, I. (2006). A Reabilitação do Património Edificado no Contexto da Regeneração Urbana. In: Costa, A. et al., A Intervenção no Património. Práticas de Conservação e Reabilitação. 2º Seminario. Porto. Faculdade de Engenharia da Universidade do Porto

Table 9 – Activity types considered in GP and values of fy (source: Silva, 2008)

	Activity type (y)	Frequency of Use	Days in a month	% of trips (INE, 2000)	f_y
Schools:					
• Infant School and Elementary school	1	Daily	21	12	4
• High school	2	Daily	21		5
• University	3	Daily	21		3
Leisure/Entertainment:					
• Parks, public gardens, squares	4	Some days per week	8	22	8
• Restaurants	5	Some days per month	2		2
• Cinema	6	Some days per month	2		2
• Shows / Theatre	7	Some days per month	2		1
• Sport	8	Some day per week	8		8
• Others (ex: Museums, Libraries, Night clubs, etc)	9	Some days per month	2		1
Shopping:					
• Food	10	Weekly	4	10	8
• Others	11	sporadic	1		2
Healthcare					
• Pharmacies	12	Sporadic	1	15	2
• Hospitals and Clinics	13	Sporadic	1		2
Other Activities					
• Public/Municipal administration offices	14	Sporadic	1		2
• Postal Office	15	Sporadic	1		2
• Banks	16	Some days per month	2		5
• Others (ex: Insurance, Lawyers, Architects, financial advisers, etc)	17	Sporadic	1		2
Employment					
• Employment	18	Daily	21	41	41
Total				100	100